ECOSYSTEM IMPACTS OF ARTIFICIAL SNOWMAKING AT ARIZONA SNOWBOWL

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Snowmaking is becoming a popular method of increasing snow cover, depth, and level according to the needs of ski areas to fulfill the expanding demand for public skiing. Due to re-occurring droughts in the U.S. Southwest, most ski areas are dependent upon artificial snowmaking techniques to counteract the problem of insufficient snowfall during the winter season (Leao and Tecle 2003). As a solution to insufficient snowfall, about 59 percent of the ski resorts in the United States produced and used artificial snow in 1984 (Kocak and Van Gemert 1988). The percentage of ski resorts using artificial snow increased to 91 percent in 2003 (Leao and Tecle 2003). The major concern on the use of artificial snow in the Arizona Snowbowl or elsewhere has been its possible impacts on natural resources (especially on soil, water, vegetation, and wildlife). However, there is little information about the intensity and severity of disturbances that may occur following the application of artificial snow made from reclaimed water. This indicates the need for a serious scientific study on the environmental impacts of snowmaking in general, and from reclaimed wastewater in particular.

The Arizona Snowbowl wants to improve the reliability and profitability of its operation through artificial snowmaking using reclaimed water from the city of Flagstaff. The rationale behind this is to ensure the continuous availability of sufficient snow on its ski facilities during the winter season to enhance their carrying capacity and meet the recreational demands on the ski facilities. The additional work will involve making new skiing trails, installing modern chairlifts, adding snow play areas, and constructing a 14.8-mile pipeline to transport the reclaimed wastewater to on-site holding tanks. For this purpose, the USDA (U.S. Department of Agriculture) Forest Service and Coconino County conducted an environmental impact study to determine the viability and environmental effects of the proposed snowmaking from reclaimed wastewater project.

In 2005, the Coconino National Forest permitted the Arizona Snowbowl to implement the proposed actions in the ski area. The proposal consists of using up to 1.5 million gallons per day of reclaimed water for artificial snowmaking from November to the end of February, whenever there is inadequate snow for skiing. However, 10 native tribes are opposing the use of reclaimed water for snowmaking on the San Francisco Peaks because they consider the peaks to be sacred and argue that the use of reclaimed water for snow will have negative impacts on the spiritual and cultural values of the Peaks as well as the vegetation and wildlife on it (Flagstaff Activist 2006). On the other hand, the Arizona Snowbowl's existence fully depends upon sufficient snow for skiing and that cannot be fulfilled by natural snowfall with the ongoing drought and increased usage. Annual visits to the ski area have increased by 157 percent over the past 20 years (Coconino National Forest 2005). Currently, the Arizona Snowbowl has 32 ski runs and 4 chairlifts (Arizona Snowbowl 2005).

Application of man-made snow, construction of ski runs, and subsequent use of these pistes (runs) by skiers have substantial impacts on soil, vegetation, and wildlife. This is so because ski slopes are machine graded and machine leveled and the addition of water and nutrients will have substantial impact on the vegetation. Ruth-Balaganskaya and Myllynen-Malinen (2000) found that ski slope construction is one of the major anthropogenic factors responsible for ecosystem degradation in mountain areas. Therefore, though snowmaking can provide many benefits to the economy of Flagstaff, there are various concerns about possible adverse impacts on the ecosystem of the San Francisco Peaks.

STUDY AREA

The Arizona Snowbowl is located 23 km north of Flagstaff within the Coconino National Forest

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and on the San Francisco Peaks (Figure 1). Three sides of the Arizona Snowbowl are surrounded by the 7533.62 ha Kachina Peaks wilderness area. At present, the size of the skiing area is 83 ha. The elevation of the skiing area ranges from 2789 m at the base to 3670 m at the top.

The climate of the San Francisco Peaks is mainly characterized by winter and summer precipitation regimes and spring and fall drought cycles. The soil type of the Peaks is primarily loamy. The Rocky Mountain Subalpine Conifer Forest and Woodland within Engelmann Spruce–Subalpine Fir series is the predominant biotic community in the Snowbowl area. In this community, the dominant forest type is corkbark fir (*Abies lasiocarpa*; Coconino National Forest 2005). The potential tree species of the Snowbowl area are Douglas-fir (*Pseudotsuga menziesii*), limber pine (*Pine flexilis*), Aspen (*Populas tremuloides*), corkbark fir (*Abies bifolia*), and some Engelmann spruce (*Picea engelmannii*). The grasses and forbs comprise mainly fescue (*Festuca* spp.), squirrel-tail (*Sitanion hystrix*), orchard grass (*Dactylis glomerata*), wheat grass (*Agropyron trachycaulum*), deers-ears (*Swertia* sps.), and silverleaf cinquefoil (*Potentilla anserina*).

The Snowbowl area also seems to be a very important habitat for various wild animal species. According to a list of threatened, endangered, and sensitive species in the Mormon Lake and Peaks Ranger District in July 2002, there are two federally listed threatened wildlife species in the Snowbowl area—the Mexican spotted owl (*Strix occdentalis lucida*) and the bald eagle (*Haliaeetus leucocephalus*).

METHODS

The primary sources of information for this study were an extensive review of the literature and interviews and written communications with concerned officials and experts in the study area. We used published and unpublished data and other information on snowmaking and its effects on the biotic and abiotic communities, as well as various articles, research papers, EIS reports, theses, books, and online media to make inferences about the impacts of applying artificial snow made from reclaimed water on ecosystem biodiversity and other environmental conditions in the Arizona Snowbowl area.

RESULTS

The reclaimed water produced by the city of Flagstaff's Rio de Flag Wastewater Treatment Plant (RFWTP) has an A water quality rating, because compared to the national drinking water standards (Van der Leeden et al. 1990), the quality of the water with respect to many parameters (except coliform bacteria) is very good. According to the Arizona Department of Environmental Quality (ADEQ), such reclaimed water with an A rating is suitable for snowmaking (Coconino National Forest and Coconino County 2005). However, because the maximum allowable amount of bacteria in drinking water is 1.0 CFU/L (colony-forming units per liter), reclaimed water with values slightly above the maximum level (counts of about 2.0 CFU/L; Van der Leeden et al. 1990) is considered unsafe for drinking. It is also important to note that the pH of the precipitation around Flagstaff ranges between 5.0 and 5.5; this is relatively acidic compared to the pH level of 7.0–7.8 of the reclaimed water (Van der Leeden et al. 1990).

Laboratory tests of water samples from different Flagstaff water supply wells and the Rio de Flag Wastewater Treatment Plant show the presence of various chemical compounds. The values for these compounds in the reclaimed water are higher than in the water samples from the wells, as shown in Table 1.

Concerning cloud seeding, an experiment conducted by Knight et al. (1979) suggests that the prolonged snow cover due to winter cloud seeding may increase the productivity of dry meadows vegetation. Such an experiment was performed in southeastern Wyoming. Treatment and control plots were established separately in dry sites and in mesic sites. In the treatment plots, snow cover was prolonged by winter cloud seeding. Researchers found an increase in the dry weight of the vegetation particularly in dry sites compared to mesic sites.

In a study conducted in Switzerland, Kammer (2002) examined the floristic changes in subalpine grasslands after 22 years of artificial snowmaking. The results showed substantial changes in floristic composition of vegetation due to the subsequent use of man-made snow. Particularly, the additional availability of water and ions in man-made snowmelt brought changes in the vigor and composition of the vegetation communities. The study also showed that faster-growing species with nutrient-rich characteristics could grab more additional nutrients from snow melt than the species with low nutrient characteristics. The chart in Figure 2 shows changes in floristic composition in the study sites after 22 years of artificial snow application. In the same study, the researcher also tested the properties of river water, artificial snow, natural snow, and precipitation, and found that

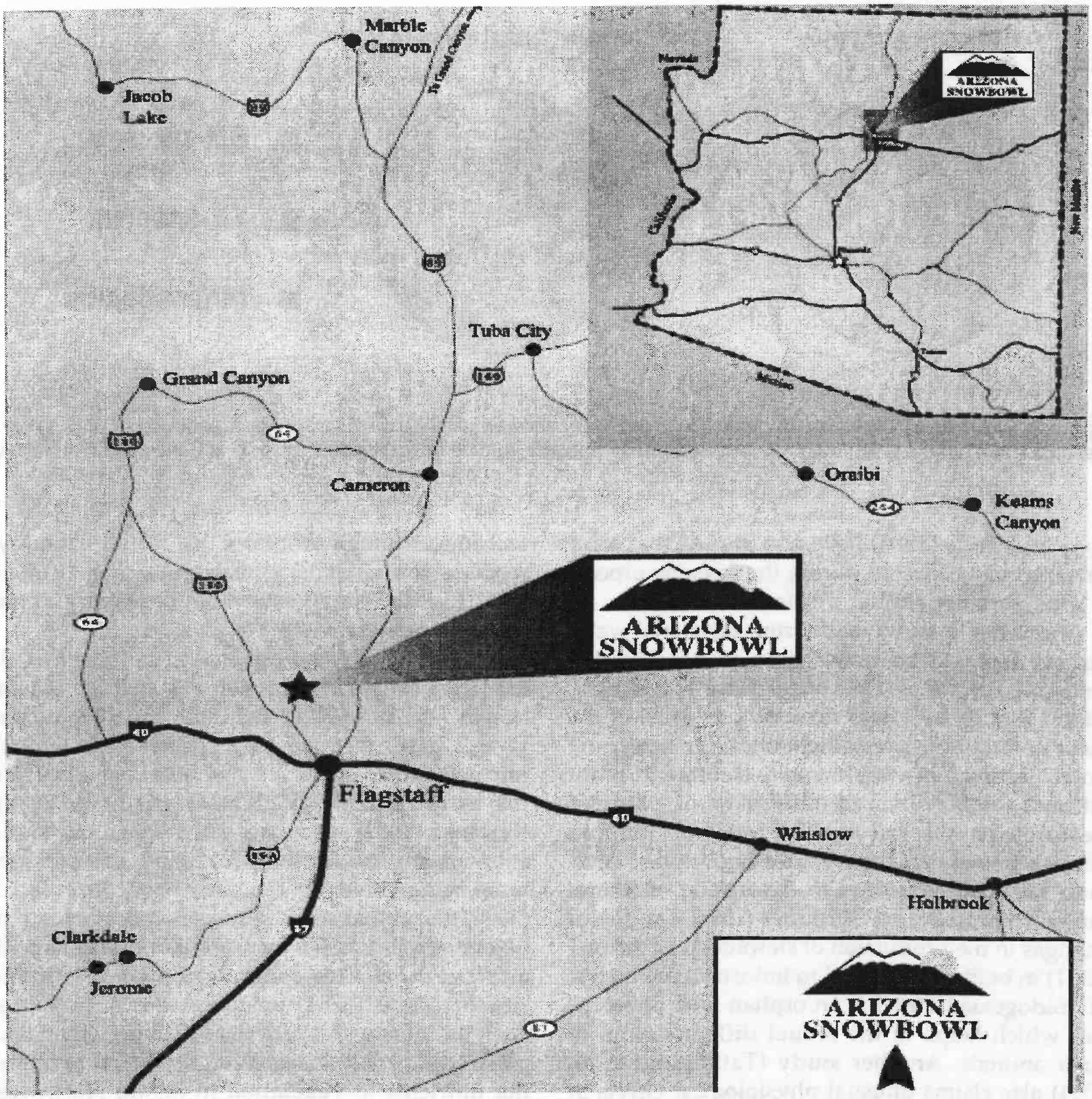

Figure 1. Location map of Arizona Snowbowl (Coconino National Forest 2005).

artificial snow has higher pH, calcium, ammonium, and nitrate concentrations than natural snow, as shown in Table 2.

DISCUSSION

The main items to consider when looking at the effects of using artificial snow from reclaimed water are pH, nutrient contents, and durability of the snow. These items can affect the use of reclaimed water to make snow at ski areas such as the Arizona Snowbowl. Currently, there is little information available on the impacts of reclaimed water on the ecosystem even though it is used for various purposes all over the world. For example, reclaimed water is used for watering golf courses and landscapes alongside roads and public parks, and also for cooling power-generating plants (USGS 2006). The main concerns regarding the use of reclaimed water for making snow are related to pH and bacterial concentration. However, a lab test showed that the pH of the reclaimed water is almost equal to that of drinking water (Van der Leeden et al. 1990) while harmful bacteria are killed using ultraviolet radiation and chlorination.

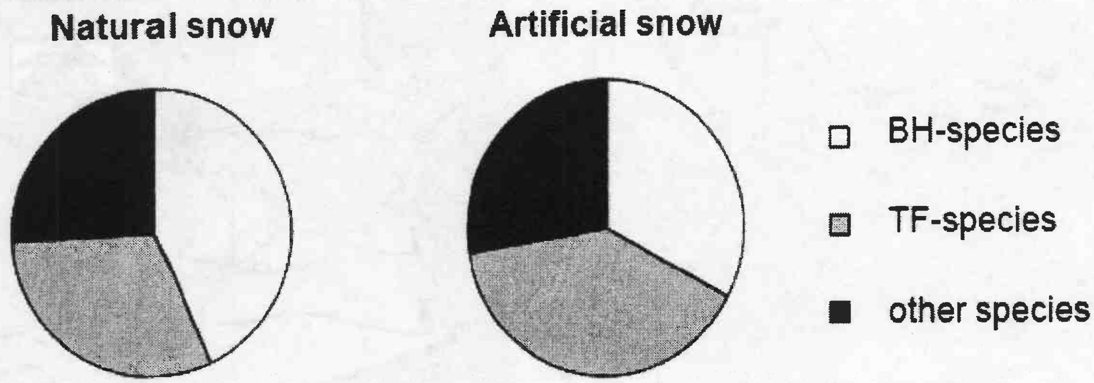

Figure 2. Changes in vegetation composition in artificially snowed plots (1 sq m) of dry hay meadows of the *Bromus/ Helictotrictron* type, nutrient-rich hay meadows of TF species, and other nonspecific species in Savognin, Switzerland.

Leao and Tecle (2003) have also argued that some bacteria may be killed during the freezing process at a temperature of 0° C or below.

Nutrients in snow made from reclaimed water do not seem to be major risks to wildlife that consume such snowmelt water. Glassmeyer et al. (2005) found that the concentrations of 35 of the most commonly detected chemicals in water are much higher in wastewater treatment plant effluent samples than in other parts of a stream. Research on the red-spotted newt by Propper (2004) showed that the animal's ingestion of common pesticides resulted in disruption of pheromonal communication. Propper (2004) also found changes in the production of steroidogenic factor 1 (SF-1) in bullfrogs exposed to industrial pollutants. Steroidogenic factor 1 is an orphan nuclear receptor, which helps in the sexual differentiation of such animals. Another study (Tatarazako et al. 2004) also claims unusual physiological effects in some aquatic animals, algae growth, and ecosystem functions. These happen partly due to the presence of some toxic ingredients like triclosan in the wastewater, although the exact and specific reasons for such changes still remain to be studied.

In another study, Sheikh et al. (1998) tested the use of tertiary-treated reclaimed water for irrigation. Their research agrees with others who have found that tertiary-treated reclaimed water is safe and can be used to irrigate food crops. Laboratory tests of reclaimed water have not shown a significant presence of the pathogenic microorganisms of concern, such as *E. coli*, Cyclospora, and Salmonella, which would affect food safety. In this particular case, the Rio de Flag reclaimed water is far better than most treated wastewater because it is reclaimed through processes that include primary, secondary, and tertiary treatments, and disinfection (Rio de Flag Wastewater Treatment Plant, based on personal visit).

The presence of nutrients such as calcium, sulfur, and phosphorus has some impact on vegetation as well as wildlife including aquatic animals. In this case, fast-growing species with higher nutrient intake capability get some benefit from the extra nutrient availability (Kammer 2002). Kammer (2002) also suggested that man-made snow makes species that like high-nutrient water more competitive. On the other hand, Rixen et al. (2004) found that some species that are capable of higher nutrient intake were avoiding ski runs with artificial snow. This contradiction may be due to site characteristics or human-induced disturbances such as the various physical activities that take place on ski runs. Research on the effects of applying nutrients to vegetation in inland Northwest conifer stands found that multi-nutrient fertilization was beneficial to overstory as well as understory vegetation. The study also revealed that such an increase in nutrient concentration is very good for wildlife because it helps produce very nutritious plants (VanderSchaaf et al. 2004).

The availability of additional water in the ski areas is one more important item to consider, since 60 cm of artificial snow cover provides approximately 200 liters of water per square meter (Mosiman 1999, cited in Rixen et al. 2004). This additional water is very beneficial to plant species, especially those that grow in dry areas (Knight et al. 1979). Through this experimental work, Knight et al. (1979) found an approximately 50 percent increase in the dry weight of dry area vegetation

Table 1. Presence of pharmaceuticals and other compounds in Flagstaff well water and the Rio de Flag Wastewater Treatment Plant's water (in micrograms per liter).

Compound	Woody Mtn Well 9	Continental Well 2	Treatment Plant Discharge	Filtered vs. Unfiltered
1,4-dichlorobenzene	< 0.5	< 0.5	E 0.2	F
3,4-dichlorophenyliso-	< 0.5	E 0.1	E 0.1	U
4-nonylphenol	< 5.0	< 5.0	E 0.1	U
9,10-anthraquinone	< 0.5	< 0.5	E 0.1	F
AHTN	< 0.5	< 0.5	3.0	F
Benzophenone	< 0.5	< 0.5	E 0.1	F
Benzophenone	< 0.5	< 0.5	E 0.1	U
Bromacil	< 0.5	E 0.4	< 0.5	U
Caffeine	< 0.5	< 0.5	E 0.1	F
Caffeine	< 0.5	E 0.1	E 0.1	U
Cholesterol	< 2.0	< 2.0	E 0.1	U
Ciprofloxacin	< 0.005	< 0.005	0.356	F
DEET	< 0.5	E 0.1	E 0.2	F
DEET	< 0.5	E 0.1	E 0.2	U
Diethoxynonylphenol total	< 5.0	E 0.1	E 0.1	U
HHCB	< 0.5	< 0.5	0.5	F
HHCB	< 0.5	E 0.1	E 0.4	U
Indole	< 0.5	< 0.5	E 0.1	U
Isochlorotetracycline	< 0.01	0.01	< 0.01	F
Phenol	E 0.2	0.7	E 0.2	F
Phenol	E 0.3	E 0.2	2.9	U
Prometon	< 0.5	E 0.1	< 0.5	U
Sulfadiazine	< 0.005	< 0.005	0.472	F
Sulfamethox-axole	< 0.005	< 0.005	1.09	F
Tetracycline	0.09	< 0.01	0.16	F

E = estimated; AHTN and HHCB refer to polycyclic musks; DEET (N,N-diethylmeta-toluamide) = insect repellent gradients.

Table 2. Comparison of ion contents (mg/l) and pH of (1) water from Gelgia River used for making artificial snow in Savognin, (2) fresh artificial snow at Savognin, (3) natural snow at Savognin, and (4) natural precipitation on Rigi Mountain, central Switzerland (from Kammer 2002).

Contents	(1) Gelgia River Water	(2) Artificial Snow	(3) Natural Snow	(4) Natural Precipitation
pH	—	8.52	4.90	4.81
NO_3	1.80	1.80	0.95	1.86
NH	0.05	0.05	0.05	0.72
Na	2.40	—	—	0.11
Mg	—	3.90	0.03	0.03
PO_3	0.008	0.005	0.06	—
SO_4	47.0	—	—	1.20
Cl	1.00	—	—	0.16
K	0.70	—	0.18	0.04
Ca	—	7.4	0.50	0.30

watered with artificial snow compared to plants watered with natural snow, but the experimental result also showed a decrease in the dry weight of vegetation growing in mesic sites that use artificial snow. As Arizona has been suffering from continuous drought over the past few years and is characterized by a drier climate with low humidity, the vegetation in the Arizona Snowbowl would get more benefit from the additional moisture from the snowmaking. Such additional water availability also provides more moisture to support more wildlife. Furthermore, Knight et al. (1979) argued that this condition may lead to more water entering the soil, helping with litter decomposition (Webber et al. 1976) and mineralization as well as an increase in nutrients leaching into the soil. On the other hand, researchers note that application of man-made snow can delay spring season vegetation growth, leading to a delay in the growing season (Rixen et al. 2004; Wipf et al. 2002). For example, Kammer and Hegg (1990, cited in Kammer 2002) reported that late-flowering species remained blooming until the end of June on the areas covered with artificial snow, while the plants on the natural snow covered areas were already fruiting. This delaying effect may be an important concern with regard to forage availability for wildlife at Arizona Snowbowl. This particular factor may compel mammals and other big game animals to move away from the Snowbowl area.

Another effect of applying man-made snow is its ability to stay longer in the ski run sites as compared to natural snow. Seed-producing trees may experience significant negative effects from the prolonged snow cover, which definitely delays the development of seed germination and seedling production, hence resulting in possibly lower amounts of vegetation cover in some areas. Walker et al. (1999) mentioned that the delay in the start of the growing season due to an artificially increased snow cover caused extensive dying of *Kobresia myosuroides*, a species that is adapted to thin winter snow cover of alpine tundra. The composition of fir and other associated seed-producing species will be affected in the case of the Arizona Snowbowl and will provide more space for other vegetation or any other invasive species to grow.

Artificial snow also has some negative impacts on soil, as it can cause severe soil frost in the soil crust. The densely compacted snowpack decreases gas permeability, leading to an elevated CO_2 concentration in the soil. This situation is not good for some vegetation communities because it may result in lowering the frost resistance of some sensitive species (Newesely et al. 1994, cited in Wipf et al. 2005).

After snow production, snow grooming is necessary to level and manage the ski runs. Various researchers have suggested that ski trail grooming also has other impacts on the vegetation regime in the area (Rixen et al. 2004; Pickering et al. 2003; Wipf et al. 2005). Wipf et al. (2005) have found lower species richness and productivity on ski piste plots. They also noted lower abundance and cover of woody plants and early flowering species. Rixen et al. (2004) observed the same results in their study.

As discussed earlier, the pH content of artificial snow is higher than that of natural snow. However, that observation was made using man-made snow produced from river or ground water. In the Arizona Snowbowl case, snow will be produced from reclaimed water. Therefore, there is no information available about the pH content or the nutrients that will be present in the snow made from reclaimed water. We can only assume that the properties of the snow produced in the Arizona Snowbowl will have at least the same properties as the snow produced from river or ground water sources. The argument in support of this view is that the treated wastewater at the Rio de Flag Treatment Plant is class A reclaimed water with standards as good as river water. Also, the only major distinctions in quality between the reclaimed water and drinking water are slight differences in pH and bacterial concentration. The higher pH value may cause some alteration in the physiological characteristics of vegetation. As some research reveals, the higher pH may change plant bodies from acidic to basic, or slowly and gradually make basophilic species cover an area over the long term (Kohler 2000, cited in Kammer 2002).

On the other hand, application of man-made snow at the Arizona Snowbowl skiing area may result in more mountain front recharge and surface flow, which eventually ends up in the Little Colorado and Verde Rivers as well as recharging the underlying aquifer. The additional water in the soil and the ground will also be a good source of moisture for the vegetation and wildlife in the area during the dry season and in periods of drought. However, the higher nutrient content (Table 2) may become problematic for aquatic organisms as well as other wildlife species, although it has some benefits for algae and other plant species by helping them to spread extensively and very quickly. The presence of large amounts of such plants can reduce the amount of O_2 available for other aquatic organisms (Purdue University 2006).

The wildlife in and around the Arizona Snowbowl may be affected by the excess nutrient availability. The extra nutrient intake may result in weight gain by some wildlife species, leading to changes in their roosting, feeding, and breeding habits. Night-time noise from snow guns may also affect the activities of the Mexican spotted owl because owls are active at night. Another school of thought however suggests that such noise might be advantageous for spotted owls because their prey—rodents and small mammals—might be disturbed and thus more visible at night.

CONCLUSIONS

The study presented in this paper suggests that artificial snow made from reclaimed water can have some moderate and manageable impacts on ecosystem biodiversity in the Arizona Snowbowl area. This is in line with previous studies such as that of Wipf et al. (2005), who concluded that artificial snow has moderate impacts on ski areas. However, we have not found any information that suggests the disappearance or elimination of any animal or plant species due to the use of artificial snow, although the presence of some threats has been argued in some studies (Rixen et al. 2004; Walker et al. 1999).

To lessen the possible impacts of man-made snow on the Arizona Snowbowl ecosystem, the nutrient content, various chemical compounds, and pH levels in the reclaimed water should be kept to the same level as that in rain or natural snowmelt water through some type of chemical treatment. Also the density and structure of the artificial snow should be maintained close to that of natural snow so that it will not last longer than natural snow on the ground. Careful periodic monitoring and evaluation of the ecosystem in the area would be helpful to note and prevent any negative impacts from applying the snow produced from reclaimed water. We also recommend that carefully designed and continuous field research should be conducted to evaluate the impacts of applying man-made snow produced from reclaimed water on the ecosystem at the Arizona Snowbowl and to help plan and develop a realistic, sustainable, environmentally safe and socially and culturally acceptable snowmaking project.

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