9 — Implications of changes in seasonal mean temperature for agricultural production systems: three case studies

- heat stress in cattle
- pest phenology
- wine production

– The performance of dairy cows will suffer from elevated temperatures, reflecting the extent and uncertainty of projected warming in different scenarios, with a marked increase in heat stress for non-intervention scenarios (A1B and A2) toward the end of the century. This calls for the adoption of protective measures in the management of indoor and outdoor animal environments.

– A substantial risk of a prolonged pest control season for the codling moth (an apple pest) is projected toward the end of the century for Northern Switzerland sites, and mid-century for the Ticino. Timely preventive programs are anticipated to represent a key ingredient of adaptation to changing risks from agricultural pests.

– Results suggest that in the near future viticulture could benefit from increasing temperatures as a wider range of grape varieties could be grown. Toward the end of the century negative impacts from extreme temperatures are nevertheless expected to become important.

‹ In the near future, moderately warmer summers could allow a wider range of grape varieties to be grown in northern Switzerland (photo: Peter Salzmann, Wein & Natur GmbH).

This chapter is dedicated to Dr. Jörg Samietz, head of the Zoology Research Group at Agroscope Changins-Wädenswil, who passed away unexpectedly on April 11, 2013, while this chapter was in preparation. We are grateful to Jörg for his initial contribution to this chapter, his continuous commitment to entomological research and his efforts to promote the modeling of orchard pest phenology.

9.1. INTRODUCTION

Agriculture is one of the economic sectors most directly exposed to climate and therefore most sensitive to climate change. Shifts in temperature and precipitation have the potential to alter the climate suitability for crop and animal production (Trnka et al., 2011), soil fertility and stability, and the distribution of agricultural pests and diseases. Climate change is already having an impact on agriculture at the global (e.g., Lobell et al., 2011), continental (e.g., Eitzinger et al., 2009; European Environmental Agency EEA, 2012), and national scale (e.g., Holzkämper et al., 2013a).

One of the main conclusions of the Working Group II IPCC Fourth Assessment Report (IPCC, 2007b) was that in Central and Northern Europe moderate warming (1 to 3°C), along with the increase in atmospheric CO_2 concentrations and associated improvement in the water use efficiency and productivity of crops (e.g., Torriani et al., 2007), would be beneficial for cereal crop and pasture yields. Yet further warming would entail negative impacts, in particular in relation to a projected shift in climate variability and an increasing incidence of extreme events.

Analogous arguments were also advanced with respect to Swiss agriculture in the CH2050 report (OcCC, 2007), with a qualitative discussion of climate change impacts on plant and animal production systems, water requirements and supply, the incidence of weeds, pests and pathogens, and the implications for farm management and national food security.

Going beyond the qualitative approach of the CH2050 assessment, this chapter examines in a quantitative way how specific aspects of agricultural production could respond to changes in long-term seasonal mean temperature as projected for the 21st century by the CH2011 scenarios (Chapter 3). Three case studies are presented, addressing animal performance (animal production), the potential shift in insect pest phenology and generation development (pest management), and the thermal conditions for viticulture (plant production). Crop suitability and crop productivity is dealt with elsewhere (Holzkämper et al., 2013b).

The case studies are chosen considering the economic importance of animal and fruit production (including viticulture) for Swiss agriculture. With 3.4 billion CHF, cattle meat and dairy production account for 35% of the total monetary output of the agricultural sector (SBV/USP, 2012). Fruit production and viticulture contribute with another 1.0 billion CHF, or 25% of the output generated through plant production and 10% of the total output (SBV/USP, 2012).

9.2. METHODS

Responses to long-term changes in seasonal mean temperature (△T), respectively, are evaluated by:

- defining response functions on the basis of either empirical equations or results of analyses carried out with process-based modeling tools;
- applying the response functions along with observed weather data for 1980–2009 to obtain a reference;
- simulating future responses by adjusting observed weather data according to the projected △T.

Dairy cows' performance as a function of temperature and air humidity is quantified using the temperature-humidity index (THI; Thom, 1958). A threshold of THI = 72 is assumed as a critical level (Johnson, 1994), and the number of days with THI > 72 is taken as a measure for the risk of heat stress. Relative humidity is evaluated as a function of daily mean and minimum temperature following Allen et al. (1998).

Pest management in fruit production is investigated relative to the shift in the seasonal phenology and generational development of the codling moth *(Cydia pomonella L.)*, a major insect pest of apple orchards worldwide. The long-term average risk of a third generation (start of larval emergence) is assessed by specifying a sigmoidal response function to changes in temperature. This function approximates the response obtained using the seasonal pest phenology model SOPRA (Samietz et al., 2008; Stoeckli et al., 2012) along with a statistical downscaling approach (Hirschi et al., 2012).

Climate suitability for viticulture is assessed on the basis of the heliothermal index (HI) introduced by Huglin (1978). The Huglin index is often adopted for impact assessments (e.g., Trnka et al., 2011) as it provides a better measure of the sugar potential of different vine varieties than the classic temperature sums (Jones et al., 2012).

Three stations (Changins, Wädenswil, and Magadino) are considered, representing the three core regions (CHW, CHNE, and CHS) defined in CH2011 (2011). Seasonal temperature anomalies needed to quantify the climate change signal are obtained for each of the three greenhouse gas scenarios (RCP3PD, A1B, and A2) and time periods (2035, 2060, and 2085) from the CH2011 SEASONAL-REGIONAL scenarios (Chapter 3).

9.3. RESULTS

The **performance of dairy cows** suffers under heat stress. THI values in excess of 72 induce a progressive decline in milk production (Johnson, 1994). Currently, this occurs on average during only five (Northern Switzerland) to 15 days (Southern Switzerland) per year. As seen in Figure 9.1, however, the average number of days with THI > 72 is projected to significantly increase in the future, more markedly starting around 2060 under the A1B and A2 greenhouse gas scenarios. The increase is most pronounced for Southern Switzerland, where the current situation already reflects higher thermal pressure. As a result, toward the end of the century critical conditions are expected on up to 70 days in Northern Switzerland and up to 90 days in Southern Switzerland.

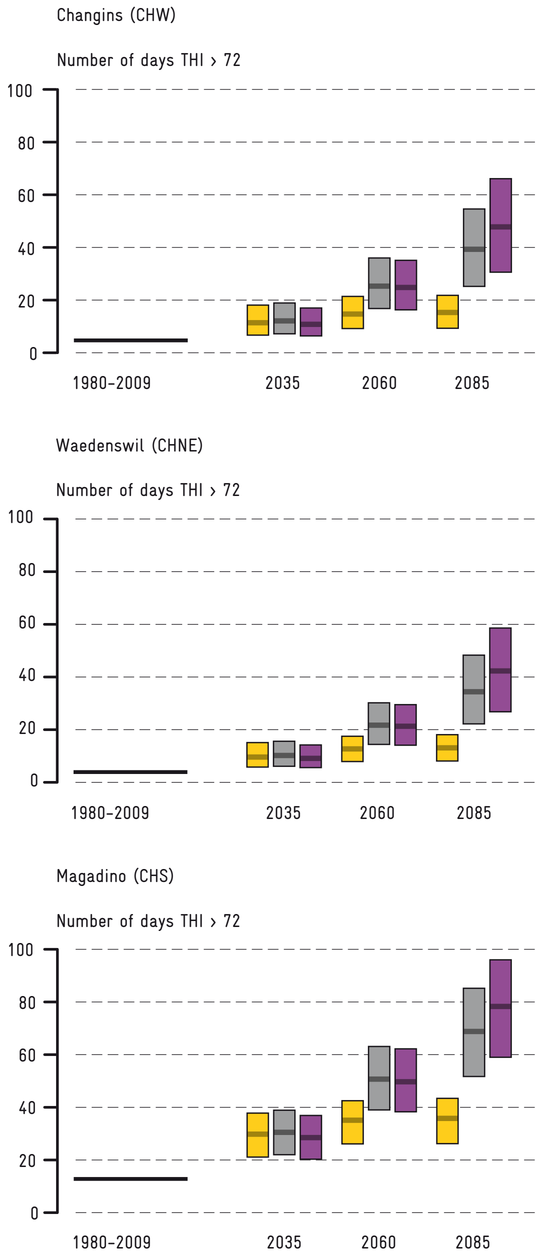

Figure 9.1: Average number of days per year with temperature-humidity index THI › 72 at Changins (top), Wädenswil (middle), and Magadino (bottom) under reference (1980–2009) and future climate conditions (2035, 2060, and 2085) as projected for the three greenhouse gas scenarios RCP3PD (yellow), A1B (grey), and A2 (purple). The corresponding CH2011 regions are indicated in parentheses.

Pest management in apple production in Switzerland is currently designed to cope with a high risk of a second generation of larval emergence start of the codling moth but a negligible risk of a third generation (Stoeckli et al., 2012). The risk of a third generation is likely to remain small for all time periods under the RCP3PD scenario in Northern and Western Switzerland (Changins and Waedenswil) but not in Southern Switzerland (Magadino, Figure 9.2), where a considerable risk is simulated for 2060 and 2085 even in this stabilization scenario as a consequence of the projected increase in temperature. For A1B and A2, a third generation risk in excess of 50% is simulated for Magadino around 2060, whereas at Changins and Wädenswil a significant increase is simulated only for 2085.

Climate suitability for viticulture as expressed by the Huglin index is essentially a linear mapping of the mean temperature during April–September. Hence, baseline values and scenarios presented in Figure 9.3 closely reflect the present and future temperature conditions at the three study sites. Current average values suggest a suitability limited to varieties with relatively low thermal requirements in Northern Switzerland (e.g., Müller-Thurgau, Pinot blanc, and Gamay), but extended to a wider range of varieties for the production areas south of the Alps. Based on the range of climate change projections considered, conditions suitable for growing varieties with higher thermal requirements are expected also for Northern Switzerland. This suggests the possibility to improve wine production in many areas in spite of the fact that negative impacts from extreme temperature could become relevant during the second half of the century (Eitzinger et al., 2009; Jones et al., 2012).

9.4. IMPLICATIONS

Appreciable impacts of changes in seasonal mean temperature on animal performance, orchard pest development, and the thermal suitability for grapevine production can be expected already by 2035 and in all cases and more markedly by 2060 and 2085. Impacts are usually more pronounced with A1B or A2 than with RCP3PD.

Given the linear or nearly linear response of the Huglin and temperature-humidity indices to changes in temperature, uncertainties relative to the projected changes in heat stress in livestock and in the thermal suitability for grapevine production closely mirror uncertainties in temperature change as exhibited in the CH2011 scenarios (Chapter 3). The codling moth responds to increasing temperatures in a more complex way and uncertainties in the impacts are conditional on the choice of greenhouse gas scenario and time frame. In any case, uncertainty ranges revealed in Figures 9.1–9.3 can only provide a partial estimate of the total uncertainty, since they do not account for simplifying assumptions and methodological limitations.

On the basis of the present results and earlier, independent assessments, there appears to be scope for adapting agriculture to climate change in Switzerland. Autonomous adaptation, as already practiced by farmers, is possibly sufficient to cope with altered climate conditions in the near future, but more specific measures could be needed later on to mitigate the adverse impacts of increasing temperatures. This holds true both in the context of plant production as well as in relation to animal husbandry. In the latter case, adaptation measures could include the identification of appropriate breeds, adjustments of the nutrition and feeding plans, as well as improvements of indoor and outdoor environments (Hugh-Jones, 1994).

The example of the codling moth underscores the importance of pest management for adaptation of agriculture to climate change. The spectrum of pests, pathogens, emerging infectious diseases and weeds that could challenge plant and animal production during the coming decades is wide (Anderson et al., 2004; Gregory et al., 2009, Bregaglio et al., 2013), and requires a full palette of preventive measures. Given the multitude of challenges, it is far from obvious how to design and implement effective approaches to pest management. In the case of the codling moth, the projected shifts in phenology and generation development will extend the pest control season for apple crops by at least one month. Regulating measures currently implemented include pheromone mating disruption, singularly or in combination with species specific biological control agents *(granulosis viruses)* in case of high population densities (Stoeckli et al., 2012). It is, however, unclear whether these measures will remain

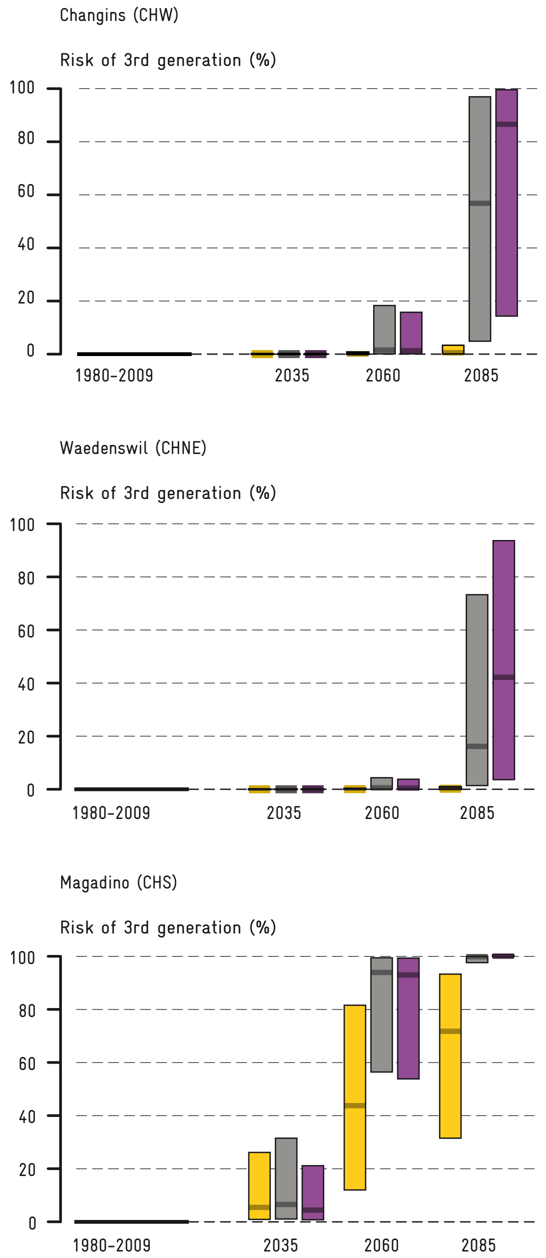

Figure 9.2: Risk of a 3rd codling moth generation at Changins (top), Wädenswil (middle), and Magadino (bottom) under reference (1980–2009) and future climate conditions (2035, 2060, and 2085) as projected for the three greenhouse gas scenarios RCP3PD (yellow), A1B (grey), and A2 (purple). The corresponding CH2011 regions are indicated in parentheses.

fully effective in the future. For instance, it is likely that with increasing temperatures and protracted pest development, current pheromone doses cannot offer protection over an entire season anymore. Similarly, the sole application of mating disruption or the combination with *granulosis viruses* may no longer be sufficient to control codling moth because during multiple generations higher population densities may build up. Additionally, resistances to chemical insecticides are expected if repeated treatments with the same group of ingredients are to be applied to cope with a longer pest control season.

Conclusions with regard to pest management are also sensitive to the assumptions on environmental factors other than temperature. As for other insect pests, the life cycle of the codling moth is regulated by day length. As days shorten toward the end of a season, winter dormancy is induced, which prevents the development of a further generation. An evolutionary shift in winter dormancy induction to a later season is likely to take place in a warmer climate (Stoeckli et al., 2012), and is assumed to be approx. 2 days/decade here. A more pronounced shift would imply a higher pest risk than projected in this study.

An implication of the present analysis is that not all effects of increasing temperatures on agricultural production systems need to be negative. In western and north-eastern Switzerland, for instance, viticulture could initially profit from warming because this would allow the cultivation of varieties with higher thermal requirements than those currently grown. For early-maturing varieties negative effects of accelerated growth on wine quality could further be avoided, e.g., through the adoption of measures for delaying maturity (Petgen, 2007). However, as warming proceeds there is an increasing risk that variety-specific, critical temperature thresholds are exceeded, with negative consequences for grape yields (Sadras and Moran, 2013).

With regard to pests and diseases affecting grapevine, increasing temperatures, along with drier summer conditions, could reduce the disease severity of fungal infections such as powdery mildew, but favor the appearance of insect pests like the European grapevine moth for similar reasons as discussed here in relation to the codling moth (Caffarra et al., 2012).

Although not explicitly examined here, shifts in the frequency and intensity of extreme weather events are likely to take place in Switzerland during the 21st century (CH2011, 2011; MeteoSchweiz, 2013). The consequence for agriculture is that production risks associated with heat waves, droughts, or extreme precipitation events are likely to be higher in the future (e.g., Calanca and Semenov, 2013).

In conclusion, risk management is going to play a crucial role in the context of adaptation (Sivakumar and Motha, 2007). In particular, precautionary measures will become necessary to cope with a more frequent occurrence of summer droughts (Calanca, 2007; CH2011, 2011). The adoption of irrigation, now limited to a few areas within the Valais and Western Switzerland, on a wider scale is one of the most obvious measures to face this situation. Along these lines, studies have already been conducted to evaluate demand and supply of water for agriculture (Fuhrer, 2012) and to analyze options for the management of water resources at the regional scale taking into account the multifunctional role of agriculture (Klein et al., 2013; 2014). Other possibilities to cope with increasing summer drought risks is through insurance instruments (Torriani et al., 2008), but in this case specific investigations are needed to develop products that can effectively cover the risks of a changing climate (Kapphan et al., 2012).

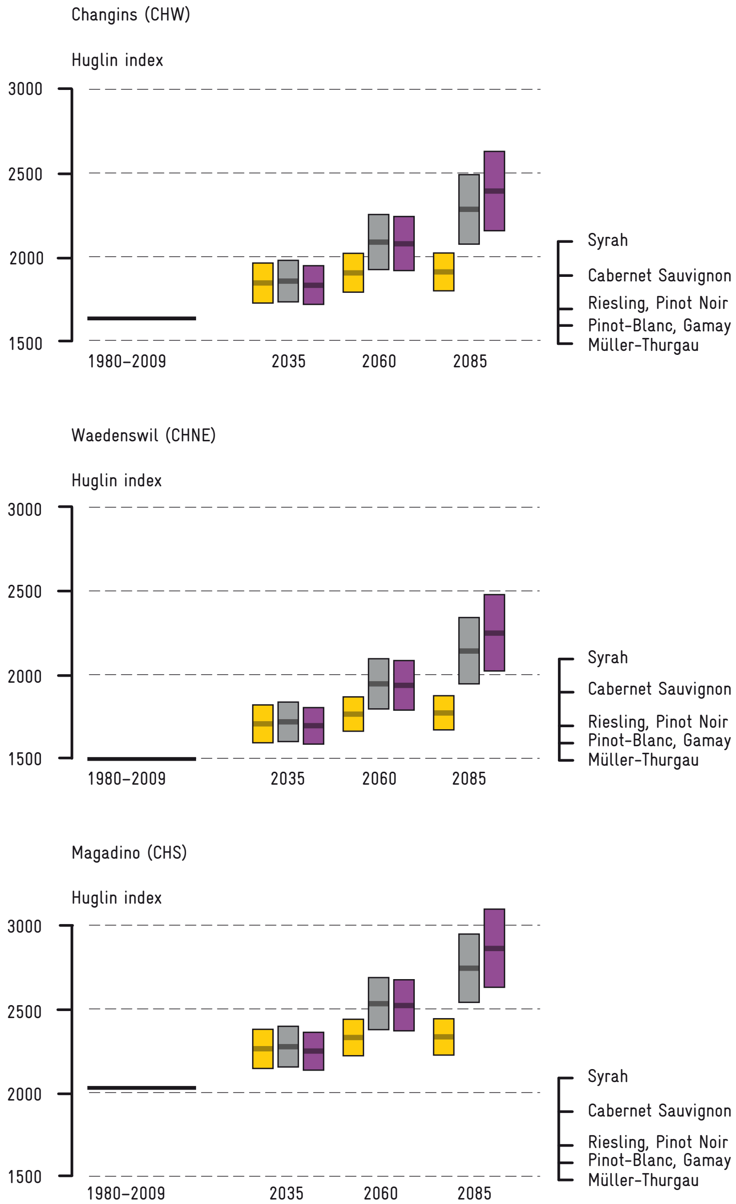

Figure 9.3: Long-term average Huglin index at Changins (top), Wädenswil (middle), and Magadino (bottom) under reference (1980–2009) and future climate conditions (2035, 2060, and 2085) as projected for the three greenhouse gas scenarios RCP3PD (yellow), A1B (grey), and A2 (purple). The corresponding CH2011 regions are indicated in parentheses, and the thermal requirements for different grape varieties are shown on the right of the graphs.