

Recreation Associated Impacts in the Lake Tahoe Basin



A review of the Literature
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Introduction

The purpose of this review is to inform the reader of potential environmental affects that can occur as a result of recreational activities in the Lake Tahoe Basin. Like the ecosystem we strive to maintain, the effects of recreation are intertwined and complex. However, not every change is important or significant to the ecosystem's persistence. Further, not every activity's impacts are easily quantifiable and not every quantifiable impact needs to be measured. Information presented in this review aims to help inform agency and stakeholder discussion groups to achieve a primary objective of the Sustainable Recreation Working Group (SRWG): *"to establish Basin-wide recreation indicators, thresholds, and a monitoring framework related to user experience and the environmental effects of recreation, and to acquire consistent and quality recreation data (i.e. site-specific user experience and recreational usage, natural resource, and recreation facility conditions)."*

The art of selecting appropriate indicators and threshold standards is to make our best judgment regarding what's important. Informed determinations of importance require (1) an understanding relevant ecological processes, (2) knowledge regarding the components at risk from recreation stressors, and (3) an understanding of the resilience of those components to absorb or withstand impacts. Further, the ability to reliably quantify, an important component over its range of meaningful change with affordable monitoring must also exist. The more strongly a given component meets these criteria the greater the likelihood it can become the basis for a reliable threshold standard.

Areas of interest

Eight basic resources of concern are highlighted in this document. They are 1) Wildlife, (including Terrestrial, aquatic and biodiversity) 2) Vegetation/Forest Health, (including wildfire risk), 3) Scenic Resources, 4) Water Quality, 5) Air Quality, 6) Soils, 7) Soundscapes/Noise and 8) the Light Environment. The Light Environment is included, to address a building awareness of the importance of diurnal cycles of light and dark to many species and the adverse effects of artificial light. In the literature wildlife consistently provides the underlying indicator of concern. Broad regulatory frameworks exist for other resource indicators such as water quality and air quality that can reflect recreational impacts. Consider amending those indicators' monitoring programs to improve our understanding of recreation's role driving observed changes. You may find however, that as yet unmeasured changes in some aspect of biology is critical to maintaining a desired species, but is not part of any existing monitoring. In this case you will be breaking new ground. Also, not every recreational impact is reflected in biological changes. The Scenic resource is one of human perception - an aesthetic quality, which is measured by quantifying opinion.

The eight resource areas are assessed against a range of recreational impacts including, hiking/trail running, camping (organized and dispersed), climbing (rock, ice), leisure activities, mountain biking, horseback riding, skiing (backcountry, resort, cross-country), motorized use (snowmobiling, ATVs, OHV), and fishing. Most of these activities are regulated to some degree, and understanding that regulatory process may provide insight into a weakness in our current approaches. Regulations may not be designed to provide

the level of resource protection currently desired, or are not monitored with sufficient resolution to detect meaningful change. Identifying resources not adequately protected with existing regulations may ultimately be the most fruitful approach to identifying useful recreation threshold standards.

Context

Recreation is very important to the Tahoe basin economy, but the effects of the recreating public on the ecology of the Tahoe Basin is often overlooked or not understood. The Lake Tahoe Basin receives over 30 million visitor days per year, about five times the visitation to Yosemite National Park (USDA 2004). Five million of these visitor days are directly related to outdoor recreation (USDA 2004). Given this level of use the concern regarding recreational impacts deserves attention.

In general, virtually all types of recreation alter some characteristics of soil, vegetation, and terrestrial or aquatic systems (Cole and Landres, 1995). The high concentration of recreation activities and type of recreation activities (i.e., motorized, non-motorized, developed, or dispersed) affect habitat conditions, and influence abundance, distribution, and community structure of native species. Recreation activities occur throughout the Basin but many highly concentrated activities occur along the lake shore where there tend to also be a variety of sensitive habitat types (e.g., meadows, marshes, etc.) and species. This is particularly true of the south shore, an area that has particularly high recreation use and also a high concentration of sensitive wildlife species and habitats. The extensive distribution of trails throughout natural areas can have pervasive environmental effects through alteration of natural drainage patterns, erosion and deposition of soil, introduction or spread of exotic vegetation, and increasing human-wildlife conflicts. Degraded trails also threaten the quality of visitor experiences by making travel difficult or unsafe, or by diminishing visitors' perceptions of naturalness, (Leung and Marion, 1996). Although more intensively visited wildland areas can be degraded by recreational visitation, the vast majority of protected lands see little use and impact (Marion et al, 2016). However, it is widely accepted that recreational use of natural areas inevitably results in some degree of change to resource conditions, and managers must consider the magnitude, social acceptability, and ecological significance of such changes in their decision-making processes, (White et. al., 2006).

This document is organized by resource areas and further broken down within those areas by recreational activities that affect each resource. Several recreational activities are discussed in multiple resource sections, since many activities affect multiple resources. Appendix A summarizes which resources are affected by each activity. Activity impacts are not exclusively extracted from the Tahoe basin literature, rather they reflect impacts identified in the broader, more extensive literature. Also, this review is not exhaustive, but it does provide the reader with a good basis for understanding which recreational activities are likely to be important. Lastly, many recreational activities in the Tahoe basin are regulated either directly through land management plans, or indirectly through water or air quality regulations. The presentation of some of those regulations is brought out to aid the reader as the discussions turn to creating new Recreation threshold standards. However, the primary goal of this document is to inform the reader of the potential impacts that recreation may impose on Tahoe Basin resources.

Wildlife and Habitat

Researchers have classified human impact to wildlife as following four main routes: exploitation, disturbance, habitat alteration, and pollution (Pomerantz et al. 1988, Knight and Gutzwiller 1995). Exploitation entails immediate death of wildlife (vehicle collisions), whereas disturbance results in harassment that can lead to the temporal or spatial displacement of wildlife from favorable to less favorable habitat. Both are forms of direct impacts and are the result of immediate wildlife behavioral responses to a recreationist or recreation activity (Cole and Landres 1996, Neumann et al. 2009, Hammitt et al. 2015). Alternatively, habitat alteration and pollution are indirect forms of impact when they cause changes to soil, water, flora or fauna, and indirectly affect the species dependent on them (Knight and Gutzwiller 1995). Indirect impacts can cause an alteration in wildlife behavior, distribution, survivorship, and reproductive ability (Pomerantz et al. 1988, Cole and Landres 1995, Hammitt et al. 2015 as cited in Marion et al, 2016). The following sections address the primary recreational activities known to influence wildlife.

Hiking

The existence of a trail network can act as a barrier or attraction to different wildlife species (Leung and Marion, 2000). Non-motorized nature based tourism and recreation, like motorized activities, has a range of negative effects on a wide range of bird species (Liddle, 1997; Buckley, 2004). Based on the results of this and previous reviews of recreation and ecotourism impacts on birds (Liddle, 1997; Buckley, 2004), it still appears that non-motorized recreation activities have a range of negative effects on birds, but there remain large research gaps on this topic (Stevens et. al, 2011).

Different animals respond differently to the presence of trail users. Most wildlife species readily adapt or become "habituated" to consistent and non-threatening recreational activities. For example, animals may notice but not move away from humans on a frequently used trail. This is fortunate, as it can allow high quality wildlife viewing experiences for visitors and cause little or no impact to wildlife (Marion and Wimpey, 2007).

The opposite conduct in wildlife - avoidance behavior - can be problematic. Avoidance behavior is generally an innate response that is magnified by visitor behaviors perceived as threatening, such as loud sounds, off-trail travel, travel in the direction of wildlife, and sudden movements. When animals flee from disturbance by trail users, they often expend precious energy, which is particularly dangerous for them in winter months when food is scarce. When animals move away from a disturbance, they may leave preferred or prime habitat and move, either permanently or temporarily, to secondary habitat that may not meet their needs for food, water, or cover (Marion and Wimpey, 2007, Taylor and Knight 2003).

The flushing response is related to the proximity of the disturbance. The shorter the perpendicular distance of an animal to the trail or line of movement, the greater the

probability that it would flush (Taylor and Knight 2003). The area of influence was greater for off-trail treatments than for on-trail treatments. For vesper sparrows, on and off-trail, and also for western meadowlarks on-trail, the dog-alone treatment resulted in a smaller area of influence than the pedestrian-alone or dog-on-leash treatments, which did not differ from each other (Miller et al. 2001).

Camping

In the Tahoe Basin there are 18 campgrounds with a total of 1,465 sites that can, in theory, support almost 12,000 people at one time. While camping occurs in fixed locations (except along the RIM trail or the Pacific Crest trails) it brings a unique set of impacts. Intentional or unintentional wildlife feeding is common at campsites, leading to attraction behavior and unhealthy food dependencies (Manley et al. 2010). Species that frequent campsites in search of food include birds, mice, rats, ground and red squirrels, skunks, raccoons, foxes and bears. Consistent human feeding can lead to increases in small animal populations, which then crash suddenly at the end of the use season. Bears that obtain food pose a serious safety threat to visitors, and many must be relocated or killed (Merrill 1978 as cited in Leung and Marion, 2000).



Undesirable bear behavior is not restricted to Lake Tahoe. Coleman et al. (2013) found that grizzly bears were 35% more likely to roam in locations less than 650 ft. away from an occupied campsite, and 56% more likely to roam within 650 and 1,300 ft. of an occupied campsite than in a random location. Even when campsite occupancy was ignored, grizzly bears were much more likely to roam within 2,000 ft. of a campsite, suggesting a learned food-

attraction behavior. In addition, moose (*Alces alces*) in the backcountry areas of Sweden have responded to skiing disturbances resulting in increased movement rates and energy expenditure and short-term relocation (Neumann et al. 2009 as cited in Marion et al, 2016).

Other forms of habituation, however, are less desirable. Visitors who feed wildlife, intentionally or from dropped food, can contribute to the development of food-related attraction behavior that can turn wild animals and birds into beggars. In places where visitors stop to eat snacks or lunches, wildlife quickly learn to associate people with food, losing their innate fear of humans and returning frequently to beg, search for food scraps, or even raid unprotected packs containing food. Feeding wild creatures also endangers their health and well being. For instance, after food-attracted deer in Grand Canyon National Park became sickly and dangerously aggressive, researchers found up to six pounds of plastic and foil wrappers obstructing intestinal passages of some individuals (Marion and Wimpey, 2007).

Dogs

Hiking with your dog at Lake Tahoe is a behavior that seems to be a part of the Tahoe culture. Researchers (outside of the Basin) have found that the presence of dogs correlated with altered patterns of habitat utilization for mule deer, small mammals, prairie dogs, and bobcats (Lenth et. al. 2008). For mule deer and small mammals, the results tease out the role of dogs beyond the cumulative disturbance of recreationists. Even in areas that prohibited dogs, mule deer were less active up to 50 m from recreational trails. But in areas that allowed dogs, deer showed reduced activity within at least 100 m of trails (Lenth et. al., 2008). Because of this depth- of-edge effect associated with dogs along recreational trails, for every protected area that allows dogs off leash, there is a certain percentage of that area that is unsuitable for certain species of wildlife, even though the habitat may be perfectly suitable otherwise (Lenth et. al., 2008). It should be noted that in the Lake Tahoe basin dogs are required to be on 6 foot leashes everywhere and are excluded from protected areas (personal communication with LTBMU, and Forest Order 19-86-99).



Even without being chased, animals that are prey of wild canids may perceive dogs as predators and may be subject to non-lethal, fear-based alterations in physiology, activity, and habitat use (MacArthur et al. 1982; Lima 1998; Miller et al. 2001), with potentially complex effects (Ripple and Beschta 2004 as cited in Lenth et. al., 2008).

In general, wildlife species that are preyed upon by native canids demonstrated sensitivity to the presence of domestic dogs. This was true at trailheads also where native carnivore activity was reduced. However, where dogs were prohibited, the presence of trailheads had no influence on carnivore activity. These inverse correlations of dog and native carnivore activity in areas that allow dogs indicate that native carnivores may be avoiding trailheads where dog activity is concentrated (Lenth et. al., 2008).

Thus, through direct and indirect interactions, dogs could potentially attract or repel native carnivores, depending on the species and nature of past interactions. Carnivores are often disproportionately important to the structure and function of ecosystems, so the ramifications of alterations in carnivore activity could be considerable, potentially cascading through an ecosystem (Soulé et al. 2005 as cited in Lenth et. al., 2008).

Lenth 2008 found that the presence of dogs correlated with altered patterns of habitat utilization for mule deer, small mammals, prairie dogs, and bobcats. Even in areas that prohibited dogs, mule deer were less active up to 50 m from recreational trails. But in areas that allowed dogs, deer showed reduced activity within at least 100 m of trails (Lenth et. al., 2008).



Predictable activities, such as recreation restricted to trails, may allow wildlife to habituate to those activities (Whittaker and Knight 1999). The spatial behavior of dogs off-leash is unpredictable; and when dogs wander off-trail, they are more likely to elicit flushing responses from deer, even if the dogs do not give chase (Miller et al. 2001 as cited in Lenth et. al, 2008).

Noise

Most of the noise in the Basin occurs along the lakeshore and in urban areas and along roadways. Away from the lake there is intermittent noise from vehicles and snowmobiles, or on ski runs, from grooming equipment. Pervasive loud noise associated with industrial facilities does not routinely occur in the Tahoe basin. At the time this was prepared, TRPA was in the process of developing a shoreline plan for the lake that will address most of the common shoreline issues. Noise created by boating activities, and strategies to mitigate related impacts, is a consideration of the shoreline plan.

The characteristics of noise vary substantially among sources. Each source type exhibits variance in amplitude (i.e., loudness), frequency profile (i.e., pitch), and spatial and temporal patterns. The interaction of these characteristics is what determines in a narrow sense the impact of noise on wildlife, setting aside the possibly confounding influence of contextual variables (Blickley and Patricelli, 2010). Moderate noise of different frequencies or volumes from background levels can interfere with wildlife who depend on their ability to detect predators and avoid them, or conversely, predators who rely on sound to detect their prey. Intermittent sound can cause temporary inefficiency that adds stress to either group's survival. The following summary reflects a broad range of findings associated with recreational noise pollution. Most of Lake Tahoe's backcountry is remarkably quiet so the reader should balance that against the research that addresses a wide range of noise levels.

Noise pollution affects birds in myriad ways, including (1) physical damage to ears; (2) stress responses; (3) fright-flight responses; (4) avoidance responses; (5) changes in other behavioral responses, such as foraging; (6) changes in reproductive success; (7) changes in vocal communication; (8) interference with the ability to hear predators and other important sounds; and (9) potential changes in populations. Reactions to noise depend on the type of noise produced, including frequency, loudness, consistency, and duration, (Ortega, 2012).

At least some birds respond to noise with vocal repertoires by changing the frequency of their songs (Arcese et al. 2002) and by singing the songs least masked by background noise (Wood and Yezerinac 2006, Halfwerk and Slabbekoorn 2009 as cited in Ortega, 2012).

Noise may affect reproductive success by limiting egg production, interrupting incubation, affecting brooding, and causing abandonment of young, as well as by restricting the ability to bond or attract a mate and the ability of parents to hear and

respond to begging calls (Ortega, 2012, Blickley and Patricelli, 2010). In addition to communication, hearing is critical for detecting predators and other dangers and opportunities in the environment (Quinn et al. 2006, Slabbekoorn and Ripmeester 2008).

Comparative evolutionary patterns attest to the alerting function of hearing: (1) auditory organs evolved before the capacity to produce sounds intentionally (Fay and Popper, 2000), (2) species commonly hear a broader range of sounds than they are capable of producing (Fay, 1988), (3) vocal activity does not predict hearing performance across taxa (Fay, 1998) (Bradbury and Vehrencamp, 1998), (4) hearing continues to function in sleeping (Rabat, 2007) and hibernating (Lyman and Chatfield, 1955) animals; and (5) secondary loss of vision is more common than is loss of hearing (Fong et. al., 1995 as cited in Barber et. al., 2009).

It is clear that the acoustical environment is not a collection of private conversations between signaler and receiver but an interconnected landscape of information networks and adventitious sounds; a landscape that we see as more connected with each year of investigation. It is for these reasons that the masking imposed by anthropogenic noise could have volatile and unpredictable consequences (Barber et. al., 2009). Taken collectively, the preponderance of evidence argues for action to manage noise in protected natural areas. Advances in instrumentation and methods are needed to expand research and monitoring capabilities. Explicit experimental manipulations should become an integral part of future adaptive management plans to decisively identify the most effective and efficient methods that reconcile human activities with resource management objectives (Blickley and Patriceli, 2010 as cited in Barber et. al., 2009).

Mountain Bikes

Mountain bikes exhibit the unusual characteristics of relative quiet, with unusual speed. These combine to seemingly increase the likelihood of surprise encounters with wildlife that elicit more flight responses than hiking the same trail. However, over a range of species, hikers and bikers elicited the same alert and flight responses (Taylor and Knight 2003).

Data analysis and statistical testing revealed that the physical impacts of hiking and biking were not significantly different for plant density, diversity or soil exposure. They also concluded that impacts from both hikers and bikers were spatially confined to the centerline of the lane (trail), (Marion and Wimpey, 2007). The impacts of biking are highly dependent on trail type (maintained trail or user created trail) (Marion and Wimpey, 2007)¹.

¹ My personal observations from 1994 to 2000 in Lake Tahoe are that the substrate, slope, and the type of use determine the risk of erosion. Racing on steep slopes, for example, can create excessive erosion, especially on some of Tahoe's erodible granitic soils types. As a point of context, mountain bike use is generally concentrated on those trails where the ride experience is positive; where the trail is challenging but not so technical that an average rider can't negotiate it. These usually are trails over flatter ground that presents lower erosion risk.



The speed of mountain bikers can create a startled response from wildlife. Taylor and Knight have explored this for bison, antelope and mule deer in 2003. They found little difference between hiking and mountain biking with respect to alert distances and flight distances. The risk from either activity is that the affected animals consume energy unnecessarily had the encounter not occurred. The consequence during the summer when food is plentiful is generally

believed to be minor. There is some evidence, especially on the internet, which suggests that the speed factor, especially in bear country, creates the greatest impacts to the rider. Not all startled wildlife flees².

Winter Sports

Downhill skiing has been extensively evaluated and can adversely affect wildlife. The primary affect occurs from the initial construction of the runs and the extensive habitat modification that occurs, but usually continues at reduced levels through the life of the resort (Buckley et al., 2000; Arlettaz et al., 2013, Rixen & Rolando, 2013, Rolando et al., 2007, 2013; Caprio et al., 2011, Brambilla et al, 2016). High elevation species are most at risk, and in the Tahoe Basin the martin has been the focus of much investigation.

The American marten (*Martes americana*) is a carnivore that occupies high-elevation (5,000-10,000 feet) late-successional conifer forests in the Sierra Nevada (Spencer et al. 1983, Zielinski et al. 2005). To create ski runs, chair lifts, and facilities, trees are removed, creating open areas and fragmenting previously contiguous forest. Martens typically avoid open areas lacking overhead cover or tree boles that provide vertical escape routes from predators (Drew 1995), are more susceptible to predation if they must cross such areas, and have been shown to avoid areas when 25-30% of mature forest is removed (Bissonette et al. 1997).

During the winter, marten occupancy of preferred habitat in the Lake Tahoe basin was significantly reduced within ski area operational boundaries. Martens occupied 52% of stations in operations areas compared to 88% outside operations areas. Station visitation rates were also significantly reduced in operations areas compared to outside them, suggesting that martens made less frequent use of habitat in operations areas during the winter. The amount of habitat affected during the winter, due to avoidance or reduced use, represented 15-37% of the total ski area study areas. Snowmobile use in contrast did not affect marten occupancy of preferred habitat (Slauson and Zielinski 2013). Other snow activities may affect marten but data from Zielinski et. al. 2008 indicate that motorcycle or snowmobile use did not affect marten occupancy or the probability of detection and that overall OHV/OSV use in the study areas was low (1 OHV/OSV pass

² This refers to a 2017 encounter in Montana between Brad Treat and a Grizzly bear. Mr. Treat was killed by the bear while mountain biking when they collided on a trail. Numerous other experiences/videos document bear encounters.

every 2 hours) and exposure occurred in less than 20% of a typical home range (Zielinski et al. 2008 as cited in LTBMU FEIS, 2016, Slauson and Zielinski 2013).

During the spring-summer season marten occupancy was not significantly different between ski areas and controls or inside or outside the operations areas (Slauson and Zielinski, 2013). This suggests that ski area impacts are greatest during the winter season and the combination of habitat alteration and winter recreation activities are the cause for the winter impact on marten occupancy. Slauson and Zielinski did not find significant effects of ski areas on estimates of population density during spring-summer, female survival, reproduction, or age structure. The primary effects on martens were season and sex-specific. Results suggest that martens and ski areas can coexist if habitat across ski areas is connected, seasonal impacts are limited to avoid the denning and kit rearing season (March-August), and reproductive habitat is maintained and enhanced (Slauson and Zielinski, 2013).

In Europe, black grouse was used to identify recreational impacts associated with the use of ski runs. Working in both comparative (measure of chronic stress response) and experimental (acute stress response) frameworks, it was shown that black grouse [Alps] living in natural, or little disturbed treeline habitats have a significantly lower general concentration of fecal corticosterone metabolites (stress hormones) than individuals occurring either in highly disturbed or moderately disturbed habitats (places outside ski resorts with backcountry skiing, snowboarding and showshoeing). The fact that the latter two categories did not differ statistically between each other suggests that even moderate levels of disturbance, such as that caused by off groomed trails, are enough to elicit a chronic stress response in the birds (Arlettaz et. al., 2013).

Aquatic Invasive Species

Invasive species, both terrestrial and aquatic have been introduced to the Tahoe basin either deliberately by government agencies or individuals, or by visitors carrying plants and animals unknowingly. Recreation is tied to this issue through contaminated equipment, clothing, or pets that can introduce new organisms.

TRPA defines an invasive species as:

“...both aquatic and terrestrial, that establish and reproduce rapidly outside of their native range and may threaten the diversity or abundance of native species through competition for resources, predation, parasitism, hybridization with native populations, introduction of pathogens, or physical or chemical alteration of the invaded habitat. Through their impacts on natural ecosystems, agricultural and other developed lands, water delivery and flood protection systems, invasive species may also negatively affect human health and/or the economy (TRPA Code of Ordinances, Chapter 79.3, TRPA Aquatic Invasives Management Plan 2014).”



It should be noted that California, through the Department of Fish and Wildlife, and Nevada through the Department of Agriculture, both have extensive programs to stop the introduction of aquatic invasives into Lake Tahoe. The Tahoe Regional Planning Agency has developed an Aquatic Invasive Species Management Plan (TRPA 2014). As a practical consideration, eradication is normally the goal, but often difficult to achieve. Management of invasive species is normally an ongoing, continuous effort.

Failure to address invasive species can have unpredictable, and far reaching consequences. The current ecology of Lake Tahoe and the loss of native Lahontan Trout is perhaps one of the best-known examples (TRPA 2014).

Because aquatic invasive species are already addressed through various agencies and recent regulations like TRPA's 2014 Aquatic Invasive Species Management Plan additional discussion here may be untimely. However, *the rate of introduction of new species needs to be identified in order to determine the effectiveness of those regulations.* Should new introductions be deemed unacceptable, then the role of recreation activities potentially linked to those introductions should be examined.

Vegetation and Forest Health

This section addresses recreational impacts to terrestrial vegetation. One recreational activity with the potential to affect vegetation, Off Highway Vehicle use, is not included here because this use occurs primarily on National Forest lands and is regulated and restricted by the Forest Service to existing designated trails or routes. These designated routes are established through the Forest Planning process and can be revised through future revisions or amendments should the need arise. Please note that this also pertains to e-bikes that are currently considered motorized vehicles by the Forest Service.

Terrestrial invasive species

Terrestrial invasive species are easily spread by livestock, pets, or people and is difficult to prevent. This is a world-wide challenge, as the following example from Australia demonstrates. Tourist's use of back country areas is a major factor in the spread of introduced pathogens such as the root-rotting fungus *Phytophthora cinnamomi* (Specht and Specht, 1999; Buckley, 2004; Worboys and Gadek, 2004; Turton, 2005). This fungus is harmful to a wide range of native plants and is listed as a key threatening process by the Australian Government (Environment Australia, 2001; as cited in CM Pickering, et al 2009).

The pictures below represent “top priority invasive weeds” in the Lake Tahoe basin (Lake Tahoe Basin Weed Coordinating Group, see tahoeinvasiveweeds.org for more information).



Diffuse knapweed



Hoary cress



Rush skeleton



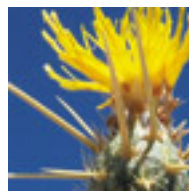
Russian
knapweed



Sulfur cinquefoil



Teasel



Yellow starthistle



Canadian thistle

Hiking

Visitor trampling the action of crushing or treading upon vegetation, either by foot, hoof, or tire - contributes to a wide range of vegetation impacts, including damage to plant leaves, stems, and roots, reduction in vegetation height, change in the composition of species, and loss of plants and vegetative cover (Leung & Marion, 1996; Thurston & Reader, 2001, Marion and Wimpey, 2007, Marion et al 2016). On formal trails, most vegetation is typically removed by construction, maintenance, and visitor use. This impact is necessary and "unavoidable" in order to provide a clear route for trail users, (Marion and Wimpey, 2007). Most of this loss is accepted as part of the activity, but is exacerbated by recreationists who stray from the beaten trail.

Herbaceous vegetation in forests is quickly lost under even relatively low levels of traffic. On a trail when the majority of vegetation cover is lost, further recreational traffic or use causes little additional impact to vegetation if visitors stay on well-established trails and recreation sites. The use-impact relationship is somewhat different for the more resistant and resilient grasses. Grasses and sedges can withstand prolonged low levels of traffic, particularly in sunny locations (Marion et al 2016).

Studies have consistently revealed that most impact occurs with initial or low use, with a diminishing increase in impact associated with increasing levels of traffic (Hammit & Cole, 1998; Leung & Marion, 1996). Furthermore, once trampling occurs, vegetative recovery is a very slow process, (Marion and Wimpey, 2007).

Data analysis and statistical testing revealed that the impacts of hiking and biking were not significantly different for plant density, diversity or soil exposure. They also concluded that impacts from both hikers and bikers were spatially confined to the centerline of the lane (trail), (Marion and Wimpey, 2007).

Once the vegetation is lost, further trampling results in compacted soils. Compacted soils are denser and less permeable to water, which increases water runoff. However, compacted soils also resist erosion and soil displacement and provide durable treads that support traffic. From this perspective, soil compaction is considered beneficial, and it is an unavoidable form of trail impact, (Marion and Wimpey, 2007).

Muddiness: When trails are located in areas of poor drainage or across highly organic soils that hold moisture, tread muddiness can become a persistent problem. Muddiness is most commonly associated with locations where water flows across or becomes trapped within flat or low-lying areas, (Marion and Wimpey, 2006). Erosion can also be self-perpetuating when treads erode below the surrounding soil level, hindering efforts to divert water from the trail and causing accelerated erosion and muddiness. Similarly, excessive muddiness renders trails less usable and aggravates tread widening and associated vegetation loss as visitors seek to circumvent mud holes and wet soils (Marion, 2006), Marion and Wimpey, 2007).

Mountain Bikes

Mountain biking has been a major activity at Lake Tahoe for several decades and has gone through an evolution of use and development of sport-specific facilities. The following discussion from the literature includes examples that may seem too simplistic to some, but are included for context and to highlight the fact that in most places, mountain biking is a relatively new sport. In the Tahoe Basin, mountain bikes do not include e-bikes, which are considered motorized vehicles. The following examples are not restricted to Tahoe Basin research.



The width of the mountain biking trails were observed to vary over time, with no consistent trend, while the width of the mountain bike racing trail grew following events but exhibited net recovery over time. Impacts were confined to the trail tread, with minimal disturbance of trailside vegetation, (Marion and Wimpey, 2006).

Bjorkman (1996) evaluated two new mountain biking trails in Wisconsin before and for several years after they were opened to use. Vegetation cover within the tread that survived trail construction work declined with increasing use to negligible levels while trailside vegetation remained constant or increased in areas damaged by construction work. Similarly, soil compaction within the tread increased steadily while compaction of trailside soils remained constant, (Marion and Wimpey, 2006). Tread impact associated with downhill travel [mountain bikes] is generally minimal due to the lack of torque and lower ground pressures. Exceptions include when riders brake hard enough to cause skidding, which displaces soil downslope, or bank at higher speeds around turns, which displaces soil to the outside of the turn. Impacts in flatter terrain are also generally minimal, except when soils are wet or uncompacted and rutting occurs, (Marion and Wimpey, 2006).

Rock Climbing



The measured impacts associated with climbing vary with the rock type and the intensity of activity. Studies have produced variable and contradictory results, often because different sites exhibit different characteristics (Clark and Hessel, 2015). Cliff faces are of interest because they can provide reservoirs of genetic material useful for recolonizing an area following major disturbances and because they contain plants and animals uniquely adapted (rare overall) to the cliff environment.

One study in Canada found significant impacts on cliff lichen communities from Rock Climbing, (Adams and Zaneiwski, 2012). This finding appears to be consistent in the literature. In this circumstance, the substrate was erodible sandstone. Another study (also sandstone) found climbing-use intensity had a small but negative effect on species richness and abundance of vascular plants (range 3–6%), no effect on bryophytes (0%) and a substantial effect on lichens (range 10–12%) (Clark and Hessel, 2015). The same study found no change in community composition as a result of climbing.

A recent study in Spain concluded moderate rock climbing activity on cliff environments might not reduce the presence of specialized rock-dwelling species; however, this activity inherently impacts the biodiversity of cliff ecosystems due to its large effect on generalist species (March-Salas et. al, 2018).



Pictures of Bryophytes (above), and Lichens (right). Bryophytes have no vascular tissue or lignin and are usually associated with wetter sites. Mosses are one of the most well known examples. Lichens are composite organisms, which means they are made up of algae or cyanobacteria that grows along filaments of multiple fungi. Bryophytes often are fairly rare on cliff faces while lichens are more common.

Scenic Resources

The history of landscape quality assessment has featured a contest between expert and perception-based approaches, paralleling a long-standing debate in the philosophy of aesthetics. The expert approach has dominated in environmental management practice and the perception-based approach has dominated in research. Landscape visual aesthetic quality is broadly represented as a joint product of particular visible features of the landscape interacting with relevant psychological perceptual, cognitive and emotional processes in the human observer Brown and Daniel, 1987, 1990; Craik and Zube, 1974; Daniel, 1976, 1977, 1990; Daniel and Boster, 1976; Parsons, 1991; Ulrich, 1983, 1993; Zube, 1974) (Daniel, 2000). In simpler terms, some pieces of aesthetics can be reliably quantified and some are a matter of personal perception.

It is as yet unclear, however, exactly what landscape features are most relevant to ecosystem management objectives and how those features should be presented to human viewers to obtain valid indications of perceived landscape quality (Daniel, 2000). In the context of landscape quality assessment, quality has been taken to encompass everything from basic utilitarian wants food, water, shelter, recreation opportunities, etc., to spiritual needs and a oneness with nature, or feeling a sense of a higher power to intrinsic natural values (Daniel, 2000). The nature of aesthetic quality is a centuries-old area of puzzlement, study and controversy for philosophers, artists/designers and now for environmental managers/policy makers (Daniel, 2000).

Motorized recreation

The positive and negative consequences of motorized recreation in wildlands have been characterized as fundamental contradictions: enhanced quality of life for the motorized recreationist (e.g., escape and enjoyment) and socio-economic stability of neighboring rural communities versus the conflict between motorized recreation and nonmotorized recreation, domestication of wilderness, and stress on ecological systems (Vail 2001; Vail and Heldt 2004) (Davenport and Borrie, 2005).

This discussion in the literature pertains mostly to snowmobile use and draws on the experience from Yellowstone National Park (YNP). In the following exchange, researchers interviewed both motorized and non-motorized park visitors. For many participants, the park meant unique wildlife experiences. The interviews revealed that experiencing wildlife in YNP was not just seeing animals but seeing an abundance of unique and diverse species *in their natural habitat* (Davenport and Borrie, 2005). This was part of the aesthetic value visitors experienced.

Study participants grappled with the dual purpose of national parks. Some argued that parks are for people, others held firm that parks are for nature and wildlife, and many appreciated the fine balance between social and ecological values. In terms of the recreation purpose of parks, perspectives converged. A prominent theme among interview participants was the idea that YNP is not the place for challenging rides or displaying snowmobiling skills. Even those who typically associate snowmobiling with adventure and challenge admitted that the park serves a different purpose: “Some people, the reason they go snowmobiling is to play on the machine and to jump around and to play around, and I’ve done that too. But I think if you’re going to come up here, the

purpose would be to see the bison, to see the wildlife. “ [How similar is this to peoples perception of Tahoe as a special place?] (Davenport and Borrie, 2005).

Snowmobiling in YNP is only a means to experiencing the park, according to many participants. Overall, study participants felt that snowmobiles were a “form of transportation” that provided them the means to achieve certain experiences, such as viewing wildlife and enjoying natural scenery. Snowmobiling gave them freedom, access, and a certain closeness to or intimacy with nature that many believed they would not have had otherwise. At the same time, several study participants emphasized that they would like to see the technology improved for snowmobiles so as to reduce noise and emissions (Davenport and Borrie, 2005).

Dustin (2003) also quoted a retired NPS official who remarked in opposition to snowmobiles, “the ride isn’t what Yellowstone is all about, the park is what Yellowstone is all about.” Interestingly enough, the perspectives of snowmobilers documented in this study support this conclusion (Davenport and Borrie, 2005).

Ski Area Development or Expansion

Ski area expansion or development of new facilities certainly would affect the scenic quality of the landscape. This eventuality however is addressed through the Special Use permitting process and environmental review. It is not further covered here

Water Quality

Of the resources discussed in this brief, the water resources at Lake Tahoe are probably the most heavily regulated. Authority for creating and enforcing those regulations lie with the Lahontan Water Quality Control Board, the Nevada Division of Environmental Protection, TRPA and the Forest Service. Most recreation presents a low level of risk, although creation, operation, or expansion of a ski resort or off highway vehicle use do present a potentially significant adverse impacts. Both are currently regulated to prevent that from happening. Other potential physical and chemical consequences of recreation are discussed below.

Physical impacts to water from recreation can bring about temperature and flow alterations, increased suspended matter, increased turbidity, biological changes or chemical changes. Biological impacts on water typically involve the introduction or spread of nonnative flora and fauna or increases in coliform bacteria (e.g., *Escherichia coli*) and protozoa (e.g., *Giardia lamblia*). Chemical impacts are primarily related to the influx of nutrients that lead to lowered dissolved oxygen rates but can also include pollution impacts from soap, sunscreen, food particles, and human and animal waste (Urtsem et al. 2009, as cited in Marion et al, 2016).

Hiking

Soil erosion and subsequent transport to water courses is a largely avoidable impact of trails and trail use. Soil can be eroded by wind, but generally, erosion is caused by flowing water. To avoid erosion, sustainable trails are generally constructed with a slightly crowned (flat terrain) or outsloped (sloping terrain) tread that is hardened in high risk locations. However, subsequent use can compact and/or displaces soils over time to create a cupped or insloped tread surface that usually intercepts and carries water. The concentrated run-off erodes the trail surface and washes soil particles downhill, effectively changing the design of the tread surface, (Marion and Wimpey, 2006).

Poorly sited and/or maintained trails can be more susceptible to erosion. Generally, if water control features such as grade reversals and outsloped treads are used to divert runoff from trails, the water drops its sediment close to trails, where it is trapped and held by organic litter and vegetation. Soils eroded from trails rarely enter water bodies, unless trails cross streams or run close to stream or lake shorelines and lack adequate tread drainage features. Since many recreational activities, such as fishing, swimming, boating, and viewing scenery (e.g., waterfalls) draw visitors and trails to the vicinity of water resources, it is often necessary to route trails to water resources or visitors will simply create their own informal trails, (Marion and Wimpey, 2006).

Waste Disposal

Trail users may also pollute water with pathogenic organisms, particularly those related to improperly disposed human or animal waste. Potential pathogenic organisms found through surveys of backcountry water sources include *Cryptosporidium spp.*, *Giardia spp.*, and *Campylobacter jejuni* (LeChevallier and others, 1999; Suk and others, 1987; Taylor and others, 1983). This is rarely a significant concern where trail use is predominantly day-oriented, and waste issues can be avoided by installing toilet facilities or following Leave No Trace practices (i.e., providing animal waste disposal bags, or digging cat holes for waste away from water resources), (Marion and Wimpey, 2006).

Fecal contamination can also occur from dispersed back-country use. In Mount Rainier National Park of Washington, up to 10,000 climbers visit the summit of Mount Rainier each year, raising the possibility of fecal contamination in high-elevation areas such as the Muir Snowfield. An initial investigation was conducted recently to determine if surface water runoff from the snowfield was contaminated by fecal microorganisms such as fecal coliforms, fecal streptococci, fecal enterococci and *E. coli* (Ells 1997). Results indicated no significant evidence of contamination (Leung and Marion, 2000).

Livestock

Personal use of horses is allowed on many National Forest System trails. There are no active cattle allotments in the Lake Tahoe basin. Commercial horse use is limited to several trail ride operations that are regulated by the Forest Service, the Lahontan Water Quality Control Board and the Nevada Division of Environmental Protection. For this reason commercial livestock use is not discussed further. Equestrian use is discussed later.

Swimming

Water quality degradation can occur from activities with direct body contact, including swimming, canoeing, and wading for example. Indirect impacts on water quality are also common, contributed by recreation activities that take place along the shoreline or in close proximity, such as hiking, camping, and wildlife viewing (Cole and Landres 1995, Cole 2008, Hammitt et al. 2015 cited in Marion et. al, 2016).





(Photo) Heavy daily summertime traffic in the Zion National Park Narrows canyon results in substantial trampling to shoreline vegetation and river substrates, causing a number of direct and indirect impacts to riparian resources (in Marion et. al, 2016)

Heavy visitation and traffic along stream and lake shorelines also causes vegetation trampling that can increase the incidence of erosion and nutrient influxes to water bodies (Madej et. al. 1994, Clow et. al. 2011, 2013). Nutrient loading in open bodies of water can contribute to algal blooms and decreased water quality (Hammitt et. al. 2015). One analysis on the Merced River in Yosemite National Park found a 27% increase in channel changes, including bank erosion due to heavy human traffic (Madej et. al., 1994) (in Marion et. al., 2016).

Equestrian Use

Wilson and Seney (1994) evaluated tread erosion from horses, hikers, mountain bikes, and motorcycles on two trails in the Gallatin National Forest, Montana. They applied one hundred passes of each use-type on four sets of 12 trail segments, followed by simulated rainfalls and collection of water runoff to assess sediment yield at the base of each segment. Control sites that received no passes were also assessed for comparison. Results indicated that horses made significantly more sediment available for erosion than the other uses, which did not significantly vary from the control sites. Traffic on pre-wetted soils generated significantly greater amounts of soil runoff than on dry soils for all uses, (Marion and Wimpey, 2006).



Heavy horse traffic has compacted and incised the main tread, which captures and retains water; subsequent hikers and horse riders seeking to avoid mud-holes and widen trails (Marion et al, 2016).

Mountain Bikes

Trail slope is a key factor influencing potential for impacts from mountain biking to soil and vegetation on recreation trails (Goetz, 2000; Wilson & Seney, 1994). Trail slopes greater than 12% typically were associated with higher potential for degradation, (White et.al., 2006). As slope increased, maximum incision from mountain bike travel increased.

Trail incision for slopes of less than 5% was significantly lower than slopes of 5% to 10% and significantly lower than for slopes of greater than 10%. The latter two slope categories were not significantly different. Generally, as bike trail slope increased, trail width increased, (White et. al., 2006).

The soil type and its vulnerability to erosion can also affect trail characteristics. Tahoe's granitic soils make the following example pertinent. In New Mexico and Arizona maximum bike trail width and incision were greatest in the mountains region, perhaps due to environmental features such as erodible soils and sparse trailside vegetation, higher use, and/or user behavior. Maximum incision increased consistently with slope for three of five routes (White et. al., 2006).

White found however that impacts to mountain bike trails, especially width, are comparable or less than hiking or multiple-use trails, and significantly less than impacts to equestrian or off-highway vehicle trails, (White et. al., 2006).

White concluded that although his study focused on only two impacts, when combined with the findings of previous studies (Goetz & Alder, 2001; Wilson & Seney, 1994), a consensus seems to be emerging that recreation impacts to mountain bike trails are largely confined to the main tread and that mountain biking is likely a sustainable activity on properly managed trails, at least in the environments studied thus far, (White et. al., 2006).

Areas of moderate to severe slopes remain an area of management concern for increased incision. This is potentially problematic as studies have shown that mountain bikers tend to prefer trails with steeper slopes, downhill features, and sharp curves (Cessford, 1995b; Goetz & Alder, 2001; Hollenhorst et al., 1995), (White et.al. 2006).

Motorized impacts

Motorized recreation in the Tahoe Basin is restricted to specific trails and seasons of use. See the Forest Service's Motor Vehicle Use Map (MVUM). Winter snowmobile use is not generally restricted once adequate snow is present. Water quality impacts from either winter or summer activities are regulated by the Lahontan Regional Water Quality Control Board and the Nevada Division of Environmental Protection, while the responsibility for avoiding those impacts generally falls to the Forest Service via implementation of Best Management Practices, the LTBMU Forest Plan, and MVUM. For this reason, creating additional regulatory guidance with recreational Thresholds and Standards appears to be unnecessary.

Boating

Motorized boating on Lake Tahoe can affect shoreline erosion, nearshore turbidity, the release of nutrients stored in sediments, and the quality of water through introduction of pollutants from fuel or boat paints as well as by introducing new aquatic invasive species, previously discussed (Mosich and Arthington, 1998, Chandra et. al, unpublished). These issues are currently regulated by the Lahontan Regional Water Quality Control Board and

the Nevada Division of Environmental Protection. TRPA's new Near Shore Management Plan (In Progress) is likely to address many of these issues as they specifically affect the nearshore area. Additional Regulatory guidance through new Thresholds or Standards in this area appears to be unwarranted at this time.

Air Quality

Recreational travel in the Lake Tahoe basin affects air quality primarily by resuspending road dust, which is the primary source for PM₁₀ emissions (Engelbrecht et. al. 2009). Wood smoke is a source for PM_{2.5} emissions primarily from residential wood burning during the fall and winter (Engelbrecht et. al. 2009). Smoke from summer camping was not cited as a significant source of particulate matter.

Travel

Abrasives (e.g., sand) have been used for many decades for winter operations to provide a temporary friction layer on the snowy or icy pavement. The environmental impacts of abrasives are generally more detrimental than chemicals. Compared to chemicals, a substantially greater amount of abrasives is needed to maintain a reasonable level of service. Abrasives used for snow and ice control can also exacerbate the environmental stress for roadside soil and vegetation (by accumulating on and around low vegetation). Particles smaller than 10 microns (0.01 mm) in diameter (PM-10) may contribute to air pollution and are listed as carcinogenic; PM-10 is regulated by the U.S. EPA (Fay and Shi, 2012).

Abrasives, as well as solid deicers, may increase the concentration of small particles in the atmosphere (Nixon 2001) and may stay suspended in the air, thus contributing to eye and throat irritation or to respiratory damage and potentially serious lung disease in sensitive populations (Fay and Shi, 2012). Paved and unpaved road dust emissions are the major source categories for PM-coarse (PM with aerodynamic diameters between 2.5 and 10 μm) and PM-large (PM with diameters $>10 \mu\text{m}$).

Wood Smoke/Campfires

Wood smoke from residential fuels combustion comprises the bulk of the PM-fine (i.e., PM $< 2.5 \mu\text{m}$) emissions (Dolislager et. al., 2009). The PM Fine fraction of road dust samples in LTADS made up roughly 20% of the total mass; concentrations of particulate nitrogen species and P were very low. On average for roadside dust samples, organic carbon was 34%, elemental carbon was 8%, aluminum was 3%, and silicon was 12% of the mass on the PM₁₀ and PM_{2.5} filters (Dolislager et. al., 2009).

The results of the source-specific wood smoke measurements were very similar to the neighborhood wood smoke sampling results of Fitz and Lents (2004), suggesting that residential wood combustion is the dominant source of the regional smoke. The very low concentrations of P in the residential wood smoke samples support the hypothesis that smoke from the burning of seasoned wood is not a significant source of P (Dolislager et. al., 2009).

Smoke from residential wood combustion appears to be the primary source of directly emitted PM_{2.5} in the Basin (Dolislager et. al., 2009, Engelbrecht et. al., 2009).

Road dust is the dominant source of PM in the Tahoe Basin as inferred both from ambient concentrations and special source- oriented monitoring results. Road dust as the dominant source of PM is also consistent with the inventory estimates of PM_{coarse} and PM_{large} provided in the current Lake Tahoe Air Basin emission inventory. Road dust and wood smoke both appear to be important sources of fine particles. However, fine particles from these two sources likely differ in solubility and this fact might be an important consideration of their potential to impact water clarity (Dolislager et. al., 2009).

The primary factor that influenced road dust emissions in the Tahoe Basin was the application of traction control material on roadways in the winter. All time series of fine dust indicated that emissions generally increased by a factor of 10 or more in the winter (from abrasive applications) compared to the summer (Zhu et. al. 2009).

The principle factors influencing road dust emissions in the Basin are season, vehicle speed (or road type), road condition, road grade, and proximity to other high-emitting roads. Combined with a traffic volume model, an analysis of the total emissions from the road sections surveyed indicated that urban areas (in particular South Lake Tahoe) had the highest emitting roads in the Basin (Zhu et. al. 2009). Fugitive dust emissions originating from motor vehicle travel on paved and unpaved roads constitute a significant fraction of the PM₁₀ (particulate matter [PM] with aerodynamic diameter 10 microns) in many areas of the western United States. These non-tailpipe emissions are largely composed of resuspended loose material from the road surface. Elevated ambient PM₁₀ levels can result, especially in winter when sand and salt are applied to roads for traction control (Zhu et. al., 2009).

No conclusions about the sources of phosphorus can be drawn from the ambient or source samples collected during LTADS due to the difficulty and uncertainties in measuring P. However, the source samples collected prior to LTADS indicate that road dust may be the primary source with contributions from the burning of live vegetative material and lubricating oils (Dolislager et. al., 2009).

Snowmobiles

The NPS launched an air-quality study in 1999 to measure snowmobile emissions (Bishop and others 2001). The study found that 27% of the yearly carbon monoxide emissions and 77% of the yearly hydrocarbon emissions in YNP come from snowmobile use (Davenport and Borrie, 2005). [Note; in 1999, most of the snow machines used air-cooled two stroke engines. Even with this reference, these results seem unusual.] Date and the types of engines in use must interpret the literature regarding snowmobiles and air quality at the time of the study. The Southwest Research Institute (8) reported 95-98% less hydrocarbons and roughly 90% less toxic hydrocarbons in exhaust emissions from commercially available four-stroke snowmobiles than from two-stroke sleds. Bishop et al. reported the mean CO and [YNP] HC emissions per mile per passenger from two-stroke snowmobiles in 1999 (CO) 71 g and HC) 92 g) and four-stroke snowmobiles in 2005 (CO) 21 g and HC) 2.5 g) and 2006 (CO) 15 g and HC) 0.8 g). The two-stroke engines emitted significantly larger quantities of air toxics (i.e., benzene, toluene, ethylbenzene, xylenes, and hexane) than either the four-stroke or diesel engines (Zhou et. al. 2009).

The distribution of VOCs from snowmobiles observed in Yellowstone National Park during February 2002 and 2003 provides striking evidence of anthropogenic influence on the air mass composition throughout the Park region. Benzene, toluene, ethyl benzene, xylenes, and *n*-hexane are the major components of two-stroke snowmobile exhaust and show large enhancements between the morning and afternoon sampling periods, with the largest increases in toluene, ethyne, and *n*-pentane (Zhou et. al. 2009).

Musselman and Korfmacher 2009, concluded that air pollutants from snowmobiles were well dispersed and diluted by strong winds common at the park, and it appears that snowmobile emissions did not have a significant impact on air quality at this high elevation ecosystem.

Other motorized uses

A great deal is known regarding motor vehicle use and their effects on air quality, however much less has been done to explore off highway vehicle impacts, principally dust. The trend towards 4-stroke engines for motorcycles and snowmobiles suggest that air quality emissions from these vehicles are diminishing. Research discussed in other sections suggest that use on designated trails (required in the Basin, except for the “Sand Pit” area) is too infrequent and limited in scale to be a problem.

Soils

In this section recreational impacts to soils are largely focused on loss of productivity or impacts on water quality caused by compaction and erosion.

Equestrian

Biophysical impacts from hiking are better researched than from horse riding and mountain biking. There are impacts in common to all three activities, although differences in the severity of the impact are greater with horse riding per user than hiking or mountain biking (White et. al, 2006).

Mountain Bikes

The literature regarding the effects of mountain biking on soils is variable. Pickering et. al, 2009 concluded that it is hard to assess relative impacts of mountain biking as there is little research, particularly using quantitative experimental methods and more realistic riding styles (Pickering et. al, 2009). Conversely, Marion et. al., (2016) found little difference between erosion from hiking and mountain biking, but both OHV use and equestrian use caused greater erosion. See the Water Quality section for more discussion of mountain bikes effects on soils and water quality.

Hiking



Although meadow grasses are more resistant and resilient to traffic than forest herbs, they are eliminated under heavy traffic. (Marion et al, 2016). [This is not a Tahoe Basin photograph.]

Impacts of hiking found in Australia and the USA include soil compaction and loss, reduced soil moisture, loss of organic litter, loss of ground cover vegetation, loss of native plant species, introduction of weeds and pathogens, and change in vegetation composition (e.g. Leung and Marion, 2000; Randall and Newsome, in press as cited in Pickering, 2009). Trail construction and use can have substantial impacts to soil and vegetation, including soil compaction, erosion, muddiness, loss of vegetative groundcover and changes in species composition, (Leung and Marion, 2000). In this case, the authors are speaking of the trail's footprint only.

Initial and low levels of trampling generally affect only vegetation and organic litter, such as dead plant leaves, grass, needles, and twigs. Initial trampling flattens and begins to degrade organic litter. Increased levels of trampling cause organic litter to be pulverized, which accelerates removal by wind or water or decomposition into the underlying organic soil. Organic soils are then exposed to traffic, but their low density and lack of structure

allows rapid displacement and loss, particularly due to erosion in sloping terrain (Marion et al, 2016).

Soil erosion and loss, especially water-based erosion problems, are perhaps the most significant long-term recreation impacts (Marion et al, 2016). Recreation trampling quickly compacts exposed mineral soil. The ground pressure of nonmotorized recreational traffic ranges from approximately 4.12 pounds per square inch for hikers, 4.98 pounds per square inch for mountain bikers (Thurston and Reader 2001) to 62.3 pounds per square inch for a shod horse and rider (Liddle 1997). These mechanical forces cause soil particles to rearrange and pack together more tightly, increasing soil density and decreasing pore space (Marion et al, 2016). When these impacts are managed to avoid expansion of tread width or trail use in muddy conditions, impacts stay within design limits and do not provide unanticipated impacts to soil productivity. Whether Tahoe Basin trails are adequately monitored to ensure long-term adherence to design standards is not addressed in this review.

Ski Resorts

Ski resorts manipulate snow conditions by altering ski slopes, and this includes extensive changes to soils and natural vegetation communities (Pickering and Hill, 2003).

Direct and indirect impacts of over-snow vehicles and snow-grooming machines have been documented, with snow grooming found to cause significant environmental degradation in ski resorts (Fahey and Wardle, 1998).

Impacts may be considered in two categories: (i) those resulting from physical damage by vehicles to the vegetation and soils; and (ii) those resulting from snow compaction and redistribution (Pickering and Hill, 2003).



Changes in the snow pack as a result of snow compaction also cause an array of secondary impacts. Compaction increases the snow's thermal conductivity and reduces its heat-insulation capacity. This can result in reductions in soil temperatures and increased frost penetration of the soil (Wanek, 1971).

Such changes in soil temperature can be dramatic. Five to sevenfold reductions in soil temperature and seven to 11-fold increases in penetration of frost into the soil beneath compacted snow have been reported (Baiderin, 1980, 1983) (Pickering and Hill, 2003).

Soil loss on recreation sites can also occur through sheet and rill erosion of exposed soils.

Most recreation sites are located in flatter terrain so soil loss is generally limited, although portions of sites, such as slopes down to and along shorelines, can experience substantial soil loss (Marion et al, 2016).

Road Salts

Road salts are included here because they are applied to facilitate safe winter recreational access. Chloride salts used for snow and ice control pose an environmental risk for soils. Salt concentrations in roadside soils have been found to positively correlate with the rate of salt application (Jones et al. 1992) (Fay and Shi, 2012). In another study, however, soil samples collected in the Lake Tahoe Basin showed no net accumulation of salts, despite the observed damage to trees by deicing salts (Munck et al. 2009) (Fay and Shi, 2012). The microstructural changes of soils induced by salt contamination have been shown to cause nutrient and heavy metal transport from the roadside to receiving waters (Defourny 2000). One concern when using magnesium- or calcium-based products is that the cations can exchange with heavy metals in soil, potentially releasing them into the environment (Public Sector Consultants 1993) (Fay and Shi, 2012).

Soundscapes and Noise

The concept of “soundscapes” is an emerging field of study. Unnatural sound interferes with many organisms’ ability to communicate, and in so doing may affect some species survival or persistence in noise-contaminated areas. Generally, noise becomes a problem when it is persistent. The noise from a passing motorcycle or snowmobile may be objectionable to a human, but its transitory nature suggests it is unlikely to be a significant problem to most native fauna. More research in this area is needed. This section is arranged differently to be largely explanatory because the field of soundscapes appears to be in the phase of describing the general impacts. Quantification of individual sources is only beginning. There are many similarities between scenic resources and soundscapes that focus on human perception, although to be clear, unnatural sound can have measurable impacts on wildlife.



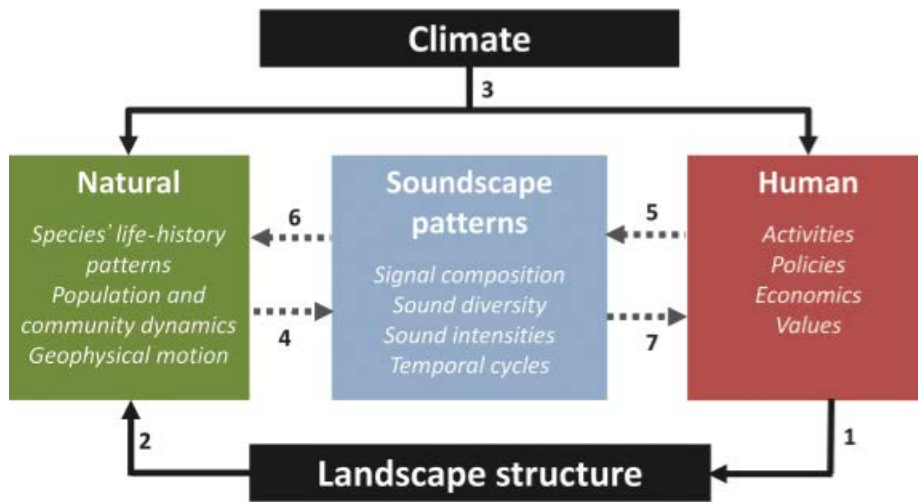
Human perception of Soundscapes

The definition of “natural quiet” includes the absence of any mechanical noise and containing only the sounds of nature such as bird song, wind or rain. Natural phenomena such as waterfalls and avalanches can be loud (louder than aircraft or other mechanical sources) but many people still view these noises as “good” and sound from aircraft noise as “bad” (Booth, 1999, Dickenson, 2012). For example, park visitors often report that escaping noise and enjoying the sounds of nature are among the most important motivations for visiting parks and related areas (Driver and others 1991). In fact, a national study found that 72% of Americans surveyed regarded opportunities to experience natural quiet and the sounds of nature as a very important reason for preserving national parks (Haas and Wakefield 1998). In another survey specific to park visitors, 91% of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald and others 1995) (Pilcher et. al. 2008).

Moreover, impacts to the soundscapes of parks and related areas can diminish the quality of the visitor experience and this also warrants more research and management attention (Pilcher et. al. 2008). Most respondents to a study at Muir Woods reported hearing human-caused sounds and most of these sounds were judged to be annoying. Most respondents reported hearing natural sounds in the park and that they judged these sounds to be pleasing. (Pilcher et. al. 2008).

Soundscapes and Wildlife

Krause (1987) later attempted to describe the complex arrangement of biological sounds and other ambient sounds occurring at a site, and introduced the terms “biophony” to describe the composition of sounds created by organisms and “geophony” to describe nonbiological ambient sounds of wind, rain, thunder, and so on. Pijanowski, et.al., (2011) extended this taxonomy of sounds to include “anthrophony”—those sounds caused by humans.



Conceptual framework for soundscape ecology (Pijanowski, et.al, 2011).

Almost all birds use sound to attract mates, defend territories, sound alarms, and communicate other types of information. Many of the passerines are especially known for producing elaborate songs (Kroodsma 2005) (Pijanowski, et.al.,2011).

Recently, considerable evidence has emerged showing that anthrophony can influence animal communication in a variety of ways. For example, American robins (*Turdus migratorius*) shift the timing of their singing in urban environments to the night (Fuller et al., 2007). In song sparrows (*Melospiza melodia*), the lowest-frequency notes were higher in environments with high ambient noise (Wood and Yezerinac 2006). Brumm (2004) found that free- ranging nightingales (*Luscinia megarhynchos*) in noisier environments sing more loudly than those in quieter environments, and Slabbekoorn and Peet (2003) determined that the great tit (*Parus major*) sings at higher pitches in urban noise conditions (Pijanowski, et.al., 2011).

Most songbirds are known to begin singing at the same time each year (Saunders 1947), and these birds sing most intensely early in the morning (Kacelnik and Krebs 1982) and late evening (referred to as the dawn and dusk chorus, respectively). Dawn chorus in birds is thought to occur when individuals, arriving back to their territory, use songs to advertise their presence (Staicer et al., 1996). This circadian pattern of singing in birds, the timing of which is largely affected by weather and climatic conditions, strongly correlates with sunrise and sunset and becomes more pronounced with the onset of breeding and migration (Pijanowski, et.al., 2011).

Wiens and Milne (1989), among others, have emphasized the need to understand landscapes from the perspective of the size of an organism; they found that from a beetle's point of view, the very near structure of a landscape influences movement patterns. Additionally, many insects produce sounds that aid in breeding or communication that may not be audible to humans or to other organisms in the landscape (Pijanowski, et.al.,2011).

Soundscapes represent the heritage of our planet's acoustic biodiversity, and reflect Earth's natural assemblage of organism. Soundscapes are an ecosystem service (MA 2005) that provides cultural and other services. Natural sounds are our auditory link to nature, and the trends toward increasing society's "nature deficient disorder" (Louv 2008) are likely to continue as we replace natural sounds with those made by humans (Pijanowski, et.al.,2011).

It has been speculated that more specialized birders depend heavily on the soundscape (Scott & Shafer, 2001). This is suspected because highly skilled birders want to observe more bird species (McFarlane, 1994) and they can record species by using bird vocalizations (American Birding Association, 2010) (Miller, 2014).

"Natural quiet" is increasingly being recognized as an important and scarce resource in parks and related ^[17]separate areas. Moreover, the ability to hear the sounds of nature without distractions of human-caused noise can affect the quality of the visitor experience (Manning et. al., 2006).

Light Environment

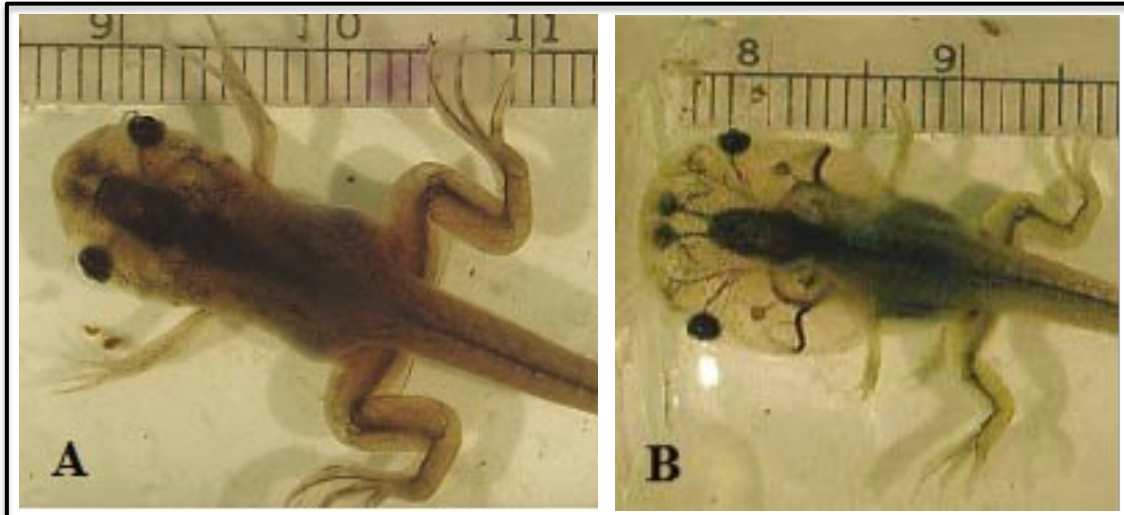


The amount of artificial light on land is continuing to increase at a rate of 6% percent per year globally (Hölker et. al., 2010; Davies, 2014). The influence of artificial night lights on organisms is a relatively new area of interest. The following section addresses a broad range of research from around the world since little has been completed in the Tahoe Basin. The presentation of these studies does demonstrate that additional Basin-specific

research may be warranted. Recreational impacts from artificial lights in the Tahoe Basin are probably concentrated along roadways originating from street lights and traffic, and ski areas that use lights for facilities and night skiing. The bulk of night lighting impacts are associated with urban development and businesses along the lake. While these are important sources, they are largely outside the scope of this report.

Light pollution seems to have a widespread, negative impact on many different species (Longcore, 2004). The evidence for the impact of light pollution in migratory birds (Gauthreaux and Belser, 2006) hatchling sea turtles (Salmon, 2006), and insects (Eisenbeis, 2006) is striking, because of the large-scale mortality that has occurred as a result of artificial night lighting. Such mortality makes the impact of light pollution on these species more obvious and quantifiable. However, for other taxa, the impact of light pollution on populations may be more subtle, yet equally important. In such species, light pollution may affect such aspects of the biology of these species as physiology (e.g. growth and metabolism) and behavior (e.g. reproduction and foraging activity) causing stress that negatively affects populations exposed to this environmental pollutant (Wise, 2007).

They found higher plasma melatonin concentrations during the dark cycle of the photoperiod than during the daylight period, but when in constant light, there was no difference in melatonin levels over the 24-hr period. Melatonin production was lowered in salamanders kept under constant light. In amphibians, melatonin is important in the regulation of thyroid hormones (involved in metamorphosis of frog tadpoles), gonadal development, reproductive behavior, skin coloration, thermoregulation, and ability to adapt visually to darkness^{14,17}. (Wise, 2007).



Tadpoles of the same age exposed to different nocturnal illuminations. The tadpole in A, from the darkest lighting treatment, is metamorphosing. The tadpole in B still retains the larval body form, and is not yet ready to metamorphose (in Wise, 2007).

Both light and darkness can act as a resource for organisms (Kronfeld-Schor & Dayan, 2003; Gerrish *et al.*, 2009). Through photosynthesis, energy is captured by autotrophs in the form of light and cycled through ecosystems; furthermore, many physiological processes and behavioural activities require either light or dark conditions to operate. The balance between hours of light and of darkness constrains the time available for these processes and so changes in the availability of both light and darkness as a resource can have positive or negative effects on an organism, dependent on whether it is the presence or absence of light that poses the greater constraint (Gaston *et al.*, 2013).

Results of all these studies demonstrate that artificial night lighting has the potential to affect foraging and breeding as well as growth and development of frogs and salamanders. Thus, artificial night lighting should be considered an additional factor that negatively impacts amphibian populations and more research is needed to assess the potential magnitude of such impacts on biological diversity of amphibians (Wise, 2007).

Similarly, nocturnal orb-web spiders *Larinioides sclopetarius* preferentially build webs in areas which are well lit at night, where higher densities of insect prey are available; a behavior that appears to be genetically predetermined rather than learned (Heiling, 1999). This suggests the possibility of evolutionary responses to utilize novel niches created by artificial lighting (cited in Gaston *et al.*, 2013).

Virtually all plants and animals possess a circadian clock, an endogenous system that regulates aspects of their activity and physiology on a cycle that approximates 24 h, but which in the absence of external cues may drift out of phase with day and night (Sweeney, 1963 as cited in Gaston *et al.*, 2013).

The widespread attraction of moth species to nighttime lights has long been exploited in the design of traps for their capture. The reasons for such disruption of their natural movement patterns remain to be fully determined, although interference with the use of moonlight for navigation is likely important (Warrant & Dacke, 2011) (In Gaston *et al.*, 2013). Further, many insects, including members of the Hymenoptera, Lepidoptera and

Coleoptera, can navigate using the pattern of polarized celestial light in the sky (Dacke *et al.*, 2003) (Gaston *et al.*, 2013).

Artificial light pollution is widespread in marine environments, altering the natural colors, cycles, and intensities of nighttime light, each of which guide a variety of biological processes. Known and potential impacts include those on navigation, reproduction and recruitment, predator-prey interactions, and communication in a myriad of marine species and ecosystems, including some of the world's most biologically diverse and functionally important (Davies, 2014).

Under natural light regimes, terrestrial invertebrates inputs to streams typically peak during the day (Angradi and Griffith 1990, Nakano *et al.* 1996) While there is variability in the timing of emergence events (Morgan and Waddell 1961) emergence and flight often follow a diel pattern, with greatest activity from late evening to early morning (Harper *et al.* 1983, Jackson 1988, Bernaith *et al.* 2004 as cited in Meyer and Sullivan, 2013).

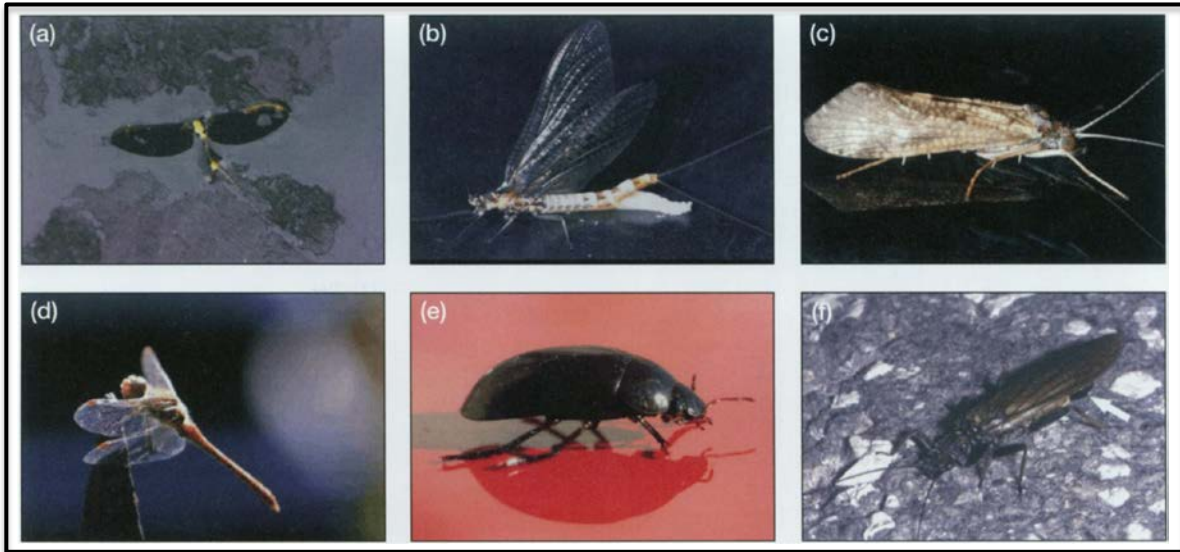
It was concluded that nocturnal pollination is an ecosystem process that may potentially be disrupted by increasing light pollution, although the nature of this disruption remains to be tested (MacGregor *et al.*, 2015).

In Great Britain, two-thirds of widespread larger moth species populations declined over a 40-year period (Fox *et al.*, 2013), with probable detrimental cascading effects on ecosystem functioning: the nature of these is considered a priority, policy-relevant question (Sutherland *et al.*, 2006) (MacGregor *et al.*, 2015).

Artificial night lighting, even at low levels, exerts an influence at every level of biological organization (Gaston *et al.*, 2013), from cell (Navara & Nelson, 2007) to organism (Longcore & Rich, 2004) and community (Davies *et al.*, 2012). However, little is currently known about the effects of light pollution on species population dynamics, whole communities, and networks of interacting species, or ecosystem functioning (MacGregor, 2015).

Polarized light pollution includes light that has undergone linear polarization by reflecting off smooth, dark buildings, or other human-made objects, or by scattering in the atmosphere or hydrosphere at unnatural times or locations. Artificial polarizers can serve as ecological traps that threaten populations of polarization-sensitive species.

Artificial polarized light can disrupt the predatory relationships between species maintained by naturally occurring patterns of polarized light, and has the potential to alter community structure, diversity and dynamics (Horvath *et al.*, 2009).



Polarotactic water-loving insects attracted to different PLP sources, (a) Mayfly trapped in a waste oil lake in Budapest, Hungary; (b) mayfly laying eggs on a horizontal black plastic sheet; (c) caddisfly on a vertical glass pane (the picture is rotated by 90); (d) male dragonfly perching above a polished horizontal black tombstone; (e) water beetle on a red car roof; (f) ovipositing stonefly (white arrow: eggs) on a dry asphalt road (IN Horvath et al., 2009).

The surprising ubiquity of anthropogenic polarizing surfaces combined with the occurrence of sensitivity to polarized light in so many animal taxa suggest that caution in the placement and use of artificial polarizers is warranted from a conservation perspective. Great potential exists for the mitigation and elimination of the ecological consequences of PLP, through the use of alternative materials that reduce the polarization signature of human activity. Because rough surfaces reflect light with lower p values at a given angle of reflection (Kriska et al. 2006b), one solution is to use building materials that are as rough as possible (avoiding shiny bricks and glass in favor of matte surfaces (Horvath et al. 2009).

There are many drivers of environmental change, but artificial night lighting is one which is uniquely important for nocturnal organisms, through direct interaction with a light source such as a streetlamp, increased background illumination at night, and altered perception of photoperiod (Hölker *et al.*, 2010b; Lyytimäki, 2013; Lewanzik & Voigt, 2014) (MacGregor et al., 2015).

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Appendix A

Recreation Impacts Summary

Recreational Impacts on Basin Resources

Activities	Resource Areas										
	Wildlife Terrestrial	Aquatic Biota	Biodiversity	Vegetation	Wildfire Risk	Scenic	Water Quality	Air Quality	Soils	Soundscapes	Lightscape
Hiking/Trail Running Mountain Biking	Localized impacts, from people and dogs	NA	Little information	Restricted to tread surface	negligible	negligible	Small on maintained trails	NA	Compaction on trails surface, erosion risk	negligible	negligible
	Small localized disturbance	NA	Little information	Localized threat from unauthorized use	negligible	negligible	Small on maintained trails	NA	Compaction on trails surface, erosion risk	negligible	negligible, night riding no
Horseback Riding Rock Climbing	Small localized disturbance	NA	Little information	usually minor	negligible	negligible	minor when managed	negligible	Compaction and erosion risk on trails	negligible	NA
	Rare plants and animals affected	NA	Inconclusive	local effects	negligible	negligible	NA	NA	NA	NA	NA
Facilities Expansion Motorized Summer uses	Wildlife displaced from footprint	minor short term possible	Cumulatively important	Normally minor	During construction	Potential impacts	Potential impacts	Short term potential impacts	Loss of productive soils	Potentially, depends on use	Potentially, depends on use
	Displacement from trails	Yes, if WQ affected	Normally minor	Yes on trails	Yes, but low occurrence of	Potential impacts, trails	Potential impacts	Potential impacts	Erosion risk	Potential impacts	Potential, but night use low
Sightseeing	negligible	negligible	negligible	negligible	Low potential	NA	Low potential	Low to moderate	Low potential	negligible	negligible
Beach Going Picnicking	negligible	Localized impacts possible	negligible	Yes along access trails	Low potential	NA	Possible impacts	NA	Compaction/Erosion along access	negligible	NA
	Yes at designated sites	negligible	negligible	Yes at Designated sites	Yes from campfires	negligible	NA	Yes, from campfires	Compaction/Erosion at designated sites	negligible	negligible
Nature Photography Camping	Flushing response possible	Little information	negligible	negligible	negligible	NA	NA	NA	NA	NA	NA
	Yes at campsites and proximate	Yes proximate to campgrounds	Yes proximate to campgrounds	Yes, proximate to campgrounds	Yes, occurrence low at	negligible	Possible impacts	Yes, from campfires	Yes at campgrounds	Potential impacts	Potential impacts
Skiing Backcountry Skiing Resorts	Potential impacts, frequency and extent	negligible	Rare examples	negligible	NA	negligible	negligible	NA	NA	NA	negligible
	Yes, at facilities	Yes, at facilities	Potential impacts at high elevations	Yes to high elevation species	Potential during summer use	Yes, significant impacts	Moderate potential, negligible	Yes, little data	Yes at facilities	Potential, depends on use	Yes, from night skiing
Snowmobiling Fishing	Potentially, risk appears low	NA	negligible	negligible	negligible	negligible in Tahoe basin	negligible	negligible, with current	negligible with adequate snow	Yes, depends on frequency and	Low potential
	NA	Yes to target species	Historically yes, currently low	NA	negligible	NA	negligible	negligible	negligible, except bank fishing	NA	NA
Motorized Watercraft Non Motorized boating	Potential shoreline impacts	Yes, exotic spp. disturbance of	Yes, exotic spp. introduction	negligible, lowpot shore line impacts	negligible	Yes, depending on use	Yes, depending on use	Yes, depending on use	NA except at facilities	Yes, depends on use	Low potential
	Near-shore disturbance possible	negligible	negligible	NA	NA	negligible	Low potential	NA	NA	NA	NA
NA means "not applicable", for example, nonmotorized boating does not impact terrestrial vegetation. Negligible means impacts are theoretically possible but unlikely.											

NA means "not applicable", for example, nonmotorized boating, does not impact terrestrial vegetation
Negligible means impacts are theoretically possible but unlikely.