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Increasingly favourable winter temperature conditions for major crop and forest insect pest species in Switzerland

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ABSTRACT

With global warming, recent winters in Switzerland have been milder than in previous decades, and this trend is predicted to continue. Survival during the cold season could increase for insect species sensitive to winter cold events. Forest pests, such as the pine processionary moth (*Thaumetopoea pityocampa*) and green spruce aphid (*Elatobium abietinum*), as well as some crop pests, such as the southern green stink bug (*Nezara viridula*), could overwinter more easily. These species are affected by temperatures below –12°C or below –8°C. In this study, we examined whether changes in winter minimum temperatures (Tmin) could potentially favour the winter survival of these pest species in various places in Switzerland. We analysed long-term daily Tmin data from the period 1980–2019 at 67 locations. We then used two climatic scenarios (RCP2.6 and RCP8.5) to analyse daily Tmin in 2020–2099. We determined the number of days with Tmin below –8°C or –12°C and the frequency of years with at least one day below these thresholds. Our results show that the frequency of cold days has decreased over the last 40 years, even though winter Tmin has increased less than yearly Tmin. However, the –8°C threshold was still reached in most years, except on the Southern side of the Alps. The –12°C threshold was reached almost every year above 800 m, but infrequently at lower elevations. Our results indicate that, by the end of the 21st century, temperatures below –12°C will occur only infrequently up to 1700 m in Switzerland, and years with occurrences of temperatures below –8°C will become rare at lower elevations. Future temperature conditions can thus be expected to favour some crop pests, by enabling them to overwinter more easily on the Swiss Plateau, as well as some forest pests, which will likely reach higher elevations.

1. Introduction

Insect pests are a major issue in the context of global warming, for both agriculture (Deutsch et al. 2018) and forestry (Netherer and Schopf 2010). Climate change has an impact on both plants and pests, as well as their interactions. Due to their short life cycle, insect species can often react faster to climatic variations than plant species (Candau 2008). Thus, it is likely that some pest species will cause more damage to forests and crops in the future (Bjorkman and Niemela 2015). In temperate climates, higher temperatures can also facilitate the arrival of new thermophile exotic species. Therefore, it is crucial to understand the changes in determining climatic parameters driving pest population dynamics.

Some expansions in pest species due to climate change have been documented in Central Europe. For example, the pine processionary moth (*Thaumetopoea pityocampa*) has extended its geographical range to northern areas in France and to higher elevations in the Italian Alps (Battisti et al. 2005). In Switzerland, the spruce bark beetle (*Ips typographus*) is now able to produce three generations per year on the Swiss Plateau (Jakoby et al. 2016). In general, global warming is likely to affect population dynamics of insect species in three main ways: shifts in spring phenology (Forrest 2016), longer development seasons (Altermatt 2010), and increased winter survival rates due to milder temperatures (Bale and Hayward 2010). Concerning the pine processionary moth, the expansion was caused by an increase in winter temperatures (Battisti et al. 2005). Daily minimum temperature (Tmin), in particular, plays a key role in the distribution of many species (Bale 2002, Bale et al. 2002).

In temperate climates, resistance to low temperatures in winter differs between insect species. While some insects are highly chill tolerant and can survive at temperatures below –25°C, other species are already affected by milder temperatures (Bale 1993). Winter Tmin is a key factor

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determining their possible range and population dynamics. In Switzerland, some invasive species are affected by Tmin, as are some native ones. As winters become milder under climate change, invasive species could overwinter more easily on the Swiss Plateau, and some native forest pests could reach higher elevations in mountain areas. For the purposes of this study, we identified three pest species spread throughout Western Europe that are sensitive to low temperatures.

Pine processionary moth

The pine processionary moth is sensitive to mean January daily Tmin and to cold events in winter (Huchon and Démolin 1970). It overwinters in the larval stage, and remains active during winter (Battisti et al. 2005). An isolated larva is usually killed by temperatures below –7°C (Hoch et al. 2009). However, when they are grouped into a nest, larvae can endure temperatures of –10 to –12°C (Huchon and Démolin 1970). The pine processionary moth is a native species in Switzerland and occurs mainly on the Southern side of the Alps, in the Valais and in the basin of Lake Geneva (Roques et al. 2014).

Green spruce aphid

Winter temperatures are critical for the population dynamics of the green spruce aphid (*Elatobium abietinum*). Cold winters lead to low survival rates and therefore cause less damage to plants during the following spring (Day and Kidd 1998). When they are detached from their host plants, aphids can survive in temperatures down to –18°C (Powell 1974). However, when they are on their host plants, most of the aphids are killed by temperatures below –10 or –12°C (Powell 1974, Halldórsson et al. 2001). In Great Britain, it has been observed that aphid populations reduce during winters with lowest temperatures of –7 to –8°C (Carter 1972, Powell and Parry 1976). In Switzerland, the green spruce aphid is a native species. Its most severe outbreaks are known to occur after mild winters (Carter and Halldórsson 1998).

Southern green stink bug

Southern green stink bugs overwinter in the adult stage (Todd 1989). This crop pest probably originates from Ethiopia or from the Mediterranean region (Jones 1988) and is now widespread in tropical, subtropical and temperate regions, including Western Europe (Rabitsch 2008). Winter mortality is one of the major limiting factors for their population size (Todd 1989). Laboratory experiments have shown that the lethal temperature is –8°C, i.e. after two hours exposed to –8°C only 20% of the bugs survive (Chanthy et al. 2012). The southern green stink bug has been noticed since 2005 in Switzerland and causes damages to vegetable, cereal and fruit crops (Pétremand, Vonlanthen and Rochefort 2017).

The aim of this study was to determine to what extent the evolution of winter Tmin could increase the winter survival rate of pest species such as the pine processionary moth, green spruce aphid and southern green stink bug in various places in Switzerland. We first analysed trends in daily Tmin averaged over the winter months and over the entire year. We then focused on events below two temperature thresholds (–8°C and –12°C) relevant for the three species mentioned above. A decrease in the frequency of these events would mean a higher potential for the overwintering of the three species in Switzerland.

2. Material and Methods

2.1. Meteorological stations

We selected all meteorological stations managed by MeteoSwiss that are located below the treeline, i.e. around 2400 m in Switzerland (Gehrig-Fasel, Guisan and Zimmermann 2007), and that have collected daily Tmin data since 1980 or earlier. We chose to start our analysis in 1980 in order to keep a sufficient number of stations. We included data series with up to 10% missing values. Missing values were not gapfilled. This selection resulted in 67 stations covering elevations between 203 and 2283 m and located in all climatic regions of Switzerland (Figure 1; see Appendix A for a summary of their elevation distribution and Appendix B for a complete list of the stations. See also Appendix C for a map of forest and cropland in Switzerland).

We then selected the same 67 stations in the CH2018 dataset provided by the National Centre for Climate Services (NCCS) to model trends for the future decades (Croci-Maspoli et al. 2018). This dataset is based on the EURO-CORDEX climate projections and provides data at the local scale. The data were produced using a downscaling method (Quantile Mapping). Daily Tmin data are available until 2099. As the dataset is calibrated on the period 1981-2010, it is likely that the modelled data do not exactly match the observed data for the recent years. We selected two climatic scenarios corresponding to two different Representative Concentration Pathways (RCP), namely RCP2.6 and RCP8.5 (IPCC 2013). RCP2.6 corresponds to the lowest greenhouse gas emissions scenario considered by the IPCC, with a peak around 2020 followed by a substantial reduction thereafter. RCP8.5 corresponds to the highest greenhouse gas emissions scenario considered by the IPCC, with a continuous rise throughout the 21st century. The EURO-CORDEX climate models we used have a spatial resolution of 12 km before downscaling. The simulations we used are DMI-HIRHAM_ECEARTH_EUR11_RCP26 (for RCP2.6) and CLMCOM-CCLM4_ECEARTH_EUR11 _RCP85 (for RCP8.5). They were both extracted from the CH2018 dataset and provide daily Tmin for each of the 67 stations. They both predict relatively moderate annual and winter warming compared to other simulations of the CH2018 dataset, with temperature deviations below the multi-model median (see Appendix D for more details).

2.2. Analysis and threshold definition

We first analysed trends over time in daily Tmin averaged over the winter (start of December to end of February) and over the entire year. We determined linear trends for past and future periods (1980-2019 and 2020-2099). We also used 11-year moving averages to better visualize the trends. We then defined two thresholds as proxies for the critical temperatures for the three selected pest species described in the introduction. Based on literature, we chose –8°C for the southern green stink bug (Chanthy et al. 2012) and –12°C for the green spruce aphid (Powell 1974, Halldórsson et al. 2001) and pine processionary moth (Huchon and Démolin 1970). Temperature-induced mortality of the green spruce aphid also occurs at the –8°C threshold but at a lower rate. We analysed the trends in the number of days with Tmin below each threshold. As cold events can occur in late autumn or early spring, we counted these days during the whole year. We started each count on 1 September of the year before, which means that the count for 1980 started on 1 September 1979 and ended on 31 August 1980. As elevation is a crucial factor determining low temperatures (Hufty 2001, Joly, Bois and Zaksek 2012), we grouped our stations into six elevation classes (<500, 500–800, 800–1100, 1100–1400, 1400–1700, and >1700 m). We added a seventh class for the stations located below 500 m on the Southern side of the Alps, as Tmin values are known to be higher in this region, especially in winter (Walther 2002). We calculated the frequency of the years with at least one day below each threshold over three periods, i.e. the last 40 years (1980–2019), the middle 30 years of the 21st century (2035–2064) and the final 30 years of the 21st century (2070–2099).

All data analyses, including linear regression models and eleven-year moving averages, were performed using R version 3.0.2 (R Core Team 2019).

Figure 1. Locations, codes and elevations of the 67 MeteoSwiss meteorological stations.

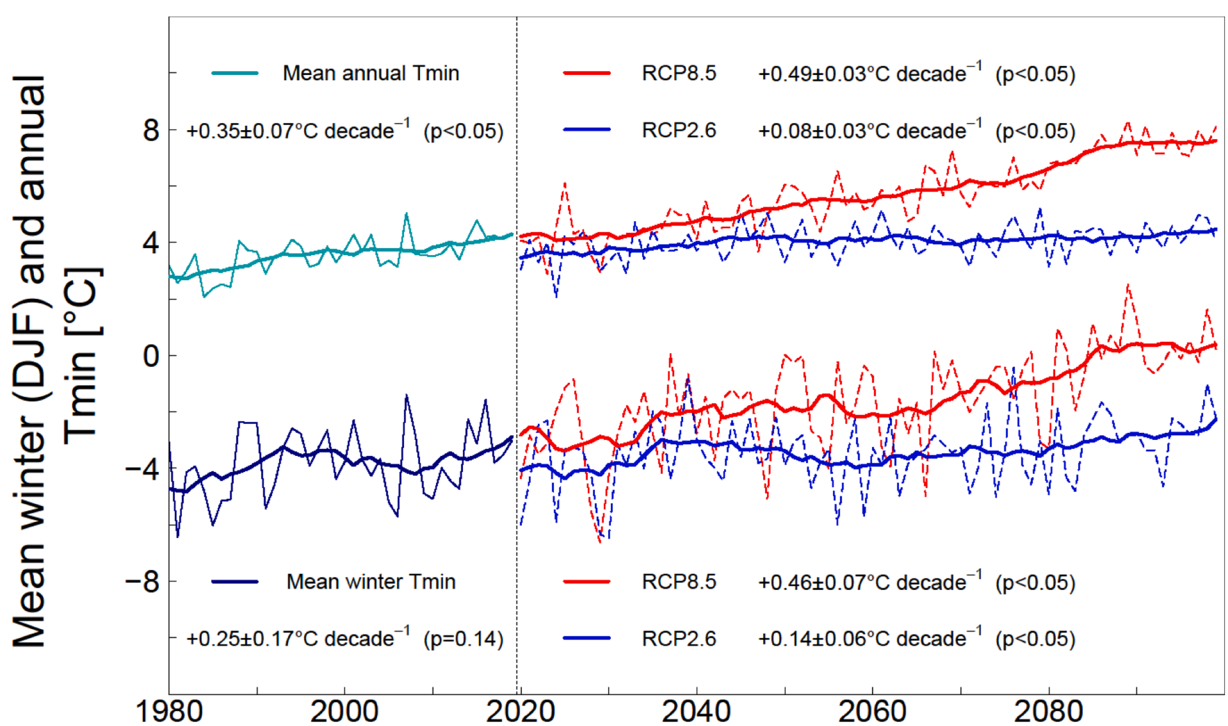

Figure 2. Trends in daily Tmin averaged over winter (start of December to end of February) and over the entire year (1 September to 31 August), averaged across the 67 meteorological stations during the periods 1980–2019 (thin solid lines) and 2020–2099 (dashed lines). Eleven-year moving averages are shown as thick solid lines, and slopes (± SE) of the linear regressions are displayed.

3. Results

3.1. Trends in winter and annual Tmin

Winter Tmin increased during the period 1980–2019 (by 0.25°C decade^{-1}), though not significantly (p=0.14 according to the linear model) and less than annual Tmin (0.35°C decade^{-1}, $p<0.05$; Figure 2). Under both future scenarios, there was a significant increase in winter and annual Tmin for the period 2020–2099. Trends differed substantially between the two scenarios, with 0.46°C decade^{-1} (winter Tmin) and 0.49°C decade^{-1} (annual Tmin) for scenario RCP8.5 compared with 0.14°C decade^{-1} (winter Tmin) and 0.08°C decade^{-1} (annual Tmin) for scenario RCP2.6. The transition between historical data and the projections suggests that temperatures are underestimated in the scenario RCP2.6, at least for the present period.

3.2. Trends in the frequency of cold days (Tmin < –8°C and Tmin < –12°C)

Overall, the number of days with daily Tmin below –8°C decreased significantly over the period 1980–2019 (Table 1), at a rate of –2.36 days decade^{-1} (p=0.02). Under both future scenarios, there was a significant decrease for the period 2020–2099, by –0.79 (RCP2.6) to –1.96 (RCP8.5) days decade^{-1}. The number of days with Tmin below –12°C also decreased slightly over the last 40 years (Table 1), but not significantly (–1.02 days decade^{-1}, p=0.06). During 2020–2099, the decrease reached –0.35 days decade^{-1} under scenario RCP2.6 and –0.76 days decade^{-1} under RCP8.5.

For both thresholds, the largest decrease was observed in the highest elevation class (>1700 m; Figure 3 and Table 1). At stations located below 500 m, trends were small, especially on the Southern side of the Alps. Note that the number of cold days was often greater between 1100 and 1400 m than between 1400 and 1700 m (Figure 3). The transition between historical data and projections clearly suggests that the number of cold days is overestimated in the scenario RCP2.6, at least for the 2020s.

3.3. Mean number of cold days per year (Tmin < –8°C and Tmin < –12°C)

The mean number of days with Tmin below –8°C was very small below 500 m on the Southern side of the Alps during the period 1980–2019, with 3 days per year on average (Table 2). Under scenario RCP8.5, similar values were reached by the middle of the 21st century at stations below 500 m on the Northern side of the Alps and by the end of the 21st century at stations between 500 and 800 m in this region. Under scenario RCP2.6 there was only a slight decrease in the mean values at all elevations during the next decades compared with the period 1980–2019.

The number of days with Tmin below –12°C was very small at stations below 800 m during the period 1980–2019, with 2 to 3 days per year on average (Table 2). Small values were also reached by the end of the 21st century between 800 and 1700 m under scenario RCP8.5 (2 to 5 days per year). Above 1700 m, the decrease between 1980–2019 and the end of the 21st century exceeded 50% under this more severe scenario (from 34 to 14 days per year). The decrease remained very slight at all elevations under scenario RCP2.6.

Substantial discrepancies occurred among the stations in each elevation class, especially those above 1100 m (Appendix B). Numbers observed during the period 1980–2019 were very large in Ulrichen (1345 m), with 85 days per year with Tmin < –8°C and 55 days with Tmin < –12°C on average. In comparison, there were only 41 days per year with Tmin < –8°C and 12 days with Tmin < –12°C on average in Le Moléson (1974 m). Stations located on valley floors like Ulrichen, Scuol, Davos and Samedan usually recorded larger numbers compared with stations located on summits (Le Moléson, Chaumont) or passes (Grimsel), independent from elevation (Appendix B).

3.4. Frequency of years with at least one cold day (Tmin < –8°C and Tmin < –12°C)

The –8°C threshold was reached in most years on the Northern side of the Alps during the period 1980–2019 (Table 3), with a frequency between 80% (<500 m) and 100% (>800 m), whereas these cold conditions were much less frequent below 500 m on the Southern side of the Alps (42%). Under scenario RCP8.5, the frequency was found to drop to 27% below 500 m and to 52% between 500 and 800 m on the Northern side of the Alps by the end of the 21st century. Results from both scenarios indicated that the frequency is likely to remain high above 800 m at the end of the 21st century (at least 86%).

The –12°C threshold was reached above 800 m in most years during the period 1980–2019 (Table 3), with a frequency between 89% (1100–1400 m) and 100% (>1700 m). The threshold was rarely reached below 500 m on the Southern side of the Alps (10%) and more often at lower elevations on the Northern side of the Alps (41% for stations below 500 m, 63% for stations between 500 and 800 m). Under scenario RCP8.5 the frequency was found to drop to 6–15% below 800 m by the end of the 21st century and to 40–49% at elevations between 800 and 1700 m. Findings from both scenarios indicated that the frequency is likely to remain high above 1700 m at the end of the 21st century (at least 83%).

4. Discussion

Our results show that winter Tmin increased less than annual Tmin during the period 1980–2019 (Figure 2). This is consistent with findings from previous studies showing that temperatures in Switzerland have been increasing more in spring and summer than in autumn and winter since the mid-1970s (Rebetez and Reinhard 2008, Matiu, Ankerst and Menzel 2016). This is valid for daily minimum and maximum temperatures (Rebetez and Reinhard 2008). In contrast, the future climatic scenarios suggest similar trends for winter and annual Tmin by the end of the 21st century. Under scenario RCP2.6, the increase is even higher for winter temperatures.

Even though winter Tmin values only increased slightly during the period 1980–2019, the number of days per year with Tmin below –8°C and below –12°C decreased significantly (Table 1). Our results are in

Table 1
Trends in the number of cold days per decade during the periods 1980–2019 and 2020–2099 (under scenarios RCP2.6 and RCP8.5) for various elevation classes. *p<0.05; **p<0.01; ***p<0.001.

Trend in number of cold days < –8°C			
Elevation range (m a.s.l.)	1980–2019	2020–2099	
		RCP2.6	RCP8.5
<500, Southern side of the Alps	-0.80	-0.33**	-0.30***
<500	-1.48*	-0.36	-0.61***
500–800	-1.89*	-0.72*	-1.18***
800–1100	-2.51	-1.15*	-2.76***
1100–1400	-1.96	-1.15*	-2.88***
1400–1700	-3.34	-1.11*	-3.08***
>1700	-6.18**	-1.39*	-5.09***
All stations	-2.36*	-0.79*	-1.96***
Trend in number of cold days < –12°C			
Elevation range (m a.s.l.)	1980–2019	2020–2099	
		RCP2.6	RCP8.5
<500, Southern side of the Alps	-0.08	-0.05*	-0.04*
<500	-0.56	-0.09	-0.14**
500–800	-0.77	-0.21	-0.31***
800–1100	-1.12	-0.59*	-0.91***
1100–1400	-0.74	-0.55*	-1.23***
1400–1700	-0.95	-0.50*	-0.98***
>1700	-3.54**	-0.92*	-2.71***
All stations	-1.02	-0.35*	-0.76***

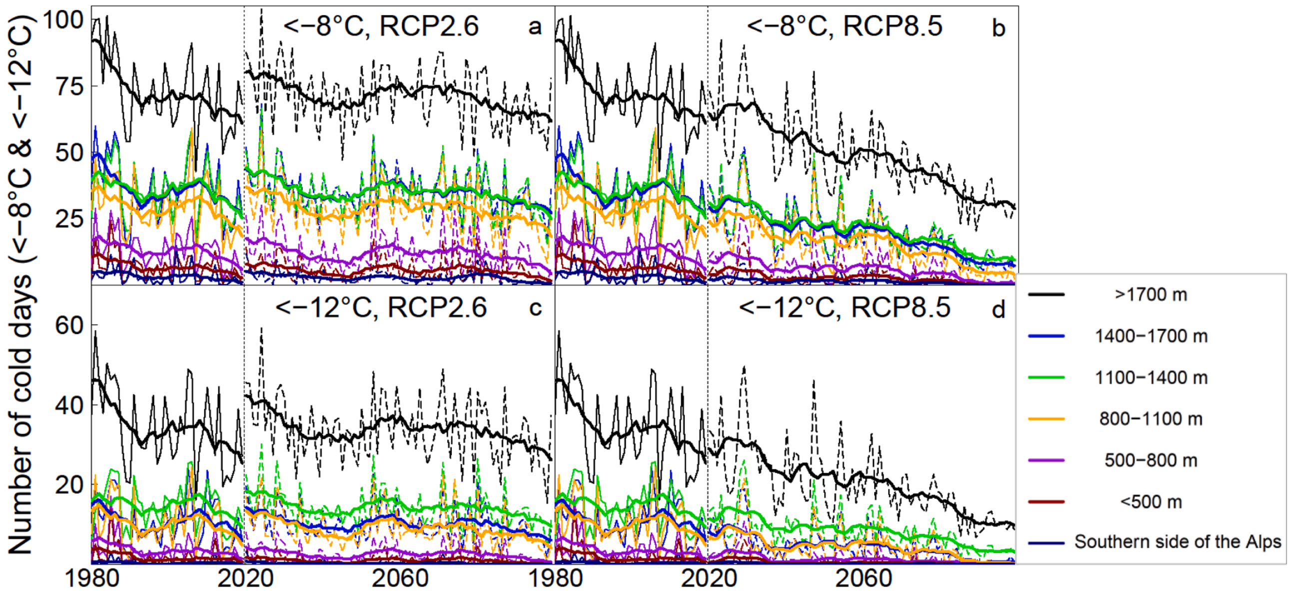

Figure 3. Trends in the number of cold days (Tmin < –8°C and Tmin < –12°C) per year for meteorological stations in different elevation classes during the periods 1980–2019 (thin solid lines) and 2020–2099 (dashed lines). Eleven-year moving averages are shown as thick solid lines.
a. Number of days with Tmin < –8°C, scenario RCP2.6
b. Number of days with Tmin < –8°C, scenario RCP8.5
c. Number of days with Tmin < –12°C, scenario RCP2.6
d. Number of days with Tmin < –12°C, scenario RCP8.5

Table 2
Mean number of cold days per year (Tmin < –8°C and Tmin < –12°C). Minimum and maximum values among the stations are indicated in brackets.

Mean number of cold days (< –8°C) per year					
Elevation range (m a.s.l.)	1980–2019	2035–2064 RCP2.6	RCP8.5	2070–2099 RCP2.6	RCP8.5
<500, Southern side of the Alps	3 (0–8)	3 (0–7)	2 (0–5)	2 (0–6)	0 (0–1)
<500	7 (2–12)	5 (1–11)	3 (0–6)	5 (1–10)	1 (0–3)
500–800	13 (5–24)	11 (3–22)	6 (2–14)	11 (3–23)	3 (1–6)
800–1100	29 (24–33)	28 (22–33)	18 (13–21)	27 (21–30)	8 (6–10)
1100–1400	36 (19–85)	35 (18–86)	23 (9–65)	33 (15–83)	14 (3–49)
1400–1700	35 (16–62)	35 (15–63)	22 (8–45)	33 (13–61)	12 (3–31)
>1700	73 (41–121)	70 (35–118)	52 (22–98)	68 (32–119)	36 (10–77)
Mean number of cold days (< –12°C) per year					
Elevation range (m a.s.l.)	1980–2019	2035–2064 RCP2.6	RCP8.5	2070–2099 RCP2.6	RCP8.5
<500, Southern side of the Alps	0 (0–1)	0 (0–1)	0 (0–0)	0 (0–0)	0 (0–0)
<500	2 (0–4)	1 (0–2)	0 (0–1)	1 (0–2)	0 (0–0)
500–800	3 (1–9)	2 (0–7)	1 (0–4)	2 (0–7)	0 (0–1)
800–1100	10 (7–14)	9 (5–13)	5 (2–6)	8 (5–10)	2 (1–3)
1100–1400	15 (4–55)	14 (3–58)	9 (1–40)	13 (2–55)	5 (0–27)
1400–1700	11 (2–26)	10 (1–26)	5 (1–14)	9 (1–25)	2 (0–6)
>1700	34 (12–86)	33 (9–87)	22 (5–67)	32 (8–86)	14 (2–52)

Table 3
Frequency of years with at least one cold day (Tmin < –8°C and Tmin < –12°C)

Frequency of years with at least one cold day (< –8°C)					
Elevation range (m a.s.l.)	1980–2019	2035–2064 RCP2.6	RCP8.5	2070–2099 RCP2.6	RCP8.5
<500, Southern side of the Alps	42%	47%	29%	36%	13%
<500	80%	83%	57%	68%	27%
500–800	95%	96%	81%	87%	52%
800–1100	100%	100%	99%	100%	98%
1100–1400	100%	100%	97%	100%	86%
1400–1700	100%	100%	99%	100%	88%
>1700	100%	100%	100%	100%	100%
Frequency of years with at least one cold day (< –12°C)					
Elevation range (m a.s.l.)	1980–2019	2035–2064 RCP2.6	RCP8.5	2070–2099 RCP2.6	RCP8.5
<500, Southern side of the Alps	10%	7%	5%	5%	3%
<500	41%	29%	17%	25%	6%
500–800	63%	54%	33%	44%	15%
800–1100	93%	99%	82%	89%	49%
1100–1400	89%	93%	71%	80%	45%
1400–1700	91%	90%	69%	80%	40%
>1700	100%	100%	97%	97%	83%

accordance with those from previous studies showing that the number of frost days (daily Tmin below 0°C) decreased in Central Europe from 1946 to 1999 by about 4–6 days per decade (Klein Tank and Können 2003) and that the number of frost days is likely to reduce by at least 50 days by the end of the century in Switzerland, especially at higher elevations (Zubler et al. 2014). Our results show that this decrease is likely to occur at colder thresholds as well, with additional possible impacts on the biosphere.

The frequency of years with at least one cold day represents the risk that specific pest species are exposed to critical temperatures. Our results show that the –8°C threshold is presently still frequently reached at all elevations on the Northern side of the Alps, but that this situation is likely to change by the end of the century (Table 3). Based on results from scenario RCP8.5, the frequency could fall to about one year out of four (27%) below 500 m and to one year out of two (52%) from 500 to 800 m. As most crop areas are located at lower elevations in Switzerland, the winter survival rate of pest species such as the southern green stink bug may increase if conditions follow this scenario. This process may become increasingly important in the context of conditions where many invasive species can enter Europe. Most of these species originate from warmer regions and are therefore naturally limited by the low winter temperatures in temperate and alpine regions like Switzerland (Vittoz et al. 2013). The occurrence of milder winters with higher Tmin values is likely to increase the survival rate and population size of new pest species in Switzerland over the next decades. In contrast, our findings demonstrate that the frequency of temperatures below –8°C will probably remain quite high at all elevations if conditions correspond to scenario RCP2.6 (68% below 500 m).

Years with temperatures below –12°C are already very rare below 500 m on the Southern side of the Alps (10%) and infrequent on the Northern side of the Alps at lower elevations (Table 3). These years are likely to become very rare in all areas below 800 m by the end of the 21st century if conditions reflect scenario RCP8.5. Furthermore, the frequency could drop below one year out of two (40–49%) at elevations between 800 and 1700 m. In this case, the green spruce aphid might overwinter more easily and cause more damage in mountain areas. The pine processionary moth could also reach higher elevations. This phenomenon was already observed in the Italian Alps, with an upwards shift of 110–230 m between 1975 and 2004 (Battisti et al. 2005).

Finally, our results highlight the importance of topography influencing the frequency of cold events. Even though elevation remains the main driving factor, topography plays a key role, especially at locations exposed to cold air pools. This phenomenon occurs on valley floors and can strongly reduce Tmin (Vitasse et al. 2017). Consequently, at Alpine valley floor stations such as Ulrichen, Scuol, Davos, Samedan and Segl-Maria, the number of cold days was larger than expected based on elevation class (Appendix B). The large number of cold days at stations like Ulrichen and Scuol help explain why, on average, more cold days occurred between 1100 and 1400 m than between 1400 and 1700 m in our dataset (Figure 3). Our results also show substantial differences below 500 m on the Southern side of the Alps, in Magadino and Stabio (valley floors) compared with Lugano and Locarno-Monti (lakeside, hillside). At the local scale, topography should therefore be considered when evaluating the potential overwintering of pest species.

4.1. Limitations of the study

As this study was based on the analysis of daily Tmin, we did not take into account the length of the cold events. The longer the cold event, the lower the survival rate of insects should be (Sinclair, Alvarado and Ferguson 2015). The impact of cold events on pest survival rate could be predicted more precisely from hourly temperature data. However, such high resolution data are generally not available over long periods.

Temperature conditions can differ at the micro-scale, especially in crop areas. Farm buildings and installations can be used as a refuge by pest species to avoid low temperatures. Variation in microclimatic conditions also exists in forest areas. In particular, Tmin has been found to remain higher in winter under a forest cover than in open landscapes (Renaud et al. 2011, Ferrez, Davison and Rebetez 2011). Thus, temperatures experienced by forest insects can differ from temperatures measured at standard meteorological stations, which are by definition situated in open sites (WMO 2018).

Even though Tmin is critical for some pest species, other factors need to be considered to determine the potential distribution and population size of the species. As this study focused only on Tmin, its results pertain only to winter survival rate and cannot be used to predict pest species distributions.

5. Conclusions

Our analyses of trends in Tmin and of the frequency of occurrences below cold thresholds (–8°C and –12°C) in Switzerland show that the number of cold events per year has been decreasing in Switzerland over the last 40 years, even though winter Tmin values have been increasing less than yearly Tmin values. The decrease has been particularly large at higher elevations. Days with Tmin below –8°C still occur in most years on the Northern side of the Swiss Alps (80% of the years at lower elevations). According to scenario RCP8.5, with the continuation of high greenhouse gas emissions during the next decades, by the end of the 21st century such cold events can be expected to become rare at lower elevations (27% of the years below 500 m, 52% of the years between 500 and 800 m) and exceptional below 500 m on the Southern side of the Alps (13% of the years). At the same time, temperatures below –12°C will likely occur in less than 50% of the years up to 1700 m if conditions follow scenario RCP8.5. The decrease in cold events is predicted to be much slighter if there is a strong reduction of greenhouse gas emissions due to human activity, i.e. following scenario RCP2.6.These results suggest that forest pests such as the green spruce aphid and pine processionary moth, are likely to reach higher elevations during the next decades, with the shift size depending on the extent to which greenhouse gas emissions are curbed. In crop areas on the Swiss Plateau, pests such as the southern green stink bug may overwinter more easily.

Declaration of competing interest

None

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.agrformet.2020.108315.

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