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Use of fluorinated ski waxes in Switzerland

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Abstracts

Fluorinated ski waxes were introduced to the market in 1987. The use of such waxes has been associated with environmental releases of persistent, bioaccumulative and toxic organofluorine compounds (per- and polyfluorinated alkyl substances, PFASs). Although fluorinated waxes with less toxic PFASs have since been developed, concerns remain about the alternatives used today due to their extreme persistence in the environment and high mobility in soil and water.

In response, the International Ski Federation (FIS) announced a ban on the use of fluorinated ski waxes at the end of 2019, which has been in force at all FIS races and International Biathlon Union events since the 2023/2024 season. As a result of the FIS requirements, leading ski wax suppliers have fulfilled their obligation to self-regulate, which is imposed by the Swiss chemicals legislation, and have switched their entire product range to fluorine-free waxes. In line with legislation recently adopted in the EU, further restrictions under chemicals legislation are in preparation in Switzerland, which will also affect ski waxes containing PFASs. For example, a regulatory proposal on perfluorohexanoic acid (PFHxA) and its precursors as well as on products containing microplastics such as polytetrafluoroethylene was published in December 2024.

In addition to an overview of the legal requirements and voluntary measures, this report also contains in-depth information on the relevance of recreational winter sports, the consumption of ski wax and its entry and occurrence in the environment. It is based on data from recent literature and on feedback from a survey of Swiss stakeholders. The report concludes with recommendations for ski wax manufacturers and recreational athletes, among others.

Fluorhaltige Skiwachse wurden im Jahr 1987 auf dem Markt eingeführt. Mit der Verwendung solcher Wachse gingen Umwelteinträge von langlebigen, bioakkumulierenden und toxischen Fluorverbindungen (per- und polyfluorierten Alkylverbindungen, PFAS) einher. Obwohl seitdem Fluorwachse mit weniger toxischen PFAS entwickelt wurden, bestehen auch hinsichtlich der heute eingesetzten Alternativen Bedenken aufgrund deren extremer Langlebigkeit in der Umwelt und hoher Mobilität in Böden und Gewässern.

Der internationale Skiverband FIS kündigte deshalb Ende 2019 ein Verbot der Verwendung fluorhaltiger Skiwachse an, das seit der Saison 2023/2024 bei allen FIS-Rennen und Veranstaltungen der Internationalen Biathlon Union gilt. Aufgrund der Vorgaben der FIS haben namhafte Anbieter von Skiwachsen ihre Pflicht zur Selbstkontrolle, die ihnen das Schweizer Chemikalienrecht auferlegt, wahrgenommen und ihr ganzes Sortiment auf fluorfreie Wachse umgestellt. Im Einklang mit in der EU verabschiedeten Erlassen sind in der Schweiz weitere chemikalienrechtliche Beschränkungen in Vorbereitung, von denen auch PFAS enthaltende Skiwachse betroffen sind. So wurde im Dezember 2024 ein Regulierungsvorschlag zur Perfluorhexansäure (PFHxA) und ihrer Vorläuferverbindungen und zu Mikrokunststoffe wie Polytetrafluorethylen enthaltenden Produkte publiziert.

Der vorliegende Bericht enthält neben einem Überblick über die rechtlichen Grundlagen und freiwilligen Massnahmen auch vertiefte Informationen zur Relevanz des Freizeit-Wintersports, den Verbrauch von Skiwachsen sowie deren Eintrag und Vorkommen in der Umwelt. Er stützt sich dabei auf Daten aus der jüngeren Literatur sowie auf Rückmeldungen zu einer Umfrage unter Schweizer Akteuren. Daraus ergeben sich Empfehlungen unter anderem an Herstellerinnen von Skiwachsen sowie an Freizeitsportlerinnen und -sportler.

Les farts de ski fluorés ont été introduits sur le marché en 1987. Leur utilisation a entraîné des émissions dans l'environnement de substances fluorées persistantes, bioaccumulatives et toxiques (substances per- et polyfluoroalkylées, PFAS). Bien que des farts fluorés contenant des PFAS moins toxiques aient été développés depuis, des inquiétudes subsistent en raison de leur extrême persistance dans l'environnement et de leur grande mobilité dans les sols et les eaux.
Fin 2019, il avait été annoncé que l'utilisation de farts de ski fluorés allait être interdite dans toutes les épreuves de la Fédération internationale de ski (FIS) et dans les manifestations sportives de l'Union internationale de biathlon (IBU) et cette interdiction est effective depuis le début de la saison 2023/2024. En raison de ces exigences, plusieurs grands fabricants et fournisseurs de farts de ski ont décidé, en application du contrôle autonome que leur impose la législation suisse sur les produits chimiques, de ne proposer plus que des produits sans fluor. Parallèlement à la législation européenne, de nouvelles restrictions sont en cours d'élaboration dans la législation sur les produits chimiques en Suisse, qui concerneront également les farts de ski contenant des PFAS. À titre d'exemple, un projet de réglementation de l'acide perfluorohexanoïque et de ses précurseurs ainsi que des produits contenant des microplastiques tels que les poudres de polytétrafluoroéthylène a été mis en consultation en décembre 2024.
Le présent rapport contient, en plus d'un aperçu des bases légales et des mesures volontaires, des informations approfondies sur l'impact des sports d'hiver de loisir, sur la consommation de farts de ski ainsi que sur leur apport et la présence de leurs composants dans l'environnement. Ce rapport s'appuie pour cela sur des données issues de la littérature récente ainsi que sur les réponses à une enquête menée auprès des acteurs du marché suisse des farts de ski. Certaines recommandations sont aussi énoncées, notamment à l'intention des fabricants de farts de ski et des amateurs de sports d'hiver.

Le scioline contenenti fluoro sono state introdotte sul mercato nel 1987. L'uso di queste scioline ha comportato l'immissione nell'ambiente di composti del fluoro persistenti, bioaccumulabili e tossici (sostanze per- e polifluoroalchiliche, PFAS). Sebbene da allora siano state sviluppate scioline fluorurate con PFAS meno tossici, le alternative utilizzate attualmente destano ancora preoccupazione a causa della loro estrema persistenza nell'ambiente e dell'elevata mobilità nel suolo e nelle acque.
Alla fine del 2019 la Federazione internazionale di sci (FIS) ha quindi annunciato il divieto di utilizzare scioline contenenti fluoro, che dalla stagione 2023/2024 si applica a tutte le gare FIS e agli eventi dell'Unione Internazionale di biathlon. In seguito alle prescrizioni della FIS, noti fornitori di scioline hanno adempiuto l'obbligo di controllo autonomo imposto loro dalla legislazione svizzera in materia di prodotti chimici. In linea con le normative emanate dall'UE, in Svizzera si stanno preparando ulteriori restrizioni relative ai prodotti chimici, che riguardano anche le scioline contenenti PFAS. Nel dicembre 2024 è stata ad esempio pubblicata una proposta di regolamentazione concernente l'acido perfluoroesanoico e i suoi precursori e le microplastiche contenenti politetrafluoroetilene.
Oltre a una panoramica sulle basi legali e sulle misure volontarie, il presente rapporto contiene anche informazioni approfondite sulla rilevanza degli sport invernali ricreativi, sul consumo di scioline e sulla loro immissione e presenza nell'ambiente. Si basa sui dati della letteratura più recente e sui riscontri di un'indagine condotta tra gli operatori svizzeri del settore. Ne risultano raccomandazioni in particolare per i produttori di scioline e per gli sportivi amatoriali.

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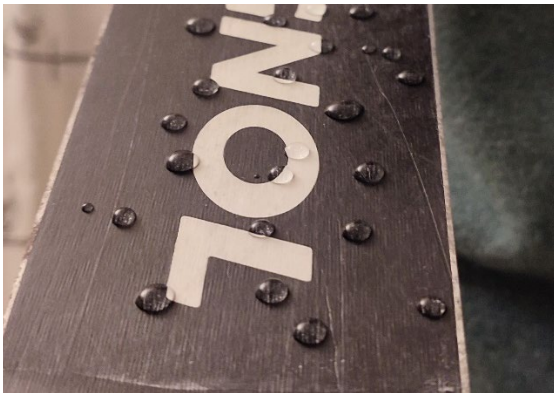
1 Introduction

The purpose of ski waxes is to reduce friction between skis and snow. Wax containing fluorine reduces the wetting of the base particularly strongly. Outdoor tests with cross-country skiers have shown that gliding performance increased by 4% immediately after applying a fluorinated wax [1]. However, some of the highly persistent per- and polyfluoroalkyl substances (PFASs) contained in the waxes are released into the environment through abrasion: In the experiment mentioned above, it was found that the friction of the ski base increased significantly after covering a distance of around 30 km, whereby this increase was accompanied by a reduced fluorine content on the base.

Fig. 1: Water droplets beading on a surface treated with fluorinated wax [2].



The consumption of PFASs in ski waxes in the European Economic Area (EEA) is stated at 1.6 tonnes per year in a report commissioned by the Norwegian Environmental Protection Agency [3]. Compared to the annual consumption of PFASs as polymers with fluorinated side chains for textile finishing of 24,000–73,000 tonnes or as fluorosurfactants in fire-fighting foams for fighting liquid fires of 100–560 tonnes [4], ski waxes are a niche application of PFASs in the EEA. Nevertheless, due to their extreme persistence in the environment, the use of PFASs should be limited to applications that are essential for society. Applications with direct releases to the environment should be particularly scrutinised. This is the aim of projects to restrict the use of PFASs in chemicals legislation of the EU and Switzerland.

The following information summarizes the knowledge about the use of ski waxes in Switzerland. It is based on information from the scientific literature and from a survey conducted among Swiss stakeholders, including manufacturers and general importers of ski waxes, sporting goods retailers, the association Swiss-Ski (which unites eleven winter sports under its umbrella) and the organizers of the Engadin Ski Marathon (the second largest cross-country ski race in the world with around 14,000 participants after the Vasaloppet (Vasa race) in Sweden). This report does not cover the inhalation exposure of professional ski waxers to PFASs during the application of fluorine-containing products as documented in the scientific literature [34][35]. With regard to the exposure of recreational athletes when waxing their skis, reference is hereby made to a fact sheet from the Federal Office of Public Health (FOPH), which recommends the use of fluorine-free products [36].

2 Obligations under chemicals legislation

According to the provisions of Chemicals Ordinance (ChemO, SR 813.11), a manufacturer of ski waxes must ensure that the wax it places on the market does not endanger human health or the environment. An importer must ensure that the manufacturer has fulfilled this obligation known as self-regulation.

Ski waxes are preparations within the meaning of chemicals legislation and must be used in accordance with the provisions of the ChemO and must be classified, packaged and labeled. If necessary, a safety data sheet for the ski wax must be prepared for the commercial user (Art. 19–20) and the ski wax must be reported to the Notification Authority (Art. 48).

In addition, a manufacturer must ensure that the ski waxes do not contain any constituents that are restricted in the Chemical Risk Reduction Ordinance (ORRChem, SR 814.81). The following applies:

- Since June 1, 2021, ski waxes may not contain more than 0.025 ppm of perfluorooctanoic acid (PFOA) and 1 ppm of PFOA precursors.
- Since October 1, 2022, ski waxes may also not contain any long-chain perfluorocarboxylic acids (C_9–C_{14} PFCAs) and their precursors; maximum levels of 0.025 ppm of the sum of the regulated PFCAs or 0.26 ppm of the sum of their precursors are tolerated.
- Furthermore, ski waxes must not contain any organofluorine compounds with a vapor pressure ≥ 0.1 mbar (20 °C) or a boiling point ≤ 240 °C (normal conditions) and with an average lifetime in the atmosphere of two years or more.

In 2009, the Parties to the Stockholm Convention on Persistent Organic Pollutants (POPs), including Switzerland, decided to phase out the production and use of PFOS and related compounds worldwide. Major ski wax manufacturers stated that PFOS and PFOS derivatives have never been used as intended in ski waxes [18]. As part of the amendment to the Stockholm Convention, it is also expected that the existing ban on PFOA (C_8 PFCA) and its precursors will be extended to perfluorocarboxylic acids with chain lengths of up to 21 carbon atoms in 2025.

In addition, a ski wax manufacturer should take note of the following restrictions that have recently been adopted in the EU. In December 2024, the Federal Council opened a public consultation on the amendment of the ORRChem, which envisages the adoption of these restrictions in Switzerland:

- The placing on the market of mixtures containing perfluorohexanoic acid (PFHxA) and its precursors intended for use by the general public will be prohibited by 10 October 2026. Ski waxes based on C_6 technology will be affected, among others.
- The first placing on the market of preparations containing microplastics – with the exception of biodegradable microplastics – has been banned in the EU since 17 October 2023. This concerns ski waxes containing powdered fluoropolymers in a wax matrix.

In addition, a phase-out management of all PFASs in all applications is planned in the EU in the medium term, unless they are essential for society.

3 Voluntary environmental standards

Voluntary environmental standards that go beyond the legal requirements in the area of ski waxes include the Nordic Ecolabel and the ban on the use of fluorinated waxes by the International Ski Federation (Fédération Internationale de Ski, FIS).

3.1 Nordic Ecolabel

Quality labels such as the European ("EU Flower"), German ("Blauer Engel"), Austrian or Nordic eco-labels ("Nordic Swan") provide consumers with reliable information about the environmental compatibility of products. As far as is known, the only award criteria for ski waxes are those of the Nordic Council of Ministers [5]. According to these criteria, a glide wax must not contain any PFASs and, among other things, the organic constituents must be readily biodegradable or at least inherently biodegradable according to the relevant tests in accordance with OECD 301 A–F, OECD 310 or 302 A–C. In addition, the award criteria require that a glide wax labeled with the "Nordic Swan" has good gliding properties, is dirt-repellent and abrasion-resistant and performs like a corresponding fluorine-containing product.

To date, one product from a German manufacturer has been awarded the Nordic Swan quality mark. According to the manufacturer, it is a hot wax for all types of snow and temperatures. The wax is also available in Switzerland via a general importer.

3.2 Prohibition of use of the FIS

At the end of 2019, the FIS Executive Board announced that a ban on the use of ski waxes containing fluorine would apply to all FIS races and International Biathlon Union (IBU) events from the 2020/2021 season. Due to extensive work to define the enforcement processes, the ban came into force delayed until the 2023/2024 season [6]. If the use of a wax containing fluorine is detected, this leads to disqualification according to the competition rules.

3.3 Concept of the association Swiss-Ski

As a member association of FIS and IBU, Swiss-Ski has agreed to implement the voluntary environmental standard and has signed the required confirmations. The Swiss-Ski regulation for the 2023/24 season for competitions in Switzerland was that the ban on fluorinated waxes would apply to FIS and IBU competitions. In order to reduce the control effort in the Nordic sports (cross-country skiing, biathlon, Nordic combined, ski jumping), a standard wax was used in the national competition series "Helvetia Nordic Trophy", "Swiss Cup Langlauf" and "Swiss Biathlon Cup". For competitions that require a Swiss-Ski license, e.g., in the U16 Alpine and Freestyle categories, the national competition regulations apply. According to these regulations, the ban on fluorinated waxes has not been applied for the 2023/24 season due to the current control capacities. To ensure fair competitions, all commercially available ski waxes could be used. From the 2024/25 season onwards, Swiss-Ski applies the fluorine ban to all competition series [6]. Finally, as a FIS race, the Engadin Skimarathon is subject to FIS regulations. According to the organizers, it is not possible to carry out extensive controls with 14,000 participants; similar to doping, random controls are feasible, especially for the top athletes.

4 Relevance of recreational winter sports

Winter sports such as alpine skiing, snowboarding and cross-country skiing are popular with the Swiss population. According to a study by the Federal Office of Sport on the sporting activity and interest of the Swiss population aged 15 and over, around 35% of 12,120 respondents stated that they ski. The average frequency of practice is eight days per year. Cross-country skiing and snowboarding were each practiced by 5.3% of respondents for an average of six days per year [7]. Extrapolated to the entire population, this results in around 24 million winter sports days, of which skiing accounts for around 80% and snowboarding and cross-country skiing for 10% each (one percent of respondents corresponds to around 70,000 people in the total population).

Winter sports enthusiasts have a well-developed infrastructure at their disposal. According to the annual surveys of the Swiss cableways, in the 2021/2022 season, twenty ski resorts accounted for around 65% of the total number of alpine skiers in Switzerland [8], with slope lengths between 60 and 650 km, totalling 4070 km [9]. According to the cableways sector, the Swiss ski slope area is 22,500 ha [10].

The most important Swiss cross-country skiing areas are the Engadin and Davos in the canton of Graubünden, the Vallée de Joux in the canton of Vaud and the Goms in the canton of Valais. The trails are laid out as classic Nordic trails with two parallel tracks and as skating trails in the form of a 3–5 m wide slope.

Fig. 2: Slope prepared for classic style cross-country skiers and skating technique [11]

According to the internet platform for mountain tourism and alpine sports “bergfex.ch”, there are around 170 cross-country skiing areas in Switzerland, in which around 4000 km of trails are prepared for the classic style or skating technique.

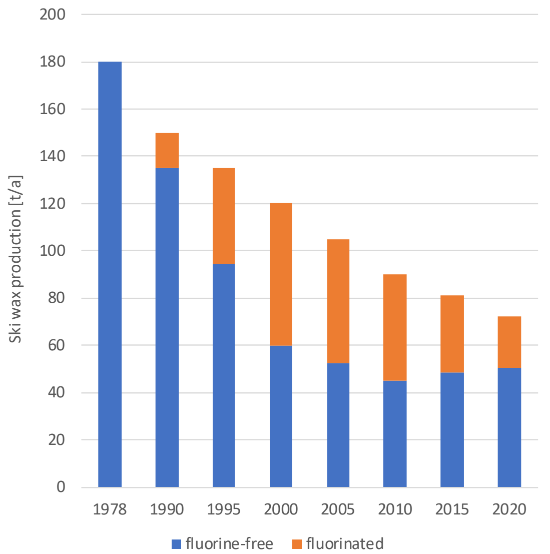
5 Type and consumption of ski waxes

The FOEN survey among manufacturers and general importers of ski waxes, sporting goods retailers and the association Swiss-Ski provides a sufficiently accurate picture of the consumption and use of ski waxes in Switzerland. As far as the type of fluorine compounds previously or currently used is concerned, the domestic manufacturers and importers confirmed the information that can be found in the scientific literature.

5.1 Development of consumption over time

A report published by the Norwegian Environmental Protection Agency estimates that around 60% of global ski wax production takes place in the European Economic Area (EEA). Production in 2020 accounted for about 70 tonnes, i.e., 40% of the volume produced in 1978. It is plausible to assume that manufacturers based in the EEA primarily serve the European market and that the development of production volumes reflects Switzerland’s relative ski wax consumption in the period from 1978 to 2020.

Fig. 3: Development of ski wax production in the EEA in the period 1978–2020 [3]



Products containing fluorine have been on the market since 1987. The market share was already 10% in 1990 and peaked at 50% between 2000 and 2010. It has been declining since 2015 and is now estimated at 30% (Fig. 3).

5.2 Financial turnover and sales

According to the respondents, products from 15 European manufacturers essentially share the Swiss market. However, it is dominated by four brands from three manufacturers. Financial sales of ski waxes in Switzerland are reported by three sporting goods retailers at CHF 4–6 million per season. Players who have switched to fluorine-free alternatives report a slight decline in financial turnover or note that it is too early to tell. Players serving the competitive ski racing market with products containing fluorine expect lower financial turnover in the future.

Ski waxes are sold by sports stores and online retailers. There, the waxes are readily available, regardless of whether they are products for racing or recreational sports. One retailer points out that the high prices of highly fluorinated waxes and pure fluorine products would deter recreational skiers from buying them: For example, a pack of 30 g of a pure fluorine product, which is enough to wax a pair of cross-country skis four times, costs CHF 100–150. Although this cost is considerable, it should be put into perspective by the fact that the average person in Switzerland spends around CHF 2000 per year on sports [7].

5.3 Consumption and use

Based on the current production of ski wax by EU manufacturers of about 70 tonnes (see Chapter 5.1) and – as a measure of ski wax consumption – the number of skier days in the EEA, the consumption of domestic ski wax can be roughly estimated at around 10,000 kg per season, because skier days in Switzerland correspond to around 15% of those in the EEA [12]. With the help of the information from the stakeholders surveyed by the FOEN, it can be estimated at 1400–8000 kg. The respondents state that 65–75% of consumption is accounted for by the waxing of alpine skis and 25–35% by the waxing of cross-country skis. The relative share of competitive sports in wax consumption is between 30% and 50%.

Two market-leading manufacturers with three brands have only offered fluorine-free waxes in Switzerland since 2021. Two other major general importers state that fluorine-free waxes account for around 90% of their sales. Based on the information received from the stakeholders surveyed, the FOEN estimates the consumption of fluorine-containing ski waxes in Switzerland at 600–800 kg per season; 500 kg of this is attributable to waxes used in FIS competitions, 100 kg to waxes used in other alpine competitions and 20 to 170 kg to waxes applied to cross-country skis by amateur athletes. The estimate for alpine ski competitions not organized by the FIS is based on the assumption of 300 alpine ski races with 100 competitors, a wax consumption of 15 g per competitor and a share of fluorine-containing products of 25%. In the estimate for the Nordic sector, the proportion of fluorinated waxes used by the general public was assumed to be 10%.

This means that prior to the season 2023/24, 55–85% of the consumption of fluorinated waxes have been used in competitive sports. Of this, 45% of the wax has been used in alpine skiing, 45% in cross-country skiing and 10% in other competitions. As of the 2024/25 season, athletes are no longer allowed to use fluorinated waxes due to the ban imposed by the FIS.

5.4 Composition of ski waxes

5.4.1 Fluorinated waxes

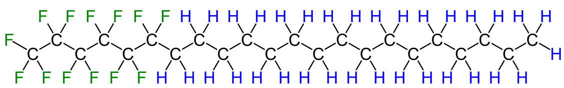
Manufacturers classify gliding waxes containing fluorine into different product types [3][5]:

- products with a low fluorine content of 0.5–1.5% (Low Fluoro, LF);
- products with a high fluorine content of 4–12% (High Fluoro, HF);
- products that contain only organofluorine compounds (Pure Fluorocarbon, FC or Cera).

Higher fluorinated waxes are used in warmer temperatures and wet snow conditions and lower fluorinated waxes are used in very cold temperatures and hard snow conditions. FC products are racing waxes. One manufacturer surveyed estimates the market shares of LF, HF and FC products at 50%, 30% and 20%, respectively.

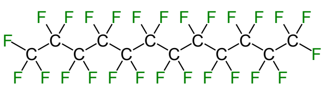
According to the scientific literature, the main PFASs used in LF and HF waxes are semifluorinated alkanes with the formula $F(CF_2)_n(CH_2)_mH$ or F_nH_m for short according to a review article on the terminology of PFASs [13]. According to a patent specification [15], the length of the fully fluorinated carbon chain is six or eight (n = 6, 8). For example, alkyl chain lengths of 16 or 20 result in waxy substances with melting points of 31–32 °C (F_6H_{16}) or 50 °C (F_8H_{16}) and 68–72 °C (F_8H_{20}). Semifluorinated alkanes are soluble in liquid paraffins (alkanes with the molecular formula C_nH_{2n+2}), with solubility increasing with increasing alkyl content (H_m).

Fig. 4: Structural formula of a semifluorinated alkane; shown here: F_6H_{16}



Preferred PFASs in FC waxes appear to be long-chain perfluoroalkanes of the formula C_nF_{2n+2} [14][16]; according to a patent specification [17] with n = 12–20. It is noted that the synthesis route proposed in the patent via the dimerization of perfluorooctane sulfonyl fluoride, a PFOS derivative, is no longer possible due to a total ban issued for this group of substances since 2011.

Fig. 5: Structural formula of a perfluoroalkane; shown here: perfluorododecane



Analyses of samples of three LF waxes and one HF wax collected in 2010 showed that semifluorinated alkanes were mostly found to be F_6H_{16}, $F_{10}H_{16}$, $F_{12}H_{16}$, $F_{14}H_{16}$ und $F_{16}H_{16}$ [16]. These semifluorinated alkanes are precursors of PFOA and the C_9–C_{14} PFCAs.

According to current legislation, ski waxes may not be placed on the market if they contain these precursors in concentrations above 1000 ppb (see Chapter 2).

The groundbreaking investigations by Merle Plassmann [16][18] in 2010 further showed that the ski wax raw materials were contaminated with long-chain perfluorocarboxylic acids (PFCAs), whereby semifluorinated alkanes (for formulating LF and HF waxes) were significantly less contaminated than perfluoroalkanes (for formulating FC waxes) (Table 1). Analyses in 2019 of FC waxes purchased in Norwegian sports stores [19] indicate that the manufacturing practices of the raw material manufacturers did not change significantly between 2010 and 2019. All FC waxes clearly exceeded the current concentration limits of PFOA and the sum of C_9–C_{14} PFCAs of 25 ppb each (Table 2). Based on these findings, eleven fluorinated ski waxes were collected from Swiss shops in a campaign conducted by three cantons in 2024. The samples were analysed for the presence of total fluorine, PFOA and C_9–C_{14}-PFCAs and their precursors [37]. Two LF block waxes with fluorine contents between 0.3 and 0.4%, one HF stick with a fluorine content of 30%, three block waxes with fluorine contents around 75%, two liquid waxes with fluorine contents of 1% and 5%, and three powder waxes with fluorine contents between 70% and 85% were analysed (Table 2). It was found that eight of the eleven products (73%) had to be withdrawn from the market because they exceeded the concentration limits for the PFASs mentioned.

It is expected that fluorine-containing waxes from 2020 will be based primarily on semifluorinated alkanes or other hydrocarbons partially substituted with fluorine, such as tetrasubstituted ethane derivatives [20] with a maximum of six CF_2 units. As mentioned in Chapter 2, the EU has recently adopted a restriction on the marketing of products intended for the general public containing these precursors of perfluorohexanoic acid (PFHxA) or PFHxA itself (as an impurity). The cantonal campaign mentioned above showed that two additional ski waxes would be affected by a similar ban in Switzerland, as they significantly exceeded the EU concentration limit of 25 ppb for PFHxA [37].

Research by a group of experts on the use of PFASs revealed that ski waxes contain per- and polyfluorinated alkanes as well as fluoropolymers [21]. Furthermore, there was no evidence of the use of a wide range of PFASs in ski waxes; however, according to a Russian patent, four fluorinated amides with the structure (R'–C=O)–NH–R'' are also possible, where R'' is an ionic group with the structural unit $–(CH_2)_3–N^+–R_3$ and R' are either perfluoroalkyl or perfluoroalkyl ether groups. A polyfluorinated alkylsilane according to a European patent and a PFOS derivative according to a Japanese patent were identified as further possible PFASs in ski waxes.

In the FOEN survey, manufacturers and general importers confirmed the use of fluoropolymers such as polytetrafluoroethylene in ski waxes as mentioned in patent specifications. The addition of fluoropolymers to paraffin waxes is only possible as micro-powders due to their lipophobic properties [22]. This use of fluoropolymers falls within the scope of the ban on microplastics in preparations that came into force in the EU in October 2023 (see Chapter 2).

5.4.2 Fluorine-free waxes

When it comes to the performance of fluorine-free versus fluorine-containing ski waxes, the opinions of the stakeholders surveyed are divided. There is agreement that fluorine-free and fluorine-containing waxes achieve the same performance in very cold conditions. But even in other snow and weather conditions, fluorine-free ski waxes with good gliding properties are now available. Swiss-Ski, on the other hand, states that athletes with skis waxed with fluorine-free products are not competitive, especially in wet conditions.

Manufacturers are cagey about the nature of the substitutes for organofluorine compounds and refer to trade secrecy. The fluorine-free ski waxes usually contain a combination of different types of wax in varying proportions [3]. According to the interviewees, the wax types used in ski waxes are mainly unbranched or straight and branched-chain hydrocarbons of different chain lengths obtained in the course of petroleum refining. Other raw materials are animal or vegetable waxes consisting of esters of long-chain fatty acids and alcohols or synthetic waxes such as polyolefin waxes.

Table 1: Levels of long-chain perfluorocarboxylic acids (PFCAs) in micrograms per kilogram (ppb) in samples of raw ski wax materials collected in 2010 [16][18]

Product	*PFOA*	*PFNA*	*PFDA*	*PFUnDA*	*PFDoDA*	*PFTrDA*	*PFTeDA*	*C_9–C_{14} PFCAs*
Raw material LF and HF wax	225	135	545	125	380	30	7	1220
Raw material FC wax	7460	950	5830	770	3750	660	2170	14,130

Table 2: Levels of long-chain PFCAs in micrograms per kilogram (ppb) in ski wax samples collected in 2010, 2019 and 2024 [18][19][37]

Product	*PFOA*	*PFNA*	*PFDA*	*PFUnDA*	*PFDoDA*	*PFTrDA*	*PFTeDA*	*C_9–C_{14} PFCAs*
LF wax 2010 (n = 3)								
- *Range*	12–65	4–120	7–39	5–6	2–10	1–4	1–8	27–135
- *Median*	15	4	11	5	5	1	3	70
LF wax 2024 (n = 2)								
- *Range*	5–17	3–5	5–14	3–5	5–12	4–5	5–9	30–45
HF wax 2010	235	175	460	225	190	120	100	1270
HF wax 2024	< 4	< 4	< 4	< 4	< 4	< 4	< 4	< 24
HF wax block 2019 (n = 3)								
- *Range*	4–235	1–200	3–3170	< 1–300	4–1830	1–210	5–940	20–6650
- *Median*	155	20	15	1	10	1	10	50
HF wax block 2024 (n = 3)								
- *Range*	7–7000	6–350	20–6100	55–340	330–11,200	20–1100	120–48,000	560–67,000
- *Median*	45	13	150	60	390	30	260	900
HF wax liquid 2019	15	20	25	30	50	300	85	500
HF wax liquid 2024 (n = 2)								
- *Range*	1–14	1–11	1–120	1–17	1–580	1–20	1–3200	6–4000
FC wax powder 2019 (n = 7)								
- *Minimum*	300	20	280	15	300	30	260	1000
- *Maximum*	30,000	2600	12,200	2300	20,000	4600	42,000	75,000
- *Mean value*	5200	570	5000	700	8300	1200	14,300	30,000
- *Median*	800	110	4200	350	8500	700	6300	26,000
FC wax powder 2024 (n = 3)								
- *Range*	5–3000	6–240	40–9800	7–590	110–16,500	8–1600	70–50,000	260–79,000
- *Median*	110	9	170	20	130	12	130	450

As a substitute for a fluorinated racing wax, one general importer names a product that contains modified polysiloxanes and zinc stearate for the necessary abrasion resistance in addition to hydrocarbon waxes. Ski wax suppliers further mention graphite and molybdenum disulphide as additives to paraffins; these two substances are known to be used in lubricating oils as anti-wear additives. Siloxanes ($R_3Si–[O–SiR_2]_n–O–SiR_3$) are repeatedly mentioned in the literature as a substitute for fluorine compounds in ski waxes [3][5][23]. The effect of four polydimethylsiloxanes ($R = CH_3$) of different viscosities was recently investigated at three temperatures and snow conditions from −10 °C dry to +5 °C wet snow [24]. On wet snow, the increased hydrophobicity of the silicone oils reduced friction by 10%, so that they exhibit the desired friction-reducing properties under these conditions. Finally, a specialty developed in Switzerland is a ski wax containing the dye indigo [25].

6 Environmental inputs

According to the report on ski waxes commissioned by the Norwegian Environmental Protection Agency, around 20% of the wax used remains on the ski bases. Around 80% of the wax is lost during application and is disposed of as waste. The experts interviewed by the FOEN agree that most of the wax applied to the base is removed, while two respondents state that significantly less than 20% of the applied wax remains on the skis and can potentially end up in the environment through abrasion.

A rough estimate for Switzerland shows that between 1987 and 2020, a maximum of 1–6 kg of long-chain perfluorocarboxylic acids (C_8–C_{20} PFCAs) were released into the environment through abrasion losses with ski waxes. It is assumed that the waxes were 20 times more contaminated with PFCAs in the period 1987–2005 than between 2006 and 2020. Pure fluorinated waxes (FC products) were mainly responsible for the environmental inputs of PFCAs. The cumulative environmental inputs of semifluorinated alkanes are estimated at 100–700 kg. They can be degraded to PFCAs in the environment.

7 Occurrence in the environment

Studies on environmental pollution with PFASs from ski wax abrasion are available from Sweden, the USA, Austria and Norway. The conclusions of these studies are summarised below; a detailed compilation of the results can be found in the appendix to this report.

Following the 2010 Vasa race in Sweden, the semi-fluorinated alkanes used in LF and HF waxes were found in snow and soil samples along the cross-country ski trail [26]. In addition, C_6–C_{22} PFCAs were detected, which are present as impurities in LF, HF and FC waxes [18]. The concentrations decreased from the start to the finish of the trail, suggesting that the ski waxes are rapidly rubbed off the ski bases. The fact that longer-chain PFCAs are found in the snow and soil in higher concentrations in the homologous distribution at km 3 than at km 52 is attributed to the abrasion of FC waxes, which are applied as a finish to skis treated with LF or HF waxes and which are postulated to contain high levels of PFCA homologues with $C > 14$ [18].

Measurements of the occurrence of PFASs in snow samples after a very small cross-country ski race (compared to the Vasa race) with about 160 competitors were carried out in a local recreation area in the USA in 2020 [28]. High levels of PFCAs (C_4–C_{14}) were detected in the starting area. Of these, 10% were short-chain PFCAs (C_4–C_7), 5% were PFOA and 85–90% were long-chain PFCAs (C9–C14). Of the 14 PFASs found in the starting area, four compounds were still detectable at race km 3.9; these were long-chain PFCAs.

The results of recent studies in Austria show that PFASs are also found in the snow of alpine ski resorts due to ski wax abrasion, with short-chain PFCAs (C_4–C_7) dominating. PFAS levels vary both within and between ski resorts. In two family ski resorts of similar size, certain PFASs were detected in all sites in one area and in none in the other. Furthermore, analyses of soil samples collected near a cross-country ski trail show that only 0.3–1.5% of the extractable organic fluorine (EOF) determined in the soils can be explained by the target analytes [29].

To get an idea of the PFAS contamination of terrestrial biota in a ski resort, samples of soils, earthworms (*Eisenia fetida*) and bank voles (*Myodes glareolus*), which, as omnivores, also feed on worms, were collected at a ski resort in Norway between 2017 and 2018. In summary, the study shows that the relative proportion of homologues in the sum of PFCAs in soils, earthworms and bank voles at the ski resort is similar to the pattern found in ski waxes, where long-chain PFCAs dominate [30].

There are no known studies on the occurrence of PFASs in Swiss ski resorts, such as those carried out in Sweden, Norway, Austria and the USA. Soil samples collected in Switzerland between 2010 and 2021 were recently analysed for the presence of PFASs [31]. Of the 147 samples, seven were from winter sports sites, six of which were grassland sites. A comparison of the 90^{th} percentiles of grassland sites (without winter sports use) with those of winter sports sites shows a 30% higher contamination for PFOA and PFNA in the latter. It is slightly lower than in forest soils. PFDA and PFUnDA are five times higher in winter sports sites than in grassland sites. In addition, the contamination with these substances is 2–3 times higher than in forest soils. Abrasion from ski waxes may have contributed to the contamination found with these C_{10}–C_{11} PFCAs.

Because the Engadin Skimarathon's 42 km cross-country ski trail, which starts near Maloja, runs across Lakes Sils, Silvaplana and Champfèr, there has been speculation about PFAS contamination of fish in the Engadin lakes caused by ski waxes. According to analyses commissioned by a Swiss consumer magazine, high levels of PFOA were found in the innards of 13 out of a total of 44 fish sampled from the three lakes. As a result, the Graubünden cantonal authorities had lake water and fish tested for the presence of PFASs in 2021 [32]. According to the authors, no difference in the PFAS contamination of fish was found between lakes with and without cross-country skiing.

8 Conclusions

The Swiss Federal Council has already imposed restrictions on several groups of PFASs in the Chemical Risk Reduction Ordinance (ORRChem, SR 814.81). These bans cover those PFASs that pose a major health risk and, with the exception of trifluoroacetic acid, are often the most abundant in the environment. These include perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), long-chain perfluorocarboxylic acids (C_9–C_{14} PFCAs) and perfluorohexane sulfonic acid (PFHxS), including all precursors that can be degraded to these PFASs. The EU has recently introduced bans on the marketing of products containing perfluorohexanoic acid (PFHxA) and its precursors, including ski waxes intended for the general public. In December 2024, the Federal Council launched a public consultation on an amendment to the ORRChem to implement these restrictions in Switzerland. The consultation also proposes restrictions on products containing microplastics. Ski waxes are affected if they contain fluoropolymers in the form of micropowders. Another initiative in the EU is a comprehensive ban on PFASs, the main features of which were published by the European Chemicals Agency on 7 February 2023. Switzerland will consider similar restrictions in due course. In addition, a fluorine ban issued internationally by the FIS to protect the environment and human health applies to all Swiss-Ski competition series from the 2024/25 season onwards.

Studies at winter sports resorts abroad have shown that particularly problematic long-chain perfluoro-carboxylic acids (PFOA and especially C_9–C_{14} PFCAs) have been released into the environment with ski wax abrasion in the past. Analyses of ski waxes in Norway and Switzerland in 2019 and 2024, respectively, suggest that this was the case until recently.

After the FIS ban has come into force, it is roughly estimated that 100–300 kg of ski waxes containing fluorine are still consumed per season in Switzerland, unless suppliers of ski waxes and recreational athletes change their behaviour. In its response to the Munz motion 20.3593 calling for a ban on fluorinated ski waxes, the Federal Council states that it intends to stick to its chosen path of harmonizing the provisions on restrictions and bans in chemicals legislation with EU law as far as possible [33]. Even in the absence of a ban, ski wax manufacturers are required to fulfil their obligation to self-regulate in order to protect the health of users of their products and the environment to avoid identified risks of exposure to PFASs. Due to the requirements of the FIS, leading suppliers of ski waxes have complied with this obligation and have switched their entire range to fluorine-free waxes. Notwithstanding the above, recreational athletes can help protect the environment by purchasing fluorine-free waxes. This can be done easily because all suppliers clearly indicate whether their waxes contain fluorine.

9 Acronyms used

6:2 FTS	6:2 fluorotelomer sulfonic acid
8:2 FTCA	8:2 fluorotelomer carboxylic acid
8:2 FTS	8:2 fluorotelomer sulfonic acid
8Cl-PFOS	8-chloroperfluorooctane sulfonic acid
10:2 FTS	10:2 fluorotelomer sulfonic acid
DONA	Perfluoro-4,8-dioxa-3*H*-nonanoic acid
FOSA	Perfluorooctane sulfonamide
FOSAA	Perfluorooctane sulfonamidoacetic acid
HFPO-DA	Perfluoro(2-propoxypropanoic acid)
N-EtFOSA	*N*-ethylperfluorooctane sulfonamide
N-EtFOSAA	*N*-ethylperfluorooctane sulfonamidoacetic acid
N-EtFOSE	*N*-ethylperfluorooctane sulfonamidoethanol
N-MeFOSA	*N*-methylperfluorooctane sulfonamide
N-MeFOSE	*N*-methylperfluorooctane sulfonamidethanol
PFASs	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutanoic acid (C_4 PFCA)
PFBS	Perfluorobutane sulfonic acid
PFCAs	Perfluorocarboxylic acids
PFDA	Perfluorodecanoic acid (C_{10} PFCA)
PFDoDA	Perfluorododecanoic acid (C_{12} PFCA)
PFDS	Perfluorodecane sulfonic acid
PFHpA	Perfluoroheptanoic acid (C_7 PFCA)
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluornonanoic acid (C_9 PFCA)
PFOA	Perfluorooctanoic acid (C_8 PFCA)
PFOPA	Perfluorooctane phosphonic acid
PFOS	Perfluorooctane sulfonic acid
PFPeA	Perfluoropentanoic acid (C_5 PFCA)
PFTeDA	Perfluorotetradecanoic acid (C_{14} PFCA)
PFTrDA	Perfluorotridecanoic acid (C_{13} PFCA)
PFUnDA	Perfluorundecanoic acid (C_{11} PFCA)
SFAs	Semifluorinated alkanes ($F(CF_2)_n(CH_2)_mH$ or F_nH_m)

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Appendix: Environmental occurrence of PFASs originating from ski waxes (literature review)

The following studies from Sweden, the USA, Austria and Norway are available on environmental pollution with PFASs from ski waxes:

Immediately after the 2010 Vasa race, one of the world's largest cross-country skiing events, snow samples were taken along the course and two months later, after the snow had melted, soil samples were taken. The content of semifluorinated alkanes (SFAs), perfluorocarboxylic acids with chain lengths of six to 22 (C_6–C_{22} PFCAs) and four perfluorosulfonic acids, namely perfluorobutane sulfonic acid (PFBS), perfluorohexane sulfonic acid (PFHxS), perfluorooctane sulfonic acid (PFOS) and perfluorodecane sulfonic acid (PFDS), were then determined in the samples [18][26].

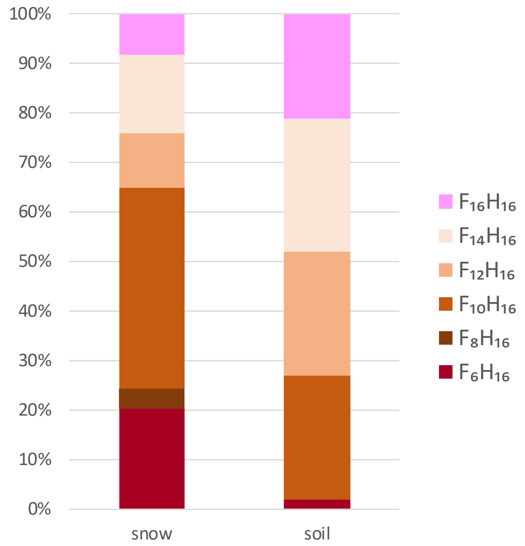
PFOS was found in the snow samples in concentrations between 0.06 and 0.57 ng/L, which were up to two orders of magnitude lower than those of the PFCAs investigated. Relatively low PFOS levels of 0.05–0.27 µg/kg (median: 0.09 µg/kg) were also found in soils (1 cm depth) compared to the PFCAs. PFBS, PFHxS and PFDS were not detected in either snow or soil. This is consistent with statements made by ski wax manufacturers, according to which derivatives of perfluoroalkanesulfonic acids were never intentionally used in waxes [18].

The SFAs, which are waxy and almost insoluble in water at room temperature, were determined in the snow and soil samples after extraction with cyclohexane as a solvent. In samples between km 3 and 82 of the run, between 370 and 17,000 ng SFAs/L were measured in near-surface snow (5 cm depth) and between 0.25 and 33 µg SFAs/kg in soils (1 cm depth).

The distribution of SFAs in snow was comparable to that found in ski waxes, indicating their abrasion. The relative distribution of SFAs found in snow and soils was significantly different: Those up to $F_{10}H_{16}$ were less represented in soils than in snow, while longer-chain SFAs ($F_{12}H_{16}$, $F_{14}H_{16}$, $F_{16}H_{16}$) were enriched in soils compared to snow (Fig. 6). This is possibly due to volatilization of the shorter-chain SFAs from snow or soils, although it is not expected due to the physico-chemical properties of the SFAs [27]. SFAs of the type F_8H_{16} to $F_{16}H_{16}$ are precursors of the now regulated C_8–C_{14} PFCAs (PFOA or C_9–C_{14} PFCAs) and may no longer be contained in today's ski waxes.

Balance calculations showed that the SFA inputs (at km 3) with the snow were higher or of the same order of magnitude as the SFA inventory in soils determined two months later, which does not indicate SFA accumulation in soils due to cross-country skiing activities over several seasons.

Fig. 6: Comparison of SFA patterns in snow and soil samples at km 3 of the 2010 Vasa race



The analyses of the occurrence of C_6–C_{22} PFCAs in snow (5 cm depth) and soil (1 cm depth) between km 3 and 82 of the run showed levels in snow between 40 and 1400 ng/L and in soil between 0.06 and 19 µg/kg. The occurrence of PFCAs in snow and soil decreases from the start to the finish of the run, suggesting that the ski waxes are quickly abraded from the ski bases. The increased occurrence of longer-chain PFCAs in the snow and soils at km 3 compared to km 52 is attributed to the abrasion of pure fluorine waxes (FC waxes), which are applied as a finish to skis treated with LF or HF waxes and for which it is postulated that they contain high levels of PFCA homologues with C > 14 [18]. In fact, in seven FC powders analysed in 2019 (see Table 2), homologues with C = 15–20 accounted for more than 50% of the contamination with C_8–C_{20} PFCAs [19].

As for the SFAs, the quotients from the soil inventory and the input with the snow on the 2010 Vasa race were also formed for the site at track km 3 for the PFCAs. The ratios for the C_6–C_{15} PFCAs were above 50, so that an accumulation of PFCAs through the abrasion of ski waxes from competitions in previous years or from recreational athletes can be assumed. Other sources of PFCAs are the partial degradation of semifluorinated alkanes.

Measurements on the occurrence of PFASs in snow samples after a very small cross-country skiing race – compared to the Vasa race – with around 160 competitors were carried out in the USA in 2020 in a local recreation area [28]. It comprises a trail of around 10 km in length, which is used by numerous recreational athletes and on which amateur competitions also take place. The analysis program comprised a total of 24 analytes; all eleven PFCAs (C_4–C_{14} PFCAs), one of seven perfluorosulfonic acids (PFOS), none of three perfluorooctane sulfonic acid amides (FOSA, *N*-MeFOSA and *N*-EtFOSA) and two of three fluorotelomers (6:2 and 8:2 FTS) were found in the samples. The limit of quantification (LOQ) was around 2 ng/L.

High PFCA levels (C_4–C_{14} PFCAs) of 7300–10,600 ng/L were measured in the starting area. Of these, short-chain PFCAs (C_4–C_7 PFCAs) accounted for around 10%, PFOA for 5% and long-chain PFCAs (C_9–C_{14} PFCAs) for 85–90%. Of the 14 PFASs found in the starting area, four compounds could still be determined at race km 3.9; these were long-chain PFCAs with a total content of 20 ng/L (Table 3).

Table 3: PFASs found in snow samples in ng/L after a cross-country skiing competition in the USA in 2020

	Snow behind the starting line	*Snow in front of the starting line*	*Snow race km 3.9*
PFBA	95	310	< LOQ
PFPeA	55	95	< LOQ
PFHxA	255	430	< LOQ
PFHpA	170	210	< LOQ
PFOA	330	560	< LOQ
PFNA	130	210	< LOQ
PFDA	580	1180	1.9
PFUnDA	435	605	< LOQ
PFDoDA	1530	1800	3.7
PFTrDA	945	1000	2.4
PFTeDA	2760	4210	13
6:2 FTS	300	100	< LOQ
8:2 FTS	4	7	< LOQ
PFOS	2	< LOQ	< LOQ

In Austria, measurements of PFAS contamination of snow and soil have recently been carried out at four winter sports locations with cross-country ski trails and alpine ski slopes [29]. The snow samples were collected between February and March 2022, soil samples were taken at a cross-country ski site in June 2021 (depth: approx. 10 cm) and at an alpine ski site in summer 2022 (depth: approx. 5 cm). The samples were analysed for the presence of thirteen perfluorocarboxylic acids (C_4–C_{14} PFCAs, C_{16} and C_{18} PFCA), eight perfluorosulfonic acids (C_4–C_{10} PFSAs and C_{12} PFSA), five perfluoroalkane sulfonamides (FOSA, FOSAA, *N*-EtFOSAA, *N*-MeFOSE, *N*-EtFOSE) and seven other PFASs (8Cl-PFOS, 8:2 and 10:2 FTS, DONA, 8:2 FTCA, HFPO-DA and PFOPA).

Table 4 summarizes the PFAS levels found in the snow of the alpine ski resorts in Klippitztörl (six sites), Teichalm (one site) and Schladming (five sites). The samples were mainly collected at the valley and mountain stations of the T-bar and chair lifts and cable cars. Of the total of 33 analytes, ten PFCAs and PFOS were detected; all other PFASs were below the limit of detection (LOD). The limits of quantification (LOQ) were between 0.3 and 20 ng/L, depending on the analytes. PFASs were never detected at three sites away from ski slopes and cross-country ski trails.

Table 4: PFASs found in snow at alpine ski resorts in Austria in 2022 in ng/L (P = percentile)

	12 sites in three alpine ski resorts (Klippitztörl, Teichalm and Schladming)				
	Min	*10 P*	*50 P*	*90 P*	*Max*
PFBA	< LOD	< LOD	≈ 1	67	113
PFPA	< LOD	< LOD	< LOD	≈ 5	10
PFHxA	< LOD	< LOD	≈ 10	22	28
PFHpA	< LOD	< LOD	< LOQ	≈ 3	5
PFOA	< LOD	< LOD	< LOD	< LOQ	< LOQ
PFNA	< LOD	< LOD	< LOQ	≈ 3	≈ 6
PFDA	< LOD	< LOD	< LOQ	≈ 16	20
PFUnDA	< LOD	< LOD	< LOD	< LOQ	< LOQ
PFDoDA	< LOD	< LOD	< LOD	< LOQ	0.3
PFTrDA	< LOD	< LOD	< LOD	< LOD	< LOQ
PFOS	< LOD	< LOD	< LOD	≈ 2	≈ 3

In the Carinthian family ski resort of Klippitztörl with its three T-bar lifts and two chair lifts as well as 28 km of long downhill slopes, PFASs were found at all six sampled sites. PFAS levels between 10 and 140 ng/L were determined. Of these, short chain C_4–C_7 PFCAs accounted for 100% at four of the six sites. The largest ski resort sampled in the study was Schladming in Styria. PFASs could be quantified at three out of five locations there. The levels ranged between 2 and 45 ng PFASs/L. As in Klippitztörl, C_4–C_7 PFCAs dominated with proportions between 75% and 100%. In the small family ski area in Teichalm with downhill and cross-country ski trails, 70 ng PFASs/L were measured at the sampled alpine ski site and 110 ng PFASs/L at the cross-country ski site at the start of the trail. The proportion of long-chain C_8–C_{10} PFCAs was slightly higher at the cross-country ski site (36%) than at the ski slope site (17%), where at both sites C_4–C_7 PFCAs predominated (62–83%); PFOS accounted for a small proportion of PFASs (2%) at the cross-country ski site. Finally, in the alpine ski area of Lachtal in Styria, where six

T-bar and two chair lifts provide access to 26 km of slopes, PFASs could never be quantified in snow samples from seven sites. This fact was not taken into account in the percentile calculations listed in Table 4.

Soil samples were collected as part of the Austrian study in the alpine ski area in Klippitztörl and in a transect of a cross-country ski trail in Lachtal. The PFAS levels in Lachtal were between 0.55 and 5.40 µg/kg. They were frequently between 0.7 and 2.1 µg/kg (20th or 80th percentile). PFNA dominated, followed by PFDA and PFUnDA (Table 5). In addition to PFCAs, only PFOS could be quantified twice at levels of 0.45 and 0.60 µg/kg. Only 0.3–1.5% of the extractable organically bound fluorine (EOF) determined in the soils can be explained by the target analytes. EOF levels in Lachtal frequently ranged between 90 and 155 µg/kg (median: 115 µg F/kg).

Table 5: PFASs found in soil (10 cm depth) in µg/kg dry weight (P = percentile) at cross-country skiing sites in Austria in 2021

	20 soil samples (23 analyses) in the transect of a cross-country ski trail (Lachtal)				
	Min	*10 P*	*50 P*	*90 P*	*Max*
PFBA	< LOD	< LOD	< LOQ	0.39	1.60
PFPA	< LOD	< LOD	< LOQ	< LOQ	0.21
PFHxA	< LOD	< LOD	< LOD	< LOQ	< LOQ
PFHpA	< LOD	< LOQ	< LOQ	0.35	0.57
PFOA	< LOD	< LOQ	< LOQ	< LOQ	1.04
PFNA	0.23	0.30	0.49	0.77	0.90
PFDA	< LOQ	0.18	0.29	0.67	0.72
PFUnDA	0.12	0.14	0.28	0.56	0.72
PFDoDA	< LOD	< LOD	< LOQ	0.18	0.23
PFTrDA	< LOD	< LOD	< LOD	< LOQ	< LOQ
PFHxS	< LOD	< LOD	< LOD	< LOD	< LOQ
PFOS	< LOD	< LOD	< LOQ	< LOQ	0.60
FOSA	< LOD	< LOD	< LOD	< LOQ	< LOQ

In the alpine ski resort of Klippitztörl in Carinthia, PFASs could be determined in two soil samples from a valley and mountain station of a chair lift and in the control soil (playground away from the lift). Relatively high PFOS levels were measured near the lifts (2.9 and 0.85 µg/kg), although the control soil also contained high levels of PFOS (0.95 µg/kg). In the soils in the area of the lifts, the sum of C_9–C_{14} PFCAs amounted to 1.05 µg/kg at the valley station and 1.95 µg/kg at the mountain station. Other PFASs could not be determined.

The results of the investigations in Austria show that PFASs are also found in the snow of alpine ski resorts, which can be attributed to the abrasion of ski wax, with short-chain PFCAs (C_4–C_7 PFCAs) dominating. The PFAS content varies both within a ski resort and between ski resorts. For example, in two similarly sized family ski resorts, PFASs were found at all sites in one resort and at none of the sites in the other resort. The increased levels of long chain C_8–C_{12} PFCAs in soils under a cross-country ski trail also point to the abrasion of ski wax. They are attributable to impurities contained therein or the partial degradation of their constituents such as semifluorinated alkanes. In fact, only a fraction of the organic fluorine (EOF) present in the soils could be explained by analysing the PFCA homologues.

To get a picture of PFAS contamination of terrestrial biota in a ski resort, earthworms (*Eisenia fetida*) and bank voles (*Myodes glareolus*), which as omnivores also consume worms, were sampled between 2017 and 2018 in the Granåsen ski resort, which is located in a recreational area of the Norwegian city of Trondheim. A natural forest area with similar vegetation, also near Trondheim, served as a reference site [30]. In addition, ten soil samples were taken in each of these areas at a depth of 3–10 cm. After sampling, the worms were immediately deep frozen so that they could be analysed together with their gut contents. The livers of the mice were analysed and it was assumed that these contributed 90% to the total body burden of PFASs. The spectrum of analytes included ten PFCAs, three perfluorosulfonic acids and five perfluorooctane sulfonamides.

Table 6: Mean and concentration range of PFASs in soils (3–10 cm depth) in µg/kg dry weight

	Winter sports site (n = 10)	*Reference site (n = 10)*
PFBA	0.15 (< LOQ – 0.56)	0.59 (< LOQ – 1.06)
PFHxA	0.05 (< LOQ – 0.18)	0.06 (< LOQ – 0.18)
PFHpA	0.09 (< LOQ – 0.29)	0.14 (< LOQ – 0.62)
PFOA	0.16 (< LOQ – 0.40)	0.10 (< LOQ – 0.22)
PFNA	0.18 (< LOQ – 0.60)	0.20 (< LOQ – 0.93)
PFDA	0.42 (< LOQ – 1.96)	0.08 (< LOQ – 0.15)
PFUnDA	0.13 (< LOQ – 0.29)	0.07 (< LOQ – 0.12)
PFDoDA	0.16 (< LOQ – 0.40)	< LOQ (< 0.09)
PFTrDA	0.09 (< LOQ – 0.20)	< LOQ (< 0.08)
PFTeDA	0.12 (< LOQ – 0.14)	< LOQ (< 0.01)
PFBS	< LOQ (< 0.01)	0.01 (< LOQ – 0.04)
PFHxS	< LOQ (< 0.03)	< LOQ (< 0.03)
PFOS	0.11 (< LOQ – 0.34)	0.30 (0.08–0.64)

The sum of PFASs in soils at the winter sports site (1.57 µg/kg) and the reference site (1.54 µg/kg) did not differ. The predominant PFCA at the reference site was PFBA (C_4 PFCA), while PFDA (C_{10} PFCA) dominated at the winter sports site (Table 6). The number of values above the limit of quantification was significantly higher for C_{12}–C_{14} PFCAs at the winter sports site than at the reference site.

In earthworms, the sum of PFASs was 35% higher at the winter sports site than at the reference site (10.5 vs. 6.9 µg/kg), but the values did not differ statistically significantly due to the high variances. As in soils, PFBA dominated at the reference site. PFTeDA (C_{14} PFCA) was predominant in soils at the winter sports site (Table 7).

Table 7: Mean and concentration range of PFASs in earthworms in µg/kg fresh weight

	Winter sports site (n = 13)	*Reference site (n = 13)*
PFBA	all: < LOQ	3.20 (< LOQ – 15.6)
PFHxA	1.41 (< LOQ – 5.56)	0.87 (< LOQ – 5.55)
PFHpA	< LOQ (< 0.23)	< LOQ (< 0.23)
PFOA	0.63 (< LOQ – 2.47)	< LOQ (< 0.28)
PFNA	0.45 (< LOQ – 1.94)	0.35 (< LOQ – 1.72)
PFDA	0.61 (< LOQ – 2.74)	0.16 (< LOQ – 0.64)
PFUnDA	0.63 (0.06–2.46)	0.21 (< LOQ – 0.71)
PFDoDA	1.73 (< LOQ – 8.35)	0.15 (< LOQ – 0.32)
PFTrDA	2.36 (0.29–15.70)	0.78 (< LOQ – 2.35)
PFTeDA	3.06 (< LOQ – 24.2)	0.43 (< LOQ – 2.41)
PFBS	< LOQ (< 0.33)	< LOQ (< 0.33)
PFHxS	< LOQ (< 0.35)	< LOQ (< 0.35)
PFOS	0.37 (< LOQ – 1.28)	0.76 (< LOQ – 1.78)
FOSA	< LOQ (< 0.24)	< LOQ (< 0.24)
N-MeFOSA	< LOQ (< 0.83)	< LOQ (< 0.83)
N-EtFOSA	< LOQ (< 0.28)	< LOQ (< 0.28)
N-MeFOSE	< LOQ (< 0.31)	< LOQ (< 0.31)
N-EtFOSE	< LOQ (< 0.40)	< LOQ (< 0.40)

The mean PFAS content in bank voles at the winter sports site was around 6 times higher than at the reference site. This difference, as well as the difference in the levels of the long-chain C_{10}–C_{14} PFCAs, was statistically significant (Table 8).

In summary, the study conducted in Norway shows that the relative proportion of homologs in the sum of PFCAs in soils, earthworms and bank voles at the winter sports site is similar to the pattern found in ski waxes, where long-chain PFCAs dominate. The only surprising finding is PFOS in bank voles at the winter sports site: While PFOS was present at higher levels in soils and earthworms at the reference site with 0.3 µg/kg and 0.8 µg/kg, respectively, compared to 0.1 µg/kg and 0.4 µg/kg at the ski resort, a level of 3.3 µg/kg was determined in bank voles at the ski resort compared to a level below the limit of quantification at the reference site.

Table 8: Mean and concentration range of PFASs in voles in µg/kg fresh weight

	Winter sports site (n = 21)	*Reference site (n = 31)*
PFBA	< LOQ (< 0.44)	< LOQ (< 1.9)
PFHxA	< LOQ (< 5.3)	1.54 (< LOQ – 3.41)
PFHpA	< LOQ (< 3.0)	< LOQ (< 1.4)
PFOA	< LOQ (< 2.2)	< LOQ (< 0.8)
PFNA	0.97 (< LOQ – 7.15)	0.74 (< LOQ – 4.03)
PFDA	1.80 (< LOQ – 11.3)	0.39 (< LOQ – 2.14)
PFUnDA	1.43 (< LOQ – 13.6)	< LOQ (< 1.0)
PFDoDA	2.11 (< LOQ – 30.4)	0.19 (< LOQ – 0.65)
PFTrDA	2.15 (< LOQ – 31.5)	< LOQ (< 0.03)
PFTeDA	2.56 (< LOQ – 48.3)	< LOQ (< 0.48)
PFBS	< LOQ (< 1.3)	< LOQ (< 1.9)
PFHxS	1.14 (< LOQ – 6.24)	< LOQ (< 1.8)
PFOS	3.30 (< LOQ – 16.0)	< LOQ (< 2.1)
FOSA	< LOQ (< 0.16)	< LOQ (< 0.17)
N-MeFOSA	< LOQ (< 0.81)	< LOQ (< 3.10)
N-EtFOSA	< LOQ (< 0.28)	< LOQ (< 4.30)
N-MeFOSE	< LOQ (< 2.20)	< LOQ (< 0.30)
N-EtFOSE	< LOQ (< 0.22)	< LOQ (< 1.31)

There are no known studies on the occurrence of PFASs in Swiss ski resorts, such as those carried out in Sweden, Norway, Austria and the USA. Soil samples collected in Switzerland between 2010 and 2021 were recently analysed for the presence of PFASs [31]. Of the 147 samples, seven were from winter sports sites, six of which were grassland sites (Obergoms and Orsières at two sites each and Evolène with sampling in 2021 and Disentis with sampling in 2013) and one forest site (Davos with sampling in 2014). Table 9 summarizes the contamination of the soils (0–20 cm depth) with PFOS and with C_6–C_{11} PFCAs. PFCAs with longer chain lengths were present above the limit of quantification in ten (PFDoDA) and two soils (PFTeDA); PFTrDA could not be quantified in any soil. Of the soils with PFDoDA findings, two were located at winter sports resorts, one of which was also contaminated with PFTeDA. PFDA and PFUnDA were detected in six (≈ 85%) and four (≈ 60%) soils, respectively, of the seven winter sports sites.

A comparison of the 90^{th} percentiles of grassland sites (without winter sports use) with those of winter sports sites shows a 30% higher load for PFOA and PFNA in the latter. It is slightly lower than that in forest soils. PFDA (0.62 versus 0.13 µg/kg) and PFUnDA (0.46 versus 0.10 µg/kg) are five times higher at winter sports sites than at grassland sites. In addition, the contamination with those substances is 2–3 times higher than in forest soils (Table 9). Abrasion from ski waxes could have contributed to the contamination found with these C_{10}–C_{11} PFCAs.

At 0.43 µg/kg, the median PFOS level at the winter sports sites was close to that of the grassland sites (0.39 µg/kg) and lower than that in soils under forest (0.69 µg/kg). The upper extreme value of 13 µg PFOS/kg at a site in Obergoms, where the second-highest PFOS content in Swiss soils was measured, is striking for two reasons. On the one hand, a much lower PFOS level of 0.12 µg/kg was measured at a second site in Obergoms. Secondly, in addition to a high PFOS content, contamination with the PFOS precursors perfluorooctane sulfonamide (FOSA) and *N*-ethylperfluorooctane sulfonamidoacetic *acid* (*N*-EtFOSAA), a metabolite of *N*-ethylperfluorooctane sulfonamidoethanol (*N*-EtFOSE), was also detected at the site in question in Obergoms. FOSA and related compounds were not found in snow in the USA [28], in snow and soil in Austria [29] or in earthworms and the liver of bank voles in Norway [30] in cross-country skiing areas. Since FOSA and related compounds (*N*-MeFOSAA) were also found at the site with the highest PFOS contamination in Switzerland, which is unaffected by skiing, the cause of the PFOS contamination found at the winter sports site in Obergoms may be something other than ski waxes.

Table 9: PFAS contents in Swiss soils (0–20 cm depth) by use (in µg/kg d.w.). Frequent contents correspond to the 20th percentile or the 80th percentile. Winter sports sites are one forest site and six grassland sites.

Locations	*PFOS*	*PFHxA*	*PFHpA*	*PFOA*	*PFNA*	*PFDA*	*PFUnDA*
Winter sports (n = 7)							
- *Range*	0.12–13.27	N.D. – 0.27	N.D. – 0.35	0.14–0.91	0.08–0.30	N.D. – 1.16	N.D. – 0.46
- *Frequent contents*	0.19–0.72	N.D.	0.07–0.23	0.18–0.57	0.10–0.26	0.08–0.24	N.D. – 0.20
- *50th percentile*	0.43	N.D.	0.10	0.26	0.25	0.16	0.09
- *90th percentile*	5.76	0.15	0.23	0.73	0.28	0.62	0.46
Grassland (n = 29)							
- *Frequent contents*	0.19–1.13	N.D. – 0.12	0.08–0.15	0.17–0.43	0.08–0.18	N.D. – 0.09	N.D. – 0.08
- *50th percentile*	0.39	N.D.	0.09	0.28	0.12	0.06	N.D.
- *90th percentile*	2.73	0.16	0.18	0.54	0.22	0.13	0.10
Forest (n = 28)							
- *Frequent contents*	0.41–1.67	N.D. – 0.28	0.09–0.18	0.42–0.74	0.14–0.30	0.07–0.26	N.D. – 0.14
- *50th percentile*	0.69	0.20	0.15	0.53	0.19	0.12	0.09
- *90th percentile*	2.34	0.40	0.24	1.10	0.38	0.31	0.25
Urban locations (n = 22)							
- *Frequent contents*	0.44–1.35	N.D. – 0.18	0.09–0.20	0.30–0.65	0.07–0.20	N.D. – 0.11	N.D. – 0.07
- *50th percentile*	0.85	0.13	0.14	0.41	0.12	0.06	N.D.
- *90th percentile*	2.18	0.26	0.22	0.78	0.21	0.14	0.08
Alpine locations (n = 7)							
- *Frequent contents*	0.09–0.24	N.D.	0.10–0.17	0.20–0.32	0.13–0.17	0.06–0.07	N.D. – 0.06
- *50th percentile*	0.15	N.D.	0.13	0.22	0.14	0.07	N.D.
- *90th percentile*	0.25	0.06	0.19	0.34	0.18	0.10	0.09

Because the 42 km long cross-country ski trail of the Engadin Skimarathon, which starts near Maloja, runs across Lakes Sils, Silvaplana and Champfèr, there has been speculation about PFAS contamination of fish in the Engadin lakes caused by ski waxes. According to an analysis commissioned by a Swiss consumer magazine, PFOA was found in high levels of between 500 and 2700 µg/kg in the innards of 13 out of a total of 44 fish sampled from the three lakes. As a result, the Graubünden cantonal authorities had lake water and fish tested for the presence of PFASs in 2021 [32]. PFCAs with chain lengths from six (PFHxA) to eight (PFOA) at levels of 0.1 to 0.4 ng/L were detected in 35 water samples from four Upper Engadin lakes (Lakes Sils, Silvaplana, Champfèr and St. Moritz). In 31 of 35 samples, PFNA was determined at a level of 0.1–0.2 ng/L, while longer-chain PFCAs (C_{10}–C_{12} PFCAs) could not be quantified in any sample at a limit of quantification of 1 ng/L. In 40 fish (brown trout, Arctic char, Namaycush, grayling) from Lake Sils, PFOA was never found in the muscle meat and ten times in the liver (25%) at levels between 1 and 9 µg/kg.

The median levels in the liver were 2.5 µg/kg (brown trout), 1.9 µg/kg (Arctic char) and 3.7 µg/kg (Namaycush). The median across all fish was around 7 times lower for PFOA at 2 µg/kg than for PFOS at 14.5 µg/kg. According to the authors, no difference was found in the PFAS contamination of fish between lakes with and without cross-country skiing.