# Scenario Planning for Sustainable Dark Skies:

## Altering Mental Models and Environmental Attitudes Through Scenario Planning

by

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ABSTRACT

Recent research within the field of natural resource management has been devoted to studying the cognitive structures, called mental models, that guide people's thoughts, actions, and decision-making. Artificial lighting threatens the sustainability of pristine night skies around the world and is growing worldwide at an average rate of six-percent per year. Despite these trends, stakeholders' mental models of night skies have been unexplored. This study will address this gap by eliciting stakeholders' mental models of dark skies. Scenario planning has become a pervasive tool across diverse sectors to analyze complex systems for making decisions under uncertainty. The theory of scenario planning hypothesizes that scenario planning contributes to learning and improves upon participants' mental models. However, there have been scant empirical studies attempting to investigate these two claims. Stakeholders' mental models of dark skies were mapped while simultaneously testing the hypotheses that participation in scenario planning results in more complex mental models and alters environmental attitudes. Twenty-one Arizona stakeholders participated in one of two workshops during September 2016. Three identical surveys were given to measure knowledge, environmental attitudes and mental model change during the workshops. Knowledge gain peaked during the introductory lecture and continued to increase during the workshop. Scenario planning increased participants' environmental attitudes from anthropocentric to nature-centered and was found to have a significant positive impact on dark sky advocates' change in mental model complexity. The most prominent drivers affecting dark skies were identified using social network analysis of the pre and post mental models. The most prominent concepts were altered significantly from pre to post workshop suggesting that scenario planning may aid practitioners in understanding exogenous factors to their area of expertise.  These findings have critical theoretical and managerial implications of mental model alteration, environmental attitudes, and the future of Arizona's night skies.  A revised theoretical framework is offered to include environmental attitudes into the theory of scenario planning and a conceptual framework was created to illustrate the most salient drivers affecting or being affected by dark skies.

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# Chapter 1

# INTRODUCTION

Natural resource management (NRM) research on human-environment interaction has primarily resorted to studying people's values, attitudes, and behaviors over the past several decades (Jones, Ross, Lynam, Perez, & Leitch, 2011). Only recently have NRM social scientists begun to investigate how people conceptualize socio-ecological problems and how these conceptualizations vary across different stakeholder groups. NRM social scientists have borrowed from cognitive psychology's mental model theory to achieve this (Johnson-Laird, 1983; Jones et al., 2011). Mental models (MM) are personal internal representations of the external world that guide people's actions, decisions, and behaviors (Craik, 1943; Glick, Chermack, Luckel, & Gauk, 2012; Johnson-Laird, 1983). In a NRM context, MMs are used by individuals to construct components of complex socio-ecological systems and map out the relationships between them. Understanding diverse stakeholders' MMs of socio-ecological systems allows NRM professionals to develop more robust strategies to effectively manage natural resources (Jones et al., 2011).

Dark skies have recently been recognized as an important natural resource to be protected, but are increasingly under threat from light pollution (National Park Service, 2015). Namely, ninety-nine percent of the United States and European Union population and eight-three percent of the world's population now live in areas above the threshold considered light polluted (Falchi et al., 2016). Hölker et al. (2010) claim that artificial lighting is increasing at a rate of 6% per year worldwide but can be anywhere between 0% to 20% depending on location. This increase is alarming due to the reported adverse effects that artificial light at night has on human health (International Dark Sky

Association, 2010; Kraus, n.d.), cultural heritage (Marin, 2011), ecosystems (Rich, & Longcore, 2006), the astronomy industry (Pavlakovich-Kochi, Charney & Mwaniki-Lyman, 2007) and numerous other factors. Thus, dark skies are a critical natural resource deserving of attention and research. Elicitation of stakeholders' mental models of dark skies can help to understand this resource better and to develop more effective management strategies. No study has yet investigated individuals' or groups' mental models of dark skies. This study fills this critical research gap.

Dark skies have been acknowledged to be a complex socio-ecological system requiring transdisciplinary research to address its sustainability (Hölker et al., 2010). A hypothetical conceptual framework was put forth by Hölker et al. (2010) to organize the factors associated with light pollution. However, the linkages between light pollution and its associated factors were only based on the authors' perspectives and experiences. There is a need to solicit these factors from a broader pool of experts to give credibility to these hypothesized linkages. One objective of this research project is to elicit MMs of dark skies from a diverse group of stakeholders to build a conceptual model of the most salient factors associated with them. The elicitation of key drivers effecting dark skies from a diverse group of experts may not only provide more evidence to support the hypothetical linkages proposed by Hölker et al. (2010), but it may also identify several other factors that were neglected from their framework.

Participatory workshops for envisioning the future have been used extensively around the word for decades, however, there is a lack of an empirically tested theory to explain their efficacy (Shipley, 2002; Shipley, & Michaela, 2006; van der Helm, 2009). Instead, those facilitating visioning and scenario workshops tend to do so with tacit assumptions about its benefits and outcomes (Shipley, 2002). The majority of the scholarship concerning visioning and scenario workshops describes step-by-step protocols for how to conduct them (Senge, 1990; Walzer, 1996; Ziegler, 1991) rather than building a theoretical foundation (Shipley, 2002). Clearly, there is a need to develop a theoretical foundation of visioning and scenario planning.

The sustainability transitions literature offers insights into some of the benefits to be gained from participatory visioning and scenario workshop. They claim that these spaces offer a deliberative, reflexive, and open space for participants from various groups to negotiate alternative sustainability visions and pathways (Leach, Scoones, & Stirling, 2007, 2010). The transitions management (Loorbach, 2010) literature discusses the need for transition arenas where persistent sustainability problems are conceptualized and alternative solutions compared and integrated. It stimulates new coalitions, partnerships, and networks to create new ways of thinking. These frameworks explain some of the benefits of scenario planning, but they do not explicitly discuss participants' cognitive processes occurring during the scenario planning process. Since understanding participants' cognitive processes are the focus of this study, Chermack's (2005) theory of scenario planning was chosen for analysis.

Chermack's (2005) theory of scenario planning claims to explain the cognitive development of participants in response to participation in scenario planning. Chermack's (2004a, 2005) theory of scenario planning associates scenario planning with improved learning, altered MMs, improved decision-making and ultimately better organizational performance and outcomes. As the theory is still in its nascent phase, it is built primarily on anecdotal evidence and conceptual links (Chermack, 2004b).

Chermack (2004b) calls for sound research to validate and understand scenario planning practices. There have been several articles which have proposed linkages between scenario planning and learning (Chermack & van der Merwe, 2003; de Geus, 1988; Schwartz, 1991; Henly-Shepard, Gray, & Cox, 2015; van der Heijden, 1996). However, there have only been a handful of empirical studies to test this claim and even fewer that have tested scenario planning's effect on MMs (Glick et al., 2012). This study will address that gap by empirically investigating the hypothesized associations of scenario planning with learning and MMs. The theory of scenario planning includes several other hypotheses aside from scenario planning's' impact on learning and mental models. However, it is beyond the scope of this one study to address all of them. Future research is needed to comprehensively test each of the claims in the theory of scenario planning.

Studies have investigated the differences in novice and expert reasoning skill in solving problems and several authors have claimed that skill in mental model development develops with learning (Ippolito, & Tweney, 1995; Neressian, 1995; 2002). Thus, greater knowledge and experience should lead to an even greater increase in MM complexity. This study will determine if this is indeed true during scenario planning.

The recreation specialization literature suggests that more advanced recreationists will have more knowledge about the management of a natural resource than non-specialists (Bryan, 1977, 2000). Therefore, experience with dark skies will also be investigated to see if it impacts the degree of increase in MM complexity during the workshops. This study will include a diverse sample of participants on the stargazing recreation specialization spectrum in order to test this.

This study will also investigate if environmental attitudes are affected by scenario planning. The theory of planned behavior (TPB) provides strong support for a relationship between attitudes, intentions and behaviors (Ajzen, 1985, 1991). The theory of scenario planning includes factors that are associated with decision-making and which it has influence over (Chermack, 2005, 2011). Therefore, if attitudes are found to be affected, it provides preliminary evidence that the nascent theory of scenario planning may need to be revised to include attitudes. The Revised New Ecological Paradigm Scale (NEP) and its various iterations have been used for decades as a valid and reliable tool for measuring environmental attitudes (Dunlap, Van Lierre, Mertig, & Jones, 2000; Dunlap, 2010). Therefore, this instrument will serve as the measure of environmental attitudes in this study.

**1.1 Research Objectives**

The purpose of this study is to provide empirical support for the nascent theory of scenario planning and to elicit stakeholders' MM of dark skies. The research objectives are (1) to elicit stakeholder's MMs of dark skies as a resource, (2) to develop a conceptual model of most salient factors associated with dark skies, (3) to test the hypotheses that scenario planning improves learning and alters participants' MMs, and (4) to investigate the impact of scenario planning on participants' environmental attitudes. Below are the research questions and associated hypotheses.

Research Question 1: Overall, does scenario planning improve learning, increase the complexity of participants' MMs, and change environmental attitudes?

Related Hypotheses:

$H_1$: Participation in scenario planning results in knowledge gain about dark skies.

$H_2$: Participation in scenario planning results in more complex MMs (i.e. comprehensiveness, linkages, density, and greater information centrality).

$H_3$: Participation in scenario planning results in higher pro-environmental attitudes.

Research Question 2: What is the effect of participants' prior knowledge and experience on their knowledge gain and change in mental model complexity during a scenario workshop?

Related Hypotheses:

$H_4$: As dark sky knowledge increases, the change in MM complexity (i.e. comprehensiveness, linkages, density, and information centrality) increases.

$H_5$: As stargazing experience increases, the change in MM complexity (i.e. comprehensiveness, linkages, density, and information centrality) increases.

$H_6$: As dark sky advocacy increases, the change in MM complexity (i.e. comprehensiveness, linkages, density, and information centrality) increases.

**1.2 Thesis Structure and Chapters**

The previous sections presented an overview of the project and the research goals. Chapter two of the thesis will present a broad overview of the literature related to this project. Chapter three presents the methods used in this study including both quantitative and qualitative methods. The operationalization of variables is discussed, the scenario workshop protocol is revealed, and the analysis methods are discussed in detail. The results are presented in chapter four. Chapter four includes descriptive statistics of participants, samples of participants' mental models, the results of statistical tests of the study hypotheses, and identification of the salient factors associated with dark skies for all stakeholder groups. A discussion of the results is presented in chapter five. Chapter five presents a suggested revision to the theory of scenario planning based on the results of the study as well as a conceptual model of the salient drivers associated with dark skies. Chapter six, the conclusion, presents the theoretical and managerial implications of this study's findings. Lastly, the appendices include all of the study's questionnaires, interview protocol, coding schemes, sample scenario narratives, and study approvals.

# Chapter 2

# REVIEW OF THE LITERATURE

This chapter will present a broad overview of the literature regarding this project. Various social, ecological, economic, cultural, and technological factors associated with artificial lighting and dark sky conservation will be discussed. A review of the literature regarding mental model theory, elicitation, and analysis is also presented as these are critical aspects of this project. This project will test the theory of scenario planning. Therefore, the theory of scenario planning is presented. The theory of planned behavior is presented to provide rationale for the inclusion of attitudes in the framework for the theory of scenario planning. Environmental attitudes will be measured in this study. Therefore, a history and discussion of the Revised New Ecological Paradigm Scale is presented and provides a rationale for why and how the scale was used in this study. Finally, an overview of the recreation specialization literature is presented to provide a rationale for why it was chosen and how it was measured in this study.

## 2.1 Dark Sky Sustainability

### 2.1.1 Artificial Lighting and Light Pollution

Cinzano, Falchi and Elvidge (2001) conducted the first atlas of artificial night sky brightness; their study shows that light pollution is a global and growing problem. Light pollution is defined as "any adverse effect of artificial light, including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste" ("The Problems of Light Pollution," n.d.). Artificial night lighting can come from streetlights, car headlights, communication towers, bridges, office buildings, security lights such as flood lights, and is pervasive throughout cities. Cinzano et al. (2001) claim that light pollution is one of the most pervasive forms of environmental alteration. Duriscoe, Luginbuhl and Moore (2011) find that light pollution can severely affect the night sky quality of areas more than 250 km from sources of major light pollution. A case in point is the fact that light domes from Los Angeles and Las Vegas can be seen in far away Death Valley National Park (Duriscoe, 2013; Falchi et al., 2016). Figure 1 shows results from CCD false-color images of Death Valley National Park with light domes from both major cities clearly visible.

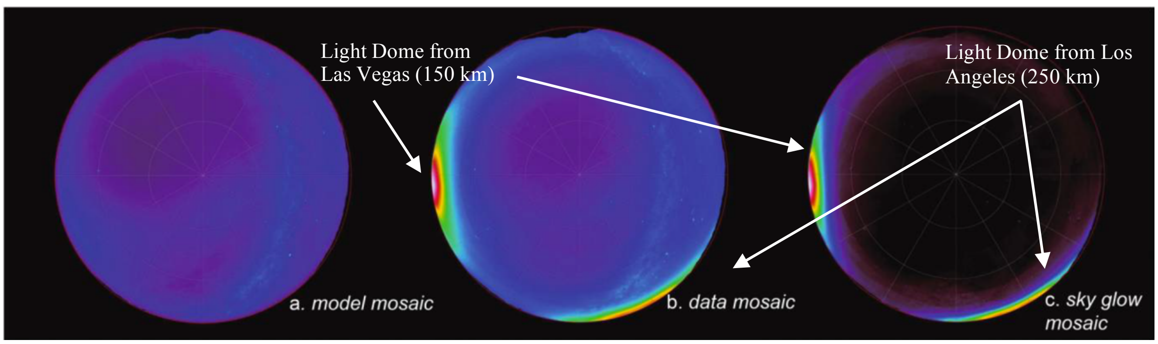



*Figure 1.* Wide field CCD false-color images of Death Valley National Park.

Source: Adapted from Duriscoe (2013)

“The First World Atlas of Artificial Night Sky Brightness” (Cinzano et al., 2001) has recently been updated using NASA’s Suomi NPP satellite’s onboard Visible Infrared Imaging Radiometer Suite Day/Night Band and new Sky Quality Meter measurements. A full length report of the atlas and worldwide light pollution is available in the article “New World Atlas of Artificial Night Sky Brightness” (Falchi et al., 2016). This data shows that worldwide development and the urban sprawl have placed most of the world’s population in heavily light polluted areas. Figures 2 and 3 show the worldwide distribution of artificial night sky brightness and the United States artificial night sky brightness respectively as published in the atlas (Falchi et al., 2016). These images reflect that ninety-nine percent of the United States and European Union population and eight-three percent of the world's population now live in areas above the threshold considered light polluted (Falchi et al., 2016). This is up from two-thirds of humanity as measured by fifteen years earlier by Cinzano et al. (2001). Moreover, eighty-percent of the US, sixty-percent of the EU and one-third of the world's population have lost the ability to see the milky way galaxy at night (Falchi et al., 2016). This is up from two-thirds of the US, fifty percent of the EU and one-fifth of humanity as measured in the first world atlas of artificial night sky brightness (Cinzano et al., 2001).

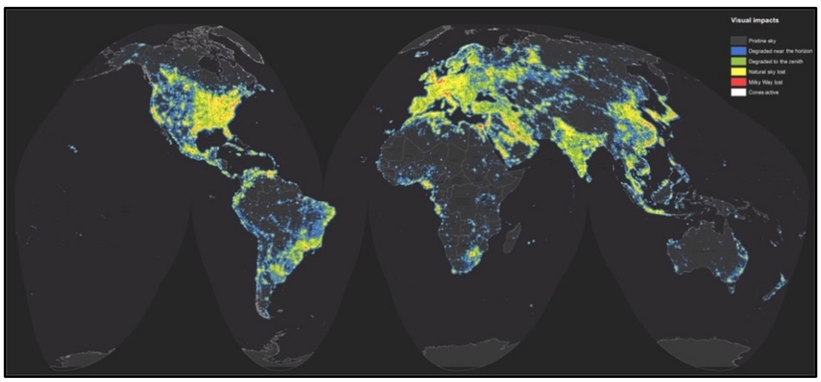



*Figure 2.* Worldwide map of artificial night sky brightness.
Source: Falchi et al., 2016, p. 2

Other researchers have confirmed this trend of increasing artificial lighting worldwide. Hölker et al. (2010) claim that artificial lighting is increasing at a rate of 6% per year worldwide but can be anywhere between 0% - 20% depending on location. For example, Flagstaff is increasing in artificial lighting at a rate of 5% per year (Lockwood et al., 1990).

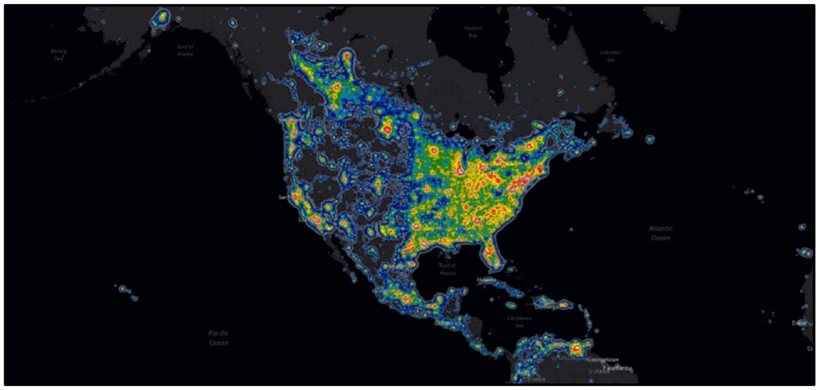


*Figure 3.* Map of artificial night sky brightness in North America.
Source: Falchi et al., 2016, p. 3

As can be seen in Figure 3, there are only a few areas left in the United States with true dark night skies. The diminishing quality of night skies in urban places has increased the need to preserve these last remaining sanctuaries for the enjoyment of current and future generations. Some organizations in the United States have taken the lead in its preservation. The next section will discuss the role the National Park Service has had in preserving its night skies.

### 2.1.2 Dark Skies as Natural Resource in Parks

In the United States, the National Park Service (NPS) is beginning to value and protect their nightscapes. Simon and Babock (1999) found that 94% of all national parks with overnight visitation considered dark night skies a valuable resource. Moreover, they found that 62% of national parks offered some sort of night sky interpretive program and 80% of national parks made efforts to preserve this resource. The National Park Service Organic Act of 1916, which created the NPS, states as part of its mission:

> To conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such

means as will leave them unimpaired for the enjoyment of future generations. ("Organic Act of 1916," n.d.)

The NPS has taken the initiative to include dark night skies as park of the unimpaired scenery that they must strive to protect for current and future generations to enjoy. The NPS has enacted lighting policies aimed at reducing artificial night lighting where it is not needed or wanted. The NPS policy manual states that "improper outdoor lighting can impede the view and visitor enjoyment of a natural dark night sky" (Moore, Duriscoe, Magargal, & Jiles, 2007, p.2). A recent NPS report, "A Call to Action", recommends that parks should "lead the way in protecting natural darkness as a precious resource and create a model for dark sky protection" (National Park Service, 2015, p.18).

One of the first parks in the system to identify dark skies as a natural resource and include them in their management plans was Chaco Culture National Historic Park (CCNHP) in 1993 (Shattuck, & Cornucopia, 2001). Since then, they have replaced bad lighting, shielded lights, or simply removed their lighting to reduce artificial night lighting in the park (Manning, & Anderson, 2012). CCNHP added an observatory in 1998 to enrich its superior stargazing programs that the park was quickly becoming known for. CCNHP is a great example, but they can not preserve night skies on their own; they need help from the large light polluters nearby. Duriscoe, Luginbuhl and Moore (2007) did a survey of over 100 national parks' lightscapes and found that artificial night lighting can travel more than 100 miles from nearby gateway cities. CCNHP has managed to preserve its night skies by working with community organizations, legislators of the state of New Mexico in developing the New Mexico Night Sky Protection Act (Rodgers & Sovick, 2001). This collaborative conservation approach is a stellar example of what must to be done in parks throughout the country to preserve their pristine dark night skies.

The NPS does not only consider dark skies as a natural resource, but they also consider them a cultural resource. The night sky protection initiatives at CCNHP are an example of preserving both the cultural and natural resources there. The next section will discuss this aspect of dark sky sustainability.

### 2.1.3 Cultural Heritage

Our astronomical heritage and the right to enjoy a night under the stars is under threat by widespread overuse of artificial light at night, population growth, urbanization and lack of responsible lighting practices such as light shielding. The Starlight Declaration, adopted in 2007 by UNESCO, claims that "an unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right of humankind equivalent to all other environmental, social, and cultural rights" (Marin, 2011, p.1). Humans have enjoyed millions of years under pristine night skies. It is only in the past hundred years that this facet of reality has become under serious threat.

The cultural heritage value ascribed to the night sky is unmeasurable; it is not something that can be weighted on a scale to measure the trade-offs associated with its loss. Nevertheless, the night sky has provided inspiration and awe to humanity for millennia in the form of art, oral histories, storytelling, creation stories, and mythologies. Famous paintings such as *Starry Night* by Vincent Van Gogh (1889) are testament to this fact. The connection to the night sky was a significant part of lived experiences of our ancestors. Ruggles and Cotte (2010) document scores of cultural heritage sites related to archaeoastronomy and astronomy from all around the world. Some examples include the Navajo star ceilings found in caves throughout the Navajo nation, Stonehenge World Heritage Site, the Pantheon in Rome, the stone circles in Poland, and several contemporary world-class astronomy observatories around the world.

It is clear that dark skies serve as both a natural and cultural resource for humans. Additionally, dark skies have been shown to have significant impacts on wildlife and ecosystems. The following section will discuss these factors.

### 2.1.4 Ecological Impacts

Artificial night lighting also has been shown to have severe negative ecological and biological effects on human, animal, and plant life (Chepesiuk, 2009; Clark, 2006; Nicholas, 2001; Pauley, 2004; Rich, & Longcore, 2006). For example, frogs' reproductive behavior may be modified in brighter night conditions than in dark conditions; they may be less discriminating of their mates in brighter conditions (Rand, Bridarolli, Dries, & Ryan, 1997). One of the most well known effects are the effects of coastal lighting on sea turtle hatchlings. Coastal lighting disorients the hatchlings and instead of heading into the ocean, they head inland toward the lights on the coast (Salmon, Tolbert, Painter, & Reiners, 1995; Witherington, 1997; Witherington, & Martin, 2000). Migratory birds' paths are diverted by towers, buildings, and street lighting during the night. They are being killed in disturbing numbers due to impacting these structures with artificial night lighting. A large body of research has been conducted which indicate that this is a pervasive and growing problem (Rich, & Longcore, 2006). Deviche and Davies (2013) provide an excellent review of the literature on the effects of artificial lighting on various behaviors of birds including reproduction. For example, female blue tits, *Cyanistes caeruleus*, who occupy areas exposed to street lights lay eggs 1.5 days earlier in the spring than females in natural night lighting areas (Kempenaers, Borgström, Loës, Schlicht, & Valcu, 2010). This could be the result of breeding behavior as male tits have been shown to obtain more copulations than non-streetlight exposed males. There have also been studies investigating the signing patterns of songbirds (Miller, 2006). Miller (2006) finds that the American robin, *Turdus migratorius*, sings later into true night when exposed to artificial night lighting than robins who reside in non-lit areas. Other studies have investigated the effects of the spectrum, or color of light, on bird behavior and hormone levels finding significant correlations especially with blue lights (Davies et al., 2011; Foster & Follett, 1985). Exposure of diurnal species to artificial night light can potentially disrupt circadian rhythms, and consequently endocrine and neurobiological parameters that can result in disruption in immune response, metabolism, social interactions, and susceptibility to disease (Deviche & Davies, 2013; Navara & Nelson, 2007).

As naturally diurnal species, humans are not exempt from the impacts of artificial lighting on our health and physiology. The following section will discuss the impacts of artificial lighting on humans specifically.

**2.1.5 Human Health Impacts**

Similar findings are echoed in the medical literature and reports by the International Dark Sky Association and American Medical Association and as to the response and impact of artificial light at night on humans (Blask et al., n.d.; International Dark Sky Association, 2010; Kraus, n.d.). Stevens (2009) presents a comprehensive literature review of more than a hundred publications of the effect of artificial night lighting on humans' circadian rhythms, melatonin production, breast cancer, and a slew of other health effects. The American Medical Association's concludes that:

> The natural 24-hour cycle of light and dark helps maintain precise alignment of circadian biological rhythms, the general activation of the central nervous system and various biological and cellular processes, and entrainment of melatonin release from the pineal gland. Pervasive use of nighttime lighting disrupts these endogenous processes and creates potentially harmful health effects and/or hazardous situations with varying degrees of harm. (Bask et al., n.d., p.1)

A particular focus of both the American Medical Association, the International Dark Sky Association and the research community has been on the impact of blue light on humans and wildlife. This issue is exacerbated by the current trends in replacing outdoor lighting with light emitting diodes (LEDs). A typical outdoor LED's light spectrum is blue-rich, as shown in Figure 4. Humans and diurnal wildlife have peak circadian sensitivity in the blue wavelengths near 450 nm and photopic sensitivity near 560 nm (International Dark Sky Association, 2010). Therefore, for minimal disruption to circadian rhythms and to promote vision at night, lighting is recommended to be in the 560 nm range. The American Medical Association estimates that white LEDs are at least five times more powerful in disrupting circadian physiology than high pressure sodium lights (Kraus, n.d.).

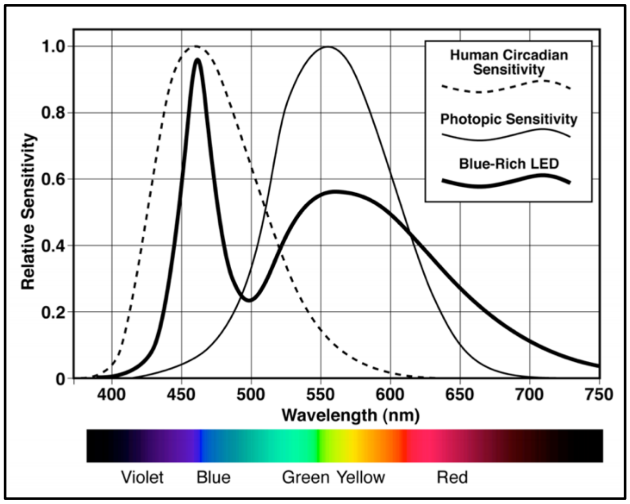



*Figure 4.* Human photopic and circadian sensitivity curves displayed against a blue-rich LED light source spectrum.

Source: International Dark Sky Association, 2010, p. 12

Falchi et al. (2016) model what France would look like if they replace all lighting fixtures with LEDs.  Figure 5 B shows the projection of perceived night sky brightness with 4,000 K LEDs installed as compared to current lighting fixtures (Figure 5 A).

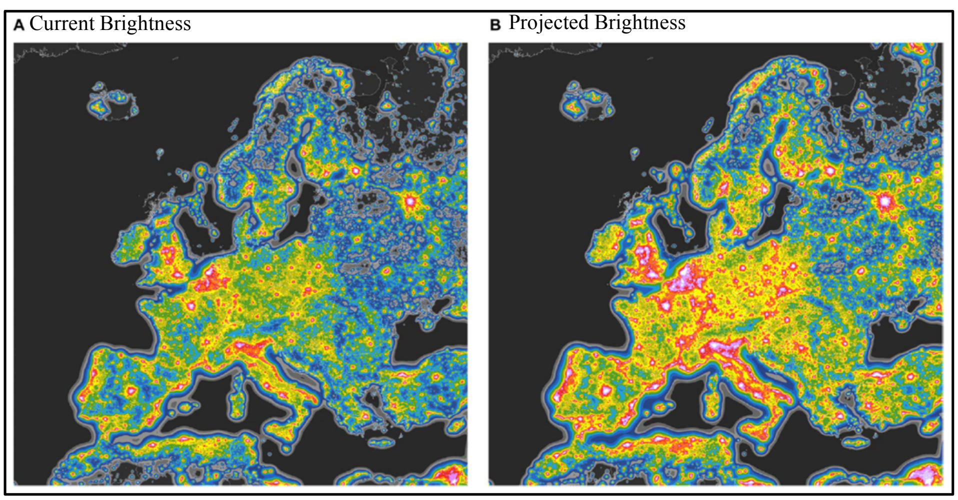



*Figure 5.* Perceived night sky brightness in France with 4000K LEDs.

Source: Adapted from Falchi et al., 2016, p. 5

Although LEDs have less overall energy output, the apparent brightness would increase due to human's photopic sensitivity, thereby exacerbating the effects of artificial night lighting on humans.

Technological innovations may have serious consequences on human and wildlife, such as the LED example, however, they can also help to curb light pollution. Technological innovations, such as LEDs, can also drastically decrease energy use and consequently reduce green house gas emissions. These impacts will be discussed in the next section.

### 2.1.6 Economy, Politics, and Energy Impacts

Artificial lighting is responsible for 19% of total global electricity usage, which is equivalent to green house gas emission of 1900 Mt of $CO_2$ per year (Waide, & Tanishima, 2006). Therefore, policies related to artificial lighting tend to be heavily weighted toward the reduction of energy waste in order to achieve goals. For example, the newly adopted Paris Climate Agreement demands rapid reductions in green house gas emissions. This agreement will be a driver for future innovative lighting projects to reduce emissions. Other factors, such as wildlife impacts, astronomy impacts, human health impacts, and others tends to be overshadowed by these economic and political motives. The Obama administration has adopted a position for more energy-efficient lighting and equipment as part of his climate change policies which could result in the reduction of as much as 20 Mt of $CO_2$ annually (White House, 2009). This focus on energy efficiency in artificial lighting is echoed around the world (Waide, & Tanishima, 2006). However, such focus on energy efficiency and reductions do not always correlate well with decreased energy use per capita. Numerous studies have actually shown the opposite correlation and increases in energy use per capita (Herring, & Roy, 2007; Fouquet, & Pearson, 2006).

Decisions to use blue-rich LEDs may or may not reduce electricity usage, but the use of blue-rich LEDs will have a deleterious affect on the ground-based optical astronomy industry. In Arizona, the economic impact from the astronomy industry is not negligible. It is a significant factor that city planners around the state must consider when weighing the economic trade-offs of using blue-rich LEDs for their artificial lighting needs. The following section will discuss the scientific and economic impacts of lighting on the astronomy industry.

### 2.1.7 Astronomy Impact

In Arizona, dark skies have been shown to have significant economic value to the state due to the state's booming astronomy industry (Pavlakovich-Kochi et al., 2007). The study finds that the astronomy industry generates approximately $252.8 million dollars of activity yearly and is responsible for providing 3,328 jobs (Pavlakovich-Kochi et al., 2007). The study also finds that between 2000 to 2005, Arizona observatories and academic institutions had been awarded $600 million in contracts and grants for astronomy and planetary science research (Pavlakovich-Kochi et al., 2007). The distribution of expenditures of Arizona's astronomy and space science industry can be seen in Figure 6. Artificial lighting threatens the long-term viability of observatories in Arizona and the competitive advantage that Arizona has in recruiting new state-of-the-art observatories. If dark sky quality deteriorates in Arizona, so will the economic impact of its astronomy industry. This situation is mirrored in other countries and cities with major astronomy observatories around the world such as those in Chile (Smith, 2001).

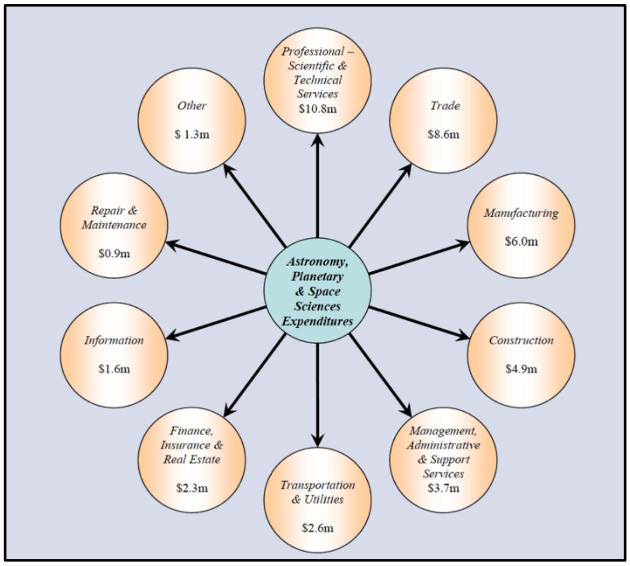
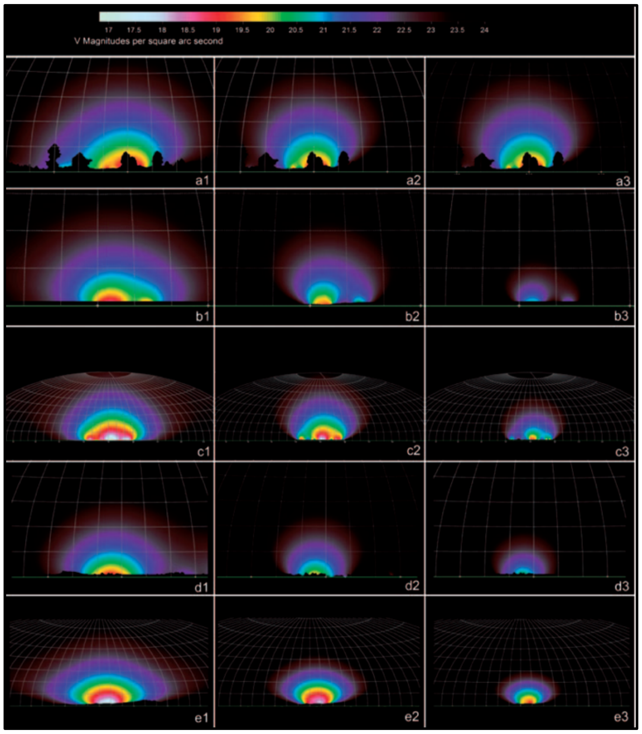



*Figure 6.* Arizona's astronomy, planetary and space science 2006 expenditures.
Source: Pavlakovich-Kochi et al., 2007, p. 21

Artificial lighting has been shown to have some negative impacts to ecosystems, human health, economic vitality, energy efficiency, the astronomy industry, park nightscapes and cultural heritage. The following section will discuss strategies to reduce some of these negative effects.

**2.1.8 Existing Artificial Lighting Mitigation Practices**

Light shield has been shown to be very effective at remedying the negative impacts of artificial lighting at the city and regional level. Duriscoe, Luginbuhl and Elvidge (2014) modeled the effect of shielding lights and adopting tight lighting policies similar to Flagstaff for the cities of Flagstaff, Winslow, Page, Moab and Las Vegas. Figure 7 shows the light domes as they are today (column 1), the predicted light domes with fully shielded lights (column 2), and the predicted light domes with lighting per capita similar to Flagstaff (column 3).




Legend

False color representations of predicted sky glow from outdoor lighting as seen at each observing site in Hammer–Aitoff projection with 108 grid overlay (horizon at bottom, zenith at top) for five cities with three outdoor lighting scenarios. Cities are arranged in rows: (a) Flagstaff, (b) Winslow, (c) Page, (d) Moab, and (e) Las Vegas. Lighting scenarios are in columns.

Column 1: Current Conditions (CC).
Column 2. CC with full shielding
Column 3. Best practices (reductions and shielding)

*Figure 7.* Predicted light domes of shielding and per capita reduction strategies.
Source: Duriscoe et al. 2014, p. 43

Their results indicate that merely shielding existing lighting results in significant decreases in sky glow near the zenith and in surrounding communities. This would have significant impacts in the reduction of light pollution for rural communities, parks and wilderness areas, wildlife, and for astronomical observations.

Combating light pollution is no longer a local issue, but will take a regional, state, and transnational solutions. As can be seen in Figure 8, light pollution from Phoenix affects areas more than one-hundred miles away. Moreover, light pollution from nearby states and the international border with Mexico affect Arizona's night sky quality. This situation is mirrored around the world. Just preserving the dark skies in remote areas will not be sufficient in the future. Therefore, to combat the deterioration of dark skies, key stakeholder groups must come together and collaboratively explore the future of dark skies. Participatory scenario planning workshops such as the scenario planning for sustainable dark skies can help bring key stakeholders together to plan for preserving them around the world.

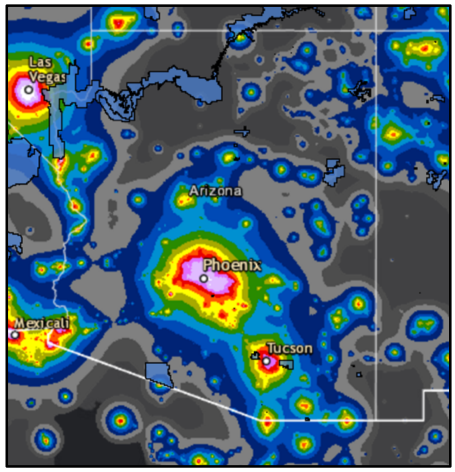



*Figure 8.* Artificial night sky brightness of Arizona.
Source: Falchi et al. (2016)

Finding solutions must take into consideration the entire social-ecological-technical system and the trade-offs that each solution will have. In order to do this, there is a critical need for scholarship which helps one understand the interrelationships between all parts of the system. The following section will discuss the need for this transdisciplinary research agenda.

### 2.1.9 Trandisciplinary Research Agenda

Hölker et al. (2010) write a critical piece of scholarship addressing the need to link research across multiple departments to engage in trandisciplinary research to address the social, ecological, health, economic, and technological issues associated with artificial light at night. Hölker et al. (2010) call for future transdisciplinary research to address five critical questions:

> (1) What characteristics of light disrupt human health and ecological communities, (2) what alternative lighting strategies and policies are politically, culturally, and economically viable, (3) to what extent are users willing to minimize light pollution and adopt alternatives, (4) how does light pollution interact with other stressors such as air, water, and noise pollution, or climate change, and (5) what technologies can address the environmental, health, and economic disadvantages of current lighting practices in different areas or settlement types? (p. 5)

Missing from their list is investigating the existing public knowledge and importance that the public gives to the various aspects of this issue. For researchers and practitioners to find viable solutions to this problem, it is equally important to understand the science of the interactions of various factors as it is how the public perceives the interaction of those factors. The current study will fill this neglected area of research.

Hölker et al. (2010) conceptualize the hypothetical impacts that light pollution has on various aspects of socio-ecological systems in Figure 9. This study will expand upon this work to investigate how stakeholders in general, and sub-groups of stakeholders perceive the importance of these sorts of factors. A similar conceptual model of artificial lighting will be produced, but specifically to model stakeholder's perceptions of the issue. This model will be developed from stakeholders' mental models of dark night skies. The following section will discuss mental model theory, elicitation methods, and analysis methods used in this study.

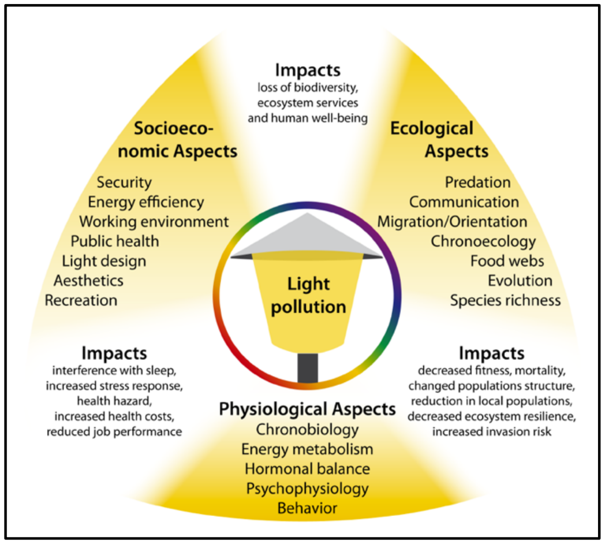



*Figure 9.* Hypothetical impacts of exposure to artificial light at night.

Source: Hölker et al., 2010, p. 5

## 2.2 Mental Models

### 2.2.1 The Development of Mental Model Theory

The concept of a MM has existed in the literature for over seventy years. MMs were first proposed by cognitive psychologist Kenneth Craik (1943). There are now millions of publications regarding MMs applied to a variety of disciplines such as human factors engineering, artificial intelligence, systems dynamics, education, psychology, organization research and NRM. MMs are personal cognitive representations of external reality that guide people's interactions with the world around them and include their individual beliefs, values, and deep set biases (Craik, 1943; Glick et al., 2012; Johnson-Laird, 1983). MMs are scaffolds that new information about the world is constructed onto and stored for future sense-making, decision-making and behaviors. Senge (1990) defines MMs as "deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action" (p.8). Craik proposed that MMs undergo the following process: (1) the translation of an external process into words, numbers, or other symbols, which can function as a model of the world, (2) a process of reasoning from these symbols leading to others, and (3) the retranslation back from the resulting symbols into external processes, or at least to a recognition that they correspond to external processes (Johnson-Laird, 2005). To summarize, they are small-scale internal representations of reality that are called upon to guide a person's interaction with the external world. Models can be run like computational simulations allowing the individual to test different scenarios in their mind before taking action. MMs also assist people with understanding casual-dynamics or the cause-effect relationship between components of the MM. This is a powerful tool for humans to understand and predict complex system behavior (Moray, 1998; Rouse, & Morris, 1986). Because of the computational and cause-effect prediction abilities of MMs, they have been found very useful in automation and artificial intelligence.

Mental model theory was formally established with the publication of cognitive psychologist Paul Johnson-Laird's (1983) book *Mental Model Theory*. Johnson-Laird took Craik's conceptualization of MMs and applied them to understanding how people comprehend information and reason with that information. Johnson-Laird (1983) claims that:

> Mental models enable individuals to make inferences and predictions, to understand phenomena, to decide what action to take and to control its execution, and above all to experience events by proxy; they allow language to be used to create representations comparable to those deriving from direct acquaintance with the world; and they relate words to the world by way of conception and perception. (p. 397)

He tested his mental model theory against formal rules of hypothetical mental logic and showed that they faired better at explaining meaning, comprehension, and discourse. Johnson-Laird (1983) acknowledges that any theory of MMs must limit the total possible sets of MMs by placing conditions or constraints on them. Therefore, central to his mental model theory are ten principle constraints on MMs. These include the principles of computability, finitism, constructivism, economy in models, predictability, innateness, structural identity, and set formation. Additionally, they are constrained by having a finite set of conceptual primitives and they are not computationally intractable, i.e. not having an exponential growth in complexity (Johnson-Laird, 1983). Each of these principles are explained in great detail in chapter fifteen of his book.

There is a prominent disagreement over the location of MMs in the human mind; they may be either embedded in the long-term memory (Bainbridge, 1992; Craik, 1943; Moray, 2004) in working-memory (Johnson-Laird, 1983) or in both (Baddeley, 1986; Nersessian, 2002). Nersessian (2002) finds that numerous studies support the claim that MMs of salient aspects of objects, situations, and processes are situated in long-term memory. Nersessian (2002) shows that MMs in working memory are instead created and used for daily comprehension and reasoning tasks. Nersessian (2002) combines these two seemingly divergent ideas by suggesting that long-term knowledge structures can be called upon to create MMs in working memory used to support reasoning and problem-solving. According to Baddeley (1986) people have different cognitive representations for different purposes such as routine activities, casual scenarios, stories, making causal attributions, problem representations, remembering information about people, and enabling judgmental forecasts. Therefore, it is possible that short-term memory MMs have different functions than long-term memory MMs. There is still no conclusive answer one way or the other. Nevertheless, systems dynamics researchers tend to think of MMs as located in long-term memory whereas those studying reasoning think of MMs as in short-term memory.

### 2.2.2 Limitations and Criticisms of Mental Models

Johnson-Laird's (1983) mental model theory was immediately challenged by proponents of orthodox logical reasoning. Ford (1985) criticized that mental model theory is too vague and crude. For example, she says that use of symbols such as Ann → Car could represent Ann loves a car, Ann owns a car or Ann is in a car. This ambiguity is at odds with formal rules of logical inference using clearly defined premises to come to conclusions. Johnson-Laird and Byrne (1989) responded to the formal logicians' criticisms by carrying out several tests between mental model theory and rule-based theories showing the superiority of MMs over rule-based theories. Rips (1994), an orthodox rule-based supporter, critiqued their study claiming that the experiments were not carried out precisely. For example, he claimed that the researchers asked participants to use spatial arrays in solving problems, which may have biased them to use an imaginal strategy favoring the predictions of mental model theory over formal rules of logic. Johnson-Laird (1997) responded to this critique to mental model theory by asserting its superiority over rule-based approaches presented in Rips (1994). Schaeken, Girotto and Johnson-Laird (1998) conducted a study to test the predictions of mental model theory and concluded that their findings were in accordance with mental model theory and were very problematic for Rips (1994). For example, mental model theory predicts that one-model problems are easiest to solve, multi-model problems are the next hardest, and multi-model problems with no-valid-conclusions are the most difficult. Their study supported these predictions and others. Schaeken, Vandierendonck, Schroyens and d'Ydenwalle's (2007) book, *The Mental Models Theory of Reasoning,* collects various studies which uphold and further refine mental model theory. Nevertheless, proponents of formal rules of logic continue to vehemently refute mental model theory and Johnson-Laird (2010) continues to tout the value of mental model theory over formal rules of logic: "perhaps the most immediate sign of the difficulty of a formal approach to reasoning is that arguments in daily life are not laid out like formal proofs" (p. 195). The jury is still out to conclusively condemn or accept mental model theory over formal rules of logic in mental reasoning. There are other criticisms of mental models beyond the formal logic arguments. These are discussed below.

Norman (1983), an author in the field of human-machine interaction, has described MMs as unstable, incomplete and even unscientific. Others in the field of human-machine interaction have confirmed his assessment of MMs as being oversimplified and inaccurate models of human-machine interactions (Borgman, 1986; Moray, 1987). Forrester (1971) criticizes the unstable and incomplete nature of MMs: "The mental model is fuzzy. It is incomplete. It is imprecisely stated. Furthermore, within one individual, a mental model changes with time and even during the flow of a single conversation" (p. 112). Forrester (1992) describes another fundamental limitation of MMs; he claims that even a skilled investigator is quite unreliable in anticipating the behavior of simple information-feedback systems of even as little as fix to six variables (p. 46). Sterman (1994) agrees with Forrester (1992) and adds further criticisms to the mental model theory claiming:

> People generally adopt an event-based, open-loop view of causality, ignore feedback processes, fail to appreciate time delays between action and response and in the reporting of information, and are insensitive to non-linearities that may alter the strengths of different feedback loops as a system evolves. (p. 305)

These limitations are well-documented in the literature (Doyle & Ford, 1998; Groesser & Schaffernicht, 2012) and have been confirmed in numerous empirical studies (Moxnes, 2000; Moxnes, 2004, Sterman 1989; Sterman, 2008). MMs suffer from critical deficiencies and should not be relied upon as infallible, accurate models of systems. This is why computer algorithms and models have superseded MMs in their computational and predictive capabilities especially for use in system dynamics.

Another major criticism of mental model theory comes from Argyris and Schon's (1974) theories of action. They claim that what people say they will do, their espoused theory, often varies widely from the actual action they take, their theory in use. One's MM may exist in one's mind but be completely divorced from what they do in reality. A person may, for instance, believe that all foreigners are evil yet invite a foreigner into their home and become friends with them. This dilemma makes it impossible for researchers to ensure that MMs are valid and reliable representations of a person's internal representation of reality.

Lastly, it is important to note that elicitation of MMs may also change one's MM during the process of eliciting them. Since MMs may exist in working memory, they are prone to alteration. Jones, Ross, Lynam and Perez (2014) explored how different methods of MM elicitation resulted in altering the MMs expressed by their subjects. They found that MMs completed at home were denser and more generic than those completed in the field which featured more concepts and were more specific. However, they found that there was no significant difference in MMs due to the type of interview task.

Despite these criticisms and limitation, MMs continue to find widespread use; this is evidenced by nearly two million journals and book publications on MMs and more than 11,000 citations of Johnson-Laird's (1983) seminal work to develop the theory. The next section discusses different techniques that are used for MM elicitation in the literature.

### 2.2.3 Mental Model Elicitation Techniques

There have been a whole host of diverse techniques applied to attempt to elicit people's MMs (Carley &Palmquist, 1992; Grenier & Dudzinsk-Przesmitzki, 2015; Jones et al., 2011). Critical reviews of these techniques can be found in Carley and Palmquist (1992), Hodgkinson, Maule and Brown (2004), and Jones et al. (2011). The classic methods were of one of three types: Content analysis (Namenwirth, & Weber 1986; Stone, Dunphy, Smith, & Ogilvie, 1966), procedural mapping (Leinhardt, 1988; vanLehn, & Brown, 1980) and task analysis (Ericsson, & Simon, 1980; Newell, & Simon, 1972), and cognitive mapping (Naveh-Benjamin, McKeachie, Yi-Guang, & Tucker, 1986; Reitman, & Rueter, 1980; Shavelson, 1972). Content analysis tends to focus on creating MMs out of textual data or interview notes. Procedural mapping and task analysis seek to explore the step by step reasoning in the development of a MMs through think-aloud protocols or the detailed analysis of how a particular task is accomplished. Cognitive mapping is the direct mapping of concepts and the relationships between them. Carley and Palmquist (1992) claim that cognitive mapping is the most effective and useful of all of these classical methods due to the ease of elicitation, comparability of experts and novice maps, classroom learning and studies of decision-making. Building on cognitive mapping, Carley and Palmquist (1992) develop a computerized systematic method for analyzing large numbers of cognitive maps using computer software. This procedure has been used extensively to elicit MMs since then.

Grenier and Dudzinski-Przemitzki (2015) suggest a composite method for eliciting MMs that combines multiple elicitation approaches into one called the Multi-method Mental Model Elicitation (MMME). They claim that relying on only one method, such as the cognitive maps, can miss key information about someone's MM. They suggest a combination of graphical elicitation either by author-generated free-hand drawings of MM maps or computer-aided software with verbal elicitation techniques. Since the MMME is a new method, the MMME has yet to be used in more than one isolated dissertation study.

Kearney and Kaplan (1997) designed a systematic approach to eliciting MMs called the Conceptual Content Cognitive Map (3CM). In this approach, the cognitive map is seen as a network of concepts or mental objects serving as nodes with associations between them serving as paths or links. Fundamental to the 3CM is the concept of ownership. Only those concepts that the person truly owns and has made sense of in their MM is included into the 3CM.

Another approach to MM elicitation is consensus analysis. Consensus analysis, originating in the field of cognitive anthropology, investigates the distribution of shared knowledge across a group of people. It is an information pool that is shared among individuals. The approach is elaborated in great detail in Stone-Jovicich, Lynam, Leitch and Jones (2011). Essentially, it includes open-ended interviews, free listing, pile-sorts, and rankings of content and then applying factor analysis and cluster analysis to measure the degree of consensus among individuals. It is superior to the others methods above in mapping a shared MM of a group of people to determine difference between them. However, it requires time-intensive resources.

A well vetted procedure that has been used in NRM to elicit MMs is called the ARDI Method and is outlined in detail in Etienne, DuToit and Pollard (2011). ARDI is an acronym of the four French words “Acteurs”, “Ressources”, “Dynamiques”, and “Interactions” that constitute a four step method of eliciting stakeholder MMs a system. In the end, it results in a shared conceptual representation of a system which describes the stakeholders, resources, dynamic processes and interactions between all components of the system. The ARDI method is therefore well poised to examine the difference between individual and collective MM, or to monitor the changes in MMs during a collaborative process (Etienne, DuToit, & Pollard, 2011; Lynam et al., 2012). Lynam et al. (2012) recommends using ARDI in conjunction with consensus analysis to gain the most robust understanding of a group’s shared MM.

Gray, Zanre, and Gray (2014) lists several method of MM elicitation for both groups and individuals for conducting cognitive mapping, as well as the tradeoffs associated with them. It is a good place to start when deciding on an elicitation technique and aligning it with a project’s research goal. There is a plethora of available methods in the literature to elicit MMs for NRM contexts and each has its advantages and disadvantage. There is clearly no one-size-fits-all approach to MM elicitation. It depends on each individual research study’s needs and the cognitive, physical, and temporal demands placed on participants.

### 2.2.4 Summary of the Mental Model Theory and Elicitation Literature

The review of the literature of mental model theory has revealed an overwhelming number of contrasting perspectives of what a MM is as well as the most appropriate ways to elicit them. Borrowed from cognitive psychology, mental model theory has permeated into all disciplines interesting in understanding how people conceptualize a problem, reason, comprehend information, or model a system. Each discipline has taken the liberty to define their own definition of MMs to suit their discipline's specific needs. This has been a powerful impetus for the growth of MMs. Although millions of publications have been written about MMs in hundreds of different disciplines, the theory itself remains in question. Mental model theory is primarily a theory of reasoning and has been challenged extensively by proponents of rule-based logic. Although numerous critiques of MMs and rule-based logic have been made over the past thirty years, there has yet to be a consensus in the literature as to which is superior to explain reasoning.

The literature reveals that MMs suffer from several critical limitations that prevent them from being valid and reliable models of reality. MMs suffer from the inability of humans to factor in time delays, feedback loops and multiple variables. Nevertheless, these limitations do not prevent a NRM social scientist from valuing the insights gained from analyzing an individual or group's MM. The limitations of individuals' MM are precisely what makes them important for a NRM social scientist. The discrepancies between how stakeholders conceptualize a system and the way the system really behaves is crucial information. MMs can help us to determine these discrepancies and allow NRM practitioners to address them. Humans are taking action and making decision about natural resources using their incomplete, inaccurate, oversimplified and dynamic MMs. These actions then alter the system resulting in negative impacts to resources. It is imperative that NRM practitioners understand how these faulty models impact natural resources to plan for their effective management. The following section will discuss how to analyze mental models once they have been elicited using one of the abovementioned approaches.

### 2.2.5 Mental Model Analysis

Mental model analysis can be descriptive, such as extracting a MM from an interview, or evaluative. Evaluative analysis has tended to focus on computational and statistical metrics after importing or directly eliciting MMs in digital formats. Carley and Palmquist (1992) pioneered these computational methods. Gray et al. (2014) lists several traditional metrics that researchers have used since then such as number of concepts, number of connections, complexity (transmitter/receiver concepts), density, number of connections divided by number of concepts, and so forth. For example, Nadkarni (2003) investigated the role of different instructional methods on students' MMs. She uses the measures of comprehensiveness, which she defines as number of concepts, and density, which she defines as number of linkages divided by number of concepts, to measure the degree of complexity of her students' MMs. Ifenthaler (2010) imports concept maps into the software HIMATT to evaluate written text versus drawn concept maps. Hoffmana, Lubella, Hillisa (2014) analyze several regional MMs of California farmers' definitions of sustainable agriculture. After creating MMs from textual definitions, the MMs are analyzed using social network analysis techniques to get the centrality values for each concept in the definition. They uploaded their MMs into ORA Network Analysis software to compute the eigenvector centrality for each concept. The occurrence probability of those concepts were then measured by taking the number of times that concept appears in any map, divided by the total number of maps in the sample. Finally, they measure prominence by multiplying the centrality score by the occurrence probability to identify the most important concepts related to the farmers' conceptualization of sustainable agriculture. Statistical analysis was then done using Stata. The MM analytical approach taken in this study will resemble the social network analysis followed by Hoffmana et al. (2014). The next section reviews in detail how social network analysis can be used to measure the centrality of mental models.

There are a variety of ways to measure the centrality of MM concepts using social network analysis. These include degree centrality, betweeness centrality, closeness centrality, eigenvecture centrality, information centrality and others (Landherr, Friedl & Heidemann, 2010).

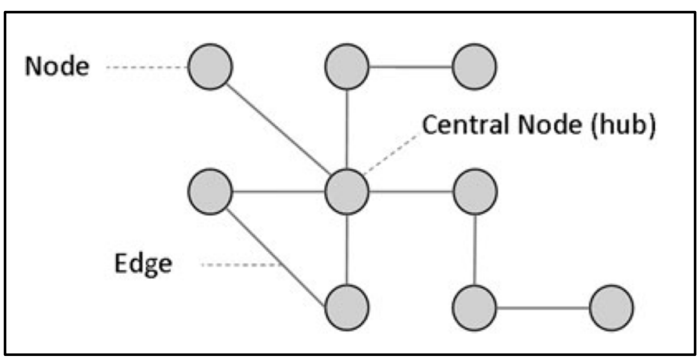



*Figure 10.* Sample social network and terminology.

Source: Landherr et al., 2010, p. 372

Figure 10 shows an example of network structure consisting of nodes and edges with a central node. Nodes are the circles, concepts, or actors in the network. Edges are the links or ties connecting nodes. Centrality refers to the measure of importance of a node in a network, such as the central node in Figure 10. Each of the abovementioned centrality measures attempts to assign a value to a nodes' centrality in a social network so that key actors or nodes can be identified. However, even for simple networks, there is no consensus for how to measure centrality (Borgatti, & Everett, 2006). Rather, a plurality of centrality measures exists for a multitude of context-specific interpretations of the centrality of a node for achieving different research objectives (Borgatti, & Everett, 2006). Degree centrality is measured as the total number of direct incoming and outgoing edges or links (Nieminen, 1974). This is the most rudimentary centrality measure. Closeness centrality is a measure of all of a node's shortest paths or geodesics to all other nodes in the network (Beauchamp, 1965). Another approach, betweeness centrality, is interested in the role of intermediaries between nodes. Betweeness centrality is calculated using the quotient of the number of geodesics with a given node appearing between nodes, and the total number of geodesics in the network (Shaw, 1954). More complex measures of centrality include the influence of adjacent nodes or actors. These include eigenvector centrality (Bonacich, 1972) and information centrality (Stephenson, & Zelen, 1989) among others (Katz, 1953; Lee, Yook, & Kim, 2009). Eigenvector centrality neglects multiple shared paths between points. The information centrality measure differs from eigenvector centrality in that it aims to make use of all possible paths between two pairs of points, rather than only the geodesic (Stephenson, & Zelen, 1989). Information centrality appreciates that it is quite possible that flows can make a more circuitous route between nodes rather than only the geodetic path. The metric gives paths relative weights associated with the amount of information each one contains. Thus, this metric is particularly useful for understanding "temporal changes in networks, and changes in networks when nodes and/or communication links are added or deleted" (Stephenson, & Zelen, 1989, p. 3). Since this project will be investigating MM changes and the addition or deletion of nodes to the MMs, information centrality is well poised to measure the change. Moreover, since information centrality incorporates all possible paths between two nodes instead of just the geodesic, it is a reasonable measure of a complex socio-ecological-technical system such as dark skies.

This project will be eliciting and analyzing mental models of dark skies and determining if they are altered during scenario planning. The following section describes the theory of scenario planning and its relationship with learning and mental model alteration.

**2.3 Theoretical Model of Scenario Planning**

Participatory workshops for envisioning the future have been used extensively around the word for decades, however, there is a lack of an empirically tested theory to explain their efficacy (Chermack, 2004a, Shipley, 2002; Shipley, & Michaela, 2006; van der Helm, 2009). Instead, those facilitating visioning and scenario workshops tend to do so with tacit assumptions about its benefits and outcomes (Shipley, 2002). The majority of the scholarship concerning visioning and scenario workshops focus on the step-by-step protocol for how to conduct them (Senge, 1990; Walzer, 1996; Ziegler, 1991) rather than building a theoretical foundation (Shipley, 2002). Shipley (2002) investigates the underlying theoretical assumptions that people hold about visioning workshops and the validity of those claims. Shipley (2002) reveals that several of the underlying theory-like statements that people attribute to visioning are suspect and deserve further investigation to determine their validity. Clearly, there is a need to develop a strong theoretical foundation of visioning and scenario planning to guide planners using this strategy.

The sustainability transitions literature offers insights into some of the benefits to be gained from participatory visioning and scenario workshops. They claim that these workshops offer a deliberative, reflexive, and open space for participants from various groups to negotiate alternative sustainability visions and pathways (Leach, Scoones, & Stirling, 2007, 2010). The transitions management literature discusses the need for transition arenas where persistent sustainability problems are conceptualized and alternative solutions compared and integrated (Loorbach, 2010). It stimulates new coalitions, partnerships, and networks to create new ways of thinking. These frameworks explain some of the benefits of scenario planning, but they do not explicitly discuss participants' cognitive processes occurring during the scenario planning process. Since understanding participants' cognitive processes is the focus of this study, Chermack's (2005) theory of scenario planning was chosen for testing and refinement. Chermack's (2005) theory of scenario planning claims to explain the cognitive development of participants in response to participation in scenario planning. The theory of scenario planning is discussed in detail below.

Chermack's (2004a, 2005) theory of scenario planning is based on the foundation that learning is a central aspect of the scenario planning process. Organizations and groups engage in scenario planning workshops to rethink assumptions, challenge existing paradigms, make sense of complexity, anticipate the uncertainties of the future, and improve their decision-making abilities under uncertainty. It seems intuitive that these all have a learning component. Several authors have suggested that learning is fundamental to scenario planning (Chermack & van der Merwe, 2003; de Geus, 1988; Schwartz, 1991; van der Heijden, 1996). Empirically, Henly-Shepard et al. (2015) demonstrated that individual and organizational learning occurred in a coastal island community doing scenario planning for disaster management. They also claim that learning is a critical aspect of building adaptative capacities and improved decision-making in preparing for hazards. Chermack (2004a, 2005) integrates the effect of scenario planning on learning into his theory.

Figure 11 shows the categorical and sequential laws that constitute the theory of scenario planning. According to the theory, every unit the process must happen in order to proceed from the act of scenario planning through improved firm, organization or group performance. If any link of the chain in the sequence is removed, the results of the scenario planning workshop are compromised. As mentioned above, scenarios are most likely associated with learning. A better understanding of the topic is purported to be reflected in one's conceptualization and model of the problem or systems (i.e. the mental model). If one has an improved and more accurate MM, it is purported that they will be able to make more accurate and effective decisions using their MM of the system. If better decisions are made, it is claimed that outcomes will improve. A classic example is Shell's weathering of the 1973 oil crisis. Shell was one of the first companies to pioneer the use of scenarios as early as 1960 (Cornelius, Van de Putte, & Romani, 2005). Shell learned strategies to mitigate their risk to an oil crisis. They adjusted their mental models of the entire oil production and use system to better understand system dynamics and feedback loops. When a shock hit the market in 1973 due to Iraq's invasion of Kuwait, they were prepared to act on the strategies they planned during the scenario workshops.

Their decisions and insights gleaned from the scenario process helped the company to survive and even thrive in volatile times like 1973 (Cornelius et al., 2005). Ultimately, scenario planning lead to learning, which lead to improved mental models, which lead to better decisions being made under uncertainty, which lead to better outcomes and performance of the company. Chermack's (2005) claim would be that better performance would not have been possible without following each step of the scenario planning process.

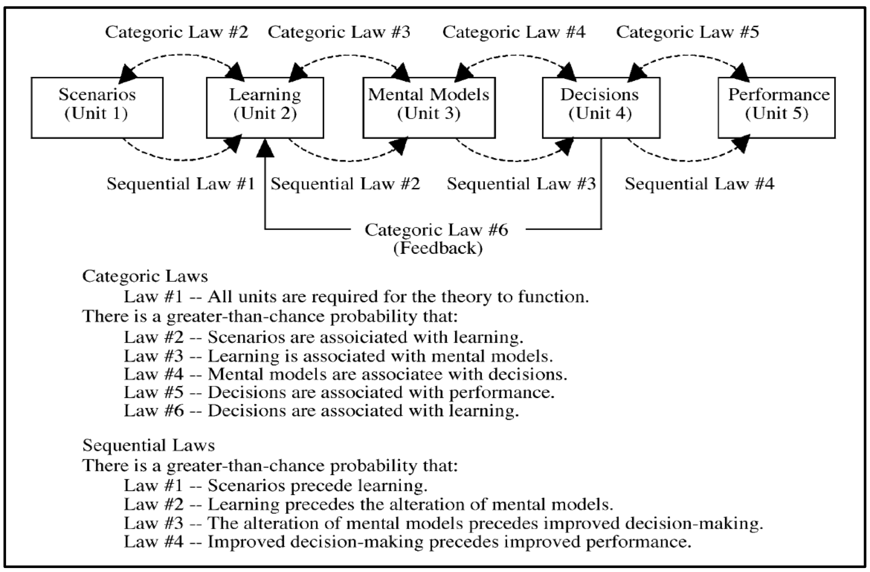



*Figure 11.* The laws and interactions in the theory of scenario planning.
Source: Chermack, 2005, p. 64

Chermack (2005) proffers several hypotheses of the effects of scenario planning that future research can seek to empirically test. Figure 12 shows the relationship between the units in the theoretical model. The proposed research study will investigate hypotheses one, two, and five of the theory using the catalyst of scenario planning as the treatment. It is beyond the scope of this one study to investigate the effects on the other factors (i.e. decision-making and performance). Delayed interviews or follow-up surveys would need to be conducted for all participants to investigate thoroughly how the scenario planning process, knowledge gain, and mental model alteration lead to improved decision-making and performance. In the context of dark sky conservation, this would mean investigating behaviors and strategies that they used to decrease their contribution to light pollution months after the workshop. This may also include investigating overall artificial light output at their home or work. This particular study did not have the time and financial resources to perform these additional tasks and analyses. Future research should test these components.

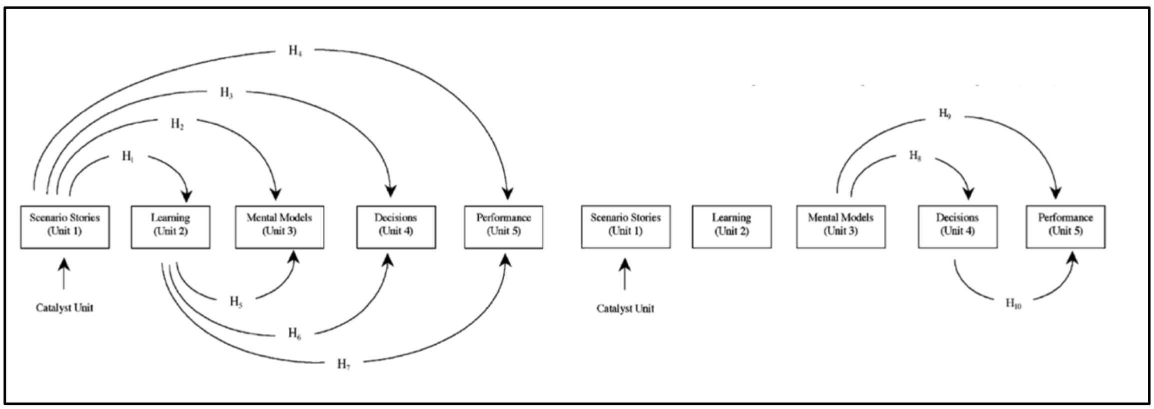



*Figure 12.* Hypotheses of the theory of scenario planning.

Source: Chermack, 2005, p. 69

Figure 13 shows the theoretical relationship between a MM and decision-making. Chermack (2003) argues that MM are used in making decisions, and if we can improve on them, we will have better decision outcomes. Mental models are used in each phase of the decision-making system from problem framing, deciding on a course of action, producing outcomes, and providing feedback to reframe new problems. As scenario planning was created to help people make decisions under uncertainty, Chermack (2005) included the link between MMs and decision-making into the sequence of the theory of scenario planning.

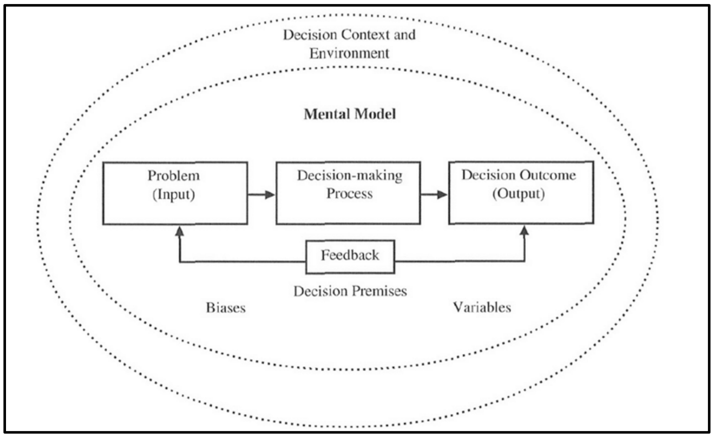



*Figure 13.* Decision-making system with mental models.

Source: Chermack, 2003, p. 415

Scenario planning has been argued in the in literature to challenge MMs and improve upon them (Chermack, 2003; Chermack, 2004b, Georgantzas, & Acar, 1995; Senge, 1994; Schwartz, 1991; van der Heijden, 1996). Franco, Meadows and Armstrong (2013) empirically show that participants' cognitive learning styles must match with the learning activities employed during the scenario workshop to maximize the benefits obtained from the workshop (e.g. learning and improved performance). Glick et al. (2012) study the effects of scenario planning on MMs. Specifically, their results show that scenario planning promotes efficiency, social, and systems MM styles, with moderate effect sizes (Glick et al, 2012). However, few empirical studies, such as these, have been done to explicitly test these relationships and rather provide anecdotal evidence for a conceptual link between the two (Chermack, 2004b). There have been studies linking MMs to improved decision-making, but not explicitly in scenario planning. Stout, Cannon-Bowers, Salas, and Milanovich (1999) empirically found that planning helped improve a team's shared MM and consequently improved decision-making. These studies suggest that a link may indeed exist. There continues to be a need for future empirical studies to explore the nature of the direct link between scenario planning and participants' MMs.

Studies have also investigated the differences in novice and expert reasoning skill in solving problems and several authors have claimed that skill in mental model development develops with learning (Ippolito, & Tweney, 1995; Neressian, 1995; 2002). Thus, greater knowledge and experience should lead to an even greater increase in MM complexity during the scenario workshops. This study will also determine if this is indeed true.

Future empirical studies may also suggest new linkages to the nascent theory. Chermack's (2004a, 2005) theory of scenario planning does not attempt to address the role of attitudes in decision-making. If attitudes are a significant factor in determining behaviors, then it may be worthwhile to explore to role of scenario planning on changing environmental attitudes.

**2.4 The Theory of Planned Behavior & Environmental Attitudes**

The section will attempt to draw a link between environmental attitudes and decision-making for natural resource management using the theory of planned behavior. Environmental attitudes in this study refer to ''both a specific attitude directly measuring intentions or more broadly to a general attitude or value orientation'' related to pro-environmentalism (Fransson & Garling, 1999, p. 370). The TPB provides a strong theoretical justification for linking attitudes to decision-making. The TPB is a robust and empirically tested theory which has linked attitudes, perceived behavioral control, and subjective norms to intentions, which ultimately affect behaviors (Ajzen, 1985; Ajzen, 1991). Figure 14 shows the conceptual model of the theory.

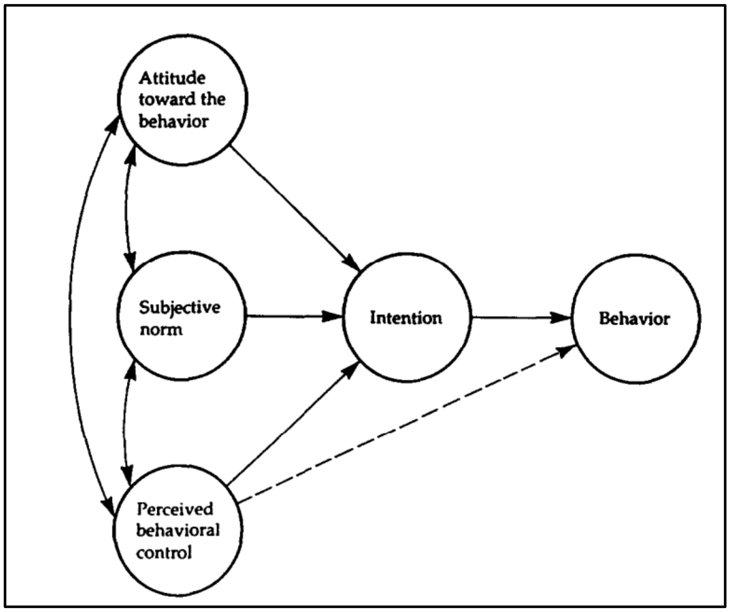



*Figure 14.* Theory of planned behavior.

Source: Ajzen, 1991, p. 182

Attitudes, subjective norms, and perceived-behavioral control are all considered behavioral beliefs in this model. Attitudes toward a behavior reflect an individuals' positive or negative evaluation of a behavior. The subjective norm is characterized by how others will approve or disapprove of the action. Perceived-behavioral control is the perception of control that a person has in actually being able to perform a behavior; it is the perception of being able to access the resources and have the opportunity to perform the behavior (Ajzen, 1991). Each of these beliefs are mediated by intentions. Intentions are the motivational factors that determine if a behavior will be performed or not; they determine how much effort someone is willing to put forward to perform the behavior (Ajzen, 1991, p. 181). For example, the more positive attitude a person has about a behavior, the stronger the intention will be to perform it. Similarly, the stronger the intention the more likely the behavior will actually be performed.

Reviews (Blue, 1995; Conner, & Sparks, 1996; Jonas, & Doll, 1996) and meta-analyses (Ajzen, 1991; Armitage, & Conner, 2001; Godin, & Kok, 1996; Hausenblas, Carron, & Mack, 1997) have demonstrated strong support of the theory. Armitage and Conner (2001) conducted the most thorough meta-analysis of the theory. They reviewed 185 articles published between 1985 and 1997 and concluded that the TPB was responsible for 27% and 39% of the variance in behaviors and intention respectively.

The TPB is presented as support for the claim that environmental attitudes should be considered as a possible link in the theory of scenario planning. The issue is then how to measure environmental attitudes. Fielding, McDonald and Louis (2008) conduct a study of environmental attitudes, identity and environmental advocacy using the TPB. To measure environmental attitudes, they used the NEP. The NEP is one of the most well-known instruments for measuring environmental attitudes, but there have been several criticisms, refinements, and suggestions for its use over the years.

Coinciding with the environmental justice movement, Dunlap and Van Liere (1978) produced a 12-point scale called the New Environmental Paradigm Scale to measure environmental concern. The scale was refined to include bipolar items: one pro-environmental worldview and anti-environmental worldview for each of the three facets in the survey (balance of nature, limits to growth, and anthropocentrism). Albrecht, Bultena, Hoiberg and Nowak (1982) first raised concerns about the scales' unidimensionality, and several ensuing studies have found the original scale to include between one to five components (Dunlap, 2008; Nooney, Woodrum, Hoban, & Clifford, 2003). In 2000, Dunlap made minor revisions to the scale attempting to increase its internal reliability (Dunlap et al., 2000). The revised scale has become known as the

Revised New Ecological Paradigm Scale and is considered more theoretically sound than the original scale (Dunlap, 2008). Dunlap recommends that researchers use the Revised NEP for measuring environmental worldview and then use the results of factor analysis to determine to treat the scale as multidimensional or not (Dunlap et al., 2000). Therefore, recent research has continued to conduct exploratory factor analysis to identify component factors of the NEP (Budruk, Thomas & Tyrell, 2009; Lou & Deng, 2008).

In addition to the NEP instrument, a recreation specialization instrument will be used in this study. The next section describes the history of the recreation specialization literature and various instrument options for measuring it.

**2.5 Recreation Specialization**

Recreationists can pursue a recreation activity with various degrees of intensity. This phenomenon has become known as recreation specialization. Bryan (1977) was the first to pioneer work in this field. Bryan (1979) defines recreation specialization as a "continuum of behavior from the general to the particular" (p. 29). Williams and Huffman (1986) define it as a "preference for and a way of thinking about the objects, events, or ideas of a domain that is comparatively advanced" (p. 343). Scott and Shafer (2001) expand Bryan's (1977) work and redefine recreation specialization as a progression in behaviors, skills and commitment.

There has been a lack of agreement in the literature on the specific dimensions of recreation specialization (Scott, & Shafer, 2001; Tsar, & Liang, 2008). This construct was first attributed to attitudes and preferences, but later Bryan (2000) emphasized a behavioral aspect of the continuum to reflect the length and degree of engagement with the activity. Over the years, some researchers have only considered the behavioral dimensions (Ditton, Loomis, & Choi, 1992; Donnelly, Vaske, & Graefe, 1986), some have only considered the attitudinal dimensions (McIntyre, 1989; Shafer, & Hammit, 1995) while the great majority have combined both attitudes and behavioral dimensions (Bricker, & Kerstetter, 2000; Kuentzel, & McDonald, 1992; McFarlane, 1994; Virden, & Schreyer, 1988). Furthermore, McIntyre and Pigram (1992) refine the recreation specialization scale to include attributes, skills and knowledge as representations of the cognitive indicators, and past experience and familiarity as behavioral indicators. The instruments created for measuring recreation specialization have primarily been used for measuring specialization in outdoor recreation activities such as hiking, biking, camping, boating, bird-watching, fishing and hunting (Scott, & Shafer, 2001). Although various instruments exist to measure recreation specialization, they tend to have several overlapping components. The current study will adapt the instrument originally created by McFarlane (1994) who approaches specialization as consisting of both attitudinal and behavioral dimensions.

Bryan (2000) suggests that recreationists toward the higher part of the spectrum may have more resource management knowledge regarding their leisure activity than those near the low or mid specialization section. In the context of dark sky resource management, recreationists such as amateur astronomers and stargazers may have more knowledge and insights into the management of this resource than do non-specialists. This perspective is supported by the specialization framework proposed by Tsar and Liang (2008).

Tsar and Liang (2008) propose four antecedents of recreation specialization which link specialization to learning: learning competency, learning will, learning assistance, and learning environment.  Their conceptual model of the relationships between learning and specialization are shown in Figure 15.

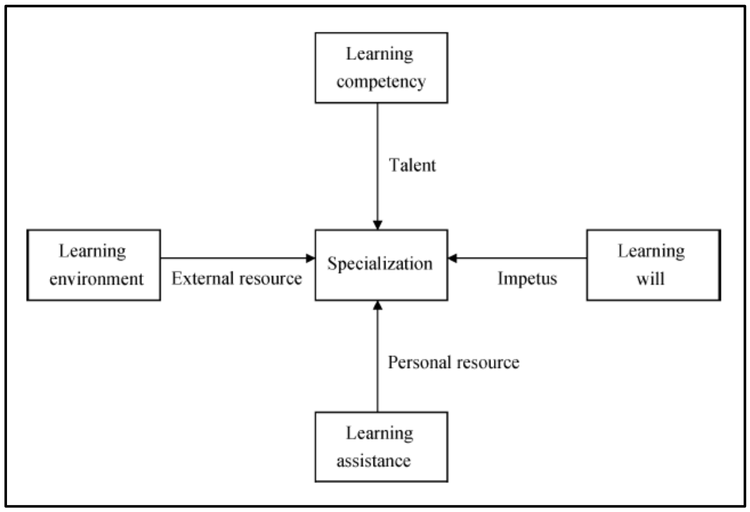



*Figure 15*. Antecedents of recreation specialization.
Source: Tsar and Tiang, 2008, p. 329

Tsar and Liang (2008) suggest that specialists attribute their success to their talents (learning competency) and effort (learning will).  The learning environment refers to the external resources, support, and training that the recreationists have access to.  The more external resources available, the more likely they are to move up in the recreation specialization continuum.  Lastly, learning assistance refers to the personal resources that recreationists have to support their activities (e.g. money and time).

**2.6 Summary of Research Gaps**

This chapter has revealed several research gaps which will be addressed in this study.  These gaps are summarized in this section.  Recent publications in natural resource management call for more studies investigating stakeholders' mental models of natural resources (Jones et al., 2011).  There does not exist any study to date which investigates MMs of dark skies. This study addresses this gap by directly eliciting stakeholders' MMs of dark skies.

Hölker et al. (2010) call for transdisciplinary research to investigate the problem of light pollution. Hölker et al. (2010) also develop a preliminary conceptual model of the factors associated with light pollution. Their list is not comprehensive enough. This study will identify other salient factors by eliciting them from expert stakeholders regarding artificial lighting.

The review of the literature revealed that an empirically sound theory of scenario planning is still yet to be developed. Although several theoretical frameworks can be used to assign value to and identify the benefits of the scenario planning process, more experiments are needed to ground them empirically. In particular, the theory of scenario planning merits further investigation. This study directly measures several of the hypotheses of the theory of scenario planning (i.e. learning and mental model alteration). The theory of scenario planning is also quiet about the effect of scenario planning on attitudes. This study will test the effect of scenario planning on environmental attitudes to determine if there could be a relationship.

# Chapter 3

# METHODOLOGY

This is a mix-methods research study employing both qualitative and quantitative research methods. Qualitative methods included interviewing, scenario planning and mental modeling. Quantitative methods included pre and post questionnaires, social network analysis, and statistical analysis of the MMs. Due to the nature of exploring stakeholder's understandings of dark night sky sustainability, qualitative methods were needed to elicit the most salient factors that were previously unknown and unexplored in the literature. Quantitative methods were required to test portions of the theory of scenario planning for learning, MM alteration, and environmental attitudes. Below is a description of each of these methods and the operationalization of the project's variables.

## 3.1 Operationalization of Variables

The dependent variables in this study were environmental attitudes, prominence of categories of MM concepts, and the complexity (comprehensiveness, linkages, density and average information centrality) of MMs. Independent variables included dark sky knowledge, stargazing experience and dark sky advocacy experience. Demographic characteristics included gender, age, ethnicity, income, education, location, city type, and stakeholder group.

Age was originally recorded as the decade and year in 1900 that they were born. Therefore, this had to be recoded using the equation, 'AgeNew' = 116 – 'Age'. The other demographic variables were coded as they appear in Appendix B part five of the pre-test.

Environmental attitudes were measured using the Revised NEP (Dunlap et al., 2000) consisting of fifteen questions which were measured on a five-point Likert scale: 1=Strongly Disagree, 2 = Moderately Disagree, 3 = Unsure, 4 = Moderately Agree, and 5 = Strongly Agree. After factor analysis, individual items belonging to a component were averaged together to obtain a mean score for each component.

A six-question instrument was created for measuring dark sky knowledge asking questions about their knowledge of social/cultural, economic, ecological, political, technological and light pollution mitigation factors. These questions are aligned to the STEEP protocol from Chermack (2011) that was used in the scenario workshops. The six questions can be found in the dark sky knowledge section of the pre-test questionnaire in Appendix B. The abovementioned five-point Likert scale was also used for measuring dark sky knowledge. Dark sky knowledge questions had to be reoriented; negatively-oriented questions one, thee and five had to be reoriented positively in order to add to questions two, four and six to produce the overall dark sky knowledge index. Specifically, the following recoding scheme was used to convert the negatively-oriented questions: 1 = 5, 2 = 4, 3 = 3, 4 = 2, and 5 = 1.

Stargazing experience questions were created according to the recreation specialization literature by transforming questions related to serious bird-watching (Tsaur, & Liang, 2008) into their equivalent questions relating to stargazing. Their instrument was adapted from McFarlane's (1994) specialization instrument which measures three dimensions of specialization: past experience, centrality-to-lifestyle, and economic commitment. Questions such as "personal involvement", "frequency of birding in 2004", "bird-identification abilities", "number of birding magazine and subscriptions", "number of birding books" , and "number of species on life list" were replaced by "level of personal involvement with stargazing", "number of times I went stargazing since September 2015", "constellation identification abilities", "number of stargazing/astronomy magazines and subscriptions",  "number of stargazing/astronomy books I own", and "approximate number of night sky objects I have seen through a telescope/binoculars (comets, nebula, galaxies, star clusters, planets, moons, the sun, etc.) over the course of my life" respectively.  The resulting list of questions can be found in parts three and four of the pre-test in Appendix B.

The stargazing experience index was operationalized as the mean of the scores of equipment cost, equipment number, number of books, stargazing times, stargazing skill level, constellation identification abilities, personal involvement with stargazing, and number of objects seen.  The stargazing skill level and constellation identification questions were recoded as: 1 = 'Poor', 2 = 'Fair', 3 = 'Good', 4 = 'Very Good', and 5 = 'Excellent'.  Level of personal involvement was recoded as: 1 = 'Very Low', 2 = 'Low', 3 = 'Medium', 4 = 'High, and 5 = 'Very High'.  The questions below were modified in order to put them on a five-point scale, like the other questions that make up stargazing experience, in order to combine them into one index.   Equipment cost was originally an interval variable, but was recoded into five groups: 1 = \$0, 2 = \$1 to \$100, 3 = \$1001 to \$2000, 4 = \$2,000 to \$3,000, and 5 = \$3,000 or higher.  Equipment number was originally an interval variable, but was also recoded into five groups: 1 = 0, 2 = 1, 3 = 2, 4 = 3, 5 = 4 or higher.  Book number was originally an interval variable, but was also recoded into five groups: 1 = 0, 2 = 1 to 3, 3 = 4 to 6, 4 = 7 to 9, 5 = 10 or higher. Stargazing times was originally an interval variable, but was also recoded into five groups: 1 = 0, 2 = 1 to 2, 3 = 3 to 4, 4 = 5 to 6, 5 = 7 or higher. The question, number of night sky objects, was originally an interval variable, but was also recoded into five groups: 1 = 1 to 25, 2 = 26 to 50, 3 = 51 to 75, 4 = 75 to 100, 5 = 100 or higher.

Dark sky advocacy experience was operationalized as the total number of 'Yes' responses on questions one to nine in the dark sky advocacy and experience section of the questionnaire. The 'Yes' and 'No' responses were coded '1' and '0' respectively.

Mental model complexity was broken down into multiple sub-components including comprehensiveness, linkages, density, and average information centrality. The comprehensiveness variable was operationalized as the total number of concepts or nodes in a MM. The linkage variable was operationalized as the number of incoming and outgoing edges per node. Density was operationalized as the quotient of the total number of edges and total number of nodes. Information centrality is defined using the Stephenson and Zelen (1989) method proposed for measuring the centrality of networks. In essence, the number represents a measure of centrality which takes into consideration all possible paths between pairs of points weighted by the information they contain. The occurrence probability of a concept is defined as the quotient of the number of times the concept appeared in any map by the total number of concept maps in the analysis. The average prominence value of a concept across all subjects is defined as the product of the average normalized information centrality score and the occurrence probability score. These variables are on the same scale: both the average normalized information centrality score and the occurrence probability score range from zero to one so multiplying these together results in a range of prominence values from zero to one.

### 3.2 Subject Recruitment

Since the study involves human participants, the subjects were recruited according to a strict protocol and informed of their rights and privacy regarding participation. The study was granted exempt category after a review by the Arizona State University Institutional Review Board pursuant to federal regulations (Appendix I). Subjects were recruited strategically for this workshop to bring together diverse professional, activist, community, and research stakeholder groups throughout Arizona with informed opinions about dark skies. Specifically, organizations and individuals representing professional and amateur astronomers, environmental conservationists, researchers, parks and recreation employees, local and state government and land managers were targeted. A few targeted graduate-level classes on sustainability and community development were also invited. Invitation letters were sent via email or handed in person to individuals and organization leaders to distribute to members of their organization. Potential participants who wanted to participate but who were unavailable for the scenario workshops were invited to participate in the interviews. Two-hundred invitation letters were distributed in this fashion. Thirty-eight participants registered for one of the workshops and four for the interview. Six registered for the rehearsal workshop on Sept 10 and twenty-one registered for the workshops on Sept 16 and Sept 21. Eleven participants did not show up to the workshops resulting in a final count of twenty-seven total participants. Therefore, a participation rate of 31/200 or 15.5% was obtained. The reasons provided by respondents for not participating was having to miss a full work day, having a conflicting engagement, or being out of town.

### 3.3 Scenario Planning Protocol

The scenario planning process was modeled after the recommendations and protocols found in Chermack (2011).   This protocol included eliciting factors using the Social, Technical, Ecological, Economic, and Political (STEEP) protocol, sorting critical factors into importance/uncertainty levels, voting on key factors, creating a two by two scenario matrix and finally creating scenario narratives.  The lecture portion of the workshop was prepared by the researcher.  Content for the lecture was prepared from the literature review presented in chapter 2.  A rehearsal scenario workshop was conducted to refine the workshop protocol as well as to test the validity and reliability of the survey instrument and mental modeling approach.  The workshop took place on September 10, 2016. Lessons learned from the rehearsal workshop include having to explicitly demonstrate the procedure for creating a concept map as many participants were not familiar with the process.  Moreover, traditional 8 in by 11 in copy paper was given to participants to draw their concept maps which was quickly apparent that it was not sufficient size for the majority of participants.  Instead, it was suggested to use 11 in by 17 in paper.  Some participants used pens to create their maps which also created issues. The researcher made sure to provide and insist that participants use pencils in the ensuing workshops.  The dark sky knowledge questions that were in negative form used to read "I do not know any…" whereas the positive form was "I know several…".  It was recommended to replace the negative form to align with the positive form because "any" may simply mean one factor or method whereas "several" means multiple factors. Therefore, the questions were changed to "I do not know several…".  The students wanted to learn more about the specific details of the results of the "New World Atlas of

Artificial Light at Night" (Falchi et al., 2016). These were added to the lecture portion of the workshop. The participants finished the scenario workshop quicker than anticipated, so the researcher adjusted the time of the subsequent workshops to finish at 3:00 P.M. rather than 4:00 P.M. as originally planned. Overall, the rehearsal workshop was critical to refine the timing and planning of the subsequent scenario workshop activities.

**3.4 Data Collection**

The interviews were conducted via phone or in-person and lasted between fifteen to forty-five minutes. The interviewees were asked questions about the key factors affecting or being affected by artificial night lighting. A semi-structured interview approach was used with key question prompts which are found in Appendix E. Informed consent was obtained verbally after reading the consent script to interviewees.

The scenario workshops used for data analysis took place from 9:00 A.M. to 3:00 P.M. on September 16 and 21, 2016. The September 21 scenario workshop agenda is included in Appendix A. The researcher facilitated the workshop and provided the initial lecture on dark sky sustainability since he has an educational background in astronomy, sustainability, parks and recreation, education and tourism. Two colleagues of the researcher were recruited to help take notes and facilitate the workshop.

First, participants signed a consent to participate form. Following introductions and an example of how to construct a concept map, the workshops began with a questionnaire to solicit participants' attitudes, demographic information, and MMs of dark skies (pre-test). The pre-test questionnaire is included in Appendix B. The questionnaire took approximately thirty minutes to complete. Following the questionnaire, there was a lecture for forty-five minutes on light pollution and dark sky sustainability which shared information on the impacts of artificial light at night and mitigation strategies. This served as the traditional lecture treatment to compare to the knowledge gain and environmental attitude change between the lecture and scenario planning parts of the workshop. Following this overview, the post-test 1 was given which only included environmental worldview and knowledge gain questions and took five minutes to complete. The post-test 1 questionnaire is included in Appendix C. After a short break, participants collectively discussed and placed factors on a scale of high/low uncertainty and high/low impact. This took about one hour and fifteen minutes. Afterwards, they ranked the factors showing high uncertainty and high impact from highest to lowest importance by voting on those factors using twenty poker chips. This took thirty minutes. The top two critical uncertainties were then selected as the critical uncertainties and placed in the scenario matrix which looks like a Cartesian graph. The four quadrants of the scenario matrix represented high factor 1 and high factor 2, high factor 1 and low factor 2, low factor 1 and high factor 2, low factor 1 and low factor 2. Participants were then broken up into three groups of three to four and asked to create a scenario narrative for one of the four quadrants. A fifteen-minute introduction to scenario planning was presented by the researcher. The scenario narrative writing part of the workshop took about forty-five minutes. These narratives were then shared aloud at the close of the workshop for about thirty minutes followed by the post-test 2 which took about thirty minutes. Post-test 2 included environmental attitude, dark sky knowledge, and MM questions. The post-test 2 questionnaire is included in Appendix D.

### 3.5 Data Analysis

The interviews were transcribed from the voice recordings and coded using Atlas.ti version 1.0.50. Coding was done inductively. The codes generated were used to create the hundred and ten concepts presented to subjects in the pre-test and post-test 2 concept mapping activity. The codes also served as a resource to obtain quotes from interviewees regarding salient concepts found in the scenario workshops.

The hand-drawn concept maps were digitalized using the online software called Mental Modeler Suite. Adjacency matrices for each concept map were exported from Mental Modeler for use in social networking analysis software. In order to compare concept maps across all stakeholders, a code-book was created to link various words used to represent the same or very similar concept. Codes were not generated from any theoretical framework or prior research; codes were generated using inductive coding. The MM code-book is included in Appendix F. Once all concepts were re-coded, the adjacency matrices were updated with the new codes and uploaded into Social Network Visualizer (SNV) 2.0. SNV was used to export the information centrality values, comprehensiveness, linkages and density of each subjects' concept map into SPSS for statistical analysis. The prominence, the product of the information centrality and occurrence probability values, was used to rank the most salient factors for all stakeholders and for individual stakeholder groups (astronomers, government/parks employees, ecologists/biologists, and sustainability scientists). In order to determine the most salient type of factors, individual concepts were further coded and classified as associated with major emergent themes (i.e. astronomy, economics, environment, politics, society/culture and technology). The categories were also coded inductively.

The category codebook created for this purpose can be found in Appendix G. The average prominence percentages of these major themes were then compared across the abovementioned stakeholder groups.

IBM's Statistical Package for the Social Sciences (SPSS) Version 23.0.0.2 64-bit edition was used to analyze all data collected from the survey instrument. Descriptive statistics (frequencies and percentages) were performed for the demographic variables (gender, age, education, income, ethnicity, residence, city type, and stakeholder groups) in the survey. Exploratory factor analysis using principal components analysis (PCA) was performed on the NEP, dark sky knowledge, dark sky advocacy experience, and stargazing experience questions to identify component factors. Factor loadings of $\geq 0.50$ were considered for further analysis. Chronbach's alphas were calculated on the resulting factors to determine their reliability: factors receiving less than the suggested alpha score of 0.70 (Cortina, 1993) were dismissed from further analysis. A one-way repeated measures ANOVA and the least significant distance (LSD) post-hoc test was used to measure statistical significance between the pre, post-test 1, and post-test 2 environmental attitudes and dark sky knowledge gain. Mauchy's Test of Sphericity was used to determine whether these variables violated assumptions of sphericity. The effect of the treatment, scenario planning, on MM complexity change was measured by conducting paired-sample t-tests on the pre-test and post-test 2 interval measures of MM complexity (i.e. concepts, linkages, density and information centrality). Paired-sample t-tests were also run to test for statistically significant differences between the pre-test and post-test prominence values for the MM concept categories. One-way ANOVA was used to determined if there was any statistically significant difference between the prominence values of the concept categories. Linear regression models were run to analyze the effect of the interval variables of dark sky expertise (i.e. dark sky knowledge, stargazing experience dark sky advocacy and average information centrality) on the complexity metrics of participants' altered MMs (number of concepts, number of linkages, density, and average information centrality).

Chapter 4

RESULTS

### 4.1 Profile of Participants

The profile or demographic characteristics of the scenario planning participants are presented in Table 1. The sample was skewed toward being more female (57.1%) than male (42.9%). Since the majority of students were recruited to join the rehearsal workshop, there are no study participants below the age of 25. The age ranged from 26 years to 75 years (mean = 52.8 years, median = 55 years). The median household income was between $100,000 to $149,000. All participants indicated that their highest earned degree was at least a four-year degree. 28.6% had graduate degrees and 23.8% earned a PhD or equivalent degree. 95.2% (n = 20) of participants reported their ethnicity as White and only 4.8% (n = 1) reported being Asian. The study consisted of stakeholder groups from Maricopa County (81%), Pinal County (9.5%), Pima County (4.8%) and Cochise County (4.8%). Participants represented various types of cities including urban (46.6%), suburban (38.1%) and rural (14.3%).

Participants were able to select all stakeholder groups which they associate themselves with. Table 2 lists the number and percentages of the various stakeholder groups who participated in the workshop. The largest stakeholder groups were sustainability scientists (28.6%), government (28.6), parks and recreation (28.6%), astronomers (28.6%), environmental organizations (28.6%), ecologists/biologists (23.8%), dark sky advocates (23.8%), and higher education (23.8%). Notable stakeholders missing from the group were economists and engineers.

Table 1

*Sociodemographic Information of Scenario Workshop Participants.*

| *Parameter* | *Frequency* | *%* |
|---|---|---|
| Gender *(N=21 )* | | |
| Male | 12 | 42.9 |
| Female | 9 | 57.1 |
| Age in years *(N =21, Mean = 52.8)* | | |
| 26-35 | 3 | 14.3 |
| 36-45 | 3 | 14.3 |
| 46-55 | 6 | 28.6 |
| 56-65 | 5 | 23.8 |
| >65 | 4 | 19.0 |
| Household Income *(N = 21, M = $100,000 - $149,000)* | | |
| $25,000 - $49,999 | 3 | 14.3 |
| $50,000 – $74,999 | 4 | 19.0 |
| $75,000 - $99,999 | 2 | 9.5 |
| $100,000 - $149,999 | 10 | 47.6 |
| > $150,000 | 2 | 9.5 |
| Education Completed *(N = 21)* | | |
| Four-year college | 10 | 47.6 |
| Master degree | 6 | 28.6 |
| PhD or equivalent | 5 | 23.8 |
| Ethnicity (N = 21) | | |
| Asian | 1 | 4.8 |
| White | 20 | 95.2 |
| Hispanic/Latino *(N = 21)* | | |
| Yes | 1 | 4.8 |
| No | 20 | 95.2 |
| Residence *(N = 21)* | | |
| Maricopa County | 17 | 81.0 |
| Pinal County | 2 | 9.5 |
| Pima County | 1 | 4.8 |
| Cochise | 1 | 4.8 |
| City Type *(N = 21)* | | |
| Urban | 10 | 47.6 |
| Sub-Urban | 8 | 38.1 |
| Rural | 3 | 14.3 |

Table 2

*Frequency and Percentage of Stakeholder Group Representation in Scenario Workshops.*

| *Stakeholder Groups (N = 21)* | *Frequency* | *%* |
|---|---|---|
| Sustainability Scientist | 6 | 28.6 |
| City Planner | 2 | 9.5 |
| Social Scientist | 4 | 19.0 |
| Ecologist/Biologist | 5 | 23.8 |
| Astronomer (Professional or Amateur) | 6 | 28.6 |
| Dark Sky Advocate | 5 | 23.8 |
| Park Manager | 3 | 14.3 |
| Educator | 4 | 19.0 |
| Graduate Student | 3 | 14.3 |
| Parks & Recreation | 6 | 28.6 |
| Government Organizations | 6 | 28.6 |
| Higher Education | 5 | 23.8 |
| Environmental Conservation Organization | 6 | 28.6 |
| Non-Government Organization | 4 | 19.0 |
| Neighborhood Group | 2 | 9.5 |

Note: Participants selected all groups to which they belong.

Table 3 lists the primary stakeholder group that individual participants were assigned based on the job title and organization supplied during registration. The primary stakeholder group classification was used for comparing prominent MM concepts and themes across stakeholder groups.

Table 3

*Subject List and Primary Stakeholder Group Representation.*

| *Subject* | *Primary Stakeholder Group* | *Subject* | *Primary Stakeholder Group* |
|---|---|---|---|
| 7 | Astronomer (Professional or Amateur) | 21 | Sustainability Social Scientist |
| 8 | Dark Sky Advocate | 22 | Ecologist/Biologist |
| 9 | Parks & Recreation | 23 | Government/Environmental Organization |
| 11 | Parks & Recreation | | |
| 13 | Sustainability Social Scientist | 24 | Parks & Recreation |
| 14 | Sustainability Social Scientist | 26 | Ecologist/Biologist |
| 15 | Astronomer (Professional or Amateur) | 27 | Ecologist/Biologist |
| 16 | Sustainability Social Scientist | 31 | Parks & Recreation/Government |
| 18 | City Planner/Government | 33 | Ecologist/Biologist |
| 19 | Dark Sky Advocate | 35 | Astronomer (Professional or Amateur) |
| 20 | City Planner/Government | 36 | Astronomer (Professional or Amateur) |

Note: Participants were assigned a primary stakeholder group based on the job title and organization supplied during registration.

### 4.2 Factor Analysis & Reliability of Measures

Exploratory factor analysis with varimax rotation and Kaiser normalization was conducted on the NEP items from post-test 2 resulting in four components with eigenvalues larger than 1. The least important, Factor 4, returned an eigenvalue of 1.26 and explained 12.16% of the variance. Scale items seven and four were loaded on Factor 4 with values of 0.852 and 0.586 respectively. Chronbach's alpha (α) for Factor 4 ($\alpha = 0.542$) was lower than the a priori decision to only retain factors with values > 0.70 as suggested by Cortina (1993). Therefore, Factor 4 was removed from further analysis along with item seven since it did not sufficiently load on any other factor. Item six loaded most on Factor 1 (-0.491). Since it did not load sufficiently on any of the factors it was discarded. Item 8 was heavily cross-loaded on Factors 1 (-0.862) and Factor 2 (0.511) and so was discarded. Item ten was also heavily cross-loaded on Factors 1 (0.685) and Factor 2 (0.580) and so was discarded. The result is three factors with Chronbach's alpha (α) of ecological limits ($\alpha = 0.91$), anthropocentrism ($\alpha = 0.74$) and balance with nature (α = 0.73) all with adequate reliability scores. Table 4 lists the individual scale items associated with each component and their respective factor loadings. Although the original scale is intended to represent one factor, these results are consistent with the literature which has shown between one and five possible factors for environmental attitudes identified using the NEP (Budruk et al., 2009; Cordano, Welcomer, & Scherer, 2003; Lou, & Deng, 2008). The three identified factors matched up fairly well with the empirical NEP results of Lou and Deng (2008) and Budruk et al. (2009).

Table 4

*Principle Components Analysis of the Revised NEP Items Ecocrisis, Anthropocentrism, and Balance with Nature*

| Component | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|
| Ecocrisis | | | |
| 1 We are approaching the limit of the number of people the earth can support. | **0.82** | 0.15 | 0.12 |
| 5 Humans are severely abusing the environment. | **0.92** | -0.11 | 0.03 |
| 13 The balance of nature is very delicate and easily upset. | **0.88** | -0.07 | 0.25 |
| 15 If things continue on their present course, we will soon experience a major ecological catastrophe. | **0.89** | -0.32 | -0.07 |
| Anthropocentrism | | | |
| 2 Humans have the right to modify the natural environment to suit their needs. | -0.17 | **0.64** | -0.24 |
| 4 Human ingenuity will insure that we do NOT make the earth unlivable. | -0.19 | **0.65** | -0.13 |
| 12 Humans were meant to rule over the rest of nature. | 0.09 | **0.76** | -0.52 |
| 14 Humans will eventually learn enough about how nature works to be able to control it. | -0.07 | **0.80** | 0.08 |
| Balance with Nature | | | |
| 3 When humans interfere with nature it often produces disastrous consequences. | 0.38 | -0.03 | **0.89** |
| 9 Despite our special abilities humans are still subject to the laws of nature. | -0.20 | -0.19 | **0.92** |
| 11 The earth is like a spaceship with very limited room and resources. | 0.44 | -0.09 | **0.56** |
| Eigenvalue | 6.39 | 2.53 | 1.82 |
| Percentage of variance explained | 42.61 | 16.88 | 12.16 |
| Total percentage of variance explained | | 59.49 | 71.65 |
| Standardized Chronbach's alpha | 0.91 | 0.74 | 0.73[a] |

[a] without item 11 α = 0.53. PCA conducted with varimax rotation and Kaiser normalization.

The dark sky knowledge questions were created by the researcher. Therefore, exploratory factor analysis was needed to determine reliability of the measurement. PCA was completed for dark sky knowledge questions one through six and produced one factor. Table 5 presents the results of the factor analysis with each questions' factor loadings. Results of reliability testing revealed a Chronbach's alpha of $\alpha = 0.94$ for Factor 1. The strong factor loadings and reliability measure suggest that these questions are a reliable measure of dark sky knowledge. Feedback from participants at the rehearsal workshop suggests that these questions are valid representations of their knowledge.

Table 5

*Principle Components Analysis of Dark Sky Knowledge Questions.*

| Component | Factor 1 |
|---|---|
| Dark Sky Knowledge | |
| 1 I do not know any socio-cultural factors associated with artificial night lighting | **-0.92** |
| 2 I know several technological factors associated with artificial night lighting | **-0.94** |
| 3 I do not know any ecological factors associated with artificial night lighting | **-0.69** |
| 4 I know several economic factors associated with artificial night lighting | **0.87** |
| 5 I do not know any political factors associated with artificial night lighting | **0.96** |
| 6 I know several methods to reduce the impact of artificial night lighting on night sky quality | **0.82** |
| Eigenvalue | 4.56 |
| Percentage of variance explained | 75.93 |
| Standardized Chronbach's alpha | 0.94 |

The dark sky advocacy questions were also created by the researcher. Therefore, exploratory factor analysis was necessary to determine reliability of the measurement. PCA was completed for dark sky advocacy questions one through nine and produced two factors. Table 6 presents the results of the factor analysis with each questions' factor loadings. Results of reliability testing revealed a Chronbach's alpha of $\alpha = 0.876$ for

Factor 1 and α = 0.838 for Factor 2. Factor 1 was identified as questions relating to dark sky advocacy whereas Factor 2 was identified as questions regarding one's commitment and behaviors to mitigate the effects of artificial night lighting defined as dark sky commitment. The total variance explained was 50.760 for dark sky advocacy and 19.539 for dark sky commitment for a total of 70.299. The strong factor loadings and reliability measure suggest that these questions are a reliable measure of dark sky advocacy and commitment.

Table 6

*Principal Components Analysis of Dark Sky Advocacy Experience.*

| Component | Factor 1 | Factor 2 |
|---|---|---|
| Dark Sky Advocacy | | |
| 1 Contacted a public/community official or manager about a dark sky conservation issue | **0.729** | 0.391 |
| 2 Attended a meeting/conference/talk on dark sky conservation issues (other than this study) | **0.661** | 0.463 |
| 3 Contributed money to a dark sky conservation organization | **0.895** | -0.032 |
| 7 Was involved in a community dark sky conservation project | **0.778** | 0.217 |
| 8 Was a member of a dark sky conservation group (e.g. International Dark Sky Association) | **0.86** | 0.078 |
| Dark Sky Commitment | | |
| 4 Reduced the amount of outdoor lighting at my work or primary residence | 0.072 | **0.868** |
| 5 Shielded outdoor lighting at my work or primary residence | 0.01 | **0.857** |
| 6 Replaced outdoor lighting fixtures to ones which are more dark-sky friendly at my work or primary residence | 0.322 | **0.805** |
| 9 Educated friends, neighbors, family about dark sky conservation issues | 0.42 | **0.608** |
| | | |
| Eigenvalue | 4.568 | 1.758 |
| Percentage of variance explained | 50.760 | 19.539 |
| Total percentage of variance explained | | 70.299 |
| Standardized Chronbach's alpha | 0.876 | 0.838 |

Note: PCA conducted with varimax rotation and Kaiser normalization.

The stargazing experience questions were adapted from McFarlane (1994). Therefore, exploratory factor analysis was needed to determine reliability of the measurement. PCA was completed for stargazing experience questions in part three of pre-test 1 and produced 1 factor. Table 7 presents the results of the factor analysis with each questions' factor loadings. Results of reliability testing revealed a Chronbach's alpha of α = 0.94 for Factor 1. The strong factor loadings and reliability measure suggest that these questions are a reliable measure of stargazing experience level. Feedback from participants at the rehearsal workshop suggests that these questions are valid representations of their knowledge.

Table 7

*Principle Components Analysis of Stargazing Experience Level.*

| Component | Factor 1 |
|---|---|
| Stargazing Experience Level | |
| Approximate number of night sky objects I have seen through a telescope/binoculars (comets, nebula, galaxies, star clusters, planets, moons, etc.) | **0.824** |
| Level of personal involvement with stargazing | **0.867** |
| My constellation identification ability level is | **0.906** |
| My stargazing skill level is | **0.938** |
| Number of times that I went stargazing since September 2015 | **0.677** |
| Number of stargazing/astronomy books I own | **0.898** |
| Number of stargazing equipment (e.g. telescopes, binoculars, planisphere, astrophotography equip, etc.) items that I own | **0.798** |
| Approximate stargazing equipment replacement value | **0.915** |
| Eigenvalue | 5.870 |
| Percentage of variance explained | 73.373 |
| Standardized Chronbach's alpha | 0.940 |

Participants' dark sky knowledge and environmental attitudes were tested at three points during the workshop: at the beginning (pre-test), after the lecture (post-test 1), and at the end of the workshop (post-test 2). Therefore, a repeated measures ANOVA test was selected to determine if there were any significant changes between tests for each of these dependent variables. Table 8 shows the results of the repeated measures ANOVA. There was a statistically significant difference in dark sky knowledge as determined by one-way repeated measures ANOVA ($F = 23.531$, $p < 0.000$). The Greenhouse-Geisser test of statistical significance was used since dark sky knowledge failed Mauchly's Test of Sphericity. A LSD post hoc test revealed that dark sky knowledge was statistically significantly improved on post-test 1 (4.317 ± 0.154, $p < 0.000$) and post-test 2 (4.650 ± 0.80, $p < 0.000$) as compared to the baseline knowledge on the pre-test (3.450 ± 0.272). There was also a statistically significant difference between the post-test 1 (4.317 ± 0.154) and post-test 2 (4.650 ± 0.80, $p = 0.008$).

Environmental attitude was broken into its new sub-components (ecological limits, anthropocentrism, and balance with nature). The variable ecological limits passed Mauchly's Test of Sphericity, but failed to show any statistically significance difference between tests as determined by one-way repeated measures ANOVA ($F = 0.059$, $p = 0.943$). The variable anthropocentrism passed Mauchly's Test of Sphericity and there was a statistically significant difference as determined by one-way repeated measures ANOVA ($F = 4.306$, $p = 0.021$). A LSD post hoc test revealed that anthropocentrism statistically significantly decreased of post-test 2 (1.750 ± 0.175, $p = 0.014$) as compared to the baseline anthropocentrism measured on the pre-test (2.083 ± 0.187). There was also a statistically significant decrease in anthropocentrism as measured between post-test 1 (2.050 ± 0.203, $p = 0.026$) and post-test 2. There was no statistically significant difference between the pre-test and post-test 1 ($p = 0.797$). The variable balance with nature failed Mauchly's Test of Sphericity so the Greenhouse-Geisser test of statistical significance was used to measure statistical significance. There was a statistically significant difference in balance with nature as determined by one-way repeated measures ANOVA ($F = 6.312$, $p = 0.009$). A LSD post hoc test revealed that balance with nature statistically significantly improved between post-test 2 (4.667 ± 0.137, $p = 0.001$) and the baseline balance with nature measured on the pre-test (4.383 ± 0.153).

There was also a statistically significant increase in balance with nature as measured between post-test 1 (4.300 ± 0.167, $p = 0.008$) and post-test 2. There was no statistically significant difference between the pre-test and post-test 1 ($p = 0.498$).

Table 8

*Results of Repeated Measures ANOVA and Post-Hoc LSD Tests.*

| *Measure* | *Pre-Test Mean* | *Post-Test 1 Mean* | *Post-Test 2 Mean* | *F Value* | *Sig* |
|---|---|---|---|---|---|
| Dark Sky Knowledge | $3.45^{a}$ | $4.32^{b}$ | $4.65^{c}$ | 23.531 | 0.000 |
| Ecological Limits | $4.34^{a}$ | $4.36^{a}$ | $4.38^{a}$ | 0.059 | 0.943 |
| Anthropocentrism | $2.08^{a}$ | $2.05^{a}$ | $1.75^{b}$ | 4.306 | 0.021 |
| Balance with Nature | $4.38^{a}$ | $4.30^{a}$ | $4.67^{b}$ | 6.312 | 0.009 |

Note: $^{a,b,c}$ indicate statistically significance differences at or below the 0.05 level, $n = 20$. The range of each measure is from one to five. Anthropocentrism is in the opposite direction as compared to the other measures. A lower score for anthropocentrism means a higher pro-environmental attitude.

Paired-samples t-tests were run to measure the effect of the scenario planning on the MM complexity dependent variables. Table 9 lists the means, standard deviations, and results of the paired-samples t-tests. There were no statistically significant differences in the MMs as measured by the following measures of complexity: comprehensiveness ($t = 1.462$, $p = 0.163$), linkages ($t = -4.773$, $p = 0.163$), density $t = -0.45$, $p = 0.964$) and information centrality ($t = -0.205$, $p = 0.840$).

Table 9

*Paired Samples T-Test Results for Participants' Pre and Post Scenario Planning Mental Models.*

| *Measure* | *Pre-Test Mean* | *Pre-Test SD* | *Post-Test Mean* | *Post-Test SD* | *t-statistic* | *Sig* |
|---|---|---|---|---|---|---|
| Comprehensiveness | 32.000 | 12.031 | 28.471 | 13.159 | 1.462 | 0.163 |
| Linkages | 38.235 | 15.853 | 33.941 | 16.806 | 1.053 | 0.308 |
| Density | 1.188 | 0.201 | 1.192 | 0.294 | -0.45 | 0.964 |
| Information Centrality | 0.4279 | .240 | 0.4453 | 0.280 | -0.205 | 0.840 |

*n = 17*

Although it was found that overall the MM complexity did not change in response to scenario planning, regression analysis was performed to measure the effect of the other independent variables, in conjunction with scenario planning, to change MM measures of complexity. Tables 10 and 11 list the results of regression analysis on the change in comprehensiveness, linkages, density, and information centrality measures by fitting a model with independent variables including stargazing experience, dark sky advocacy, and dark sky knowledge. The scores on the pre-test for dark sky knowledge were used as the measure of dark sky knowledge. The only model that was significant was the linear model for change in density (Adjusted $R^2 = 0.417$, $F = 4.810$, $p = 0.018$). Of the factors influencing the model, dark sky advocacy ($\beta = 0.91$, $p = 0.033$) was the only statistically significant coefficient. The resulting equation is

$$\Delta\, Density = 0.007x + 0.969y - 0.164z + 0.198$$

(x = Stargazing Experience, y = Dark Sky Advocacy Experience, z = Dark Sky Knowledge)

Dark sky advocacy ($p = 0.022$) was also found to be statistically significant for the change in linkages, but the overall model was not significant ($F = 2.50$, $p = 0.105$).

Table 10

*Regression Analysis of Comprehensiveness and Linkages Change Using Measures of Expertise.*

| | Δ Comprehensiveness | | | Δ Linkages | | |
|---|---|---|---|---|---|---|
| | B | SEB | β | B | SEB | β |
| Stargazing Experience | -5.70 | 3.27 | -0.70 | -7.66 | 5.05 | -0.56 |
| Dark Sky Advocacy | 24.15 | 13.65 | 0.86 | 54.91 | 21.04 | 1.15* |
| Dark Sky Knowledge | -0.86 | 2.74 | -0.10 | -6.25 | 4.22 | -0.44 |
| Adjusted $R^2$ | | 0.06 | | | 0.22 | |
| *F* | | 1.359 | | | 2.50 | |
| *Sig* | | 0.299 | | | 0.105 | |

Note: Asterisk indicates significant at p < 0.05. *n = 17*. The symbol Δ signifies change in post – pre scores.

Table 11

*Regression Analysis of Density and Information Centrality Change Using Measures of Expertise.*

| | Δ Density | | | Δ Information Centrality | | |
|---|---|---|---|---|---|---|
| | B | SEB | β | B | SEB | β |
| Stargazing Experience | 0.01 | 0.10 | 0.02 | 0.07 | 0.11 | 0.26 |
| Dark Sky Advocacy | 0.97 | 0.41 | 0.91* | 0.48 | 0.44 | 0.48 |
| Dark Sky Knowledge | -0.16 | 0.08 | -0.52 | -0.09 | 0.09 | -0.29 |
| Adjusted $R^2$ | | 0.42 | | | 0.20 | |
| *F* | | 4.810 | | | 2.307 | |
| *Sig* | | 0.018 | | | 0.125 | |

Note: Asterisk indicates significant at $p < 0.05$. *n = 17*. The symbol Δ signifies change in post – pre scores.

### 4.3 Mental Models of Dark Sky Sustainability

#### 4.3.1 Sample Mental Models of Dark Skies

Figure 16 is a MM elicited from Subject 23 at the beginning of the workshop as an example from an environmental advocate. Figure 16 shows 40 components, 52 connections, and a density score of 1.30. The concepts with highest information centrality are light pollution (1), dark skies (0.96), artificial lighting (0.91), northern lights (0.80), government (0.76), and dark sky ordinances (0.76).

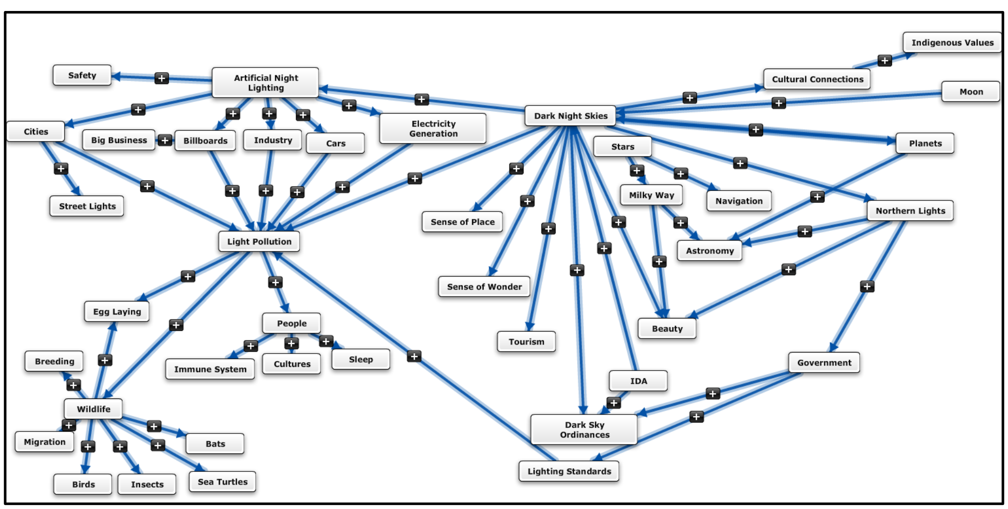



*Figure 16.* Sample mental model from an environmental advocate (Subject 23).

Figure 17 is MM elicited from Subject 20 as an example from a city planner. The MM shows 9 components, 12 connections, and a density score of 1.33. The concepts with highest information centrality are lighting ordinance (1), natural environment (0.88), artificial night lighting (0.75), connection with the universe (0.67), and navigation (0.67).

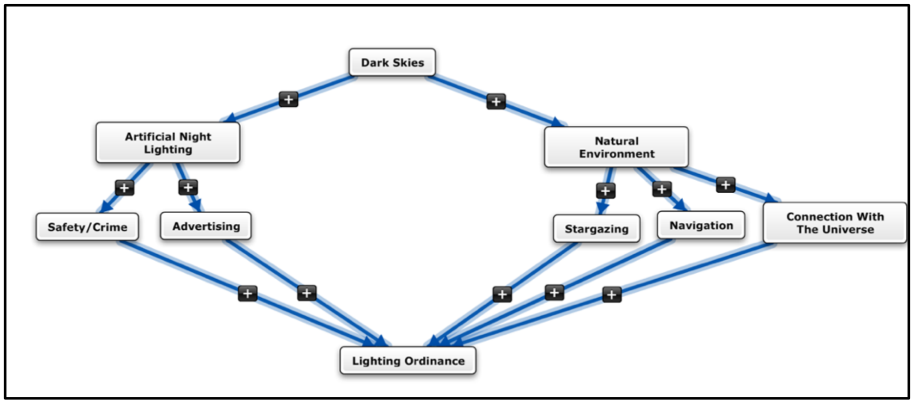



*Figure 17.* Sample mental model from a city planner (Subject 20).

Figure 18 is a MM elicited from Subject 24 as an example from a parks and recreation professional. The MM shows 62 components, 71 connections, and a density score of 1.15. The concepts with highest information centrality are dark skies (1), artificial lighting (0.86), inspiration (0.80), education (0.80), health (0.79), national/state parks (0.76).

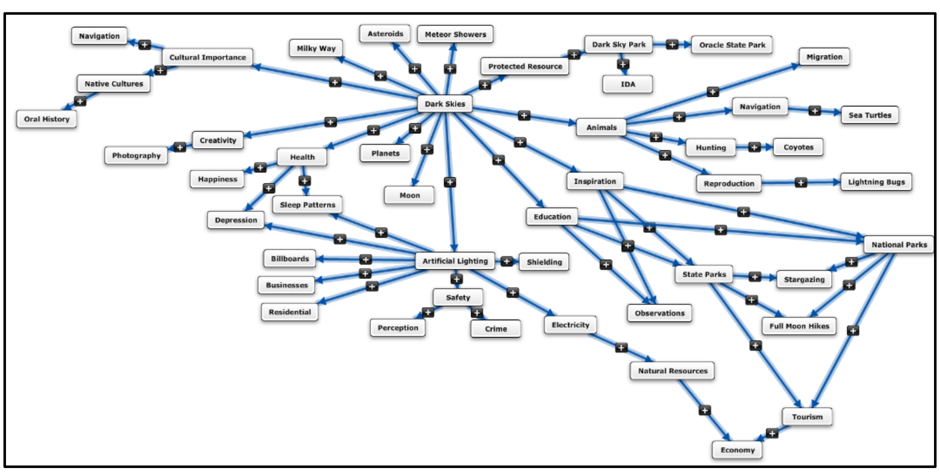



*Figure 18.* Sample mental model of dark skies from a parks & recreation professional (Subject 24).

Figure 19 is a MM elicited from Subject 15 as an example from an astronomer. The MM shows 40 components, 46 connections, and a density score of 1.15. The concepts with highest information centrality are dark skies (1), lighting (0.97), education (0.84), politics (0.82), cities/municipalities (0.80), and money (0.80).

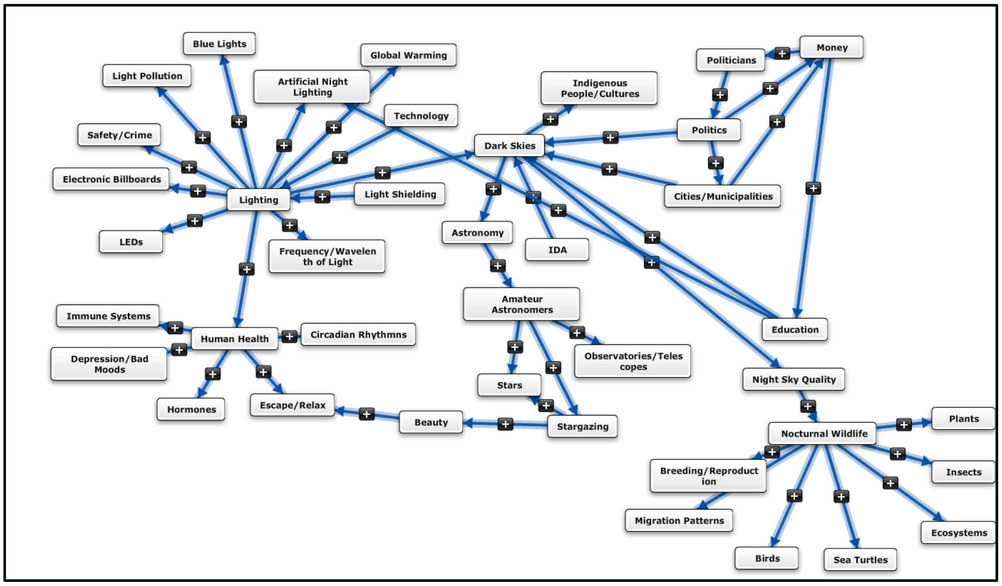



*Figure 19.* Sample mental model from an astronomer (Subject 15).

Figure 20 is a MM elicited from Subject 27 as an example from an ecologist/biologist. The MM shows 42 components, 59 connections, and a density score of 1.40. The concepts with highest information centrality are artificial night lighting (1), education (0.79), human health physiology (0.79), dark skies (0.75), type of illuminant (0.74), and wildlife (0.73).

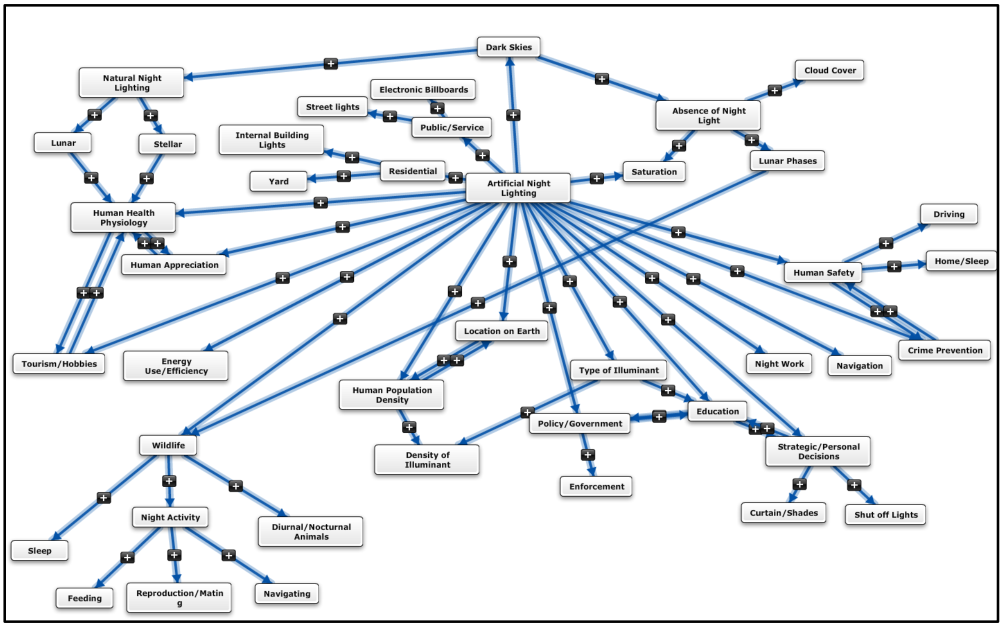



*Figure 20.* Sample mental model from expert ecologist/biologist (Subject 27).

Figure 21 is a MM elicited from Subject 16 as an example from a sustainability scientist. The MM shows 22 components, 28 connections, and a density score of 1.27. The concepts with highest information centrality are night sky quality (1), light pollution (0.89), human evolution (0.88), human happiness (0.87), unanticipated consequences (0.83) and leisure and recreation (0.81).

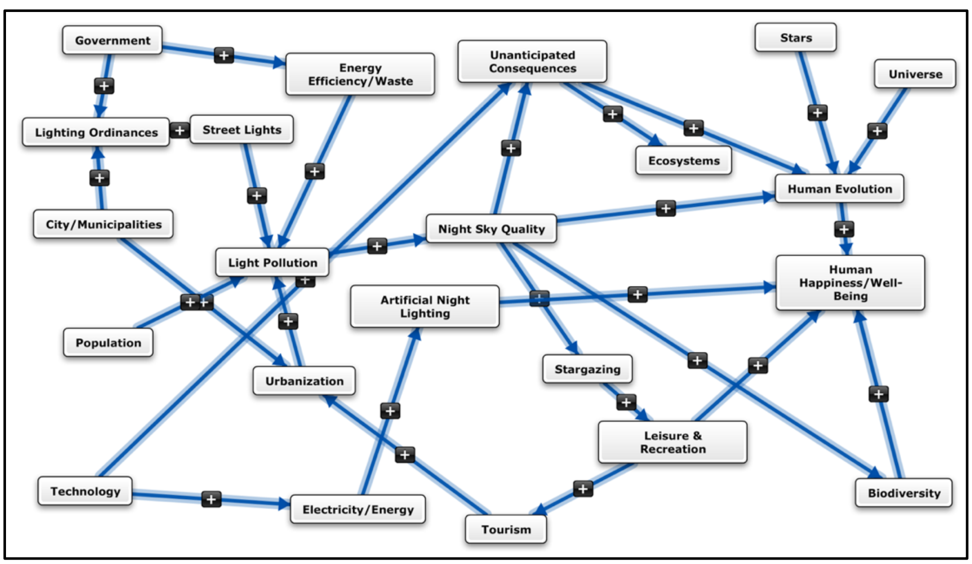



*Figure 21.* Sample mental model from sustainability scientist (Subject 16).

### 4.3.2 Aggregated Mental Model Results

Subjects' individual MMs were aggregated by averaging the mean information centrality score of each concept across all MMs and multiplying that value by the occurrence probability of that concept in all maps. This resulted in a prominence score for each concept. Table 12 lists the most prominent elicited concepts across all subjects from greatest during the pre-test. Table 12 only includes concepts above a prominence value of 0.16 as there were 176 distinct concepts elicited during the pre-test concept mapping exercise. The most prominent concepts were dark skies (*prom = 0.66)*, artificial lighting (*prom* = 0.49), safety and security (*prom* = 0.46), human health (*prom = 0.39*), parks and wilderness areas (*prom* = 0.38), and education (*prom* = 0.37).

Table 12

*Information Centrality, Occurrence Probability and Prominence of Participants' Pre-Test Mental Model Concepts.*

| *Rank* | *Concept* | *Information Centrality* | *Occurrence Probability* | *Prominence* |
|---|---|---|---|---|
| 1 | Dark Skies | 0.84 | 0.79 | 0.66 |
| 2 | Artificial Lighting | 0.78 | 0.63 | 0.49 |
| 3 | Safety/Security | 0.67 | 0.68 | 0.46 |
| 4 | Human Health | 0.73 | 0.53 | 0.39 |
| 5 | Parks & Wilderness Areas | 0.72 | 0.53 | 0.38 |
| 6 | Education | 0.71 | 0.53 | 0.37 |
| 7 | Light Pollution | 0.78 | 0.47 | 0.37 |
| 8 | Cities/Municipalities | 0.74 | 0.47 | 0.35 |
| 9 | Lighting Legislation/Rules | 0.69 | 0.47 | 0.32 |
| 10 | Stargazing | 0.64 | 0.47 | 0.30 |
| 11 | Technology | 0.61 | 0.47 | 0.29 |
| 12 | Humans/People | 0.77 | 0.37 | 0.28 |
| 13 | Billboards/Advertising | 0.66 | 0.42 | 0.28 |
| 14 | Night Sky Quality | 0.75 | 0.37 | 0.28 |
| 15 | Reproduction | 0.57 | 0.47 | 0.27 |
| 16 | Connection with Night Sky/Nature | 0.63 | 0.42 | 0.27 |
| 17 | Government | 0.69 | 0.37 | 0.25 |
| 18 | Wildlife | 0.68 | 0.37 | 0.25 |
| 19 | Animal Migration | 0.59 | 0.42 | 0.25 |
| 20 | Sleep | 0.59 | 0.42 | 0.25 |
| 21 | Energy/Electricity | 0.67 | 0.37 | 0.25 |
| 22 | Tourism | 0.58 | 0.42 | 0.24 |
| 23 | Leisure & Recreation | 0.65 | 0.37 | 0.24 |
| 24 | Stars | 0.57 | 0.42 | 0.24 |
| 25 | Nocturnal Creatures | 0.65 | 0.37 | 0.24 |
| 26 | Biodiversity | 0.75 | 0.32 | 0.24 |
| 27 | Animals | 0.72 | 0.32 | 0.23 |
| 28 | Transportation | 0.67 | 0.32 | 0.21 |
| 29 | Street Lights | 0.58 | 0.37 | 0.21 |
| 30 | Human Happiness | 0.65 | 0.32 | 0.20 |
| 31 | Day/Night Cycles | 0.62 | 0.32 | 0.20 |
| 32 | International Dark Sky Association | 0.61 | 0.32 | 0.19 |
| 33 | Plants | 0.60 | 0.32 | 0.19 |
| 34 | Cultural Heritage & Values | 0.60 | 0.32 | 0.19 |
| 35 | Ecosystems | 0.71 | 0.26 | 0.19 |
| 36 | Economics & Economic Development | 0.59 | 0.32 | 0.19 |
| 37 | Astronomers (Professional & Amateur) | 0.57 | 0.32 | 0.18 |
| 38 | Land Management | 0.84 | 0.21 | 0.18 |
| 39 | Evolution & Adaptation | 0.83 | 0.21 | 0.18 |
| 40 | Escape/Relaxation | 0.66 | 0.26 | 0.17 |
| 41 | Politics | 0.83 | 0.21 | 0.17 |
| 42 | Color of light | 0.65 | 0.26 | 0.17 |
| 43 | Curiosity/Inspiration | 0.63 | 0.26 | 0.16 |
| 44 | Shielded Lights | 0.62 | 0.26 | 0.16 |
| 45 | Urbanization | 0.77 | 0.21 | 0.16 |

Note: 19 pre-scenario mental models were used in the above analysis. Only concepts with prominence values of 0.16 and higher are shown. Total concepts elicited were 176 in all pre-scenario mental models.

Table 13 lists the most prominent elicited concepts across all subjects from greatest to least during the post-test. Table 13 only includes concepts above a prominence value of 0.15 as there were 143 distinct concepts elicited during the post-test 2 concept mapping exercise. The most prominent concepts were dark skies (*prom = 0.60)*, humans and people (*prom* = 0.049), tourism (*prom* = 0.45), animals (*prom = 0.45*), human health (*prom* = 0.42), and ecosystems (*prom* = 0.41). It is notable to mention that only dark skies and human health concepts remained at the very top of the list as compared to their pre-test ranking. Noteworthy are the newfound importance of animals and ecosystems as well as tourism and humans/people in general. Safety and security ranked number three in the pre-test, but dropped down to number ten in the post-test ranking.

Table 14 lists the concepts that were altered the most in participants' MMs as measured by the difference in prominence. The concepts that increased the most in prominence were tourism (Δ = +0.22), ecosystems (Δ = +0.20), animals (Δ = +0.18), humans/people (Δ = +0.17), astronomy (Δ = +0.14). The concepts that decreased the most in prominence were artificial lighting (Δ = -0.23), stargazing (Δ = -0.22), energy/electricity (Δ = -0.20), human happiness (Δ = -0.19). street lights (Δ = -0.18).

Table 13

*Information Centrality, Occurrence Probability and Prominence of Post-Test 2 Mental Models.*

| *Rank* | *Concept* | *Information Centrality* | *Occurrence Probability* | *Prominence* |
|---|---|---|---|---|
| 1 | Dark Skies | 0.92 | 0.65 | 0.60 |
| 2 | Humans/People | 0.75 | 0.65 | 0.49 |
| 3 | Tourism | 0.55 | 0.82 | 0.45 |
| 4 | Animals | 0.73 | 0.59 | 0.43 |
| 5 | Human Health | 0.71 | 0.59 | 0.42 |
| 6 | Ecosystems | 0.78 | 0.53 | 0.41 |
| 7 | Light Pollution | 0.76 | 0.53 | 0.40 |
| 8 | Education | 0.72 | 0.53 | 0.38 |
| 9 | Cites/Municipalities | 0.63 | 0.53 | 0.33 |
| 10 | Safety/Security | 0.61 | 0.53 | 0.32 |
| 11 | Lighting Legislation/Rules | 0.61 | 0.53 | 0.32 |
| 12 | Economics and Economic Development | 0.59 | 0.53 | 0.31 |
| 13 | Astronomy | 0.72 | 0.41 | 0.30 |
| 14 | Urbanization | 0.61 | 0.47 | 0.29 |
| 15 | Plants | 0.61 | 0.47 | 0.29 |
| 16 | Reproduction | 0.57 | 0.47 | 0.27 |
| 17 | Stakeholders | 0.74 | 0.35 | 0.26 |
| 18 | Cultural Heritage & Values | 0.61 | 0.41 | 0.25 |
| 19 | Parks & Wilderness Areas | 0.70 | 0.35 | 0.25 |
| 20 | Nature/Natural Resource | 0.69 | 0.35 | 0.24 |
| 21 | Animal Migration | 0.59 | 0.41 | 0.24 |
| 22 | Leisure & Recreation | 0.68 | 0.35 | 0.24 |
| 23 | Sleep | 0.57 | 0.41 | 0.24 |
| 24 | Wildlife | 0.63 | 0.35 | 0.22 |
| 25 | Milky Way | 0.62 | 0.35 | 0.22 |
| 26 | Predator/Prey Relationships | 0.61 | 0.35 | 0.22 |
| 27 | Scientific Investigations | 0.72 | 0.29 | 0.21 |
| 28 | Lighting | 0.71 | 0.29 | 0.21 |
| 29 | Artificial Lighting | 0.88 | 0.24 | 0.21 |
| 30 | Politics | 0.69 | 0.29 | 0.20 |
| 31 | Stars | 0.49 | 0.41 | 0.20 |
| 32 | Biodiversity | 0.63 | 0.29 | 0.19 |
| 33 | Technology | 0.60 | 0.29 | 0.18 |
| 34 | Billboards/Advertising | 0.58 | 0.29 | 0.17 |
| 35 | Day/Night Cycles | 0.55 | 0.29 | 0.16 |
| 36 | Escape/Relaxation | 0.68 | 0.24 | 0.16 |
| 37 | Money | 0.54 | 0.29 | 0.16 |
| 38 | Depression/Irregular Moods | 0.54 | 0.29 | 0.16 |
| 39 | Government | 0.67 | 0.24 | 0.16 |
| 40 | Insects | 0.63 | 0.24 | 0.15 |
| 41 | Moon | 0.63 | 0.24 | 0.15 |

Note: 17 post-scenario mental models were used in the above analysis. Only concepts with prominence values of 0.15 and higher are shown. Total concepts elicited were 143 in all post-scenario mental models.

Table 14

*Mental Model Concepts that were Altered the Most from Pre-Test to Post-Test 2.*

| *Concept* | *Pre-Prominence* | *Post-Prominence* | *Δ* |
|---|---|---|---|
| Positive Change (+) | | | |
| Tourism | 0.23 | 0.45 | +0.22 |
| Ecosystems | 0.21 | 0.41 | +0.20 |
| Animals | 0.25 | 0.43 | +0.18 |
| Humans/People | 0.32 | 0.49 | +0.17 |
| Astronomy | 0.15 | 0.30 | +0.14 |
| Fear | 0 | 0.13 | +0.13 |
| Scientific Investigations | 0.10 | 0.21 | +0.11 |
| Predator/Prey Relationships | 0.11 | 0.22 | +0.11 |
| Urbanization | 0.18 | 0.29 | +0.11 |
| Stakeholders | 0.15 | 0.26 | +0.11 |
| Economics & Economic Development | 0.21 | 0.31 | +0.10 |
| Milky Way | 0.13 | 0.22 | +0.09 |
| Nature/Natural Resource | 0.15 | 0.24 | +0.09 |
| Human Health | 0.34 | 0.42 | +0.07 |
| Plants | 0.21 | 0.29 | +0.07 |
| | | | |
| Negative Change (-) | | | |
| Artificial Lighting | 0.43 | 0.21 | -0.23 |
| Stargazing | 0.34 | 0.12 | -0.22 |
| Energy/Electricity | 0.28 | 0.08 | -0.20 |
| Human Happiness | 0.23 | 0.04 | -0.19 |
| Street Lights | 0.21 | 0.03 | -0.18 |
| Parks & Wilderness Areas | 0.42 | 0.25 | -0.18 |
| Nocturnal Creatures | 0.24 | 0.07 | -0.17 |
| Night Sky Quality | 0.27 | 0.11 | -0.16 |
| Safety/Security | 0.47 | 0.32 | -0.15 |
| Beauty | 0.14 | 0 | -0.14 |
| Connection with Night Sky/Nature | 0.22 | 0.08 | -0.14 |
| Light Trespass | 0.12 | 0 | -0.12 |
| Immune System | 0.15 | 0.03 | -0.12 |
| Billboards/Advertising | 0.29 | 0.17 | -0.12 |
| Color of light | 0.11 | 0 | -0.11 |

Note: 17 pairs of mental models were used in the above analysis. Only the concepts with the 15 largest positive and 15 largest negative difference are listed. Total concepts elicited were 182 between both pre and post scenario planning for these 17 stakeholders. Δ is the post-prominence – pre-prominence score.

Individual concepts were aggregated into the broader themed categories of astronomy, economy, environment, human health and wellness, politics, society/culture, and technology according to the category codebook in Appendix G. Figure 22 shows the prominence distribution of concepts in the pre-test and post-test 2 concept maps by category type for all subjects. Paired-sample t-tests were run on the prominence values from pre-test to post-test 2 for each concept. Although differences can be seen between the prominence means for each category, there were no statistically significant differences between concepts. Technology had the largest decrease (Δ = - 0.032 ± 0.018) but it was not a statistically significant difference (*p = 0.086*). The other categories also did not experience a statistically significant difference either: Astronomy (Δ = 0.014 ± 0.020, *p* = 0.484*)*, economy (Δ = - 0.009 ± 0.012, *p*= 0.448*)*, environment (Δ = - 0.017 ± 0.010, *p*= 0.099), human health and wellness (Δ = - 0.020 ± 0.016, *p*= 0.237), politics (Δ = - 0.015 ± 0.014, *p*= 0.301), social/cultural (Δ = - 0.00 ± 0.013, *p*= 0.965). It was also found that there was no statistically significant difference between the prominence scores between categories for both the pre-prominence (*F* = 0.583*, p* = 0.744) and post-prominence (*F* = 0.533*, p* = 0.782*)* as determined from one-way ANOVA. Therefore, no particular category received more attention after the workshop than the baseline levels.

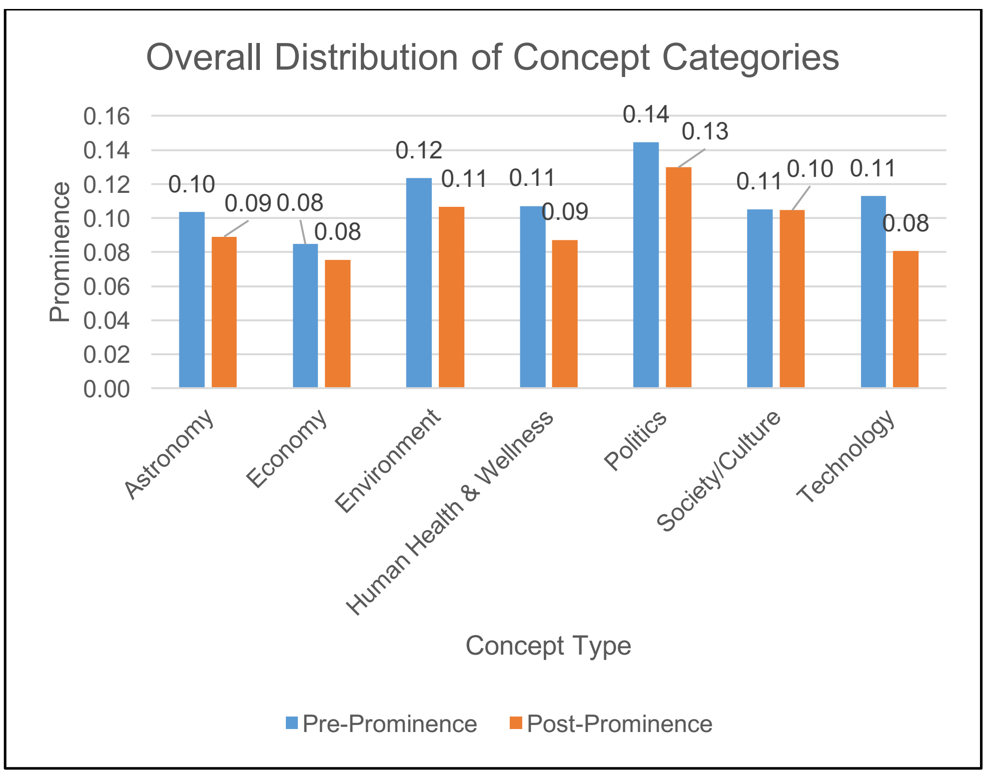



*Figure 22.* Overall distribution of concept categories pre and post scenario workshops.

Figure 23 shows the distribution of concept categories' prominence percentages by primary stakeholder group as elicited during the pre-test. Astronomers gave most importance to astronomy (16.4%), government and parks employees gave most importance to politics (18.9%), ecologists/biologists gave most importance to the environment (17.6%) and sustainability scientists gave most importance to technology (18.4%) and human health/wellness (18.0%).

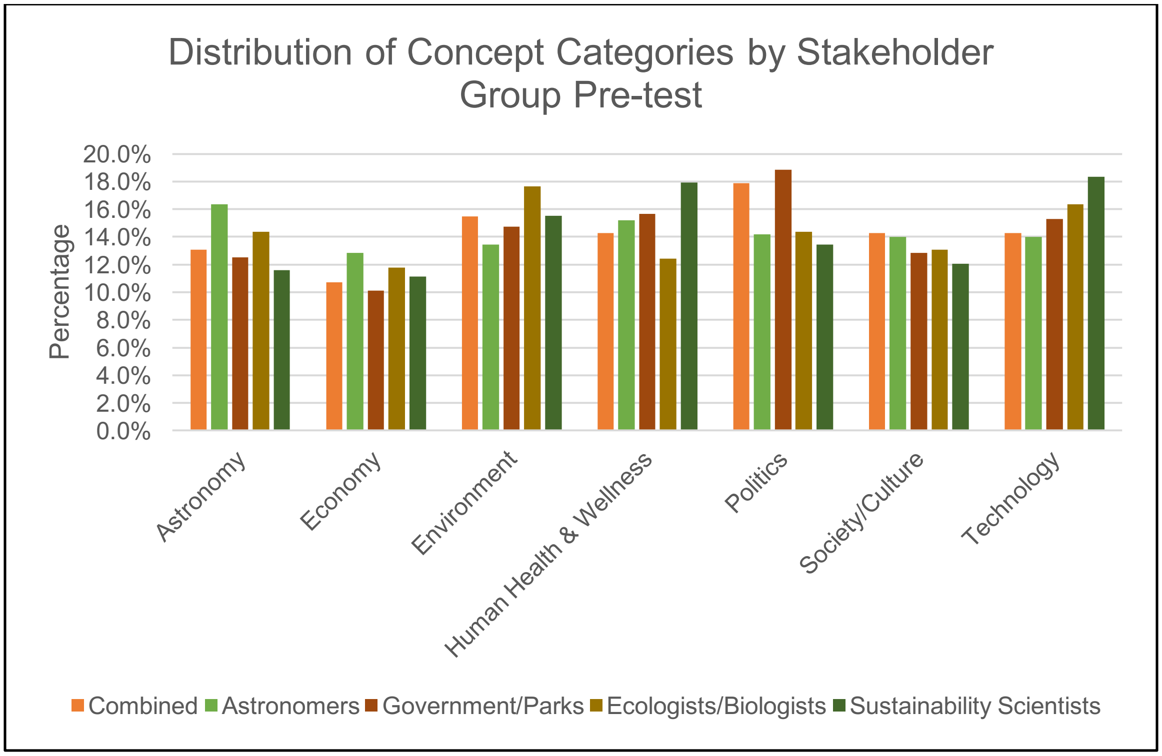



*Figure 23.* Distribution of concept categories by stakeholders during pre-test.

Figure 24 shows the distribution of concept categories' prominence percentages by primary stakeholder group as elicited during the post-test 2. Astronomers gave equal importance to astronomy, economics and the environment (15.5%), government and parks employees gave equal importance to the environment and society/culture (18.3%), ecologists/biologists continued to give most importance to the environment (18.6%) and sustainability scientists gave most importance to human health and wellness (17.5%).

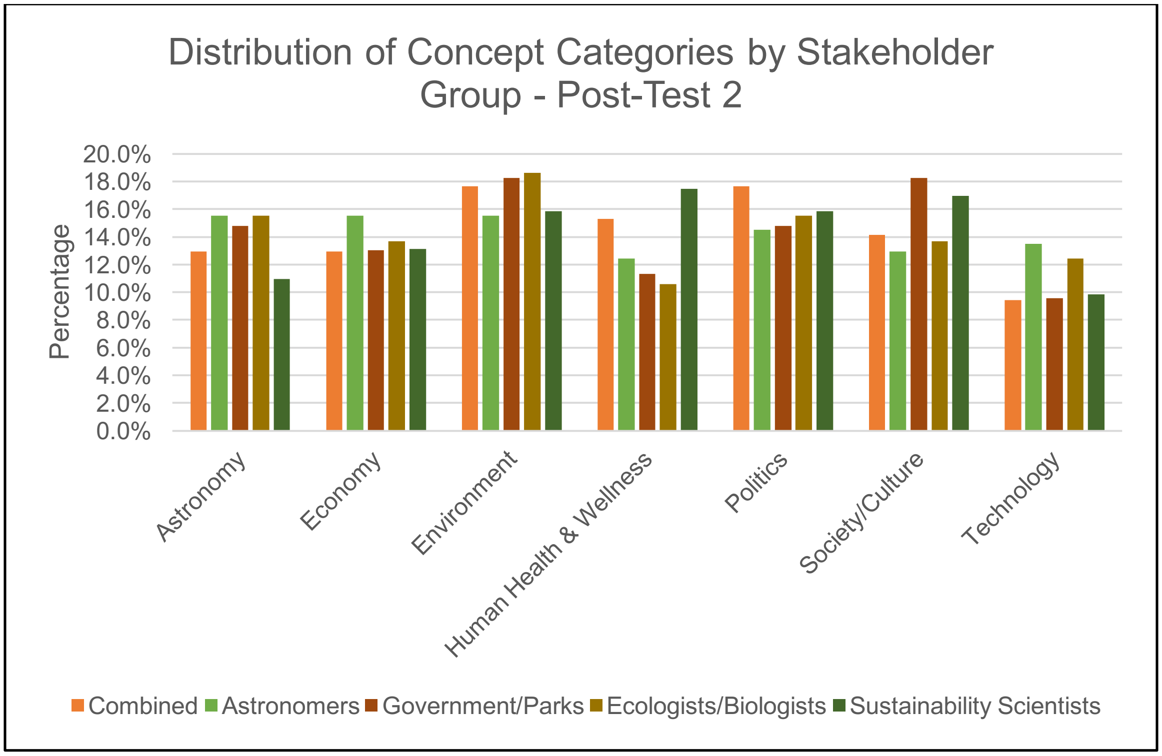



*Figure 24.* Distribution of concept categories by stakeholders during post-test 2.

Table 15 shows the most prominent individual concepts for amateur and professional astronomers on both the pre-test and post-test 2. Notable removals are astronomers (professional and amateur), knowledge and technology which were the most prominent concepts in the pre-test from the list of the top ten concepts in their post-test 2. Notable additions are lighting legislation/rules (*prom* = 0.42), billboards/advertising (*prom* = 0.37) and tourism (*prom* = 0.37) to their list of prominent concepts at the end of the workshop. Figure 25 shows the pre-test and post-test 2 distribution of concept categories for astronomers. It is worthwhile to mention that astronomers gave more importance to the environment ($\Delta = +2.1\%$) and economic ($\Delta = +1.7\%$) categories by the end of the workshop. On the other hand, health and wellness (Δ = -2.8%) decreased in importance.

Table 15

*Amateur & Professional Astronomers' Prominent Mental Model Concepts.*

| *Rank* | *Pre-Concept* | *Pre-Prominence* | *Post-Concept* | *Post-Prominence* |
|---|---|---|---|---|
| 1 | Dark Skies | 0.67 | Astronomy | 0.74 |
| 2 | Human Health | 0.63 | Dark Skies | 0.60 |
| 3 | Education | 0.50 | Human Health | 0.59 |
| 4 | Astronomy | 0.44 | Artificial Lighting | 0.55 |
| 5 | Artificial Lighting | 0.41 | Safety/Security | 0.51 |
| 6 | Astronomers (Prof. & Amateur) | 0.41 | Lighting Leg./Rules | 0.42 |
| 7 | Safety/Security | 0.39 | Education | 0.40 |
| 8 | Knowledge | 0.39 | Plants | 0.39 |
| 9 | Technology | 0.37 | Billboards/Advertising | 0.37 |
| 10 | Plants | 0.37 | Tourism | 0.37 |

Note: *n = 3*. The most 10 prominent items are displayed from the pre and post scenario mental models.

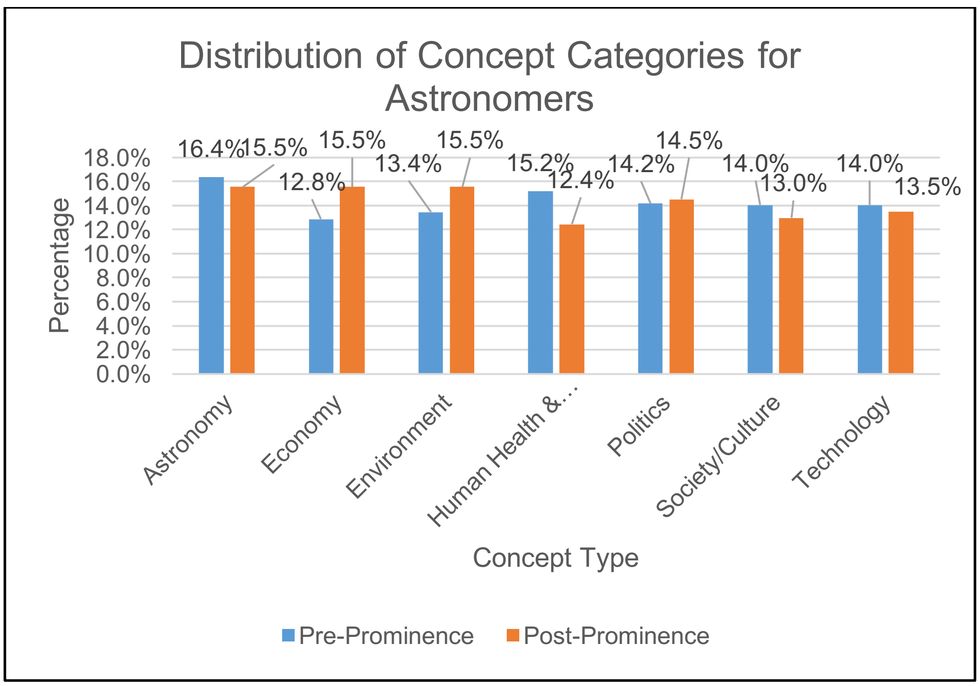



*Figure 25.* Distribution of concept categories for astronomers during pre-test and post-test 2.

Table 16 shows the most prominent individual concepts for government and parks and recreation employees both the pre-test and post-test 2. Notable changes are the removal of lighting legislation/rules, safety/security, cities/municipalities, billboards/advertising which were the most prominent concepts in the pre-test from the list of the top ten concepts in their post-test 2. The post-test 2 saw the addition of concepts such as animals (*prom* = 0.51), education (*prom* = 0.48), plants (*prom* = 0.45) scientific investigations (*prom* = 0.42), ecosystems (*prom* = 0.41), astronomy (*prom* = 0.40), cultural heritage/values (*prom* = 0.39) and tourism (*prom* = 0.37) to their list of most prominent concepts. Figure 26 shows the pre-test and post-test 2 distribution of concept categories for government and parks and recreation employees. It is worthwhile to mention that government and parks employees gave more importance to society/culture (Δ = +5.4%), the environment (Δ = +3.6%), economy (Δ = +2.9%) and astronomy (Δ = +2.3%) categories by the end of the workshop. On the other hand, technology (Δ = -5.7%), human health and wellness (Δ = -4.3%), and politics (Δ = -4.0%) decreased in importance.

Table 16

*Government and Parks & Recreation Employees' Prominent Mental Model Concepts.*

| *Rank* | *Pre-Concept* | *Pre-Prominence* | *Post-Concept* | *Post-Prominence* |
|---|---|---|---|---|
| 1 | Dark Skies | 0.73 | Dark Skies | 0.68 |
| 2 | Parks & Wilderness Areas | 0.62 | Animals | 0.51 |
| 3 | Lighting Legislation/Rules | 0.61 | Education | 0.48 |
| 4 | Artificial Lighting | 0.57 | Plants | 0.45 |
| 5 | Safety/Security | 0.57 | Scientific Investigations | 0.42 |
| 6 | Cities/Municipalities | 0.54 | Ecosystems | 0.41 |
| 7 | Education | 0.48 | Astronomy | 0.40 |
| 8 | Billboards/Advertising | 0.40 | Cultural Heritage & Vs. | 0.39 |
| 9 | Wildlife | 0.38 | Parks & Wilderness Ar. | 0.38 |
| 10 | Connection with Night Sky/Nature | 0.37 | Tourism | 0.36 |

Note: $n = 7$. The most 10 prominent items are displayed from the pre and post scenario mental models.

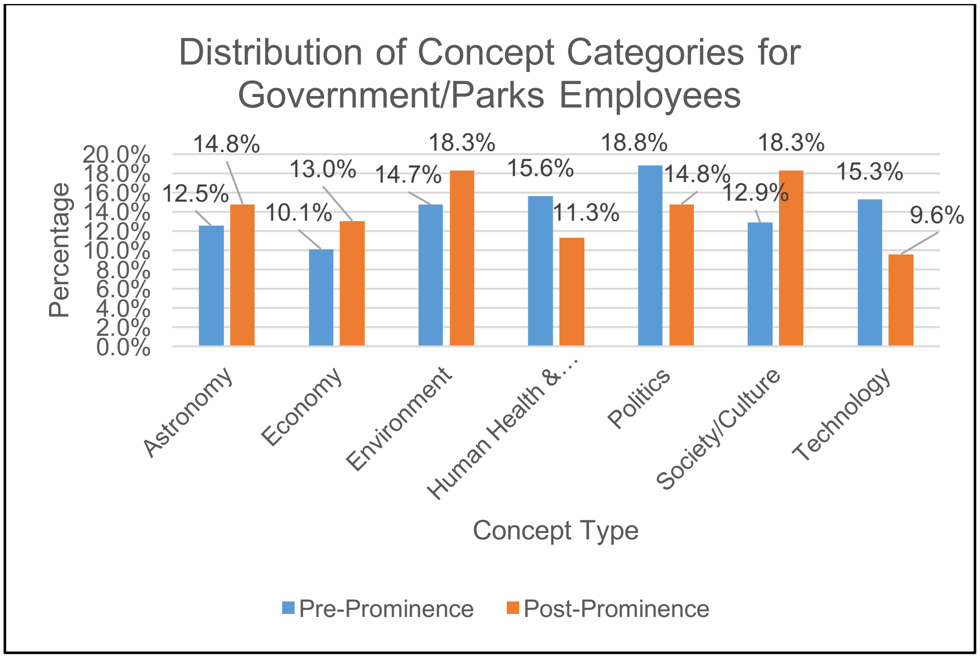



*Figure 26.* Distribution of concept categories for government and parks employees during pre-test and post-test 2.

Table 17 shows the most prominent individual concepts for ecologists and biologists for both the pre-test and post-test 2. Notable changes are the removal of artificial lighting, safety/security, and reproduction which were the most prominent concepts in the pre-test from the list of the top ten concepts in their post-test 2. The post-test 2 saw the addition of concepts such as ecosystems (*prom* = 0.78), cities/municipalities (*prom* = 0.60), nature/natural resource (*prom* = 0.55), tourism (*prom* = 0.53) and sleep (*prom* = 0.46) to their list of most prominent concepts. Figure 27 shows the pre-test and post-test 2 distribution of concept categories for ecologists/biologists. It is worthwhile to mention that ecologists/biologists gave more importance to the economy ($\Delta$ = +1.9%), politics ($\Delta$ = +1.1%), astronomy ($\Delta$ = +1.1%), and the environment ($\Delta$ = +1.0%) categories by the end of the workshop. On the other hand, technology ($\Delta$ = -3.9%) and human health and wellness ($\Delta$ = -1.8%) decreased in importance.

Table 17

*Ecologists & Biologists' Prominent Mental Model Concepts.*

| Rank | *Pre-Concept* | *Pre-Prominence* | *Post-Concept* | *Post-Prominence* |
|---|---|---|---|---|
| 1 | Dark Skies | 0.78 | Ecosystems | 0.78 |
| 2 | Light Pollution | 0.72 | Humans/People | 0.77 |
| 3 | Artificial Lighting | 0.60 | Cites/Municipalities | 0.60 |
| 4 | Reproduction | 0.53 | Light Pollution | 0.58 |
| 5 | Safety/Security | 0.51 | Nature/Natural Resource | 0.55 |
| 6 | Day/Night Cycles | 0.47 | Tourism | 0.53 |
| 7 | Animal Migration | 0.47 | Wildlife | 0.53 |
| 8 | Connection with Night Sky/Nature | 0.42 | Sleep | 0.46 |
| 9 | Humans/People | 0.40 | Dark Skies | 0.45 |
| 10 | Wildlife | 0.40 | Econ. &Economic Develop. | 0.40 |

Note: *n = 3*. The most 10 prominent items are displayed from the pre and post scenario mental models.

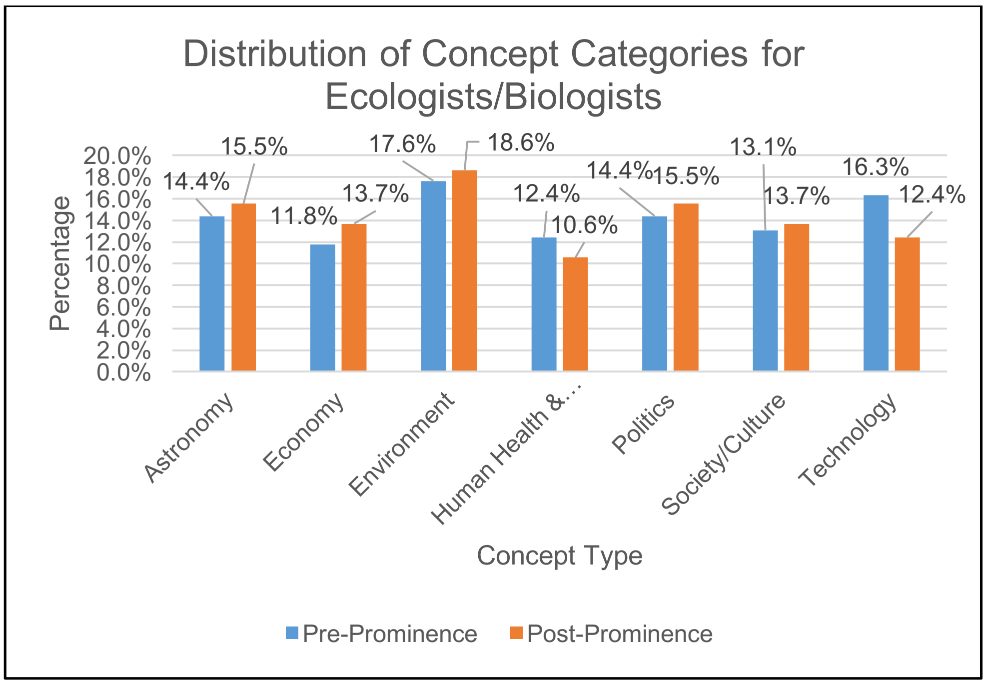



*Figure 27.* Distribution of concept categories for ecologists/biologists during pre-test and post-test 2.

Table 18 shows the most prominent individual concepts for sustainability scientists for both the pre-test and post-test 2. Notable changes are the removal of leisure and recreation, human happiness, and energy/electricity which were the top three most prominent concepts in the pre-test from the list of the top ten concepts in their post-test 2. The post-test 2 saw the addition of concepts such as dark skies (*prom* = 0.70), humans/people (*prom* = 0.68), animals (*prom* = 0.56), safety/security (*prom* = 0.45) and big business (*prom* = 0.37) to their list of most prominent concepts. Figure 28 shows the pre-test and post-test 2 distribution of concept categories for sustainability scientists. It is worthwhile to mention that sustainability scientists gave more importance to the economy (Δ = +2.0%), politics (Δ = +2.8%), astronomy (Δ = +1.1%), the environment (Δ = +0.3%), and society/culture (Δ = +4.9%), categories by the end of the workshop. On the other hand, technology absorbed the majority of the decreases (Δ = -8.5%).

Table 18

*Sustainability Scientists' Prominent Mental Model Concepts.*

| *Rank* | *Pre-Concept* | *Pre-Prominence* | *Post-Concept* | *Post-Prominence* |
|---|---|---|---|---|
| 1 | Leisure & Recreation | 0.65 | Dark Skies | 0.70 |
| 2 | Human Happiness | 0.63 | Humans/People | 0.68 |
| 3 | Energy/Electricity | 0.57 | Tourism | 0.64 |
| 4 | Animals | 0.56 | Human Health | 0.58 |
| 5 | Transportation | 0.55 | Animals | 0.56 |
| 6 | Stargazing | 0.50 | Cites/Municipalities | 0.54 |
| 7 | Street Lights | 0.49 | Safety/Security | 0.45 |
| 8 | Technology | 0.49 | Ecosystems | 0.45 |
| 9 | Government | 0.47 | Light Pollution | 0.45 |
| 10 | Light Pollution | 0.46 | Big Business | 0.37 |

Note: *n = 4*. The most 10 prominent items are displayed from the pre and post scenario mental models.

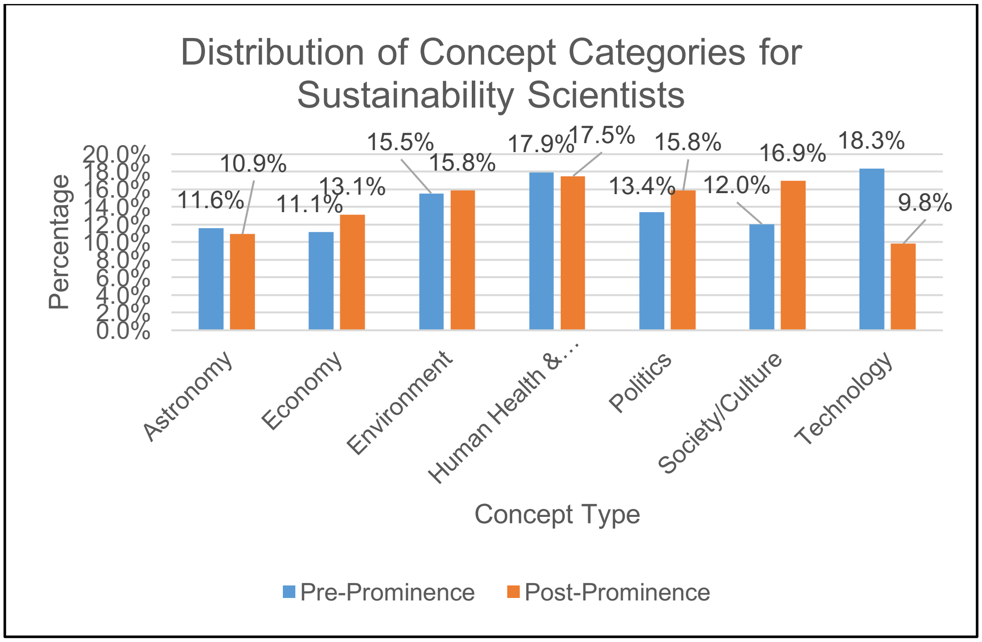



*Figure 28.* Distribution of concept categories by sustainability scientists during pre-test and post-test 2.

**4.4 Scenario Planning Results**

The scenario planning workshops allowed participants to engage with each other in a deliberative space. The brainstorming session, following the pre-test mental model mapping exercise, lead to scores of factors being posted around the room. These factors were then discussed amongst the group, and categorized into their respective quadrants of the scenario matrix as described in the methods section. Figures 29 and 30 show the results of the brainstorming exercise and categorization of factors from September 16 and 21 respectively. High impact factors are listed on the right side of the matrix with the high uncertainty factors in the top corner and low uncertainty factors in the bottom corner. Participants also rated the factors in the high uncertainty/high impact quadrant for level of importance. The number of votes a factor received is listed in brackets next to the factor description. The number of votes a factor received is a reflection of the salience of that factor on the future of Arizona's dark skies. The most salient factors with high uncertainty and high impact during the September 16 workshop were education (52 votes), light ordinances/policies (43 votes), media communication (23 votes) and astrotourism/ecotourism (19 votes). The most salient factors with high uncertainty and high impact during the September 21 workshop were human appreciation/wilderness values (60 votes), strategies for deployment of new lighting technologies (45 votes), regulation/legislation (38 votes) and education/awareness (27 votes). If the two workshops' votes are combined, the most salient factors are lighting regulations (81 votes), education (79 votes), human appreciation/wilderness values (60 votes), and strategies for deployment of new lighting technologies (45 votes). In the September 16 workshop, the two most salient factors were finally operationalized for the two by two scenario matrix as 'dark sky friendly lighting' and 'public awareness'. In the September 21 workshop, the two most salient factors were operationalized for the two by two scenario matrix as 'planning and development strategies that include the nighttime environment' and 'appreciation of wilderness'. Although the wording is slightly different, these concepts are closely related. It is important to recognize that both groups, although completely independent, came to nearly the same conclusion as to the most salient factors with highest uncertainty and highest impact to night skies. Moreover, both workshop groups were in general agreement about most of the factors with low uncertainty but high impact such as population growth, urbanization, predatory/prey relationships, the astronomy industry, vested interest groups, and night work or services.

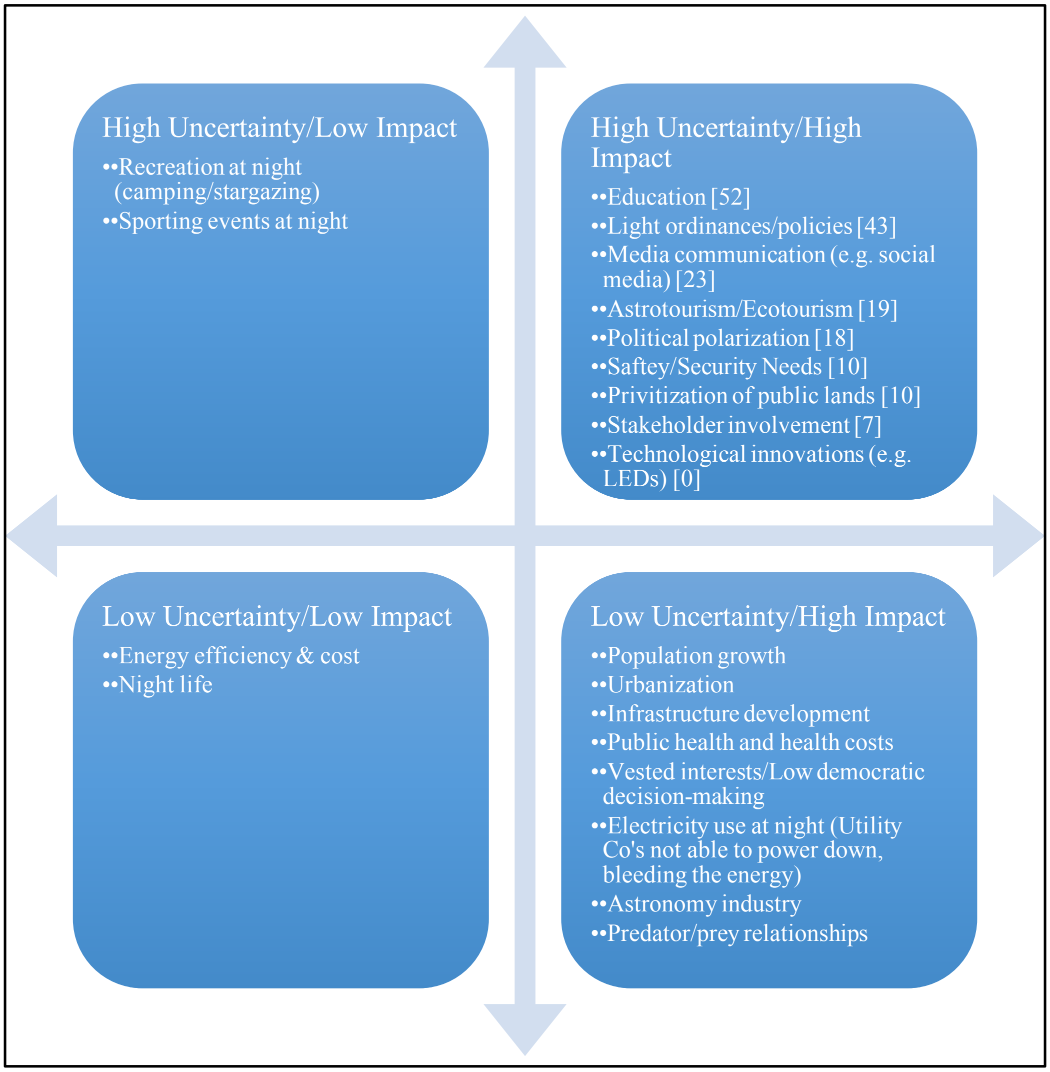



*Figure 29.* Scenario matrix from September 16 workshop.

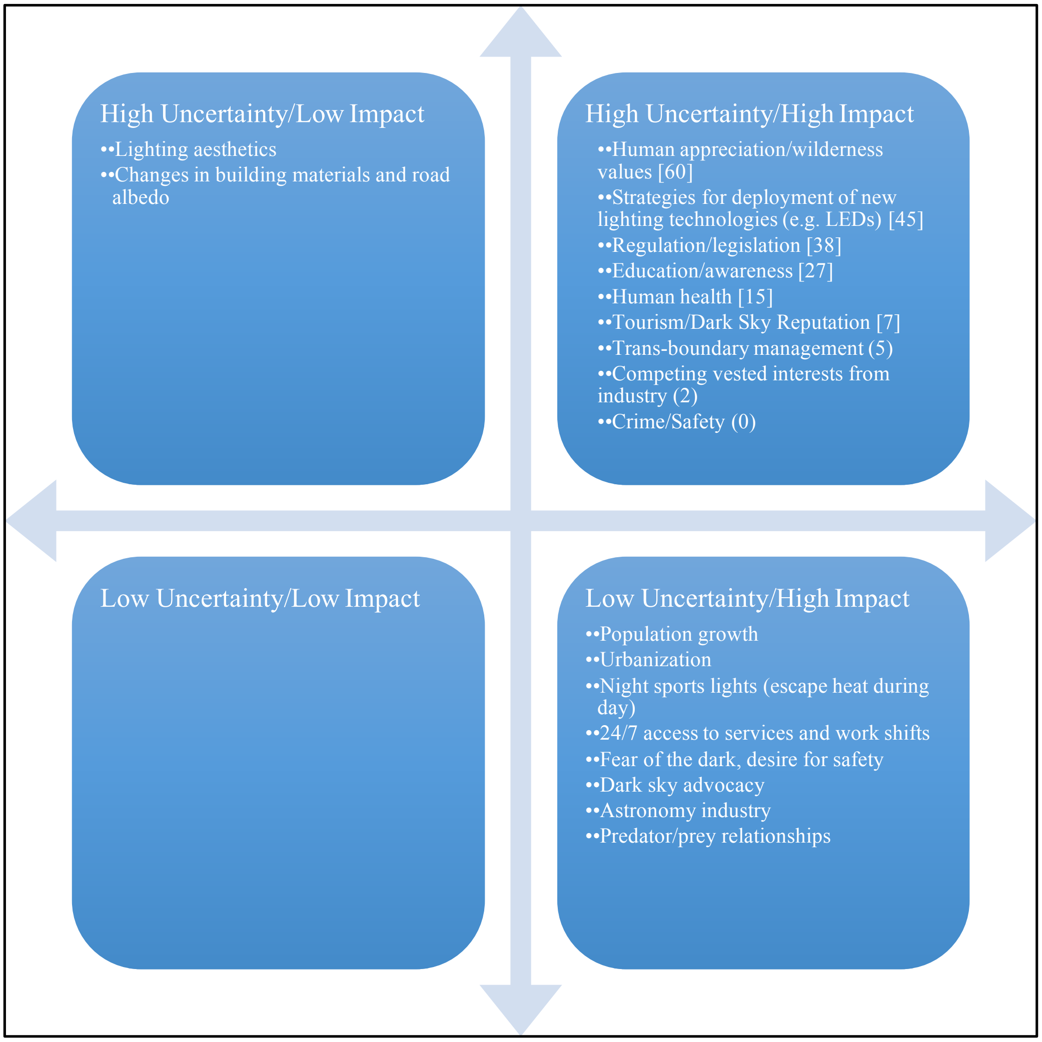



*Figure 30.* Scenario matrix from September 21 workshop.

Following the generation of the scenario matrices, participants broke out into small groups and developed scenario narratives for the top two critical factors that were voted on. Sample scenario narratives can be found in Appendix H. Following the writing of these narratives, participants were encouraged to discuss short-term and long-term strategies that Arizonians can take to prevent undesirable futures from happening or to promote desirable futures. The strategies that were developed are listed in Table 19.

Table 19

*Short-Term and Long-Term Strategies for Sustainable Dark Skies.*

| Strategies |
| --- |
| Short-term |
| 1. Adopt or follow IDA lighting guidelines and standards. |
| 2. Legislature passes stimulus funding for innovation in lighting. |
| 3. Public information campaign to inform the public about artificial lighting. |
| 4. Attract/market to draw industries to the area. |
| 5. Expand education programs at environmental education centers to incorporate dark sky knowledge and lighting strategies. |
| 6. Lighting should be considered in environmental impact assessments for large-scale development projects. |
| 7. Development organizations and city governments should be inclusive from the very start. Don't do plans behind closed doors without key stakeholder involvement upfront. |
| 8. Turn off lights when they are not needed. |
| 9. Educate policy-makers and planners about artificial lighting and dark skies. Share best practices with them. |
| 10. Learn from the city of Flagstaff. They have robust lighting policies and dark skies despite being an urban city. |
| Long-term |
| 1. Ecotourism campaign to draw visitors and develop rural economies. |
| 2. Enact building/lighting regulation regarding lighting advertising. Must be reviewed by the city council and presented to the public. |
| 3. Create a public policy that calls for more public involvement and transparency on construction proposals that may fall outside lighting guidelines. |

Strategies listed in Table 19 are primarily strategies regarding education, raising awareness, and developing smart lighting regulations. This is due to the fact that these were determined to be the most uncertain and highly impactful factors. These strategies were developed hastily in the last few minutes of the workshop so do not reflect an exhaustive list. A second workshop is necessary to fully flush out these and other strategies.

Chapter 5

DISCUSSION

**5.1 Summary of the Results**

This study tested Chermack's (2005) hypotheses that scenario planning improves learning and alters MMs. Results indicate that learning did indeed occur during the traditional lecture, from the lecture to the end of the day, and throughout the duration of the entire day. Therefore, hypothesis $H_1$ is supported. The results of the MM analysis did not statistically support the claim that scenario planning alters participants' MM complexity. MM structure retained nearly the same comprehensiveness, linkages, density, and information centrality from the pre-test to post-test 2. Therefore, hypotheses $H_2$ was refuted. Nevertheless, there were differences seen at the individual concept level in the prominence of specific factors. Some factors which were marginal in the pre-test became the most salient factors in the post-test (e.g. tourism, ecosystems, animals). Similarly, some of the most salient factors elicited in the pre-test were demoted in rank (e.g. artificial lighting, human happiness, stargazing energy/electricity, street lights). The shifting of individual concepts was also noticeable when breaking the participants into sub-groups of astronomers, government and parks employees, ecologists/biologists, and sustainability scientists. Therefore, although scenario planning was not shown to statistically alter the overall structure of MMs, these findings suggest that MMs are altered at the individual factor level. The level of importance assigned to individual factors may be altered during the course of a scenario workshop.

This study also investigated the effect of scenario planning workshops on participants' environmental attitudes. Results show that participants' anthropocentrism and balance with nature variables were significantly different between the beginning to end of the workshop, but not significantly different from pre-test to post-test 1. A traditional lecture format, where a great deal of learning occurred, did not significantly alter participants' environmental attitudes. However, once scenario planning began after post-test 1, there were significant changes in environmental attitudes toward more pro-environmental dispositions. Therefore, hypothesis $H_3$ was confirmed. Scenario planning focuses on dealing with trade-offs, unanticipated consequences of human decisions, systems thinking, negotiating the uncertainties of the future, and appreciating the complexities of dynamic systems such as the system investigated in this workshop. This could be the reason why anthropocentrism and balance with nature variables were altered. Anthropocentrism reflects attitudes such as 'humans with eventually learn enough to control nature' and 'human ingenuity will ensure that we do not make the earth unlivable'. Balance with nature reflects attitudes such as 'despite our special abilities, we are still subject to the laws of nature' and 'when humans interfere with nature it often produces disastrous consequences'. In the context of dark sky sustainability, participants learned that there are unintended consequences of our actions and that systems are very complex. For example, replacing all street lights with blue-spiked LEDs may be desirable to decrease electricity needs and carbon emissions, but they also have significant impacts on human health and wellbeing, wildlife, and observatories. Self-reflection and learning about these trade-offs, uncertainties, and complexities during the workshop was likely responsible for altering both anthropocentrism and balance with nature attitudes.

It is important to acknowledge that scenario planning was not found in this study to alter participants' ecocrisis attitudes. Ecocrisis represented attitudes such as 'if things continue on their present course, we will soon experience a major ecological catastrophe' and 'we are approaching the limit of the number of people the earth can support'. Participants entered the workshop with high levels of ecocrisis attitudes (pre-test mean = 4.34) and this value did not significantly depart from the mean ($p$ = 0.943) for the remainder of the day. This could also be due to the ceiling effect of starting with a very high baseline. However, balance with nature also had a high baseline (pre-test mean = 4.38) and still experienced a significant increase during scenario planning.

Figure 31 shows a suggested revision to Chermack's (2004a, 2005) theory of scenario planning to include one additional variable (environmental attitudes) and two additional relationships: the links between scenario planning and environmental attitudes, and MMs and environmental attitudes. The traditional lecture portion had a significant impact on learning, but it did not alter environmental attitudes. However, the scenario workshop did. Therefore, no direct link is proposed between learning and environmental attitudes. However, the reconfiguration of MMs may be a mediating variable between learning and environmental attitudes as depicted in Figure 31. Specifically, the researcher proposes categoric law 7 that scenario planning is associated with environmental attitudes. This modification is offered as a more nuanced version for scenario planning for NRM contexts. While this lone study does not claim to conclusively support the addition of this variable, it calls on future research to consider it as a potentially important variable for further investigation.

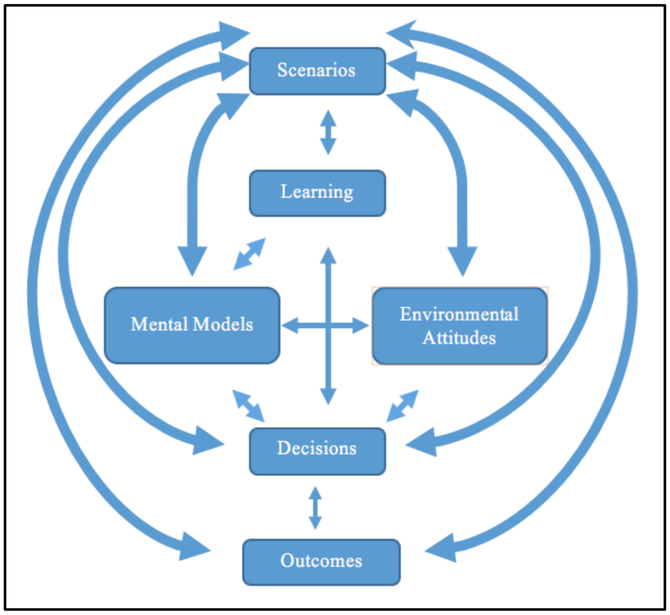



*Figure 31.* Revised scenario planning theoretical framework.

Source: Adapted from Chermack (2005)

Hypotheses $H_4$ stated that as dark sky knowledge increases, the change in MM complexity (i.e. comprehensiveness, linkages, density, and information centrality) increases. Results of regression analysis found no correlation between dark sky knowledge and change in MM complexity for any of the complexity metrics. This result is contrary to the literature which suggests it should increase (Ippolito, & Tweney, 1995; Neressian, 1995; 2002).

Hypothesis $H_5$ stated that as stargazing experience increases, the change in MM complexity (i.e. comprehensiveness, linkages, density, and information centrality) increases. Results of regression analysis found no correlation between stargazing experience and change in MM complexity for any of the complexity metrics.

Hypothesis $H_6$ stated that as dark sky advocacy experience increases, the change in MM complexity (i.e. comprehensiveness, linkages, density, and information centrality) increases. Results of regression analysis show that dark sky advocacy experience does not have any effect on the change in number of nodes and information centrality. However, it was found to have a positive effect on the change in MM density and number of linkages. It could be that dark sky advocates had much more interest in participating in the workshop, were more eager to learn, and self-reflect on their learning. Therefore, they got more out of the workshop and found new connections they hadn't thought about before. Hypothesis $H_6$ is therefore partially supported. As dark sky advocacy experience increases, the change in MM complexity (i.e. linkages, density) increases. However, MM comprehensiveness and linkages do not change as dark sky advocacy experience increases.

**5.2 Sustainability & Managerial Implications**

The suggested revised theory of scenario planning may have important sustainability and managerial implications. Environmental attitudes are well-known to be difficult to change. Indeed, they remained obdurate to change during the forty-five-minute traditional lecture. However, participatory scenario planning workshops have been shown in this study to be linked to environmental attitude change. If environmental conservation organizations, sustainability scientists or parks and recreation managers seek to change the public's environmental attitudes, participatory scenario planning with stakeholders may be a viable strategy for doing so. As a bonus, the scenario planning workshops also have been shown to improve learning and change the prioritization of salient factors affecting the system under investigation. If a particular set of factors are of utmost importance to an organization, hosting a scenario planning workshop may serve to give greater appreciation of those factors to stakeholders. In return, it is also clear that the workshop facilitators, as participants in the workshop, will also come to appreciate alternative perspectives and factors exogenous to their original system framing. If Chermack's (2005) theoretical linkages between altered MMs, decision-making, and performance are valid, this may mean better conservation and sustainability outcomes overall.

Specifically concerning the conservation of dark skies, the results of the MM analysis of twenty-one Arizona stakeholders may be used by government leaders, parks and recreation employees, astronomers, sustainability scientists, ecologists, tourism professionals, and other concerned individuals and organizations to decide how to work collectively to create solutions for the preservation of this resource. The analysis highlights the dynamic complexities inherent in this system. Figure 32 shows a conceptual model of the most salient drivers found to affect or be affected by dark skies in Arizona as determined by the post-test 2 concept mapping exercise. The individual components of these drivers are found in Appendix G. Whereas most people only think initially of a small handful of factors associated with artificial lighting (i.e. safety/security, lighting, and astronomers), the conceptual model calls to attention several other salient factors that should be considered in decision-making regarding lighting such as tourism, human health, ecosystems, sleep, cultural heritage, and light shielding. Figure 32 shows new dimensions of the light pollution problem originally proposed by Hölker et al. (2010). The new dimensions to the conceptual model include governance, technology and technological solutions, astronomy, and cultural heritage under social/cultural.

Results of the scenario planning workshops keyed in on the factors with the highest impact and uncertainty. Across both workshops, these included dark sky friendly lighting policy, appreciation of wilderness, and public awareness. Future efforts to protect Arizona's night skies can be strengthened by leveraging these critical factors. Workshop participants drafted a short-list of strategies that can be implemented to protect Arizona's night skies. This list of short-term and long-term strategies should be further expanded and should consider solutions at various scales: individual, business, local, state, regional, national, and international. Lighting solutions that can be considered at multiple scales can include: (1) lighting only what you need, (2) use energy efficient light bulbs and only as bright as you need, (3) shield and direct lights down, (4) only use light when you need it, and (5) choose warm color lights ("Outdoor Lighting Basics," n.d.). As shown in the results of the scenario workshops, the main solution opportunity is educating the general public about these strategies to promote their use and raise awareness.

The workshops also clearly identified multiple factors that have high impact on night skies with great certainty. These factors should also be considered for future planning and included urbanization, population growth, predator/prey relationships, the astronomy industry, vested interest groups, and night work or services. Population and urbanization projections for cities should be used as primary factors when modeling the growth of artificial lighting. Also, these results suggest that home owners, city planners and developers can be certain that their artificial night lighting decisions will affect predator/prey relationships and the astronomy industry.

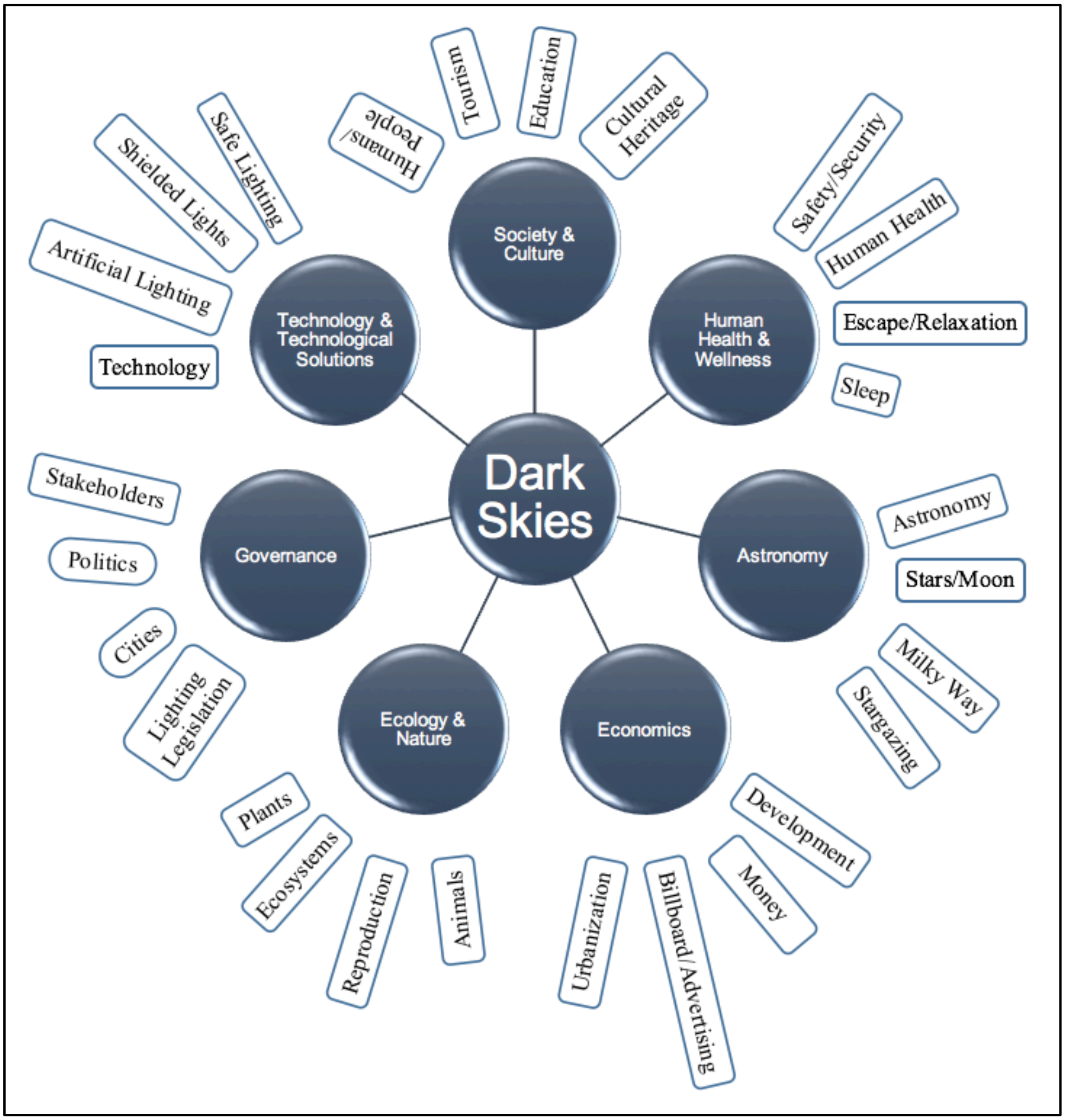



*Figure 32.* Conceptual model of salient factors associated with dark skies.

**5.3 Limitations**

This study has several limitations. The primary limitation is the small sample size of only twenty-one participants. Out of those twenty-one, only seventeen subjects had both pre-test and post-test 2 MMs further attenuating the sample size. Future research should attempt to collect data over a much larger sample size. Another major limitation is maturation internal validity which refers to the effects of the passage of time. Participants could have been more tired, less interested, and eager to leave around the time that they completed the post-test 2. Maturation could have resulted in less complex MMs than could have theoretically been possible if they were at the same interest and energy level as they started the workshop. The study is also limited by the dynamic nature of mental models. It is difficult to claim that MMs changed due to scenario planning when MMs often change between elicitation periods without any interventions. Testing factors could have also affected the internal validity. Participants took the same test three times. Having seen the test multiple times could have impacted the answers on subsequent tests. The subject pool was also more female, richer, more white, and more educated than the general population. The conceptual model and statistical results can only represent what those educated with at least a bachelor degree, white, and high income would produce, and may not reflect low-income, ethnically diverse, and non-college educated stakeholders.

# Chapter 6

# CONCLUSIONS

Mental models have great potential to inform natural resource managers about divergent stakeholder perspectives and conceptualizations of resources they are charged to protect. There is an increasing trend in the use of participatory methods for environmental governance and NRM around the world. Studying individuals' MMs or collective MMs is one such approach that can help managers combat misconceptions in different stakeholder groups or to realize new approaches to solve a problem within a specific context. Eliciting stakeholders' MMs of dark skies can provide valuable insights into how different stakeholders conceptualize the key factors, components, critical issues, and casual links in the system.

Artificial lighting is growing at a worldwide rate of 6% per year. There is insufficient research and action to address this growing problem. To date no study has investigated any stakeholder's or group's MMs of dark skies. Natural resource managers, city planners, ecologists, astronomers, scientists, and dark sky advocates have been left to manage this resource using only their own MMs of dark skies which are well-documented in the literature to be incomplete representations of reality. This study allows stakeholders to peer into the minds of diverse expert stakeholders to understand a plurality of perspectives of this issue to form a more complete and dynamic picture of the system. These results and new conceptual model of dark skies will allow stakeholders to develop the most robust and efficient strategy to preserve this valuable natural resource.

Participants identified and ranked the factors with the highest uncertainty and impact on dark skies during the scenario workshops. These factors are high-leverage areas for dark sky advocates to address and include public awareness, lighting regulations, and appreciation of wilderness. Participants created a list of potential strategies that can be implemented in the short and long-term to address light pollution and preserve dark skies. Future scenario workshops should expand this short-list of strategies and clarify the details for how to implement them.

Perhaps the most important contribution of this study is the empirical results it has provided for testing the theory of scenario planning. Scenario planning has indeed shown to positively affect learning and has also positively increased the change in density and linkages of dark sky advocates' MMs. However, the link between scenario planning and altering the complexity of MM structure was overwhelmingly not seen. Instead, reshuffling of the importance of individual concepts in participants' MMs was observed. It is unclear whether this change is due to participation in scenario planning or simply because MMs may change naturally between elicitation periods. Nevertheless, it seems clear the overall MM structure does not change much after participation in a one-day workshop. Future research should investigate if the accuracy of MMs is improved or if MMs better appreciate feedback loops and dynamism after participation in scenario planning. Future research may also explore the long-term impacts on MMs from participating in several scenario workshops rather than one isolated event. Future research should also investigate the other hypothesized interactions in the theory of scenario planning (i.e. decision-making and outcomes).

This study has found that scenario planning alters participants' environmental attitudes from anthropocentric to more nature-centered dispositions. This finding has critical theoretical implications. The TPB shows that attitudes affect intentions, and intensions affect behaviors. Since scenario planning is designed to improve decision-making under uncertainty, it should include all factors associated with decision-making that it may positively influence. The TPB would suggest that attitudes may impact decision-making. This study has argued that attitudes should be further investigated as a critical component of the theory of scenario planning since they have been shown to be altered during the scenario planning workshop. A refinement to the theory of scenario planning was presented for the consideration of future research. Future research should investigate the long-term environmental attitude change to see if it persists long after the workshop. Future research may also investigate the role of environmental attitudes in decision-making during the scenario planning process.

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# APPENDIX A

# SAMPLE SCENARIO WORKSHOP AGENDA

**Scenario Planning for Sustainable Dark Skies**

**Agenda**

Date: Wednesday, September 21, 2016

Location: Wrigley Hall (WGHL), Room 401, 800 Cady Mall, Tempe, AZ 85287

Parking: Visitor parking is available in the Fulton Center Structure Garage. Entrance to the garage is on University Drive, just east of College Ave between FULTN & PVW buildings. It is one block northeast of WGHL. Please see the map below for visual directions. Parking validation will be given at the end of the workshop.

| | |
|---|---|
| 8:30 AM | Coffee and refreshments available |
| 9:00 AM | Welcome/Introductions |
| 9:15 AM | Introduction to Scenario Planning & Concept Mapping |
| 9:30 AM | Pre-Test & Concept Mapping |
| 10:00 AM | Dark Skies Presentation |
| 10:30 AM | Post-Test 1 & Break |
| 10:45 AM | Identifying & Categorizing Key Factors/Drivers |
| 12:00 PM | Ranking Factors & Defining Scenarios |
| 12:30 PM | Lunch |
| 1:00 PM | Overview of Scenario Narrative Writing |
| 1:15 PM | Creating Scenario Narratives |
| 2:00 PM | Sharing Scenario Narratives |
| 2:30 PM | Post-Test 2 |
| 3:00 PM | Adjourn |

**Research Goal:** This study will measure the effect of participatory scenario planning workshops about sustainable dark night skies on participants' mental models and knowledge gain.

**Research Purpose:** Assist participants in making sense of the complex issues associated with dark night skies and to help cities, natural resource managers, and community activists anticipate possible major impacts to Arizona's pristine dark night skies.

**Research Objectives:** (1) to examine the community's and experts' understanding of dark skies as a resource, (2) to develop a conceptual framework to model the complex issues related to dark skies, and (3) to test Chermack's (2005) scenario planning theory's hypothesis that scenario planning alters participants' mental models.

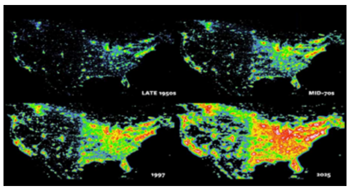
# APPENDIX B

# SCENARIO PLANNING PRE-TEST

# Scenario Planning for Sustainable Dark Skies

**Questionnaire Pre-Test**




## Participant Number: _____

### Part 1 - Environmental Worldview

Listed below are statements about the relationship between humans and the environment. For each one, please indicate whether you STRONGLY AGREE, MILDLY AGREE, are UNSURE, MILDLY DISAGREE or STRONGLY DISAGREE with it.

| Questions | Strongly Agree | Mildly Agree | Unsure | Mildly Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| We are approaching the limit of the number of people the earth can support | | | | | |
| Humans have the right to modify the natural environment to suit their needs | | | | | |
| When humans interfere with nature it often produces disastrous consequences | | | | | |
| Human ingenuity will insure that we do NOT make the earth unlivable | | | | | |
| Humans are severely abusing the environment | | | | | |
| The earth has plenty of natural resources if we just learn how to develop them | | | | | |
| Plants and animals have as much right as humans to exist | | | | | |
| The balance of nature is strong enough to cope with the impacts of modern industrial nations | | | | | |
| Despite our special abilities humans are still subject to the laws of nature | | | | | |
| The so-called "ecological crisis" facing humankind has been greatly exaggerated | | | | | |
| The earth is like a spaceship with very limited room and resources | | | | | |
| Humans were meant to rule over the rest of nature | | | | | |
| The balance of nature is very delicate and easily upset | | | | | |
| Humans will eventually learn enough about how nature works to be able to control it | | | | | |
| If things continue on their present course, we will soon experience a major ecological catastrophe | | | | | |

## Part 2 – Topic Knowledge

Listed below are statements about artificial night lighting. For each one, please indicate whether you STRONGLY AGREE, MILDLY AGREE, are UNSURE, MILDLY DISAGREE or STRONGLY DISAGREE with it.

| Questions | Strongly Agree | Mildly Agree | Unsure | Mildly Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| I do not know several socio-cultural factors associated with artificial night lighting | | | | | |
| I know several technological factors associated with artificial night lighting | | | | | |
| I do not know several ecological factors associated with artificial night lighting | | | | | |
| I know several economic factors associated with artificial night lighting | | | | | |
| I do not know several political factors associated with artificial night lighting | | | | | |
| I know several methods to reduce the impact of artificial night lighting on night sky quality | | | | | |

## Part 3 – Stargazing Specialization

Listed below are statements about your stargazing experience, centrality to your lifestyle, and economic commitment. Please check one of the boxes provided or enter a number where a blank pace is provided.

| | |
|---|---|
| My stargazing skill level is | ❑ Poor ❑ Fair ❑ Good ❑ Very Good ❑ Excellent |
| My constellation identification ability level is | ❑ Poor ❑ Fair ❑ Good ❑ Very Good ❑ Excellent |
| Level of personal involvement with stargazing | ❑ Very low ❑ Low ❑ Medium ❑ High ❑ Very High |
| Approximate number of night sky objects I have seen through a telescope/binoculars (comets, nebula, galaxies, star clusters, planets, moons, the sun, etc.) over the course of my life. | _____ |
| Number of times that I went stargazing **since September 2015** | _____ |
| Number of stargazing/astronomy magazines and subscriptions | _____ |
| Number of stargazing/astronomy books I own | _____ |
| Number of stargazing equipment (e.g. telescopes, binoculars, planisphere, astrophotography equip, etc.) items that I own | _____ |
| Approximate stargazing equipment replacement value | $ _____ USD |

## Part 4 - Dark Sky Advocacy Experience

Listed below are statements about your dark sky advocacy. In the past couple of years, have you done any of the following? For each one, please indicate YES (Y) or NO (N).

| Questions | Y | N |
|---|---|---|
| Contacted a public/community official or manager about a dark sky conservation issue | | |
| Attended a meeting/conference/talk on dark sky conservation issues (other than this study) | | |
| Contributed money to a dark sky conservation organization | | |
| Reduced the amount of outdoor lighting at my work or primary residence | | |
| Shielded outdoor lighting at my work or primary residence | | |
| Replaced outdoor lighting fixtures to ones which are more dark-sky friendly at my work or primary residence | | |
| Was involved in a community dark sky conservation project | | |
| Was a member of a dark sky conservation group (e.g. International Dark Sky Association) | | |
| Educated friends, neighbors, family about dark sky conservation issues | | |

## Part 5 – Demographic information

Finally, we would like to collect some information about you. This is to determine if we have adequately represented stakeholder groups and will be used for statistical purposes only. Remember that your personal information is kept completely confidential.

1. Please select the type of city you reside in *(Check one.)*
   ❑ Urban ❑ Sub-urban ❑ Rural ❑ Other (please specify): ______________
2. Do you live in Arizona? *(Check one.)*
   ❑ Yes. Which city do you reside in? _______________
   ❑ No. What state/country do you reside in? ____________________________
3. In what year were you born? 19 __ __
4. What is your gender? *(Check one.)* ❑ Male ❑ Female
5. Are you Hispanic or Latino? *(Check one.)* ❑ Yes ❑ No
6. What is your race/ethnicity? *(Check all that apply.)*
   ❑ American Indian or Alaska Native ❑ Native Hawaiian or Other Pacific Islander
   ❑ Asian ❑ White
   ❑ Black or African American ❑ Other (please specify): ______________
7. What is the highest level of formal education you have completed? *(Check one.)*
   ❑ Less than high school ❑ Vocational/trade school certificate ❑ Four-year college degree
   ❑ Some high school ❑ Some college ❑ Master's Degree
   ❑ High school graduate ❑ Two-year college degree ❑ Ph.D., M.D., J.D., or equivalent
8. What was your approximate household income before taxes in 2015? *(Check one.)*
   ❑ Under $25,000 ❑ $75,000-$99,999 ❑ $200,000 or over
   ❑ $25,000-$49,999 ❑ $100,000-$149,999
   ❑ $50,000-$74,999 ❑ $150,000-$199,999
9. Which stakeholder groups do you belong to or represent? *(choose all that apply.)*
   ❑ Sustainability Scientist ❑ Professional Astronomer ❑ Utility Provider
   ❑ Engineer ❑ Amateur Astronomer ❑ Parks & Recreation
   ❑ City Planner ❑ Dark Sky Advocate ❑ Government Organization
   ❑ Social Scientist ❑ Park Manager ❑ Higher Education
   ❑ Ecologist/Biologist ❑ Educator ❑ Environmental Conservation Organization
   ❑ Economist ❑ Student ❑ Non-Government Organization (NGO)
   ❑ Other (Please specify): ______________________________

## Part 6 - Concept Map

Concept maps are graphical tools for organizing and representing knowledge. They include **concepts**, usually enclosed in circles or boxes of some type, and **relationships** between concepts indicated by an arrow linking two concepts. **Please create a concept map on the large 11x17 paper provided** which shows the linkages between the concepts you believe are important and related to dark sky sustainability. You are welcome to use all, some, or none of the concepts listed below as well as add your own concepts to your map. **Please only use those which you feel that you own**. Concepts should have a circle around them. Arrows should be used to show connections or linkages with other concepts. Each concept may have multiple linkages or arrows between other concepts. It is helpful to start with a concept that you believe is the most central to the issue and build it off of that concept. A sample concept map is provided on Page 5. You can use page 6 to quickly brainstorm a structure for your map (for a few minutes), but please put your final completed concept map on the large 11x17 paper.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Lighting | Education | Circadian rhythm | Navigation | Sleep | Sunlight | Fear | Milky Way | Space Exploration | Engineers |
| Humans | Safety/ Crime | Connection with night sky | Nocturnal Animals | Stargazing | White light | Enforce-ment | Plants | Artistic Expression/ Creativity | Telling Time |
| Night Sky | Economy | Decisions & Decision-makers | Utility companies | Warm light | Arizona | Global warming | Population | Transportati on | Immune system |
| Politics | Ecosystems | Human Health | Cultural resource | Birds | Beauty | Hardware Stores | Rural | Asteroids | Universe |
| Artificial night lighting | Wildlife | Public | Fossil Fuels | Leisure and Recreation | Curiosity | Hormones | Sea Turtles | Bad moods/ Depression | Manufact-urers |
| Frequency/ Wavelength /Color of Light | Animals | Work at night | Insects | Migration patterns | Curtains /Shades | Observat-ories/ Telescopes | The moon | Border disputes | Neighbor-hoods |
| Cities & Municipal-ities | LEDs | Astronomy/ Astronomer s | Lighting Ordinances | Organizati-ons | Earth | Human evolution | Tourism | Breeding/ Reproducti-on | Park & Wilderness Areas |
| Technology | Money | Blue Lights | Mystery/ Unknown | Safe Lighting | Energy Efficiency | Land manageme-nt | Urbanizati-on | e-waste | Predator/ Prey Relationsh-ips |
| Electricity/ Energy | Night | Internation-al Dark Sky Association | Night life | Stars | Escape/ Relaxation | Light Shielding/ Dimming/ Turning Off | Age | Electronic Billboards/ Advertising | Social Equity |
| Light Pollution | Scientific investigate-ons | Natural resource | Night sky quality | Street lights | Eyes/ Vision | Light trespass | Amateur Astronome-rs | Politicians | Environme-nt |
| Unanticipa-ted consequen-ces | Biodiversity | Globalizati-on | Species | Human Happiness/ Wellness | Indigenous People & Cultures | Native Americans | Stakeholde-rs | Energy Waste | Governme-nt |

# Sample Concept Map – Superheroes

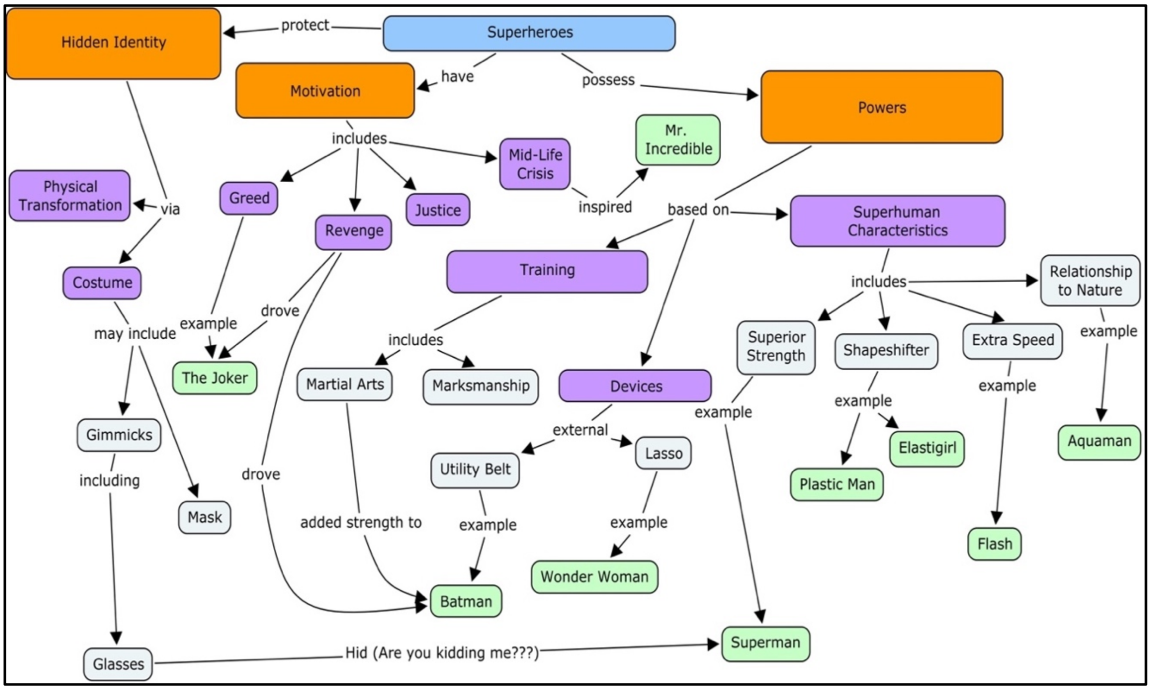



Image Credit: Mike Wazowski

# APPENDIX C

## SCENARIO PLANNING POST-TEST 1

## SCENARIO PLANNING POST-TEST 1

**Participant Number: ______**

### Part 1 - Environmental Worldview

Listed below are statements about the relationship between humans and the environment. For each one, please indicate whether you STRONGLY AGREE, MILDLY AGREE, are UNSURE, MILDLY DISAGREE or STRONGLY DISAGREE with it.

| Questions | Strongly Agree | Mildly Agree | Unsure | Mildly Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| We are approaching the limit of the number of people the earth can support | | | | | |
| Humans have the right to modify the natural environment to suit their needs | | | | | |
| When humans interfere with nature it often produces disastrous consequences | | | | | |
| Human ingenuity will insure that we do NOT make the earth unlivable | | | | | |
| Humans are severely abusing the environment | | | | | |
| The earth has plenty of natural resources if we just learn how to develop them | | | | | |
| Plants and animals have as much right as humans to exist | | | | | |
| The balance of nature is strong enough to cope with the impacts of modern industrial nations | | | | | |
| Despite our special abilities humans are still subject to the laws of nature | | | | | |
| The so-called "ecological crisis" facing humankind has been greatly exaggerated | | | | | |
| The earth is like a spaceship with very limited room and resources | | | | | |
| Humans were meant to rule over the rest of nature | | | | | |
| The balance of nature is very delicate and easily upset | | | | | |
| Humans will eventually learn enough about how nature works to be able to control it | | | | | |
| If things continue on their present course, we will soon experience a major ecological catastrophe | | | | | |

### Part 2 – Topic Knowledge

Listed below are statements about artificial night lighting. For each one, please indicate whether you STRONGLY AGREE, MILDLY AGREE, are UNSURE, MILDLY DISAGREE or STRONGLY DISAGREE with it.

| Questions | Strongly Agree | Mildly Agree | Unsure | Mildly Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| I do not know several socio-cultural factors associated with artificial night lighting | | | | | |
| I know several technological factors associated with artificial night lighting | | | | | |
| I do not know several ecological factors associated with artificial night lighting | | | | | |
| I know several economic factors associated with artificial night lighting | | | | | |
| I do not know several political factors associated with artificial night lighting | | | | | |
| I know several methods to reduce the impact of artificial night lighting on night sky quality | | | | | |

# APPENDIX D

## SCENARIO PLANNING POST-TEST 2

## SCENARIO PLANNING POST-TEST 2

**Participant Number: ______**

### Part 1 - Environmental Worldview

Listed below are statements about the relationship between humans and the environment. For each one, please indicate whether you STRONGLY AGREE, MILDLY AGREE, are UNSURE, MILDLY DISAGREE or STRONGLY DISAGREE with it.

| Questions | Strongly Agree | Mildly Agree | Unsure | Mildly Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| We are approaching the limit of the number of people the earth can support | | | | | |
| Humans have the right to modify the natural environment to suit their needs | | | | | |
| When humans interfere with nature it often produces disastrous consequences | | | | | |
| Human ingenuity will insure that we do NOT make the earth unlivable | | | | | |
| Humans are severely abusing the environment | | | | | |
| The earth has plenty of natural resources if we just learn how to develop them | | | | | |
| Plants and animals have as much right as humans to exist | | | | | |
| The balance of nature is strong enough to cope with the impacts of modern industrial nations | | | | | |
| Despite our special abilities humans are still subject to the laws of nature | | | | | |
| The so-called "ecological crisis" facing humankind has been greatly exaggerated | | | | | |
| The earth is like a spaceship with very limited room and resources | | | | | |
| Humans were meant to rule over the rest of nature | | | | | |
| The balance of nature is very delicate and easily upset | | | | | |
| Humans will eventually learn enough about how nature works to be able to control it | | | | | |
| If things continue on their present course, we will soon experience a major ecological catastrophe | | | | | |

### Part 2 – Topic Knowledge

Listed below are statements about artificial night lighting. For each one, please indicate whether you STRONGLY AGREE, MILDLY AGREE, are UNSURE, MILDLY DISAGREE or STRONGLY DISAGREE with it.

| Questions | Strongly Agree | Mildly Agree | Unsure | Mildly Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| I do not know several socio-cultural factors associated with artificial night lighting | | | | | |
| I know several technological factors associated with artificial night lighting | | | | | |
| I do not know several ecological factors associated with artificial night lighting | | | | | |
| I know several economic factors associated with artificial night lighting | | | | | |
| I do not know several political factors associated with artificial night lighting | | | | | |
| I know several methods to reduce the impact of artificial night lighting on night sky quality | | | | | |

## Part 3 - Concept Map

Concept maps are graphical tools for organizing and representing knowledge. They include **concepts**, usually enclosed in circles or boxes of some type, and **relationships** between concepts indicated by an arrow linking two concepts. **Please create a concept map on the large 11x17 paper provided** which shows the linkages between the concepts you believe are important and related to dark sky sustainability. You are welcome to use all, some, or none of the concepts listed below as well as add your own concepts to your map. **Please only use those which you feel that you own**. Concepts should have a circle around them. Arrows should be used to show connections or linkages with other concepts. Each concept may have multiple linkages or arrows between other concepts. It is helpful to start with a concept that you believe is the most central to the issue and build it off of that concept. Additional blank pages are available upon request.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Lighting | Education | Circadian rhythm | Navigation | Sleep | Sunlight | Fear | Milky Way | Space Exploration | Engineers |
| Humans | Safety/ Crime | Connection with night sky | Nocturnal Animals | Stargazing | White light | Enforceme-nt | Plants | Artistic Expression/ Creativity | Telling Time |
| Night Sky | Economy | Decisions & Decision-makers | Utility companies | Warm light | Arizona | Global warming | Population | Transportat-ion | Immune system |
| Politics | Ecosystems | Human Health | Cultural resource | Birds | Beauty | Hardware Stores | Rural | Asteroids | Universe |
| Artificial night lighting | Wildlife | Public | Fossil Fuels | Leisure and Recreation | Curiosity | Hormones | Sea Turtles | Bad moods/ Depression | Manufactu-rers |
| Frequency/ Wavelength /Color of Light | Animals | Work at night | Insects | Migration patterns | Curtains/ Shades | Observator-ies/ Telescopes | The moon | Border disputes | Neighborh-oods |
| Cities & Municipali-ties | LEDs | Astronomy/ Astronome-rs | Lighting Ordinances | Organizati-ons | Earth | Human evolution | Tourism | Breeding/ Reproducti-on | Park & Wilderness Areas |
| Technology | Money | Blue Lights | Mystery/ Unknown | Safe Lighting | Energy Efficiency | Land manageme-nt | Urbanizati-on | e-waste | Predator/ Prey Relationsh-ips |
| Electricity/ Energy | Night | Internation-al Dark Sky Association | Night life | Stars | Escape/ Relaxation | Light Shielding/ Dimming/ Turning Off | Age | Electronic Billboards/ Advertising | Social Equity |
| Light Pollution | Scientific investigate-ons | Natural resource | Night sky quality | Street lights | Eyes/ Vision | Light trespass | Amateur Astronome-rs | Politicians | Environme-nt |
| Unanticipa-ted consequen-ces | Biodiversity | Globalizati-on | Species | Human Happiness/ Wellness | Indigenous People & Cultures | Native Americans | Stakeholde-rs | Energy Waste | Governme-nt |

# APPENDIX E

# SEMI-STRUCTURED INTERVIEW PROTOCOL

## Scenario Planning for Sustainable Dark Skies Interview Protocol

I am an MS graduate student under the direction of Dr. Gyan Nyaupane, Associate Professor, in the School of Community Resources and Development at Arizona State University. I am conducting a study to measure the effect of participatory scenario planning workshops about sustainable dark night skies on participants' mental models and knowledge gain. In preparation for the workshops, I am conducting interviews to identify key factors affecting and being affected by artificial night lighting. The interview should take no longer than 15-30 minutes. I would like to interview you and document your thoughts about these factors. The interview will be recorded. Your participation in this study is entirely voluntary. You do not have to answer every question during te interview and can leave the interview at any time if you wish. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. You must be 18 or older to participate in the study.

Your responses will be helpful in the sustainable management of dark skies in Arizona and areas around the globe. There are no foreseeable risks or discomforts to your participation. Your responses will be anonymous, and to ensure this, you will not be asked to include any personal identification. Your answers will be used with many others in an aggregated form. The results of this study may be used in reports, presentations, or publications but your name will not be known.

Please read the consent form and if you consent, please let me know verbally. I'm happy to answer any questions you may have before we get started.

**Interview prompts:**

1. What do you believe are the major social factors affecting or being affected by artificial night lighting?
2. What do you believe are the major technological factors affecting or being affected by artificial night lighting?
3. What do you believe are the major economic factors affecting or being affected by artificial night lighting?
4. What do you believe are the major ecological factors affecting or being affected by artificial night lighting?
5. What do you believe are the major political factors affecting or being affected by artificial night lighting?
6. Would you like to revisit any of the 5 factor categories and add to them?
7. Is there anything else you would like to mention?

Thank you so much for your time today!

APPENDIX F

MENTAL MODEL CODEBOOK

# Mental Model Codebook

1. **Advocacy/Conservation**
    a. Environmentalists
    b. Advocacy
    c. Conservation
    d. Wilderness Ethic
2. **Aesthetics**
    a. Aesthetics
3. **Airports**
    a. Airports
4. **Albedo**
    a. Albedo
5. **Animal Behavior**
    a. Behaviors
6. **Animal Foraging/Feeding**
    a. Foraging
    b. Feeding
7. **Animals**
    a. Animals
8. **Animal Physiology**
    a. Animal Physiology
9. **Animal Interaction with Humans**
    a. Animal Interaction with Humans
10. **Animal Migration**
    a. Migration
    b. Migration Patterns
    c. Dispersal Migration
11. **Arizona**
    a. Arizona
12. **Artificial Lighting**
    a. Artificial Night Lighting
    b. Artificial Light at Night
    c. Artificial Light
    d. Artificial Lighting
13. **Asteroids**
    a. Asteroids
14. **Astronomers (Professional & Amateur)**
    a. Astronomers
    b. Professional astronomers
    c. Amateur Astronomers
15. **Astronomy**
    a. Astronomy
    b. Astronomy Industry
    c. Astronomy/Astronomers
    d. Dark Sky Objects
16. **Atmosphere**
    a. Atmosphere
17. **Bats**
    a. Bats
18. **Beauty**
    a. Beauty
19. **Big Business**
    a. Big Business
    b. Vested Interests
    c. Influence of Lighting Industry
20. **Big Eyes**
    a. Big Eyes
21. **Billboards/Advertising**
    a. Electronic Billboards
    b. Advertising
    c. Billboards
22. **Biodiversity**
    a. Biodiversity
    b. Species Diversity
    c. Species Abundance
    d. Biodiversity Loss
    e. Endangerment
    f. Biological Diversity
23. **Birds**
    a. Birds
24. **Blue Lights**
    a. Blue Lights
25. **Borders**
    a. Borders
26. **Business**
    a. Business
27. **Casinos**
    a. Casinos
28. **Cities/Municipalities**
    a. Cities
    b. Municipalities
    c. Developed Areas
    d. Development of Urban Spaces
    e. Urban
29. **Color of Light**
    a. Frequency of light
    b. Wavelength of light
    c. Color
    d. Color of light
    e. Wavelength
    f. Frequency
    g. Type of Illuminant
30. **Consciousness**
    a. Consciousness
31. **Connection with Night Sky/Nature**
    a. Connection with Night Sky
    b. Contact with Nature
    c. Cultural Connections
    d. Human Appreciation
    e. Connection With The Universe
    f. Connection to Universe
32. **Constellations**
    a. Constellations

33. **Coyotes**
    a. Coyotes
34. **Creativity**
    a. Creativity
    b. Art
    c. Aesthetics
35. **Crime**
    a. Crime
    b. Crime Prevention
36. **Cultural Heritage & Values**
    a. Cultural Heritage
    b. Cultural Resource
    c. Cultures
    d. Cultural Importance
    e. Cultural
    f. Values
    g. Culture
37. **Curiosity/Inspiration**
    a. Curiosity
    b. Sense of Wonder
    c. Inspiration
    d. Mystery/Unknown
    e. Wonderment
38. **Curtains/Shades**
    a. Curtains
    b. Shades
39. **Dark Skies**
    a. Night Sky
    b. Dark Night Skies
    c. Dark Skies
    d. Dark Sky
    e. Biology of Dark Skies
    f. Pristine Night Sky
40. **Dark Sky Parks**
    a. Dark Sky Parks
41. **Darkness**
    a. Darkness
    b. Absence of Night Light
    c. Nighttime
42. **Day/Night Cycles**
    a. Circadian Rhythm
    b. Day/Night Cycle
    c. Daily Patterns
    d. Day/Night
    e. Natural Cycles
43. **Daytime Heat Avoidance**
    a. Avoid heat
44. **Decision-Makers**
    a. Decision-makers
    b. Strategic/Personal decisions
45. **Density of Illuminant**
    a. Density of Illuminant
46. **Depression/Irregular Moods**
    a. Moods
    b. Depression
    c. Mood disorders
47. **Desert Night**
    **a.** Desert Night
48. **Doctors**
    a. Doctors
49. **E-Waste**
    **a.** E-waste
50. **Earth**
    a. Earth
    b. Earth's Place in Universe
51. **Economics and Economic Development**
    a. Economics
    b. Economic Development
    c. Economic Stimulus
    d. Economy
    e. Socio-Economic
    f. Economic Drivers
52. **Ecosystems**
    a. Ecosystems
    b. Ecological
    c. Ecology
    d. Biological
    e. Desert ecosystems
53. **Education**
    a. Education
    b. Public Education
54. **Energetic Costs**
    a. Energetic Costs
55. **Energy/Electricity**
    a. Energy
    b. Electricity
    c. Electricity Generation
    d. Electricity/Energy
56. **Energy Efficiency**
    a. Energy Efficiency
57. **Energy Waste**
    a. Energy Waste
58. **Enforcement of Legislation/Regulations**
    a. Enforcement
59. **Environment**
    a. Environment
60. **Escape/Relaxation**
    a. Escape
    b. Relaxation
    c. Solitude
    d. Quietness
    e. Serenity
61. **Evolution & Adaptation**
    a. Human Evolution
    b. Evolution
    c. Night Time Adaptation
    d. Biological Fitness
    e. Success/Fitness

62. **Family Time**
    a. Family Play
63. **Fear**
    a. Fear
    b. Fear of Darkness
64. **Federal Regulation**
    a. Federal Regulation
65. **Fireflies**
    a. Fireflies
    b. Lightning Bugs
66. **Food Quality/Quantity**
    a. Food Quality
    b. Food Quantity
67. **Full Moon Hikes**
    a. Full Moon Hikes
68. **Galaxies**
    a. Galaxies
69. **Glare**
    a. Glare
70. **Global Warming/Climate Change**
    a. Global Warming
    b. Climate Change
71. **Globalization**
    a. Globalization
72. **Government**
    a. Government
73. **Homeowners/Households**
    a. Homeowners
    b. Households
    c. Household management
74. **Hormones**
    a. Hormones
75. **Hospitals**
    a. Hospitals
76. **Housing/Residential**
    a. Housing
    b. Residential
77. **Human Eyes**
    a. Chemical Sensory
    b. Human Eyes
    c. Rods/Cones/Pupils
78. **Human Happiness**
    a. Happiness
    b. Well-being
    c. Quality of Life
    d. Wellness
79. **Human Health**
    a. Human Health
    b. Health
    c. Human Physiology
    d. Human Health Physiology
    e. Health Benefits
    f. Mental Health
80. **Human Population Growth & Density**
    a. Population
    b. Population Growth
    c. Human Population Density
81. **Humans/People**
    a. Humans
    b. People
    c. Public
    d. Individuals
82. **Humility**
    a. Humility
83. **Illnesses/Diseases**
    a. Disease
    b. Cancer
84. **Immune System**
    a. Immune System
85. **Impacts**
    a. Impacts
86. **Indigenous People & Cultures**
    a. Indigenous People
    b. Indigenous Cultures
    c. Native Americans
    d. Indigenous Values
    e. Native Cultures
87. **Industry**
    a. Industry
88. **Insects**
    a. Insects
    b. Moths
89. **Internal Building/Home Lights**
    a. Internal Building Lights
90. **International Dark Sky Association**
    a. IDA
    b. IDSA
    c. International Dark Sky Association
91. **Invertebrates**
    a. Invertebrates
92. **Knowledge**
    a. Knowledge
    b. Perception
    c. Wisdom
    d. Perspective
93. **Land Management**
    a. Land Management
    b. Land Ownership Change
94. **LEDs**
    a. LEDs
    b. Light Emitting Diodes
95. **Leisure & Recreation**
    a. Leisure
    b. Leisure Choices
    c. Recreation
    d. Recreation Opportunities
    e. Leisure & Recreation

96. **Light Bounces**
    a. Bounces
97. **Light is a Wave**
    a. Wave
98. **Light Pollution**
    a. Light Pollution
    b. Pollution
    c. Light Domes
    d. Centralized Compounds
    e. Light Corridors
99. **Light Properties**
    a. Properties of Light
100. **Light Scatters**
    a. Scatters
101. **Light Trespass**
    a. Trespass
102. **Lighting**
    a. Lighting
    b. Light
    c. Light Needs
103. **Lighting Legislation/Rules**
    a. Lighting Regulation
    b. Light Ordinance
    c. Regulation
    d. Legislation
    e. Lighting Standards
    f. Laws/Ordinances
    g. Dark Sky Ordinances
    h. Light Management Change
104. **Location**
    a. Location
    b. Location on Earth
105. **Luminosity = 1/(Distance)^2**
    a. L=1/d^2
106. **Lunar Phases**
    a. Lunar Phases
107. **Manufacturing**
    a. Manufacturing
    b. Manufacturers
108. **Meetings**
    a. Meetings
109. **Meteor Showers**
    a. Meteor Showers
110. **Milky Way**
    a. Milky Way
111. **Modernization**
    a. Modernization
112. **Money**
    a. Money
    b. Costs to society
    c. Cost of lights
    d. Costs of new technology
113. **Moon**
    a. Moon
    b. Lunar
114. **Monsoon/Haboob**
    a. Monsoons
    b. Haboobs
115. **Music**
116. **National Parks**
    a. National Parks
117. **Natural Night Lighting**
    a. Natural Night Lighting
118. **Nature/Natural Resource**
    a. Natural Resource
    b. Nature
119. **Navigation**
    a. Navigation
    b. Navigating
120. **Neighborhoods**
    a. Neighborhoods
    b. Neighbors
121. **Networking**
    a. Networking
122. **Night Hawks**
    a. Night Hawks
123. **Night Life**
    a. Night Life
    b. Night Activity
    c. After-hours Human Activity
    d. Outdoors at Night
124. **Night Sky Quality**
    a. Night Sky Quality
    b. Dark Sky Quality
125. **Night Vision/Saturation**
    a. Saturation
    b. Visual Discrimination
    c. Transition Time
    d. Max Contrast Ratio
    e. Increased visibility
126. **Night Work/Night Shifts**
    a. Night Workers
    b. Night Work
    c. Work
    d. 24/7 Ethic
127. **Nocturnal Creatures**
    a. Nocturnal wildlife
    b. Nocturnal animals
    c. Nocturnal creatures
128. **Northern Lights**
    a. Northern Lights
129. **Observatories/Telescopes**
    a. Observatories/Telescopes
130. **Organizations**
    a. Organizations
    b. Non-Profits
131. **Parks & Wilderness Areas**
    a. Parks & Wilderness Areas
    b. Parks
    c. Wilderness

d. Wilderness Areas
e. Pristine Wilderness Areas
f. Open spaces
g. Parks and Wilderness Systems
h. Natural Environment
i. Urban Space for Wildlife
j. Undeveloped
k. Protected Resource

**132. Particle Properties of Light**
a. Particle

**133. Parties**
a. Parties

**134. Pathogen Resistance**
a. Pathogen Resistance

**135. Patience**
a. Patience

**136. Photography**
a. Photography

**137. Photosynthesis**
a. Photosynthesis

**138. Planets**
a. Planets

**139. Planning/Design**
a. City Planning
b. Landscape Design
c. Small Community Development
d. Planning

**140. Plants**
a. Plants
b. Vegetation

**141. Politicians/Legislature**
a. Politicians
b. Politicians/Decision-Makers
c. Legislature

**142. Politics**
a. Politics
b. Political
c. Policy
d. Policies

**143. Predator/Prey Relationships**
a. Predation
b. Hunting
c. Predator/Prey Relationships

**144. Public Services**
a. Services
b. 24/7 Services
c. Public service

**145. Reproduction**
a. Breeding
b. Reproduction
c. Mating
d. Egg Laying
e. Pollination

**146. Resource Acquisition (for animals)**
a. Resource Acquisition

**147. Restaurants/Bars**
a. Restaurants
b. Bars

**148. Rural**
a. Rural

**149. Safe Lighting**
a. Safe Lighting
b. Good lighting
c. Dark Sky Friendly Lights
d. Proper Lighting

**150. Safety/Security**
a. Safety
b. Security
c. Public Safety
d. Human Safety

**151. School Nights/Events**
a. School Nights

**152. Scientific Investigations**
a. Scientific investigations
b. Research
c. Research & Exploration
d. Science
e. Discovery

**153. Seasonal Cycles**
a. Daily/Seasonal Cycles

**154. Sense of Place**
a. Sense of Place

**155. Shielded Lights**
a. Light Shielding
b. Shielding
c. Reduction Strategies

**156. Skies**
a. Skies

**157. Sleep**
a. Sleep
b. Sleep Patterns
c. Sleep Disorders
d. Sleep Deprivation
e. Sleep Cycles

**158. Small Business**
a. Small Business

**159. Social**
a. Social

**160. Social Equity**
a. Equity
b. Social Equity

**161. Solutions**
a. Solutions

**162. Sounds/Ears**
a. Sounds/Ears

**163. Species**
a. Species
b. Spatial Distribution of Species

**164. Spiritual/Religious**
  a. Creation Stories
  b. Spiritual Health

**165. Sports**
  a. Sports
  b. Sports Fields

**166. Stakeholders**
  a. Stakeholders

**167. Stargazing**
  a. Stargazing

**168. Stars**
  a. Stars
  b. Stellar

**169. State Parks**
  a. State Parks
  b. Oracle State Park

**170. Storytelling**
  a. Storytelling
  b. Stories
  c. Oral history

**171. Street Lights**
  a. Street Lights

**172. Stress**
  a. Stress

**173. Sun**
  a. Sun

**174. Taxpayers**
  a. Taxpayers

**175. Technology**
  a. Technology
  b. Technology Changes

**176. Telling Time**
  a. Telling Time

**177. Temperature**
  a. Cold Temps

**178. Tourism**
  a. Tourism
  b. Tourism Industry
  c. Visitation Numbers
  d. Hobbies/Tourism
  e. Ecotourism
  f. Astrotourism
  g. Ecotourism/Outdoor Recreation
  h. Wildlife Tourism

**179. Transportation**
  a. Transportation
  b. Cars
  c. Driving
  d. Traffic

**180. Turtles**
  a. Sea Turtles
  b. Turtles

**181. Unanticipated Consequences**
  a. Unanticipated Consequences

**182. Universe**
  a. Universe
  b. Heavens

**183. Urbanization**
  a. Urbanization
  b. Encroachment

**184. Use Light Only When Needed**
  a. Light Timers
  b. Shut Off Lights

**185. Utility Companies**
  a. Utilities
  b. Utility Companies

**186. Warm Light**
  a. Warm Light

**187. Weather**
  a. Clouds
  b. Cloud Cover
  c. Weather

**188. White Light**
  a. White Light

**189. Wildlife**
  a. Wildlife

**190. Yard**
  a. Yard

# APPENDIX G

# CATEGORY CODEBOOK

| | |
|---|---|
| Asteroids | Astronomy |
| Astronomers (Professional & Amateur) | Astronomy |
| Astronomy | Astronomy |
| Constellations | Astronomy |
| Full Moon Hikes | Astronomy |
| Lunar Phases | Astronomy |
| Meteor Showers | Astronomy |
| Milky Way | Astronomy |
| Moon | Astronomy |
| Northern Lights | Astronomy |
| Observatories/Telescopes | Astronomy |
| Planets | Astronomy |
| Stargazing | Astronomy |
| Stars | Astronomy |
| Sun | Astronomy |
| Universe | Astronomy |
| Airports | Economics |
| Big Business | Economics |
| Billboards/Advertising | Economics |
| Business | Economics |
| Casinos | Economics |
| Economics & Economic Development | Economics |
| Energy Waste | Economics |
| Globalization | Economics |
| Industry | Economics |
| Manufacturing | Economics |
| Meetings | Economics |
| Money | Economics |
| Networking | Economics |
| Night Work/Night Shifts | Economics |
| Planning/Design | Economics |
| Public Services | Economics |
| Restaurants/Bars | Economics |
| Small Business | Economics |
| Urbanization | Economics |
| Utility companies | Economics |
| Animal Behavior | Environment & Ecosystems |
| Animal Foraging/Feeding | Environment & Ecosystems |
| Animal Interaction with Humans | Environment & Ecosystems |
| Animal Migration | Environment & Ecosystems |
| Animal Physiology | Environment & Ecosystems |
| Animals | Environment & Ecosystems |
| Atmosphere | Environment & Ecosystems |
| Bats | Environment & Ecosystems |
| Big Eyes | Environment & Ecosystems |
| Biodiversity | Environment & Ecosystems |
| Birds | Environment & Ecosystems |
| Coyotes | Environment & Ecosystems |
| Dark Skies | Environment & Ecosystems |
| Dark Sky Park | Environment & Ecosystems |
| Darkness | Environment & Ecosystems |
| Day/Night Cycles | Environment & Ecosystems |
| Desert Night | Environment & Ecosystems |

| | |
|---|---|
| Earth | Environment & Ecosystems |
| Ecosystems | Environment & Ecosystems |
| Energetic Costs | Environment & Ecosystems |
| Environment | Environment & Ecosystems |
| Evolution & Adaptation | Environment & Ecosystems |
| Fireflies | Environment & Ecosystems |
| Food Quality/Quantity | Environment & Ecosystems |
| Global Warming | Environment & Ecosystems |
| Insects | Environment & Ecosystems |
| Light Pollution | Environment & Ecosystems |
| Monsoon/Haboob | Environment & Ecosystems |
| National Park | Environment & Ecosystems |
| Natural Night Lighting | Environment & Ecosystems |
| Nature/Natural Resource | Environment & Ecosystems |
| Night Sky Quality | Environment & Ecosystems |
| Nocturnal Creatures | Environment & Ecosystems |
| Parks & Wilderness Areas | Environment & Ecosystems |
| Photosynthesis | Environment & Ecosystems |
| Plants | Environment & Ecosystems |
| Predator/Prey Relationships | Environment & Ecosystems |
| Reproduction | Environment & Ecosystems |
| Resource Acquisition (for animals) | Environment & Ecosystems |
| Skies | Environment & Ecosystems |
| Sounds/Ears | Environment & Ecosystems |
| Species | Environment & Ecosystems |
| State Parks | Environment & Ecosystems |
| Temperature | Environment & Ecosystems |
| Turtles | Environment & Ecosystems |
| Unanticipated Consequences | Environment & Ecosystems |
| Weather | Environment & Ecosystems |
| Wildlife | Environment & Ecosystems |
| Daytime Heat Avoidance | Human Health & Wellness |
| Depression/Irregular Moods | Human Health & Wellness |
| Doctors | Human Health & Wellness |
| Escape/Relaxation | Human Health & Wellness |
| Fear | Human Health & Wellness |
| Hormones | Human Health & Wellness |
| Hospitals | Human Health & Wellness |
| Human Eyes | Human Health & Wellness |
| Human Happiness | Human Health & Wellness |
| Human Health | Human Health & Wellness |
| Humility | Human Health & Wellness |
| Illnesses/Diseases | Human Health & Wellness |
| Immune System | Human Health & Wellness |
| Light Trespass | Human Health & Wellness |
| Night Vision/Saturation | Human Health & Wellness |
| Pathogen Resistance | Human Health & Wellness |
| Patience | Human Health & Wellness |
| Safety/Security | Human Health & Wellness |
| Sense of Place | Human Health & Wellness |
| Sleep | Human Health & Wellness |
| Stress | Human Health & Wellness |
| Advocacy/Conservation | Governance |

| | |
|---|---|
| Cities/Municipalities | Governance |
| Decision-makers | Governance |
| Enforcement of Legislation/Regulations | Governance |
| Federal Regulation | Governance |
| Government | Governance |
| International Dark Sky Association | Governance |
| Land Management | Governance |
| Lighting Legislation/Rules | Governance |
| Organizations | Governance |
| Politicians/Legislature | Governance |
| Politics | Governance |
| Stakeholders | Governance |
| Taxpayers | Governance |
| Beauty | Society/Culture |
| Concsciousness | Society/Culture |
| Connection with Night Sky/Nature | Society/Culture |
| Creativity | Society/Culture |
| Crime | Society/Culture |
| Cultural Heritage & Values | Society/Culture |
| Curiosity/Inspiration | Society/Culture |
| Education | Society/Culture |
| Family Time | Society/Culture |
| Homeowners/Households | Society/Culture |
| Housing/Residential | Society/Culture |
| Human Population Growth & Density | Society/Culture |
| Humans/People | Society/Culture |
| Indigenous People & Cultures | Society/Culture |
| Knowledge | Society/Culture |
| Leisure & Recreation | Society/Culture |
| Location | Society/Culture |
| Music | Society/Culture |
| Navigation | Society/Culture |
| Neighborhoods | Society/Culture |
| Night Life | Society/Culture |
| Parties | Society/Culture |
| Photography | Society/Culture |
| Rural | Society/Culture |
| School Nights/Events | Society/Culture |
| Scientific Investigations | Society/Culture |
| Spiritual/Religious | Society/Culture |
| Sports | Society/Culture |
| Storytelling | Society/Culture |
| Telling Time | Society/Culture |
| Tourism | Society/Culture |
| Yard | Society/Culture |
| Artificial Lighting | Technology & Technological Solutions |
| Blue Lights | Technology & Technological Solutions |
| Color of light | Technology & Technological Solutions |
| Curtains/Shades | Technology & Technological Solutions |
| Density of Illuminant | Technology & Technological Solutions |
| Energy Efficiency | Technology & Technological Solutions |
| Energy/Electricity | Technology & Technological Solutions |
| Internal Building/Home Lights | Technology & Technological Solutions |

| | |
|---|---|
| LEDs | Technology & Technological Solutions |
| Light Bounces | Technology & Technological Solutions |
| Light is a Wave | Technology & Technological Solutions |
| Light Properties | Technology & Technological Solutions |
| Light Scatters | Technology & Technological Solutions |
| Lighting | Technology & Technological Solutions |
| Luminosity = 1/(Distance)^2 | Technology & Technological Solutions |
| Particle Properties of Light | Technology & Technological Solutions |
| Safe Lighting | Technology & Technological Solutions |
| Shielded Lights | Technology & Technological Solutions |
| Solutions | Technology & Technological Solutions |
| Street Lights | Technology & Technological Solutions |
| Technology | Technology & Technological Solutions |
| Transportation | Technology & Technological Solutions |
| Use Light Only When Needed | Technology & Technological Solutions |
| Warm Light | Technology & Technological Solutions |
| White Light | Technology & Technological Solutions |

APPENDIX H

SAMPLE SCENARIO PLANNING DARK SKY NARRATIVES

**Scenario Title:** Electing to Take Back the Night
**Setting:** Arizona in 2050
**Impact/Uncertainty**: High appreciation of wilderness & planning and development strategies that do not include time time environment.

**Plot:** Serious light pollution has obliterated the dark night skies throughout the state. Tourists no longer come to see the night sky. People still enjoy the wilderness in the day time, but biological diversity has been lost. In fact, the zoo has installed a dark canopy dome that goers over the zoo at night, so the animals can survive. Light has disrupted sleeping patterns and made people edgy. Governor Gordon Lightsky has a vested interested in the lighting industry and has promoted a "well lit" state for years. People haven't seen more than 9 stars in the sky for the last five years. They are taking to the streets with their guns and shooting out lights. Be A. Star has organized a new political party, the Dark Sky Party, with the platform "Make Our Nights Dark Again". She conducts rallies in the dark, as there is so much light pollution that they're not needed. Be A. Star encourages votes to turn out the lights on Governor Light Sky and "vote dark". She wins with a decisive mandate and a new dusk for Arizona begins.

**Scenario Title:** The Citation Crackdown
**Setting:** Phoenix, Arizona in 2050
**Impact/Uncertainty:** Low appreciation of wilderness, planning and pevelopment strategies that include time time environment.

**Plot:** The Phoenix Sun Bring You…Breaking news! The Citation Crackdown! The Phoenix Lighting Organization (PLO) has begun enforcing Ordinance No. 2016-1. This ordinance was written into law in 2016 to limit light pollution. Currently, there is only one star visible to Phoenicians, unlike the original Phoenicians. This has grown to be the worst case of light pollution in the world; even New York City can see the sun and 8 other stars! PLO is going door to door issuing citations for improper light use, inadequate shielding and overall light waste. The courts are flooded by people contesting their citations. They are refusing to pay or change their ways. Vinnie says "what could possibly be better than the sun! It's the biggest and brightest star! Forget about it! and he goes back to his sun tanning. The city is overflowing with lighting law breakers and murderers! It's time for Phoenix to face its destiny. Arise from the ashes and pay its fines! The future is starry and bright! Live from Phoenix. – Sam Sparks.

# APPENDIX I

# INSTITUTIONAL REVIEW BOARD LETTER

EXCEPTION GRANTED

Gyan Nyaupane
Community Resources and Development, School of
602/496-0166
Gyan.Nyaupane@asu.edu

Dear Gyan Nyaupane:

| | |
|---|---|
| Type of Review: | Initial Study |
| Title: | Scenario Planning for Sustainable Dark Skies |
| Investigator: | Gyan Nyaupane |
| IRB ID: | STUDY00004687 |
| Funding: | Name: Sustainability, Julie Ann Wrigley Global Institute of (GIOS) |
| Grant Title: | |
| Grant ID: | |
| Documents Reviewed: | • Interview Questions 8.2.2016.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• Interviewee Invitation Letter 8.2.2016.pdf, Category: Recruitment Materials;<br>• Interview Consent Form 8.2.2016.pdf, Category: Consent Form;<br>• SP4SDS Pre-Test Final.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• SP4SDS Post-Test 2 Final.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• SP4SDS Post-Test 1 Final.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);<br>• IRB - Dark Skies 8.2.2016.docx, Category: IRB Protocol;<br>• Sustainable Dark Skies Presentation.pdf, Category: Technical materials/diagrams; |

| | |
|---|---|
| | • SP4SDS Scenario Workshop Agenda.pdf, Category: Other (to reflect anything not captured above);<br>• Scenario Workshop Invitation Letter 8.2.2016.pdf, Category: Recruitment Materials;<br>• Scenario Workshop Consent Form 8.2.2016.pdf, Category: Consent Form; |

On 8/3/2016 the ASU IRB reviewed the following protocol:

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 8/3/2016.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Robert Hobbins
Robert Hobbins