11 Skiing, Snowboarding, and Snowshoeing

Chapter Summary
This chapter first defines some of the different disciplines of skiing (alpine, Nordic, telemark, ski mountaineering), snowboarding, and snowshoeing. It then examines snow sport competition before examining participation numbers. The final part of the chapter focuses on specific environmental impacts of snow sports: damage to soil, vegetation, water, and the impacts on wildlife. There is discussion about artificial snowmaking and its environmental impacts. The final section considers the management of these activities and the impacts of climate change on snow sport.

11.1 Definitions

Skiing can be a means of transport, a recreational activity, or a competitive winter sport in which skis are used to glide on snow. Many types of competitive skiing events are recognised by the International Olympic Committee (IOC) and the International Ski Federation (FIS). The term snow sport encompasses alpine, freestyle, snowboard, and Nordic skiing (UK Snow Sports 2018).

11.1.1 Alpine Skiing

Alpine skiing, also called downhill skiing, typically takes place on a piste at a ski resort. It is characterised by fixed-heel bindings that attach at both the toe and the heel of the skier's boot (Fig. 11.1A, B). Because the alpine equipment is somewhat difficult to walk in, ski lifts (Fig. 11.1C), including chairlifts (Fig. 11.1D), bring skiers up the slope. Clearly these have impacts on the environment which are discussed later in this chapter. Backcountry skiing can be accessed by helicopter, snowcat, hiking, and snowmobile. Facilities at resorts can include night skiing, après-ski (which can include bars with outdoor music and dancing on the ski slopes), and snowmaking facilities (discussed later). Alpine skiing branched off from the older Nordic skiing around the 1920s when the advent of ski lifts meant that it was not necessary to walk any longer.

11.1.2 Nordic Skiing

The Nordic disciplines include cross-country skiing and ski jumping, which both use bindings that attach at the toes of the skier's boots but not at the heels (Fig. 11.2A). Cross-country skiing may be practised on groomed trails or in undeveloped backcountry areas. Ski jumping skiing is practised at certain areas that are deemed for ski jumping only.

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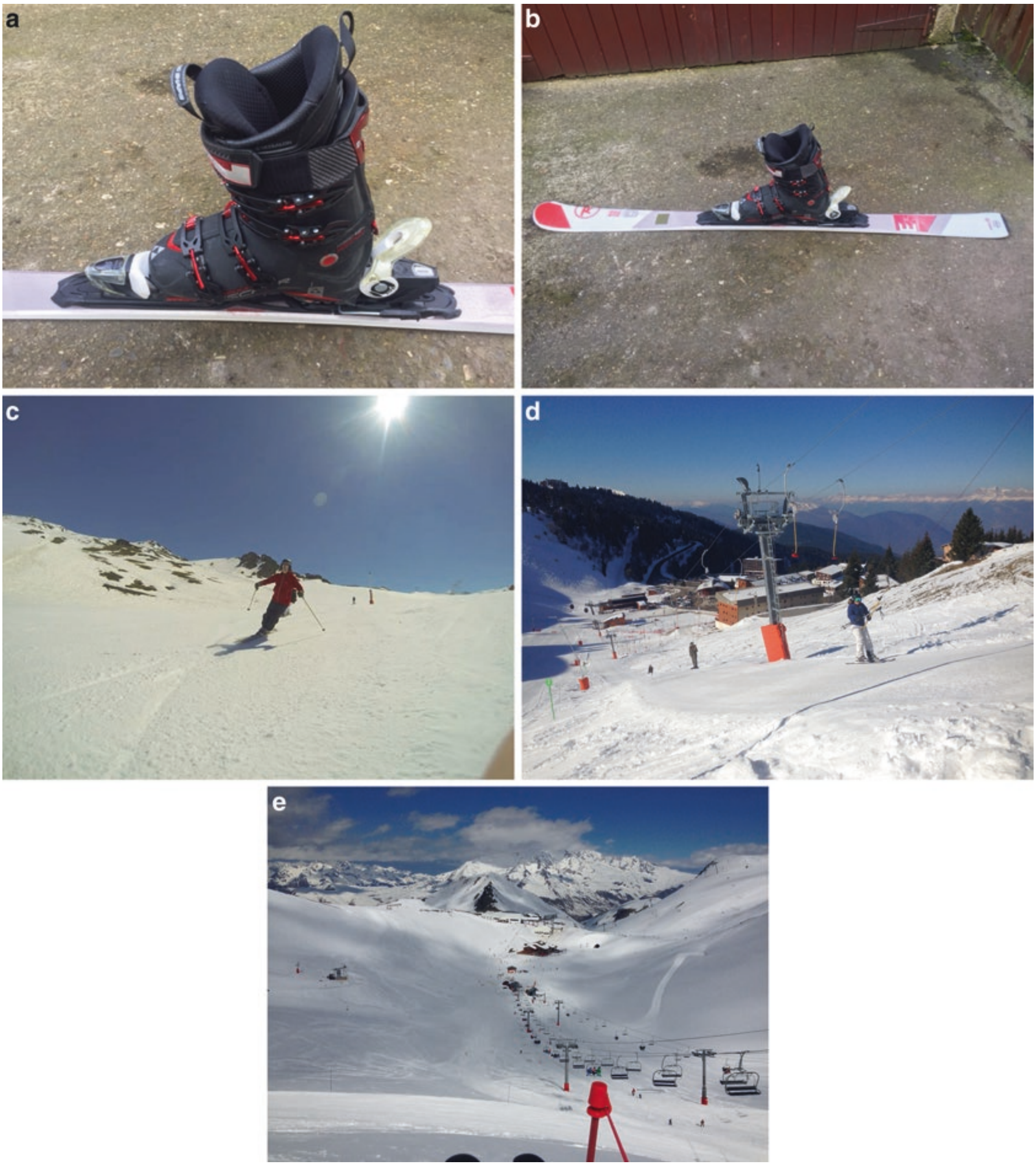

Fig. 11.1 (A) An Alpine ski boot and bindings. The boot is held at the toe and the heel. The bindings will release under force to minimise the risk of injury in even of a fall. Photo by Tim Stott. (B) An Alpine ski is shaped to enhance its turning capability. Photo by Tim Stott. (C) Alpine ski technique with skis parallel. Photo by Tim Stott. (D) Drag lift (also called a poma tow) at Chamrousse 1650, France, used to take Alpine skiers up the mountain. Photo by Tim Stott. (E) Chairlift and ski resort infrastructure at Les Deux Alpes, France, for transporting Alpine skiers up the mountain. Photo by Tim Stott

11.1.3 Telemark

Telemark skiing is a ski turning technique and FIS-sanctioned discipline. It is named after the Telemark region of Norway. The equipment similar to Nordic skiing, with the ski bindings having the ski boot attached only at the toe (Fig. 11.3A) and the ski shaped (Fig. 11.3B) more like an Alpine ski, which facilitates turning. The "free-heel" binding allows the skier to raise his/her

Fig. 11.2 (A) Nordic ski boot and binding. This type of binding, known as a 3-pin binding, attached to the toe of the boot only. The ski and boot are much lighter and more flexible than the Alpine set up so permitting faster travel. Photo by Tim Stott. (B) A Nordic ski is longer and narrower than an Alpine ski. It is designed to move faster and has more directional stability (but is more difficult to turn). Photo by Tim Stott. (C) Nordic skiing at the Plateau D'Alsace, Chamrousse, France. The technique in this photograph is called "skating" which allows the skiers to go uphill. At other times the skiers follow pre-cut parallel tracks, cut by a special machine. Photo by Tim Stott

heel throughout the turn (Fig. 11.3C). Hence, telemark skiing is known as "free-heel" skiing in North America.

11.1.4 Ski Mountaineering

Ski mountaineering is a skiing discipline that involves climbing mountains either on skis (skins which grip the snow are fixed to the base of the ski for uphill travel) or carrying them (Fig. 11.4G), depending on the steepness of the ascent, and then descending on skis. There are two major categories of equipment used, free-heel telemark skis and skis based on Alpine skis (Figs. 11.4A, B), where the heel is free for ascent but is fixed during descent. The discipline may be practised recreationally or as a competitive sport.

Competitive ski mountaineering is typically a timed racing event that follows an established trail through challenging winter alpine terrain while passing through a series of checkpoints. Racers climb and descend under their own power using backcountry skiing equipment and techniques. More generally, ski mountaineering is an activity that variously combines ski touring, telemark, backcountry skiing, and mountaineering.

11.1.5 Snowboarding

Snowboarding is a recreational activity and Olympic and Paralympic sport that involves

Fig. 11.3 (A) Telemark boot and binding. The boot is made from plastic but a rubber section above the toe makes it flexible. The boot is only fixed to the binding at the toe. There is a cable around the heel. In the event of a fall, the boot and metal part of the binding and cable come away from the ski. Photo by Tim Stott. (B) A telemark ski is shaped like an Alpine ski. Photo by Tim Stott. (C) Telemark ski technique. Photo by Tim Stott

descending a snow-covered slope while standing on a snowboard attached to a rider's feet (Fig. 11.5A, B).

The development of snowboarding was inspired by skateboarding, sledding, surfing, and skiing. It was developed in the USA in the 1960s, became a Winter Olympic Sport at Nagano in 1998, and was first featured in the Winter Paralympics at Sochi in 2014. Its popularity (as measured by equipment sales) in the USA peaked in 2007 and has been in a decline since. Snowboarding styles now include jibbing, freeriding, freestyle, Alpine snowboarding (Fig. 11.5B), slopestyle, big air; half-pipe; boardercross, and snowboard racing (Fig. 11.5C).

11.1.6 Snowshoeing

A snowshoe is footwear for walking over snow. Snowshoes work by distributing the weight of the person over a larger area so that the person's foot does not sink completely into the snow, a quality called "flotation." Snowshoeing is a form of hiking. The origin and age of snowshoes is not precisely known, although historians believe they were invented from 4000 to 6000 years ago, probably starting in Central Asia. Two groups of snowshoe pioneers diverged early on, setting patterns that can still be seen today. One group abandoned the snowshoe as it migrated north to what is now Scandinavia, eventually turning the design into the forerunners of the Nordic ski. The other went northeast, eventually crossing the Bering Strait into North America. In 2016, Italian scientists reported "the oldest snowshoe in the world" discovered in the Dolomites and dated to between 3800 and 3700 BC. As snowshoes resemble a tennis racquet, the French use the term is *raquette de neige*.

Traditional snowshoes have a hardwood frame with rawhide lacings. Most modern snowshoes

Fig. 11.4 (A) Ski mountaineering boot and binding. These bindings are fixed at the toe with two pins so the boot articulates. The heel can be free (for uphill travel) with three risers (for increasingly steep slopes) and are then clipped down for the ski descent. Photo by Tim Stott. (B) Ski mountaineering boots, bindings, and skis are lighter than Alpine equivalents. The skis are usually wider and longer to support the skier in soft snow "off-piste." Photo by Tim Stott. (C) A ski mountaineering party in northern Norway skinning uphill. Photo by Tim Stott. (D) Ski mountaineers make zigzag tracks up steep slopes. Photo by Tim Stott. (E) Ski mountaineering ski technique for the descent is basically the same as for Alpine skiing, though the snow conditions can be variable. Photo by Tim Stott. (F) Ski mountaineering descent in Kvaloya, near Tromso, Norway. Photo by Tim Stott. (G) Ski mountaineers sometimes have to walk in carrying their skis (on approach to the Komna plateau, Slovenia). Photo by Tim Stott. (H) Ski mountaineers reaching a summit in Norway. Sometimes they take off their skis and replace them with crampons and an ice axe for the final part of the ascent. Photo by Tim Stott

Fig. 11.4 (continued)

Fig. 11.5 (A) Snowboarders use soft boots which they strap into bindings. Photo by Tim Stott. (B) Snowboarding on a piste. Photo by Tim Stott. (C) Snowboarders in a play park. Photo by Tim Stott

Fig. 11.6 Modern snowshoes made from plastic have bindings, heel lift, and small spikes on the underside for grip on hard snow. Photo by Tim Stott

are made of materials such as lightweight metal, plastic, and synthetic fabric (Fig. 11.6). In addition to distributing the weight, snowshoes are generally raised at the toe for manoeuvrability. They must not accumulate snow, hence the latticework, and require bindings to attach them to the feet.

In the past, snowshoes were essential tools for fur traders, trappers, and anyone whose life or living depended on the ability to get around in areas of deep and frequent snowfall, and they remain necessary equipment for forest rangers and others who must be able to get around areas inaccessible to motorised vehicles when the snow is deep. However, snowshoes are mainly used today for recreation, primarily by hikers and runners who like to continue their hobby in wintertime. Snowshoeing is easy to learn and in appropriate conditions is a relatively safe and inexpensive recreational activity.

11.2 Snow Sport Competition

The following disciplines are sanctioned by the FIS. Many have their own world cups and are in the Winter Olympic Games.

- *Cross-country*: the sport encompasses a variety of formats for cross-country skiing races over courses of varying lengths. Such races occur over homologated, groomed courses designed to support classic (in-track) and freestyle events, where the skiers may employ skate skiing. It also encompasses cross-country ski marathon events, sanctioned by the Worldloppet Ski Federation, and cross-country ski orienteering events, sanctioned by the International Orienteering Federation, and biathlon, a combination of cross-country and shooting.
- *Ski jumping*: contested at the Olympics, the FIS Ski Jumping World Cup, the summer FIS Grand Prix Ski Jumping, and the FIS Ski-Flying World Championships.
- *Nordic combined*: contested at the Olympics and at the FIS Nordic Combined World Cup, it is a combination of cross-country skiing and ski jumping.
- *Alpine skiing* disciplines include combined, downhill, slalom, giant slalom, super-G, and para-alpine. There are also combined events that include two events, one run of each event like one run of super-G and one run of slalom skiing, called a super combined.
- *Speed skiing* dates from 1898 with official records being set as of 1932 with an 89-mile-per-hour (143 km/h) run by Leo Gasperi. It became an FIS sport in the 1960s and a demonstration Olympic sport at the 1992 Winter Olympics in Albertville.
- *Freestyle skiing*: includes mogul skiing, aerials, ski cross, half-pipe, and slopestyle.
- *Snowboard* competition includes slopestyle, cross, half-pipe, alpine, parallel slalom, and parallel giant slalom.
- Other competition includes grass skiing and *telemark*.
- *Skiboarding*: consists of a combination of skiing and snowboarding. It uses ski boots with a snowboard.

11.3 Participation Numbers

In the USA, during the 2016 calendar year, a total of 24,134 online interviews were carried out with a nationwide sample of individuals and households from the US Online Panel of over one million people operated by Synovate/IPSOS (Outdoor Foundation 2017). A total of 11,453 individual and 12,681 household surveys were completed. The total panel is maintained to be representative of the US population for people ages six and older. Over sampling of ethnic groups took place to boost response from typically under responding groups. The 2016 participation survey sample size of 24,134 completed interviews provides a high degree of statistical accuracy.

As can be seen in Table 11.1, The Outdoor Foundation (2017) survey data for the USA show that, of the six snow sports disciplines measured in the survey:

- Alpine/downhill skiing had the greatest number of participants in 2016 (9,267,000) and a 12.4% increase over the previous three years (2014–2016),
- Snowboarding had the second greatest number of participants in 2016 (7,602,000), showing a 3.4% increase over the previous three years.
- Cross-country skiing had 4,640,000 participants but the greatest three-year increase of 40.3%.
- Freestyle skiing with 4,640,000 participants in 2016 had the same number participating as cross-country skiing but with only a 2.7% three-year increase.
- Telemark (downhill) skiing has the smallest participation numbers in the six disciplines surveyed (2,848,000) and a 3.0% three-year increase.
- Snowshoeing had 3,533,000 participants but showed a −12.3% decrease in participation in the 2014–2016 period.

Cordell's (2012) survey showed snowboarding (Table 11.2) as having 12,200,000 participants in the 2005–2009 period with a 33.7% increase between the 1999–2001 and 2005–2009 periods. Comparing that with the Outdoor Foundation's (2017) data, it appears that snowboarding had declined after it peaked in 2010 at 8,196,000.

Table 11.2 also shows that both cross-country skiing and snowshoeing showed declines of −21.7% and −9.4%, respectively, in the numbers participating between the 1999–2001 and 2005–2009 periods

Cordell (2012) stated that "across the demography of Americans generally, just over 11% participated in some form of snow skiing or boarding in 2005–2009. Participation rates are high relative to the general population for males, non-Hispanic Whites, people ages 16–34 (especially those under age 25), people with college to postgraduate education, people earning more than $75,000 annually, and urban residents (Table 11.3). Less likely than the population to participate in snow skiing or boarding activities are females, Blacks, Native Americans, people over 55 years of age, those lacking college degrees, people with low incomes, and rural residents" (Cordell 2012, p. 65).

Bowker et al. (2012) projected changes in total outdoor recreation participants between 2008 and 2060 (Table 11.4). There was an estimated 24 million participants in 2008 taking part in developed skiing (downhill skiing and snowboarding), and this was predicted to become 21–23 million by 2060. For undeveloped skiing (cross-country skiing and showshoeing), there was an estimated eight million participants in 2008 taking part), and this was predicted to decline to one to four million by 2060.

Table 11.5 shows the changes over the same period for the total number of outdoor recreation days. There was an estimated 178 million days in 2008 where people took part in developed skiing (downhill skiing and snowboarding), and this was predicted to become 165–179 million days by 2060. For undeveloped skiing (cross-country skiing and showshoeing), there was an estimated 52 million days in 2008 where people took part, and this was predicted to decline to 5–29 million days by 2060 (Bowker et al. 2012).

In England, data are available from the Sport England Active People Survey (APS). For this survey Sport England defined snow sport to

Table 11.1 Outdoor participation by activity (ages 6+) in the USA, 2006–2016 (The Outdoor Foundation 2017, p. 8)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	3-year change (%)
Adventure racing	725	698	920	1089	1339	1065	2170	2213	2368	2864	2999	35.5
Backpacking overnight >¼ mile from vehicle/home	7076	6637	7867	7647	8349	7095	8771	9069	10,101	10,100	10,151	11.9
Bicycling (BMX)	1655	1887	1904	1811	2369	1547	2175	2168	2350	2690	3104	43.2
Bicycling (mountain/non-paved surface)	6751	6892	7592	7142	7161	6816	7714	8542	8044	8316	8615	0.9
Bicycling (roads/paved surface)	38,457	38,940	38,114	40,140	39,320	40,349	39,232	40,888	39,725	38,280	38,365	−6.2
Birdwatching (more and ¼ mile from home/vehicle)	11,070	13,476	14,399	13,294	13,339	12,794	14,275	14,152	13,179	13,093	11,589	−18.1
Boardsailing/windsurfing	938	1118	1307	1128	1617	1151	1593	1324	1562	1766	1737	31.2
Camping (RV)	16,946	16,168	16,517	17,436	15,865	16,698	15,108	14,556	14,663	14,699	15,855	8.9
Camping (with ¼ mile of home/vehicle)	35,618	31,375	33,686	34,338	30,996	32,925	29,982	29,269	28,660	27,742	26,467	−9.6
Canoeing	9154	9797	9935	10,058	10,553	9787	9839	10,153	10,044	10,236	10,046	−1.1
Climbing (sports/indoor/boulder)	4728	4514	4769	4313	4770	4119	4592	4745	4536	4684	4905	3.4
Climbing (traditional/ice/mountaineering)	1586	2062	2288	1835	2198	1609	2189	2319	2457	2571	2790	20.3
Fishing (fly)	6071	5756	5941	5568	5478	5683	6012	5878	5842	6089	6456	9.8
Fishing (freshwater/other)	43,100	43,859	40,331	40,961	38,860	38,868	39,135	37,796	37,821	37,682	38,121	0.9
Fishing (saltwater)	12,466	14,437	13,804	12,303	11,809	11,983	12,017	11,790	11,817	11,975	12,266	4.0
Hiking (day)	29,863	29,965	32,511	32,572	32,496	34,491	34,545	34,378	36,222	37,232	42,128	22.5
Hunting (bow)	3875	3818	3722	4226	3908	4633	4075	4079	4411	4564	4427	8.5
Hunting (handgun)	2525	2595	2873	2276	2709	2671	3553	3198	3091	3400	3512	9.8
Hunting (rifle)	11,242	10,635	10,344	11,114	10,150	10,807	10,164	9792	10,081	10,778	10,797	10.3
Hunting (shotgun)	8987	8545	8731	8490	8062	8678	8174	7894	8220	8438	8271	4.8
Kayak fishing	n/a	n/a	n/a	n/a	1044	1201	1409	1798	2074	2265	2371	31.8

(continued)

Table 11.1 (continued)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	3-year change (%)
Kayaking (recreational)	4134	5070	6240	6212	6465	8229	8144	8716	8855	9499	10,017	14.9
Kayaking (sea/touring)	1136	1485	1780	1771	2144	2029	2446	2694	2912	3079	3124	16.0
Kayaking (white water)	828	1207	1242	1369	1842	1546	1878	2146	2351	2518	2552	18.9
Rafting	3609	3786	4226	4342	3869	3725	3958	3915	3924	4099	4095	–10.6
Running/jogging	38,559	41,064	41,130	43,892	49,408	50,713	52,187	54,188	51,127	48,496	47,384	–12.6
Sailing	3390	3786	4226	4342	3869	3725	3958	3915	3924	4099	4095	4.6
Scuba diving	2965	2965	3216	2723	3153	2579	2982	3174	3145	3274	3111	–2.0
Skateboarding	10,130	8429	7807	7352	6808	5827	6627	6350	6582	6436	6442	1.5
Skiing (alpine/downhill)	**n/a**	**10,362**	**10,346**	**10,919**	**11,504**	**10,201**	**8243**	**8044**	**8649**	**9378**	**9267**	**12.4**
Skiing (cross-country)	**n/a**	**3530**	**3848**	**4157**	**4530**	**3641**	**3307**	**3377**	**3820**	**4146**	**4640**	**40.3**
Skiing (freestyle)	**n/a**	**2817**	**2711**	**2950**	**3647**	**4318**	**5357**	**4007**	**4564**	**4465**	**4640**	**2.7**
Snorkelling	8395	9294	10,296	9358	9305	9318	8011	8700	8752	8874	8717	0.2
Snowboarding	**n/a**	**6841**	**7159**	**7421**	**8196**	**7579**	**7351**	**6418**	**6785**	**7676**	**7602**	**3.4**
Snowshoeing	**n/a**	**2400**	**2922**	**3431**	**3823**	**4111**	**4029**	**3012**	**3501**	**3885**	**3533**	**–12.3**
Stand up paddling	n/a	n/a	n/a	n/a	1050	1242	1542	1993	2751	3020	3220	61.6
Surfing	2170	2206	2607	2403	2767	2195	2895	2658	2721	2701	2793	3.0
Telemarking (downhill)	**n/a**	**1173**	**1435**	**1482**	**1821**	**2099**	**2766**	**1732**	**2188**	**2569**	**2848**	**3.0**
Trail running	4558	4216	4857	4833	5136	5610	6003	6792	7531	8139	8582	26.4

Note: All participation numbers are in thousands (000)

Table 11.2 Trends in number of people of ages 16 and older participating in recreation activities in the USA, 1999–2001 and 2005–2009 for activities with fewer than 15 million participants from 2005 through 2009 (Source: Cordell 2012, p.40)

	Total participants (*millions*)			Percent participating	Percent change
	1994–1995	1999–2001	2005–2009	2005–2009	1999–2001 to 2005–2009
Kayaking	3.4	7.0	14.2	6.0	103.8
Mountain climbing	9.0	13.2	12.4	5.3	−5.9
Snowboarding	**6.1**	**9.1**	**12.2**	**5.2**	**33.7**
Ice skating outdoors	14.2	13.6	12.0	5.1	−11.5
Snowmobiling	9.6	11.3	10.7	4.5	−5.5
Anadromous fishing	11.0	8.6	10.7	4.5	24.1
Sailing	12.1	10.4	10.4	4.4	−0.4
Caving	9.5	8.8	10.4	4.4	18.4
Rock climbing	7.5	9.0	9.8	4.2	9.5
Rowing	10.7	8.6	9.4	4.0	8.9
Orienteering	4.8	3.7	6.2	2.6	−21.7
Cross-country skiing	**8.8**	**7.8**	**6.1**	**2.6**	**−21.7**
Migratory bird hunting	5.7	4.9	4.9	2.1	−1.1
Ice fishing	4.8	5.7	4.8	2.1	−15.5
Surfing	2.9	3.2	4.7	2.0	46.3
Snowshoeing	**–**	**4.5**	**4.1**	**1.7**	**−9.4**
Scuba diving	–	3.8	3.6	1.5	−5.6
Windsurfing	2.8	1.5	1.4	0.6	−10.1

Missing data are denoted with "–" and indicate that participation data for that activity were not collected during that time period. Percent change was calculated before rounding

Source: USDA Forest Service (1995) (n = 17,217), USDA Forest Service (2001) (n = 52,607), and USDA Forest Service (2009) (n = 30,398)

Note: The numbers in this table are *annual* participant estimates on data collected during the three time periods

1994–1995 participants based on 201.3 million people of ages 16+ (Woods & Poole Economics, Inc. 2007)

1999–2001 participants based on 214.0 million people of ages 16+ (U.S. Department of Commerce 2000)

2005–2009 participants based on 235.3 million people of ages 16+ (U.S. Department of Commerce 2008)

include Alpine skiing, freestyle skiing, Nordic skiing, and snowboarding. Table 11.6 shows that there were an estimated 127,400 participants (0.31% of the population of England) in the October 2005–October 2006 survey period. This had declined to 99,800 (0.23% of the population) by the October 2016–October 2066 survey period.

Figure 11.7 displays the number of people who ski per country in Europe as of 2016. In 2016, there were approximately 1.1 million people in the Ukraine who skied. Germany had the highest number of ski participants with a total of approximately 14.6 million, followed by France with 8.6 million and the UK with 6.3 million. This estimate is clearly significantly higher than the Sport England APS (Table 11.6). When considering the total population, the share of people who ski in European countries was the highest in Switzerland with 37% and in Austria with 36%.

Clearly there are some discrepancies in the various estimates for snow sport, but from Table 11.1 (The Outdoor Foundation 2017) we can see that in the US snow sport activities fall behind running/jogging (47,384,000), hiking (42,128,000), road cycling (38,365,000), fishing (38,121,000), camping (26,467,000), hunting/canoeing/kayaking (all around the 10 million mark), then follows Alpine skiing (9,267,000).

Table 11.3 Percentage of participants and population, rations of percentages, and statistical test results for the activity group snow skiing or boarding

Demographic	Stratum	Percent of participants	Percent of nation	Ratio (1)/(2)	Percent participating
All groups	All people age 16 and older	100.0	100.0	1.00	11.2
Gender*	Male*	63.0	48.2	1.31	14.5
	Female*	37.0	51.8	0.71	8.1
Race/ethnicity*	White, non-Hispanic*	75.9	67.3	1.13	12.7
	Black, non-Hispanic*	5.5	13.9	0.40	4.2
	American Indian, non-Hispanic	0.4	0.8	0.50	6.5
	Asian or Pacific Islander, non-Hispanic	3.6	3.6	1.00	11.3
	Hispanic	14.6	14.4	1.01	11.5
Age*	16–24*	38.8	15.8	2.46	27.6
	25–34*	18.6	16.2	1.15	13.0
	35–44	17.7	16.9	1.05	12.1
	45–54*	16.5	17.6	0.94	10.4
	55–64*	5.7	13.6	0.42	4.6
	65+*	2.7	20.0	0.14	1.5
Education*	Less than high school**	21.3	24.0	0.89	9.9
	High school graduate*	19.4	26.9	0.72	8.1
	Some college***	24.6	26.8	0.92	10.3
	College degree*	21.5	14.4	1.49	16.7
	Postgraduate degree*	13.2	7.9	1.67	18.7
Annual family income*	<$15,000*	9.3	16.5	0.56	6.6
	$15,000–$24,999*	5.7	11.4	0.50	5.8
	$25,000–$49,999*	18.7	27.4	0.68	7.9
	$50,000–$74,999***	19.0	18.3	1.04	12.5
	$75,000–$99,999*	14.5	11.1	1.31	14.5
	$100,000–$149,999*	18.0	9.4	1.91	21.5
	$150,000+*	14.8	6.0	2.47	27.6
Place of residence*	Nonmetro resident*	13.0	17.5	0.74	8.4
	Metro area resident**	87.0	82.5	1.05	11.8
Residence status	Native born or US citizen	96.3	96.7	1.00	11.2
	Foreign born	3.7	3.3	1.12	11.7

Source: Cordell (2012, p. 69); USDA Forest Service (2009), Versions 1–4 ($N = 14{,}070$). Interview dates: 1/05 to 4/09
Note: Test statistic in the "Demographic" column is chi-square goodness of fit which tests independent of the observed proportions in the categories of each demographic group. Test statistic in the "Stratum" column are binomial tests of significance between the stratum participation rate ("Percent participating") and the participation rate for all people age 16 and older shown in line 1. Significance levels indicated by: *$p < 0.01$, ** $p < 0.05$, *** $p < 0.10$
Percentages sum down to 100 within each demographic group in the first two columns—may not sum to 100% exactly due to rounding. In fourth column, compare stratum percent to the percent participating for all respondents in line 1. Sample sizes may vary by activity because not all activities were asked in every NSRE version

11.4 Environmental Impact

As in previous chapters, it is reasonable to examine the impacts of snow sport on the environment in three categories: impacts on soils and vegetation, impacts on wildlife, impacts on water resources.

11.4.1 Impacts of Snow Sport on Soil and Vegetation

The rising popularity of Alpine skiing and snowboarding has raised concerns of potential environmental impacts. A considerable amount of research has been carried out to assess the impact of the development of a relatively small (by world

Table 11.4 Changes in total outdoor recreation participants between 2008 and 2060 across all activities and scenarios (Source: Bowker et al. 2012, p. 28)

Activity[a]	2008 Participants[b] (millions)	2060 Participant range[c] (millions/ [percent])	2060 Average participant change[c] (millions)	2060 Participant range[d] (millions/ [percent])	2060 Average participant change[d] (millions)
Visiting developed sites					
Developed site use—family gatherings, picnicking, developed camping	194	273–346 [42–77]	116	271–339 [40–75]	112
Visiting interpretive sites—nature centres, zoos, historic sites, prehistoric sites	158	231–294 [48–84]	106	231–289 [46–83]	104
Viewing and photographic nature					
Birding—viewing/photographing birds	82	118–149 [42–76]	53	115–144 [40–76]	47
Nature viewing—viewing, photography, study, or nature gathering related to fauna, flora, or natural settings	190	267–338 [42–76]	114	268–333 [41–75]	112
Backcountry activities					
Challenge activities—caving, mountain biking, mountain climbing, rock climbing	25	38–48 [50–86]	19	37–48 [47–90]	18
Equestrian	17	24–31 [44–87]	11	25–35 [50–110]	13
Hiking—day hiking	79	117–150 [50–88]	55	114–143 [45–82]	50
Visiting primitive areas—backpacking, primitive camping, wilderness	91	120–152 [34–65]	47	119–145 [31–60]	42
Motorised activities					
Motorised off-road use	48	62–75 [29–56]	21	62–76 [28–58]	21
Motorised snow use (snowmobiles)	10	10–13 [10–37]	3	4–10 [(56)–6]	(2.5)[e]
Motorised water use	62	87–112 [41–81]	40	84–111 [35–78]	35
Consumptive					
Hunting—all types of legal hunting	28	30–34 [8–23]	5	29–34 [5–21]	4
Fishing—anadromous, cold-water, saltwater, warm water	73	92–115 [28–56]	33	89–115 [22–58]	30
Non-motorised winter activities					
Downhill skiing, snowboarding	**24**	**38–54 [58–127]**	**23**	**36–54 [50–126]**	**21**
Undeveloped skiing—cross-country, snow-shoeing	**8**	**10–13 [32–67]**	**4**	**5–10 [(42)–28]**	**(1)**
Non-motorised water					
Swimming, snorkelling, surfing, diving	144	210–268 [47–85]	99	212–266 [47–85]	99
Floating—canoeing, kayaking, rafting	40	52–65 [30–62]	20	47–62 [18–56]	13

Source: National Survey of Recreation and the Environment (NSRE) 2005–09, Versions 1 to 4 (January 2005 to April 2009). $n = 24{,}073$ (USDA Forest Service 2009)

[a]Activities are individual or activity composites derived from the NSRE. Participants are determined by the product of the average weighted frequency of participation by activity for NSRE data from 2005 to 2009 and the adult (>16) population in the USA during 2008 (235.4 million)

[b]Because of small population and income differences, initial values for 2008 differ across PRA scenarios, thus an average is used for a starting value

[c]Participant range across Resources Planning Act (RPA) scenarios A1B, A2, and B2, without climate considerations

[d]Participant range across RPA scenarios A1B, A2, and B2, each with three selected climate futures

[e]Parentheses denote negative number

Table 11.5 Changes in total outdoor recreation days between 2008 and 2060 across all activities and scenarios (Source: Bowker et al. 2012, p. 29)

Activity[a]	2008 Days[b] (millions)	2060 Days range[c] (millions/ [percent])	2060 Average days change[c] (millions)	2060 Days range[d] (millions/ [percent])	2060 Average days change[d] (millions)
Visiting developed sites					
Developed site use—family gatherings, picnicking, developed camping	2246	3121–3949 [40–74]	1294	3055–3796 [36–69]	1185
Visiting interpretive sites—nature centres, zoos, historic sites, prehistoric sites	1249	1899–2417 [53–91]	952	1935–2435 [55–95]	988
Viewing and photographic nature					
Birding—viewing/photographing birds	8255	11,680–14,322 [40–74]	4859	10,050–13,313 [36–69]	3764
Nature viewing—viewing, photography, study, or nature gathering related to fauna, flora, or natural settings	32,461	41,805–52,835 [31–61]	14,635	41,550–51,288 [28–58]	13,597
Backcountry activities					
Challenge activities—caving, mountain biking, mountain climbing, rock climbing	121	178–219 [49–83]	4859	179–232 [48–92]	89
Equestrian	263	388–503 [49–92]	196	369–482 [40–83]	166
Hiking—day hiking	1835	2901–3682 [59–98]	1470	2825–3541 [54–93]	1366
Visiting primitive areas—backpacking, primitive camping, wilderness	1239	2046	622	1562–1946 [26–57]	519
Motorised activities					
Motorised off-road use	1053	1264–1532 [21–46]	357	1274–1611 [21–53]	385
Motorised snow use (snowmobiles)	69	74–91 [8–33]	16	23–65 [(6)–(67)]	(27)[e]
Motorised water use	958	1304–1806 [37–90]	596	1245–1763 [30–84]	495
Consumptive					
Hunting—all types of legal hunting	538	506–576 [(5)–8]	14	494–575 [(8)–7]	(8)
Fishing—anadromous, cold-water, saltwater, warm water	1369	1665–2020 [23–46]	514	1602–1958 [17–41]	397
Non-motorised winter activities					
Downhill skiing, snowboarding	**178**	**274–437 [61–150]**	**179**	**258–422 [50–146]**	**165**
Undeveloped skiing—cross-country, snow-shoeing	**52**	**69–87 [35–70]**	**29**	**28–64 [(45)–25)**	**(5)**
Non-motorised water					
Swimming, snorkelling, surfing, diving	3476	5037–6429 [46–83]	2446	4396–6257 [42–80]	2298
Floating—canoeing, kayaking, rafting	262	338–422 [30–62]	128	309–409 [18–56]	83

Source: National Survey of Recreation and the Environment (NSRE) 2005–2009, Versions 1 to 4 (January 2005 to April 2009). $n = 24{,}073$ (USDA Forest Service 2009)

[a]Activities are individual or activity composites derived from the NSRE. Participants are determined by the product of the average weighted frequency of participation by activity for NSRE data from 2005 to 2009 and the adult (>16) population in the USA during 2008 (235.4 million)

[b]Because of small population and income differences, initial values for 2008 differ across PRA scenarios, thus an average is used for a starting value

[c]Participant range across Resources Planning Act (RPA) scenarios A1B, A2, and B2, without climate considerations

[d]Participant range across RPA scenarios A1B, A2, and B2, each with three selected climate futures

[e]Parentheses denote negative number

Table 11.6 Once a week participation in funded sports (16 years and over)—Sport England: Active People Survey 10 (October 2015–September 2016) (Source: https://www.sportengland.org/media/11746/1x30_sport_16plus-factsheet_aps10.pdf)

Sport England NGB 13-17 Funded sports	Active People Survey 10 (October 2015–September 2016)	
	%	*n*
Swimming	5.67	2,516,700
Athletics	5.01	2,217,800
Cycling	4.40	1,950,300
Football	4.21	1,844,900
Golf	1.64	729,300
Exercise, movement, & dance	0.98	437,200
Badminton	0.97	425,800
Tennis	0.90	398,100
Equestrian	0.64	282,400
Bowls	1.33	211,900
Squash & racquetball	0.45	199,500
Rugby union	0.46	199,000
Netball	0.42	180,200
Boxing	0.36	159,000
Cricket	0.36	158,500
Basketball	0.35	150,800
Mountaineering	0.25	110,200
Table tennis	0.24	107,100
Angling	0.24	106,200
Snowsport	**0.23**	**99,800**
Hockey	0.22	92,700
Weightlifting	0.20	88,100
Rowing	0.19	83,400
Gymnastics	0.15	65,100
Shooting	0.13	56,600
Sailing	0.10	45,600
Rugby league	0.10	44,900
Canoeing	0.09	41,900
Volleyball	0.08	33,800
Archery	0.07	32,400
Taekwondo	0.06	23,900
Judo	0.04	18,900
Rounders	0.03	12,800

Source: Sport England's Active People Survey

standards) ski resort in the northern Cairngorm mountains in Eastern Scotland. Since 1960, the construction of chairlifts, ski tows, and buildings on Cairngorm has resulted in the exposure of areas of mineral soil. Watson et al. (1970) reported that the building of new roads and ski lifts, and a consequent increase of human traffic in summer and winter, had damaged vegetation and soils on mountain tundra in Scotland. This made an eyesore in a tourist area of high environmental quality and led to erosion which is a serious potential threat to the roads and ski lifts themselves. Watson et al. (1970) carried out field surveys and experimental studies of erosion, compaction, vegetation damage, and the use of paths, as well as assessments of the success of various methods of rehabilitation on different kinds of substrate. In places accelerated erosion (since 1964) had occurred and surface material had been deposited in fans downslope, often onto otherwise undamaged vegetation. Later, Bayfield (1974) found that the extent of accelerated ero-

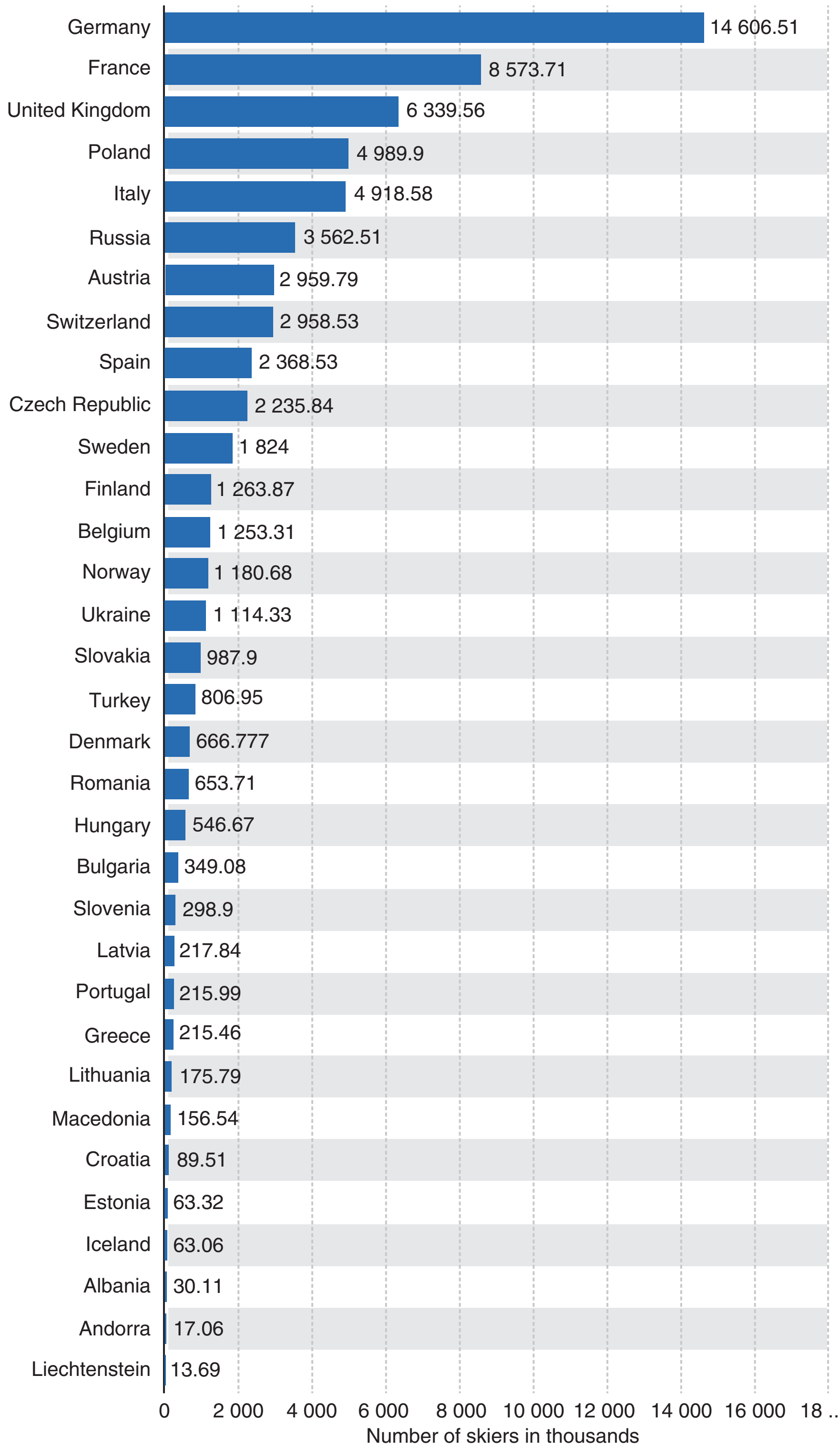

Fig. 11.7 Number of people who ski in Europe as of 2016, by country (in 1000). Source: https://www.statista.com/statistics/660546/europe-number-of-people-skiing-by-country/, accessed 20 March 2018

sion from ground damaged near ski lifts reached a peak in about 1969, with a marked decline since then. This decline was attributable to reseeding of damaged ground, provision of drains, and grading of dirt roads. Burial experiments showed that where erosion debris had covered vegetation, recovery at best took several years and with depths above about 7 cm, was almost negligible.

Bayfield (1980) reported that areas of disturbed ground up to 1100 m in altitude, used for skiing in the Cairngorm Mountains, Scotland, and the verges of a new road to the ski area, had been seeded by the chairlift operators and the roads authorities, between 1966 and 1968. The establishment of the seed mixtures, and the subsequent invasion by self-sown species, was followed from 1969 to 1976. On the lower ground (up to 850 m) invasion by heather (*Calluna vulgaris*) was very successful, but on higher ground colonisation by indigenous species was poor. Bryophytes, however, were successful at all altitudes, producing about 20% cover after one year and 50% or more after eight years. Most colonising vascular plants were also present in the surrounding undisturbed vegetation, but there were also a number of opportunist species. These survived better than the local species in places such as road margins, where disturbance continued. Lowland (60–210 m) turves transplanted satisfactorily to altitudes up to 1200 m but did not increase much in size except at the lowest sites (650–690 m).

Watson (1985) conducted a survey at Cairngorm during 1981 which showed severe damage extending on to the adjacent plateau well inside the Cairngorms National Nature Reserve. It was distinguished from natural damage by diagnostic features associated with human footprints. Areas visited by many people showed more plant damage and soil erosion than areas seldom visited. Disturbed land covered 403 ha, 17% of it in the Reserve. Disturbed land had a higher proportion of grit lying on vegetation than undisturbed land, a lower proportion of ground covered by vegetation, a higher proportion of damaged vegetation, and a higher frequency of plant burial, rill erosion, and dislodged stones and soil. Disturbed land had less bilberry, least willow, ground lichens and mosses, and other species besides grasses, sedges, and rushes. On slopes of 15–29°, foot-slipping increased with slope gradient on disturbed but not undisturbed land. Disturbed soil had less water, fine particles, and organic matter.

Bayfield (1996) examined the long-term effects of grass seeding at the Cairngorm ski area on the colonisation of bulldozed ground by native species. He monitored the colonisation of three bulldozed pistes (ski runs) on Cairngorm over 25 years. Two pistes were seeded and fertilised at the time of construction and the third was left unsown. By the end of the study, the seeded ground blended well with the surrounding ground, but the unsown piste remained visually conspicuous because of the high proportion of bare ground (>60%). Cover on seeded ground was mainly sown grasses and mosses for the first nine years, but after that the cover of sown grasses declined whereas moss cover peaked after 18 years. Cover of local vascular plant species gradually increased, and after 25 years it exceeded that of the sown grasses. Vascular species made up 21% of the total at 1180 m and 32% at 1000 m. On unseeded ground, vegetation cover was much lower than on seeded ground on every occasion. Mosses, grasses, and forbs tended to be more prevalent at seeded sites than on intact ground. Some characteristic species of intact ground, such as *Empetrum nigrum* and *Carex bigelowii*, were uncommon on seeded ground. Most local vascular species were more effective colonists of seeded than of untreated ground. An exception was *Juncus trifidus*, which was more successful on unsown ground. Some sown species had persisted for 25 years and might take another 10–15 years or longer to disappear. It seems likely that the vegetation of disturbed ground will remain botanically distinct from that of the surroundings because of ineffective colonisation by certain key species and because of the influence of late snowlie. Bayfield concluded that grass seeding substantially enhanced colonisation by native species.

Snow grooming is the process of manipulating snow for recreational uses with a tractor, snowmobile, piste caterpillar, truck, or snowcat towing specialised equipment. The process is used to maintain ski hills, cross-country ski trails, and snowmobile trails by grooming (moving, flattening, or compacting) the snow on them. A snow groomer is usually employed to pack snow and improve skiing and snowboarding and snowmobile trail conditions. The resulting pattern on the snow is known as corduroy and is widely regarded as a good surface on which to ski or ride. Snow groomers can also move accumulated snow made by snow machines as part of a process, called "snow farming." Skiing at the end of season (Fig. 11.8A) or on thin snow cover (Fig. 11.8B) can result in damage to soil and vegetation from the passing of the sharp edges of skis.

Fahey et al. (1999) investigated the effect of snow grooming on snow properties at Treble Cone Ski Field north of Queenstown in South Island, New Zealand. Snow depth, density, equivalent water content, and hardness were monitored in the NZ winter along transects at five non-groomed and four groomed slopes in late July, late August, and late September 1997. Average densities measured for transects on groomed slopes were 36% higher than those on non-groomed slopes. There was 45% more water available on average from the snowpack on groomed slopes than on non-groomed slopes. Snow hardness was 400% higher across groomed transects in late July but only 40% higher in late September. Increases in snow density and hardness attributed to snow grooming are similar to those observed overseas but lie at the low end of the range. They are probably sufficient to inhibit or delay soil bacterial activity and subsequent litter decomposition.

The production of artificial snow and the use of snow additives in ski resorts have increased considerably during the last two to three decades. The impact on the environment provokes concern. Rixen et al. (2003) compiled a review of studies about the ecological implications of preparing and grooming ski-pistes in general and of artificial snow production in particular. In common with Fahey et al. (1999), they found that the main direct impacts of ski-piste preparation on the vegetation were related to the compaction of the snow cover, namely, the induction of soil frost, the formation of ice layers, mechanical damage, and a delay in plant development. The vegetation reacts with changes in species composition and a decrease in biodiversity. Artificial snowmaking modifies some of these impacts: the soil frost is mitigated due to better insulation of the snowpack, whereas the formation of ice layers is not considerably changed.

The mechanical impacts of snow-grooming vehicles are reduced after artificial snowmaking due to the deeper snow cover. The delay of the vegetation development is enhanced by a considerably postponed snowmelt. Furthermore, artificial snowmaking induces new impacts to the alpine environment which include the input of water and ions to ski-pistes, which can have a fertilising effect and hence change the plant species

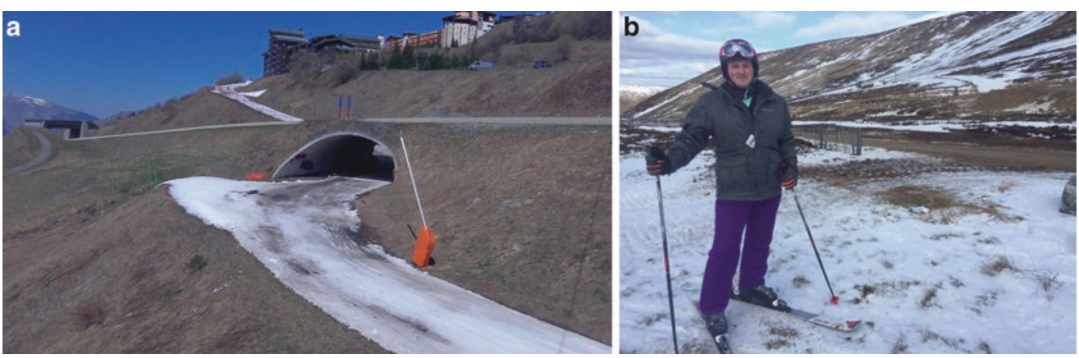

Fig. 11.8 (A) End-of-season skiing at Val Thorens, France, shows some damage to the soil and vegetation on runs and how artificial snowmaking can be used to extend the ski season at lower altitudes. Photo by Tim Stott. (B) Skiing on thin snow cover at Lecht Ski Resort in Scotland can result in damage to soil and vegetation around the edges of runs. Photo by Tim Stott

composition. Increasingly, snow additives, made of potentially phytopathogenic bacteria (Lagriffoul et al. 2010), are used for snow production. They enhance ice crystal formation due to their ice nucleation activity. Although sterilised, additives are reported to have affected the growth of some alpine plant species in laboratory experiments. Salts are applied not only but preferably on snowed pistes to improve the snow quality for ski races. The environmental impacts of most salts have not yet been investigated, but a commonly used nitrate salt has intense fertilising properties. Although snowmaking reduces some of the negative impacts of ski-piste preparation in general, new impacts induced by snowmaking might be non-beneficial to the vegetation.

Following their review, Rixen et al. (2004) measured snow depth and density from groomed ski-pistes with compacted snow and their effects on ground temperatures and timing of snowmelt. They analysed groomed pistes with and without artificial snow (ten each) as well as adjacent ungroomed off-piste control plots beside the piste. On pistes with natural snow, the thin and compacted snow cover led to severe and long-lasting seasonal soil frost. On pistes with artificial snow, soil frost occurred less frequently because of increased insulation due to the greater snow depth. However, due to the greater snow mass, the beginning of the snow-free season was delayed by more than two weeks. Average winter ground temperatures under a continuous snow cover were decreased by approximately 1 °C on both piste types compared with off-piste control plots. The results suggest that the heat balance of alpine soils is changed by both piste types, either by an extensive heat loss on pistes with natural snow or by prolonged snow cover on pistes with artificial snow.

Wipf et al. (2005) investigated the effects of ski-piste management on vegetation structure and composition in 12 Swiss alpine ski resorts using a pairwise design of 38 plots on ski-pistes and 38 adjacent plots off-piste. Plots on ski-pistes had lower species richness and productivity, and lower abundance and cover of woody plants and early flowering species, than reference plots. Plots on machine-graded pistes had higher indicator values for nutrients and light and lower vegetation cover, productivity, species diversity, and abundance of early flowering and woody plants. Time since machine-grading did not reduce the impacts of machine-grading, even for those plots where revegetation had been attempted by sowing. The longer artificial snow had been used on ski-pistes (2–15 years), the higher the moisture and nutrient indicator values. Longer use also affected species composition by increasing the abundance of woody plants, snowbed species, and late-flowering species and decreasing windedge species. Wipf et al. (2005) concluded that all types of ski-piste management cause deviations from the natural structure and composition of alpine vegetation and lead to lower plant species diversity. Machine-grading causes particularly severe and lasting impacts on alpine vegetation, which do not improve with time or by revegetation measures. The impacts of artificial snow increase with the period of time since it was first applied to ski-piste vegetation. Extensive machine-grading and snow production should be avoided, especially in areas where nutrient and water input are a concern. They recommended that ski-pistes should not be established in areas where the alpine vegetation has a high conservation value.

Rolando et al. (2007) stated that treeless mountainous areas at high altitudes have increased in value as wildlife habitat but have been increasingly threatened by ski-resort developments, in particular by the construction and enlargement of ski-pistes. They compared bird diversity and community composition in circular plots centred on (1) ski runs of recent construction, (2) grassland habitats adjacent to ski runs, and (3) natural grassland habitats far from the ski runs. Not surprisingly, plots located in natural grasslands supported the greatest bird species richness and diversity and the greatest grassland species density, whereas those set in ski-pistes presented the lowest values. Plots located beside ski runs did not support smaller numbers of bird species and diversity than plots of natural areas, but they supported a significantly lower bird density. This suggests that ski-pistes, besides exerting a negative direct effect on the structure of local bird communities, may also exert an indirect, detrimental effect on bird density in nearby patches. Generalised linear models showed that species richness and diversity, and abundance of grassland species were best modelled by combinations of factors, including habitat type (the three categories defined above) and altitude. The category ski run, in particular, was negatively correlated with species richness, diversity, and abundance, and altitude was negatively associated with richness and diversity. Richness and abundance of arthropods were significantly lower in ski-pistes than in the other plot types. Given that many invertebrates were preyed upon by birds, low food availability on ski runs may be one of the factors reducing the attractiveness of these patches to birds. Retaining the avifauna around ski resorts is likely to involve developing new, environmentally friendly ways of constructing pistes, such as only removing rocks and/or levelling the roughest ground surfaces, to preserve as much soil and natural vegetation as possible. They recommended that restoration of ski-pistes should promote the recovery and maintenance of local vegetation to enhance invertebrate and bird assemblages. However, in order to not compromise the safety of the ski runs, they conceded that it may be necessary to control encroaching shrubs through pruning and/or cattle grazing.

Barni et al. (2007) conducted their study at the Monterosa Ski Resort (Val d'Ayas, Aosta, Italy) and aimed to evaluate (1) how disturbance related to ski-run construction at high altitude (2200–2600 m a.s.l.) had affected vegetation and soil properties compared to undisturbed sites and (2) how vegetation and soil properties changed in machine-graded ski runs with increasing time after hydroseeding (a planting process that uses a slurry of seed and mulch). Herbaceous cover and specific composition, root density, physico-chemical soil properties, and aggregate stability were evaluated to determine the vegetation and soil dynamics of four runs constructed above timberline and hydroseeded 4, 6, 10, and 12 years ago, respectively, and of the adjacent undisturbed alpine pasture as control. The seeded species had quickly formed a cover that was still high even after ten years. However, cover values were always extremely low for wild species, and this could be related to their strategies and to altered soil properties (higher pH, organic matter impoverishment, and loss of both fine particles and aggregates). The study indicated that more has to be done to conserve or restore physico-chemical soil properties as a decisive factor in establishing a self-sustaining native plant community.

Burt and Rice (2009) pointed out that ski-run creation always results in some level of disturbance, but disturbance intensity varies greatly with the construction method. Ski runs may be established either by clearing (cutting and removing tall vegetation) or by clearing and then machine-grading (levelling the soil surface with heavy equipment). In order to quantify how these different intensities of initial disturbance affected ecosystem properties, they extensively surveyed vegetation, soils, and environmental characteristics on cleared ski runs, graded ski runs, and adjacent reference forests across seven large downhill ski resorts in the northern Sierra Nevada, USA. They found that the greater disturbance intensity associated with grading resulted in greater impacts on all ecosystem properties considered, including plant community composition and diversity, soil characteristics relating to processes of nutrient cycling and retention, and measures of erosion potential. They also found that cleared ski runs retained many ecological similarities to reference forests and may even offer some added benefits by possessing greater plant species and functional diversity than either forests or graded runs. Because grading is more damaging to multiple indicators of ecosystem function, they recommended that clearing rather than grading should be used to create ski slopes wherever practical.

Using the latest survey technology, Fidelus-Orzechowska et al. (2018) examined the impact of new ski developments in Poland. The purpose of their study was to quantify ongoing change patterns via: (1) a determination of spatial and quantitative changes in catchment covered by new ski runs, (2) a determination of the effect of new ski runs on the rejuvenation of relief in valleys adjacent to ski runs, and (3) an identification of changes in the surface runoff pattern before and after the construction of ski runs. The research was carried out on two ski runs in the Remiaszów catchment (southern Poland). Airborne Laser Scanning (ALS) data from 2013 and 2016 were used in the study along with Terrestrial Laser Scanning (TLS) data from 2015. LiDAR (Light Detection and Ranging) point clouds were interpolated to create multi-temporal digital elevation models (DEMs), and then by subtraction, these DEMs were used to identify erosion and accumulation zones. The largest changes in relief were observed in areas with ski runs, with one ski run lowering an average of 0.07 m (±0.03 m) and the other an average of 0.12 m (±0.03 m). By comparison the entire area lowered about 0.02 m. The construction of new ski runs therefore resulted in a rejuvenation of denudation valleys located in the vicinity of existing ski runs. Valley incisions reaching 1.5 m (±0.15 m) were observed. Both the convergence and divergence zones for surface runoff were identified, which made it possible to show changes in the geometry of flow direction. The identification of these sites may help forecast erosion and deposition zones.

de Jong et al. (2014) investigated the soil properties, compaction, and infiltration characteristics on ski slopes and compared to natural sites for three different ski resorts (Les Menuires, La Rosière, and Foppolo) in the French and Italian Alps. The results showed that soil properties differed substantially, with lower nitrogen and carbon content and higher pH on ski runs. Soil compaction was up to three times higher, and infiltration took up to four times longer on ski slopes compared to natural sites. Some new ski slopes were even 100% impermeable. This explains why ski slopes are more prone to landslides and sheet, rill, and gully erosion and have a distinct vegetation cover.

There is less research into the environmental impacts of "off-piste" skiing which includes cross-country (or Nordic) skiing, ski mountaineering, and snowshoeing. Törn et al. (2009) examined the impacts of hiking, cross-country skiing, and horse riding on trail characteristics and vegetation in Northern Finland. Widths and depths of existing trails and vegetation on trails and in the neighbouring forests were monitored in two research sites during 2001 and 2002. Trail characteristics and vegetation were clearly related to the recreational activity, research site, and forest type. Horse trails were as deep as hiking trails, even though the annual number of users was 150-fold higher on the hiking trails. Simultaneously, cross-country skiing had the least effect on trails due to the protective snow cover during winter.

Steinbauer et al. (2017) proposed that space requirements by winter sports and accelerating global warming are usually perceived as stressors for mountain meadow plant communities. Cross-country ski track preparation (i.e. grooming), however, might retard the effects of climate change and, being limited in space requirements, might increase abiotic heterogeneity. The effect of cross-country ski tracks on meadow vegetation was quantified along a representative ski track that had been operated for 30 years in the Fichtelgebirge, a low mountain range in central Europe. Paired sampling was implemented to assess the effect of skiing operations on snow and soil properties, plant phenology, biomass production, and species composition. Additionally, boosted regression tree analyses were used to quantify the relative importance of the cross-country ski track compared to other environmental conditions. In common with the aforementioned research on snow grooming on pistes, they found that the cross-country ski track strongly increased snow density, enhanced soil frost, and retarded snowmelt, thereby delaying flower phenology (by 2.1 days) and the early development stages of plant species on the track. However, biomass, species richness, and species composition were unaffected by skiing operations except for one species (*Leontodon autumnalis*) which showed exclusive occurrence on the track, while four others showed reduced relative occurrence on the track.

While snow and soil properties were influenced by cross-country ski track preparation, natural environmental variability was more influential for species composition and biomass production than the ski track. They therefore concluded that the ski track—without artificial snow—did not negatively affect species composition. By delaying flower phenology, the effects of the ski track even counteracted global warming to some degree. Due to their small spatial extent in the landscape, these ski tracks may add to environmental heterogeneity and thus support sustaining diverse species compositions during environmental changes.

11.4.2 Impacts of Snow Sport on Wildlife

Since 1960, the construction of chairlifts, ski tows, and buildings on Cairngorm has resulted in the exposure of areas of mineral soil. Watson et al. (1970) noted that these developments posed a threat to populations of animals, due to direct disturbance or indirectly to habitat change. In their 1970 paper, Watson et al. compared conditions in the Scottish mountains and in arctic North America and described a research programme by a small team studying human impact near the Scottish ski lifts. Research on animal populations showed that there had been no effect at that point on rock ptarmigan or red grouse (willow ptarmigan) populations or on dotterel and other species; however there had been less daylight use of the developed areas by deer.

In further work, Watson (1979) made counts of animals on Scottish skiing areas to find whether human impact was affecting their numbers. More people, dogs, crows, and snow buntings were seen on these disturbed areas after than before the ski developments. After the developments, however, more people and dogs were on disturbed areas than on undisturbed areas visited by very few people. He found that spring densities and breeding success of the native ptarmigan and red grouse did not differ between disturbed and undisturbed areas, and likewise neither did spring densities of meadow pipits and wheatears. Although ski-lift wires killed some ptarmigan and red grouse, this had no detectable influence on their breeding populations. At Cairngorm, more sheep, reindeer, and the native mountain hares occurred on disturbed areas; they concentrated on small patches that had been treated with grass seeds and fertiliser to reduce soil erosion. More pied wagtails, crows, rooks, gulls, and snow buntings, which fed frequently on waste human food, were seen on disturbed than on undisturbed areas, especially around car parks. Watson concluded by saying that the influx and increase of these scavenging bird species had occurred on ground adjacent to two national nature reserves on fairly natural, rare arctic-alpine habitats.

Continuing these studies at the same ski area in the Cairngorms, Watson and Moss (2004) reported adverse impacts on numbers and breeding success of ptarmigan (*Lagopus mutus*) between 1967 and 1996, where ptarmigan normally shows ten-year population cycles. An influx of carrion crows (*Corvus corone*), generalist predators, followed the ski area development. On the most developed area near the main car park, ptarmigan occurred at high density but then lost nests to frequent crows, reared abnormally few broods, died flying into ski-lift wires, and declined until none bred for many summers. On a nearby higher area with fewer wires, ptarmigan lost nests to frequent crows and reared abnormally few broods, but seldom died on wires. Adult numbers declined and then became unusually steady for over two decades, with no significant cycle. On a third area further from the car park, ptarmigan lost fewer nests to the less frequent crows but bred more poorly than in the massif's centre and showed cycles of lower amplitude. On a fourth area yet further away, with few or no crows, ptarmigan bred as well as in the massif's centre and showed cycles of the same amplitude.

Negro et al. (2009) assessed the effect of forest clearing for winter sport activities on ground-dwelling arthropods (viz. ground beetles and spiders) and small mammals (shrews and voles) at two ski resorts in north-western Italian Alps by pitfall trapping. Measures of diversity (mean abundance, species richness, and Shannon index) of spiders and macropterous carabids increased from forest interior to open habitats (i.e. ski-piste or pasture), whereas parameters of brachypterous carabids significantly decreased from forest interior to open habitats. Diversity measures of macropterous ground beetles were higher on pastures than on ski-pistes. Small mammals were virtually absent from ski-pistes. Observed frequencies in the three adjacent habitats were significantly different from expected ones for the bank vole *Myodes glareolus* and the pygmy shrew *Sorex minutus*. Generalised linear models showed that abundance, species richness, and diversity of spiders and macropterous carabids of ski-pistes were best modelled by a combination of factors, including grass cover and width of the ski-piste. Indicator species analysis showed that species that significantly preferred ski-pistes were less than those preferring pastures, and species which were exclusive of ski-pistes were very few. They recommended that in order to retain the arthropod ground-dwelling fauna of open habitats, environmentally friendly ways of constructing pistes should be developed. After tree clearing, only the roughest ground surfaces should be levelled, in order to preserve as much natural vegetation as possible. Where necessary, ski-pistes should be restored through the recovery of local vegetation. In a second study, Negro et al. (2010) analysed the effect of ski-pistes on the abundance and species richness of arthropods (viz. carabids, spiders, opilionids, and grasshoppers) trapped in grasslands adjacent to the ski run, on ski-pistes, and at the edge between these two habitat types. Their results showed that diversity of brachypterous carabids, spiders, and grasshoppers decreased significantly from natural grasslands to ski-pistes. This was not true for the macropterous carabid guild, which included species with contrasting ecological requirements. Analysis of indicator species showed that most of the species (some of them restricted areas in the north-western Alps) had clear preferences for natural grassland and few taxa were limited to ski-pistes. Generalised linear models suggested that the local extent of grass and rock cover can significantly affect assemblages: the low grass cover of ski-pistes, in particular, was a serious hindrance to colonisation by spider, grasshopper, brachypterous, and some macropterous carabid species. The results obtained, support concerns over the possible disruption of local ecosystem functionality, and over the conservation of arthropod species which are endemic to restricted alpine areas. In order to retain arthropod ground-dwelling fauna they suggested that: (i) new, environmentally friendly ways of constructing pistes should be developed to preserve as much soil and grass cover as possible and (ii) existing ski-pistes should be restored through management to promote the recovery of local vegetation.

Finally, Caprio et al. (2016) found that restoration of grasslands on ski-pistes caused a recovery in the bird community, but not to the extent that it was equivalent to a natural Alpine grassland community. The bird communities in two ski resorts in the Italian Maritime Alps were surveyed using a standardised area count method in three different plot types: non-restored ski-pistes (newly constructed), restored ski-pistes, and control plots in grassland far from ski-pistes. In 49 independent plots, 32 species were recorded. Species richness and abundance of birds were significantly higher on restored than on non-restored ski-pistes, independently of the species group considered and the analyses carried out. Bird community parameters of restored ski-pistes were still lower than those of natural grassland, as shown by results of typical grassland species. Their results suggest that an apparently successful restoration of ski-pistes may be not enough to promote a complete recovery of bird communities. The complete recovery of local bird communities may be promoted only if an integral recovery of the original vegetal communities is achieved. They suggested that the best conservation option is to adopt techniques to maintain as far as possible original grassland if construction of new ski-pistes is unavoidable.

11.4.3 Impacts of Snow Sport on Water Resources

Artificial snowmaking discussed earlier presents challenges to the water resource requirements of many ski resorts (de Jong and Barth 2007; de Jong and Biedler 2012) because it usually draws water directly from local lakes which are also the main water supply of the resort. The Alpine Convention (2011), in its report "Water in the alps; striking the balance" stated that:

> …. water requirements for snowmaking can be substantial at a local level, using a considerable share of the annual water abstraction and can lead to water conflicts especially in the winter season in areas where snowmaking stations are connected to the drinking supply network; this can cause temporary water shortages. (p. 92)

In an earlier report, the same organisation (Alpine Convention 2011) criticises that: "The EU Framework Directive does not include problems relating to artificial snow installations such as the impact of chemical snow-making additives on water quality or the tapping of water to create artificial snow in times of water shortage." However, the 2010 report no longer addresses this issue. Such shortcomings were mentioned by de Jong (2014) proposing a new EU tourist directive, that is, to restrict increasing water use for tourist resorts and carefully monitor environmental impacts from an interdisciplinary point of view to avoid opposing the EU Water and EU Soils directive.

Kangas et al. (2012) investigated the impact of ski resorts on water quality of lakes near two popular ski resorts in Finland. They examined how water quality problems induced by ski resorts relate to effects of agriculture and forestry on similar lake types. Human impact significantly increased nutrient concentrations, although the differences observed between impact and control lakes were generally small. Water quality of the ski resort lakes and lakes polluted by agriculture and forestry appeared to be quite similar, with the exception of a small, humic ski-resort lake with extremely high nutrient concentrations. Two ski-resort lakes and one agricultural lake failed the total phosphorus criteria set for reaching good ecological status. Their results indicated that water protection measures should be considered more carefully in management of ski resorts.

Forrester and Stott (2016) investigated the spatial distribution of stream water faecal coliform concentrations in specific winter recreation areas in the northern Corries of the Cairngorm Mountains, Scotland. A total of 207 water samples were collected from ten sites during two winter seasons, 2007–2008 and 2008–2009, and analysed for the presence of faecal coliforms, specifically *Escherichia coli* (*E.coli*). *E.coli* was not detected at the seven sites above 635 m, but three sites below 635 m (the altitude of the ski area buildings and car park) had positive detection rates for *E.coli*, these being 32%, 35%, and 31% respectively, suggesting that snow holing was not associated with elevated faecal coliform levels (their site 1 was right next to the popular snow-holing sites in Ciste Mhearad) but that the ski infrastructure was somehow contributing *E. coli* to the streams running through it.

Apollo (2017) pointed out how millions of mountaineers (which presumably includes ski mountaineers) visiting high-mountain areas generate tonnes of faeces and cubic hectometres of urine annually. The proper disposal of human waste is important for the conservation and appropriate management of high-mountain areas. The management can address the issue in three ways: the good (complete/non-invasive), the bad (partial/superficial), and the ugly (invasive). With use of those categories, 20 selected summits from different parts of the world were evaluated, separately in respect to faeces and urine. It was expected that correct or incorrect disposal of human waste would depend on the changing altitude and/or development level. Disappointingly, the correlation between selection criteria (better or worse solution) and the increase of altitude does not exist. Similarly, the increase of the development level does not play a significant role, especially when urine is taken under consideration. The problem is more global than was thought. The paper makes recommendations which could lead to reduction of this problem.

In Chap. 5 we discussed how lead and hydrocarbons from snowmobile exhaust were found in the water at high levels during the week following ice-out in a Maine pond (Adams 1975), and that fingerling brook trout (*Salvelinus fontinalis*) held in fish cages in the pond showed lead and hydrocarbon uptake. Snowmobiles, and a range of other snow-grooming machines, are used at most ski resorts and so it is quite possible that hydrocarbons from both exhaust fumes and petrol or oil spills or leakages can contaminate snow which, when it melts, reaches soil water, groundwater, and streams/lakes.

During a three-month monitoring campaign by Kallenborn et al. (2011) in very high atmospheric levels of benzene-toluene-xylene (BTX)-related emissions were found during daytime along the main snowmobile routes in Longyearbyen, Svalbard, during the late winter season (main tourist season) in 2007. Total emissions of about 81 t/year were estimated for 2007 solely for snowmobile activities. Two-stroke engine-driven vehicles were estimated to contribute around 92% (74 t/a) of the hydrocarbon emissions. Such data are likely to apply to snowmobiles used for transport (and sometimes tourist tours) in ski resorts.

11.5 Management and Education

Future management of snow sport must surely take account of the predicted future changes in climate.

11.5.1 Effects of Climate Change on Snow Sport

Changes in the spatial extent and duration of winter snow cover, both in Scotland and in a wider global context, have a number of socio-economic and environmental implications. Evidence from Scottish climatological presented by Harrison et al. (2001) stations appeared to suggest that the most marked decrease in the number of days with snow lying has occurred since the late 1970s. Information on the effects of these changes was gathered using a questionnaire which was sent to key stakeholders. Responses suggest deleterious effects on winter recreation and sports, upland habitats, and flood regimes in Scottish rivers. An extended snow-free season has affected access to, and management of, Scottish land.

Moen and Fredman (2007) reported that annual snow cover extent in the northern hemisphere had decreased by about 10% since 1966, and in Sweden, the last decade was wetter and warmer than the preceding 30-year period. These changes will affect many aspects of utilisation patterns that are dependent on the physical environment, such as alpine winter tourism. In their paper they discuss the future development of the downhill skiing industry in Sweden, (1) reviewing trends in alpine winter tourism in relation to climate change, (2) examining trends in climate parameters relevant to alpine winter tourism in Sweden during the last 30 years, and (3) using these parameters, together with regional projections of climate change, predicting the effects on the number of skiing days in order to estimate the monetary loss for the skiing industry in Sweden. Their analyses showed predicted losses that were larger than current ski-ticket sales. Adaptation strategies such as the development of year-round tourist activities that should be developed as soon as possible were recommended.

While the ski industry has become one of the main economic activities for many mountain regions worldwide, Gilaberte-Búrdalo et al. (2014) examined the economic viability of this activity and stated how it is highly dependent of the interannual variability of the snow and climatic conditions and that it is jeopardised by climate warming. In their study, they reviewed the main scientific literature on the relationship between climate change and the ski feasibility under different climate change scenarios. In spite of the different methodologies and climate change scenarios used in the reviewed studies, their findings generally point to a significant impact of climate change on the ski industry caused by a reduction in the natural availability of snow as well as a contraction in the duration of seasonal conditions suitable for skiing. It emphasises that the problem was real and should not be ignored in the study and management of tourism in mountain regions. However, there were significant differences in the impacts between different areas. These differences were mainly associated with the elevation of the ski resorts, their infrastructures for snowmaking, and the various climate models, emission scenarios, time horizons, and scales of analysis used. Their review high-

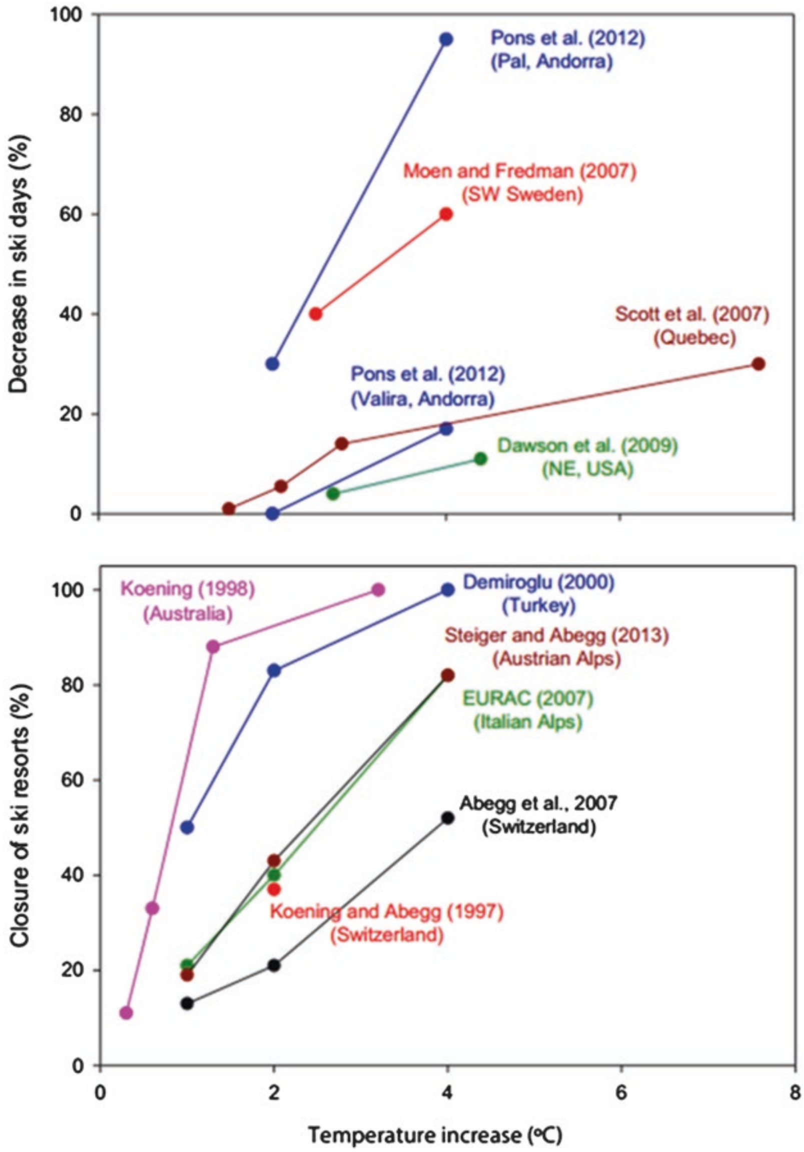

Fig. 11.9 Reduction in the number of ski days and the percentage closure of ski resorts in various regions as a function of temperature increase (adapted from Gilaberte-Búrdalo et al. 2014)

lighted the necessity for scientists to harmonise indicators and methodologies to allow a better comparison of the results from different studies and to increase the clarity of the conclusions transmitted to land managers and policy makers. Moreover, a better integration of the uncertainty in the model's outputs, as well as the treatment applied to the snowpack in ski slopes is necessary to provide more accurate indications on how this sector will respond to climate change.

Figure 11.9 shows the decrease in the number of ski days and the percentage of ski resorts within a particular region that should be closed as a function of various scenarios of climate warming. The studies from which Fig. 11.9 was derived, and the other studies reviewed by Gilaberte-Búrdalo et al. (2014), highlight how sensitive the ski industry is to increasing temperature but also the large variability in skiability in response to similar warming rates. For example, changes in the number of ski days in response to climate warming at two resorts located in Andorra differed markedly (Pons-Pons et al. 2012). These differences can be largely explained by the average altitude of the resorts, or the latitude of the mountain regions involved. Thus, colder areas (because of high altitude or latitudinal location) are less affected by climate change or may even benefit through spillover from lower-altitude resorts that are more vulnerable to the effects of climate change.

Wobus et al. (2017) used a physically based water and energy balance model to simulate natural snow accumulation at 247 winter recreation locations across the continental USA. They combined this model with projections of snowmaking conditions to determine downhill skiing, cross-country skiing, and snowmobiling season lengths under baseline and future climates, using data from five climate models and two emissions scenarios. Projected season lengths were combined with baseline estimates of winter recreation activity, entrance fee information, and potential changes in population to estimate the financial cost of impacts to the selected winter recreation activity categories for the years 2050 and 2090. Their results identified changes in winter recreation season lengths across the USA that vary by location, recreational activity type, and climate scenario. However, virtually all locations were projected to see reductions in winter recreation season lengths, exceeding 50% by 2050 and 80% in 2090 for some downhill skiing locations. They estimated that these season length changes could result in millions to tens of millions of foregone recreational visits annually by 2050, with an annual financial cost of hundreds of millions of dollars. Comparing results from the alternative emission scenarios shows that limiting global greenhouse gas emissions could both delay and substantially reduce adverse impacts to the winter recreation industry.

11.5.2 Do Ski Resorts Need to Become "Greener" for Tourism to Become Sustainable?

For a growing number of skiers, the sport represents one of the great dilemmas and conflicts between recreational enjoyment of the countryside and the conservation of the fragile Alpine and mountain areas where skiing inevitably takes place. Hudson (1996) pointed out how the situation was particularly acute in the European Alps where, in the 1990s, the issue had been given a high profile by many concerned environmentalists. Hudson's paper looks at the impact of skiing on the environment both in North America and in Europe and at the emerging concept of sustainability. The author looks at the marketing opportunities for destinations seeking to green their operations and uses Verbier in Switzerland as a case study.

The development of tourism in mountain areas can have profound influences on both the local economy and physical environment. Holden (1999) claimed that as the concept of sustainability became more important in policy making and that the future of downhill skiing in mountain areas would become more uncertain. However, the extent to which policy might shift from an anthropocentric bias towards a more eco-centric approach is uncertain. One mountainous area that has recently developed a sustainable management strategy is the Cairngorms area of the Scottish Highlands. The development of downhill skiing in this area is highly contentious owing to the uniqueness of the physical environment. Using the case study and different perspectives on sustainability, Holden evaluated the role of downhill skiing as part of a sustainable policy for mountain areas.

One could argue that in terms of agricultural production, the high altitude mountain areas used for skiing are not taking up land which much economic value in terms of agriculture production. Instead, they are turning this marginal (almost waste?) land into a valuable economic resource. The actual area of the world's mountains that is taken up by ski infrastructure is tiny in comparison to the total. So, there are still plenty of mountains left for others to enjoy.

The United Nations (UN) claimed that "whenever a person engages in sport there is an impact on the environment" (UN 2010). Spector et al. (2012) examined the safeguarding of the natural environment, or environmental sustainability (ES), in sport by studying the level of environmentally responsible actions for ski resorts in the USA. They focused specifically on the USA ski industry and examined Ski Resort's

Environmental Communications (SRECs) stated on each of 82 resort websites. The methods included rating these communications for their prominence, breadth, and depth based on the environmental categories in the US Sustainable Slopes Program (SSP) Charter. Based on both these SREC ratings and the grades assigned to each resort by the Ski Area Citizens Coalition (SACC), the resorts were classified as inactive, exploitive, reactive, or proactive using an adaptation of Hudson and Miller's (2005) model. The results provided an assessment of the level of environmentally responsible actions taken by the ski resorts. Future research still needs to examine the motivations behind ski resort publications on environmental communications and the likelihood of skiers selecting resorts based on the environmental communications posted on websites.

11.5.3 Concluding Comments

Clearly there are a number examples of research which indicate that the development of ski resorts, in particular bulldozing the ground to make it suitable for ski-pistes, results in soil erosion; modification of the natural landscape shape, gullies, and fans; removal of vegetation; and changes in species composition years after the runs were constructed. Reseeding experiments have had some degree of success but still do not return the flora back to its natural state. There are reported changes in soil structure, compaction, and the addition of chemicals resulting from artificial snowmaking. The research also showed reductions in bird species like ptarmigan and increases in crows. All these studies demonstrate some impact, but how to mitigate this is more difficult. It is likely that with the future climate scenarios (or warming) that ski resorts are likely to become even more dependent on artificial snowmaking, bringing greater pressures on the water resources of ski resorts and surrounding mountain communities.

Off-piste skiing (ski mountaineering, cross-country/Nordic, and showshoeing) is not associated with these same issues. The main concerns with these pursuits are those discussed in Chap. 8 about waste disposal in wilderness environments in winter.

Conclusions

1. Skiing can be a means of transport, a recreational activity, or a competitive winter sport in which skis are used to glide on snow. Many types of competitive skiing events are recognised by the IOC and the FIS. The term snow sport encompasses alpine, freestyle, snowboard, and Nordic skiing.
2. Off-piste snow sport includes ski mountaineering, cross-country, and snowshoeing.
3. The Outdoor Foundation (2017) survey data for the USA show that, of the six snow sports disciplines measured in the survey:
   - Alpine/downhill skiing had the greatest number of participants in 2016 (9,267,000) and a 12.4% increase over the previous three years (2014–2016).
   - Snowboarding had the second greatest number of participants in 2016 (7,602,000), showing a 3.4% increase over the previous three years.
   - Cross-country skiing had 4,640,000 participants but the greatest three-year increase of 40.3%.
   - Freestyle skiing with 4,640,000 participants in 2016 had the same number participating as cross-country skiing but with only a 2.7% three-year increase.
   - Telemark (downhill) skiing has the smallest participation numbers in the six disciplines surveyed (2,848,000) and a 3.0% three-year increase.
   - Snowshoeing had 3,533,000 participants but showed a −12.3% decrease in participation in the 2014–2016 period.

4. Some of the first research into the impacts of ski resort development on soils and vegetation from the Cairngorms, Scotland, began in the late 1960s and involved field surveys and experimental studies of erosion, compaction, vegetation damage, and the use of paths, as well as assessments of the success of various methods of rehabilitation on different kinds of substrate. The construction of chairlifts, ski tows, and buildings on Cairngorm has resulted in the exposure of areas of mineral soil followed by erosion.
5. Plant species diversity was changed following ski-run construction and bird species and arthropod populations declined.
6. Snow grooming (moving, flattening, or compacting the snow) increases snow density and hardness which in turn inhibits or delays soil bacterial activity and subsequent litter decomposition.
7. Artificial snowmaking induces new impacts to the alpine environment which include the input of water and ions to ski-pistes, which can have a fertilising effect and hence change the plant species composition.
8. While snow and soil properties were influenced by cross-country ski track preparation, natural environmental variability was more influential for species composition and biomass production than the ski track. The cross-country ski track—without artificial snow—did not negatively affect species composition. By delaying flower phenology, the effects of the ski track even counteracted global warming to some degree.
9. Water consumption for snowmaking can be substantial at a local level, using a considerable share of the annual water abstraction and can lead to water conflicts especially in the winter season in areas where snowmaking stations are connected to the drinking supply network, which can cause temporary water shortages.
10. Several studies have examined the effect that future predictions for climate change will have on the winter tourism industry. The relationship between temperature increase and the percent of resorts predicted to close is generally linear with between 50% and 90% of ski resorts closing with a temperature increase of 4 °C, but the relationship varies from region to region. High altitude resorts would be least affected.

References

Adams, E. S. (1975). Effects of lead and hydrocarbons from snowmobile exhaust on brook trout (*Salvelinus fontinalis*). *Transactions of the American Fisheries Society, 104*(2), 363–373.

Alpine Convention. (2011). Water in the alps; striking the balance. In *3rd International Conference and Preparatory Workshops 2010*, Rome, p. 104.

Apollo, M. (2017). The good, the bad and the ugly—Three approaches to management of human waste in a high-mountain environment. *International Journal of Environmental Studies, 74*(1), 129–158.

Barni, E., Freppaz, M., & Siniscalco, C. (2007). Interactions between vegetation, roots, and soil stability in restored high-altitude ski runs in the Alps. *Arctic, Antarctic, and Alpine Research, 39*(1), 25–33.

Bayfield, N. G. (1974). Burial of vegetation by erosion debris near ski lifts on Cairngorm, Scotland. *Biological Conservation, 6*(4), 246–251.

Bayfield, N. G. (1980). Replacement of vegetation on disturbed ground near ski lifts in the Cairngorm Mountains, Scotland. *Journal of Biogeography, 7*, 249–260.

Bayfield, N. G. (1996). Long-term changes in colonization of bulldozed ski pistes at Cairn Gorm, Scotland. *Journal of Applied Ecology, 33*, 1359–1365.

Bowker, J. M., Askew, A. E., Cordell, H. K., Betz, C. J., Zarnoch, S. J., & Seymour, L. (2012). *Outdoor Recreation Participation in the United States—Projections to 2060: A Technical Document Supporting the Forest Service 2010 RPA Assessment*.

Ashville: Southern Research Station. Retrieved from www.srs.fs.usda.gov.

Burt, J. W., & Rice, K. J. (2009). Not all ski slopes are created equal: Disturbance intensity affects ecosystem properties. *Ecological Applications, 19*(8), 2242–2253.

Caprio, E., Chamberlain, D., & Rolando, A. (2016). Ski-piste revegetation promotes partial bird community recovery in the European Alps. *Bird Study, 63*(4), 470–478.

Cordell, K. (2012). *Outdoor Recreation Trends and Futures: A Technical Document Supporting the Forest Service 2010 RPA Assessment*. Ashville: Southern Research Station. Retrieved from www.srs.fs.usda.gov.

de Jong, C. (2014). A white decay of winter tourism. Climate change adaptation manual. In A. Prutsch, S. McCallum, T. Grothmann, R. Swart, I. Schauser, & R. Swart (Eds.), *Lessons Learned from European and Other Industrialized Countries* (pp. 226–233). London and New York, NY: Routledge.

de Jong, C., & Barth, T. (2007). Challenges in hydrology of mountain ski resorts under changing climate and human pressures. In *ESA, Proceedings of the 2nd Space for Hydrology Workshop, "Water Storage and Runoff: Modeling, In-Situ Data and Remote Sensing"*, Geneva.

de Jong, C., & Biedler, M. (2012). Shadow of a drought. *European Science and Technology, 14*, 208–209.

de Jong, C., Carletti, G., & Previtali, F. (2014). Assessing impacts of climate change, ski slope, snow and hydraulic engineering on slope stability in ski resorts (French and Italian Alps). In G. Lollino, A. Manconi, J. Clague, W. Shan, & M. Chiarle (Eds.), *Engineering Geology for Society and Territory—Climate Change and Engineering Geology* (pp. 51–55). Cham: Springer.

Fahey, B. D., Wardle, K., & Weir, P. (1999). *Environmental Effects Associated with Snow Grooming and Skiing at Treble Cone Ski Field*. Department of Conservation.

Fidelus-Orzechowska, J., Wrońska-Wałach, D., Cebulski, J., & Żelazny, M. (2018). Effect of the construction of ski runs on changes in relief in a mountain catchment (Inner Carpathians, Southern Poland). *Science of the Total Environment, 630*, 1298–1308.

Forrester, B. J., & Stott, T. A. (2016). Faecal coliform levels in mountain streams of winter recreation zones in the Cairngorms National Park, Scotland. *Scottish Geographical Journal, 132*(3–4), 246–256.

Gilaberte-Búrdalo, M., López-Martín, F., Pino-Otín, M. R., & López-Moreno, J. I. (2014). Impacts of climate change on ski industry. *Environmental Science and Policy, 44*, 51–61.

Harrison, S. J., Winterbottom, S. J., & Johnson, R. C. (2001). A preliminary assessment of the socio-economic and environmental impacts of recent changes in winter snow cover in Scotland. *Scottish Geographical Journal, 117*(4), 297–312.

Holden, A. (1999). High impact tourism: A suitable component of sustainable policy? The case of downhill skiing development at Cairngorm, Scotland. *Journal of Sustainable Tourism, 7*(2), 97–107.

Hudson, S. (1996). The 'greening' of ski resorts: A necessity for sustainable tourism, or a marketing opportunity for skiing communities? *Journal of Vacation Marketing, 2*(2), 176–185.

Hudson, S., & Miller, G. (2005). The responsible marketing of tourism: The case of Canadian Mountain Holidays. *Tourism Management, 26*(2), 133–142.

Kallenborn, R., Schmidbauer, N., Reinmann, S., Trümper, M., & Tessmann, M. (2011). Local contaminant sources in the Arctic: Volatile and non-volatile residues from combustion engines in surface soils from snow mobile tracks in the vicinity of Longyearbyen (Svalbard Norway). Retrieved from https://www.researchgate.net/profile/Roland_Kallenborn/publication/282317733_Local_contaminant_sources_in_the_Arctic_Volatile and nonvolatile_residues_from_combustion_engines_in_surface_soils_from_snow_mobile_tracks_in_the_vicinity_of_Longyearbyen_Svalbard_Norway/links/560b8cda08ae576ce6411cf2/Local-contaminant-sources-in-the-Arctic-Volatile-and- non-volatile-residues-from-combustionengines-in-surface-soils-from-snow-mobile-tracks-in-the-vicinity-of-Longyearbyen-Svalbard-Norway.pdf

Kangas, K., Vuori, K. M., Määttä-Juntunen, H., & Siikamäki, P. (2012). Impacts of ski resorts on water quality of boreal lakes: A case study in northern Finland. *Boreal Environment Research, 17*, 313–325.

Lagriffoul, A., Boudene, J. L., Absi, R., Ballet, J. J., Berjeaud, J. M., Chevalier, S., et al. (2010). Bacterial-based additives for the production of artificial snow: What are the risks to human health? *Science of the Total Environment, 408*, 1659–1666.

Moen, J., & Fredman, P. (2007). Effects of climate change on alpine skiing in Sweden. *Journal of Sustainable Tourism, 15*(4), 418–437.

Negro, M., Isaia, M., Palestrini, C., & Rolando, A. (2009). The impact of forest ski-pistes on diversity of ground-dwelling arthropods and small mammals in the Alps. *Biodiversity and Conservation, 18*(11), 2799–2821.

Negro, M., Isaia, M., Palestrini, C., Schoenhofer, A., & Rolando, A. (2010). The impact of high-altitude ski pistes on ground-dwelling arthropods in the Alps. *Biodiversity and Conservation, 19*(7), 1853–1870.

Pons-Pons, M., Johnson, P. A., Rosas-Casals, M., Sureda, B., & Jover, E. (2012). Modelling climate change effects on winter ski tourism in Andorra. *Climate Research, 54*, 197–207.

Rixen, C., Haeberli, W., & Stoeckli, V. (2004). Ground temperatures under ski pistes with artificial and natural snow. *Arctic, Antarctic, and Alpine Research, 36*(4), 419–427.

Rixen, C., Stoeckli, V., & Ammann, W. (2003). Does artificial snow production affect soil and vegetation of ski pistes? A review. *Perspectives in Plant Ecology, Evolution and Systematics, 5*(4), 219–230.

Rolando, A., Caprio, E., Rinaldi, E., & Ellena, I. (2007). The impact of high-altitude ski-runs on alpine grassland bird communities. *Journal of Applied Ecology, 44*(1), 210–219.

Spector, S., Chard, C., Mallen, C., & Hyatt, C. (2012). Socially constructed environmental issues and sport: A content analysis of ski resort environmental communications. *Sport Management Review, 15*(4), 416–433.

Steinbauer, M. J., Kreyling, J., Stöhr, C., & Audorff, V. (2017). Positive sport—Biosphere interactions?—Cross-country skiing delays spring phenology of meadow vegetation. *Basic and Applied Ecology., 20*(11), 1405–1413.

The Outdoor Foundation. (2017). *Outdoor Participation Topline Report 2017*. Washington, DC: The Outdoor Foundation. Retrieved from www.outdoorfoundation.org.

Törn, A., Tolvanen, A., Norokorpi, Y., Tervo, R., & Siikamäki, P. (2009). Comparing the impacts of hiking, skiing and horse riding on trail and vegetation in different types of forest. *Journal of Environmental Management, 90*(3), 1427–1434.

UK Snow Sports. (2018). Retrieved March 20, 2018, from http://www.uksnowsports.co.uk/.

United Nations. (2010). United Nations Environmental Programme: Sport and environment. Retrieved from http://www.unep.org/sport_env/.

Watson, A. (1979). Bird and mammal numbers in relation to human impact at ski lifts on Scottish hills. *Journal of Applied Ecology, 16*, 753–764.

Watson, A. (1985). Soil erosion and vegetation damage near ski lifts at Cairn Gorm, Scotland. *Biological Conservation, 33*(4), 363–381.

Watson, A., Bayfield, N., & Moyes, S. M. (1970). Research on human pressures on Scottish mountain tundra, soils and animals. In W. A. Fuller & P. G. Kevan International Union for Conservation of Nature and Natural Resources (Eds.), *Productivity and Conservation in Northern Circumpolar Lands* (Vol. 16, pp. 256–266). Switzerland: IUCN Publications Morges. Retrieved from https://portals.iucn.org/library/sites/library/files/documents/NS-016.pdf#page=258

Watson, A., & Moss, R. (2004). Impacts of ski-development on ptarmigan (*Lagopus mutus*) at Cairn Gorm, Scotland. *Biological Conservation, 116*(2), 267–275.

Wipf, S., Rixen, C., Fischer, M., Schmid, B., & Stoeckli, V. (2005). Effects of ski piste preparation on alpine vegetation. *Journal of Applied Ecology, 42*(2), 306–316.

Wobus, C., Small, E. E., Hosterman, H., Mills, D., Stein, J., Rissing, M., et al. (2017). Projected climate change impacts on skiing and snowmobiling: A case study of the United States. *Global Environmental Change, 45*, 1–14.