Codling Moth

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Abstract

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Keywords:— Codling Moth, pest, pesticide, pest management

1 Introduction

Limited work characterizing the impacts of climate change on insects. Touch upon shifts that have already been observed based on historical records as well (see references). Higher pest pressure is widely noted as a potential climate change risk to food production and pests are a particular concern for specialty crops for which product quality is paramount. Across the globe, shifts in the ranges of insect pests have been documented in response to climate changes [1, 7, 12], though some [6] have argued that there is in fact a surprising paucity of documented examples, raising the possibility that trophic interactions or other mechanisms may make insect pests less sensitive to direct climate effects than previously thought.

Washington State in an economically important apple production area, representing 66% of US apple production (USDA NASS 2018) (making it PNW only raises this to 68%; WA also represents 43% of the pear production but not sure if that's relevant here). Apples are the leading commodity in Washington State, accounting for $2.4 billion in 2016, 22% of the total value of agricultural production (USDA NASS 2017). Importance of controlling the codling moth for the tree fruit industry. Some industry statistics

Our objective.

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2 Background(Kirti, Georgine)

2.1 Study Area (Georgine)

2.2 Codling moth life cycle (Sonia, Ute)

2.3 Codling moth management (Ute)

2.4 Climate and climate change impacts on pests(Georgine/Sonia)

We need a thorough literature review for pests in general and codling moth in particular. Looks like it is most related to aphids. Temperature has a strong and direct influence on insect development, reproduction and survival [5], and climate is thus expected to directly impact insect pests through effects on their ranges [10,12], winter mortality (citation), development timing (citation needed), voltinism (the number of annual generations) [4](Leudling et al. 2011), and the duration of the reproductive period [20]. Indirect effects are also possible, including effects on natural enemies, competitors, or responses to climate-induced changes on the host plant [5,11]. The IPCC has concluded that work to date projecting likely climate impacts has suggested a tendency for risk of insect damage to agricultural plants to increase, though but also notes that current scenario analyses of pests are typically limited by simplistic assumptions, and it remains to be seen how conclusions may change when scenarios incorporate more sophisticated factors such as migration and invasion patterns and other types of global change (Porter et al. 2014). A number of different researchers have examined the potential impacts of climate change on codling moth in different areas of the world, including in Norway [15], eastern Washington [2], California (Leudling et al. 2011), Switzerland [19], and Poland [13]. In general, studies have suggested an advancement in key phenological stages, and a concomitant increase in the number of generations per season. This in turn suggests a need for control measures over a longer time period in the future, with negative economic implications and higher risk for the development of resistance.

Can we add something related to gaps. That is what are we offering beyond rehashing what is out there?

3 Methods

3.1 Input data (Sonia)

3.2 Codling moth degree day model (Vince)

3.3 Diapause induction assumptions (Ute)

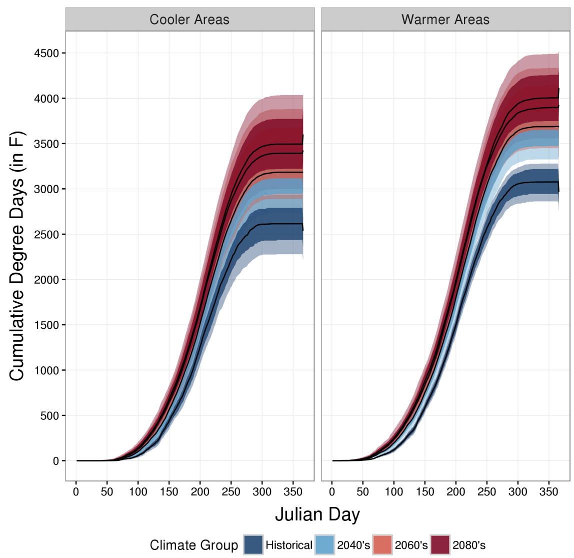
3.4 Model application framework (Ute)

Also discuss distinction between warmer and colder areas (Giridhar)

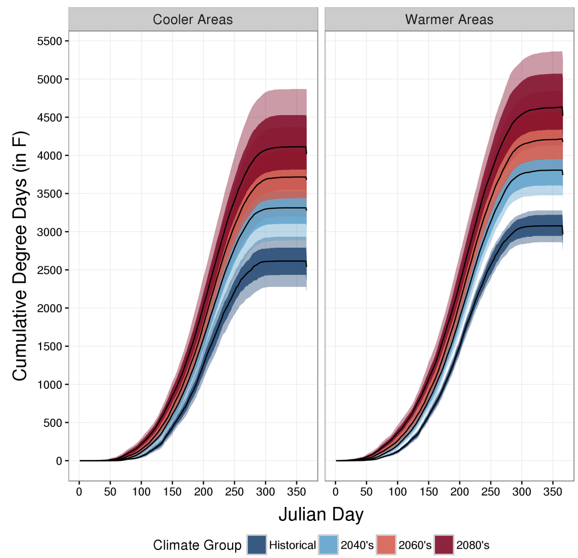
4 Results (Hossein, Giridhar)

4.1 Changes in degree day accumulation (Min to help Hossein)

Show annual and seasonal changes



(a) Degree Day Changes (rcp 4.5)

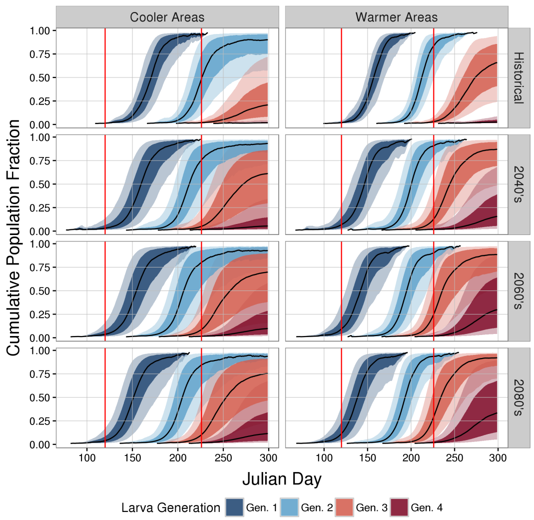


(b) Degree Day Changes (rcp 8.5)

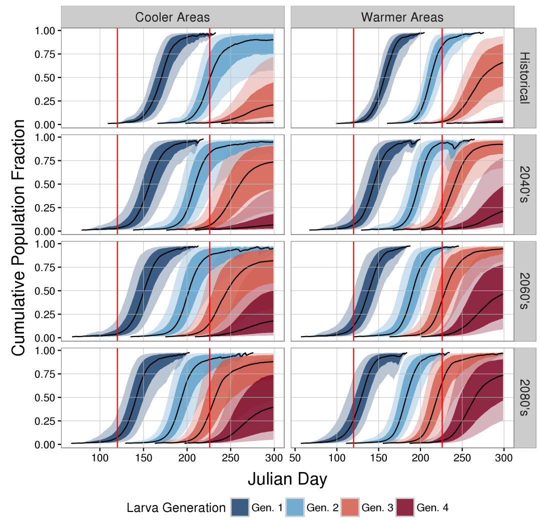
Figure 1: Degree Day changes over a year

4.2 Changes in timing of events critical for pest management

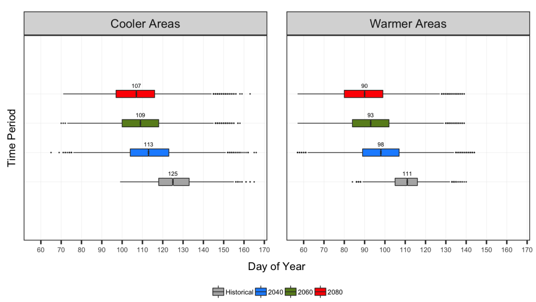
Adult first flight and egg hatch into larvae (Are these the critical times at which pesticide applications are made?)



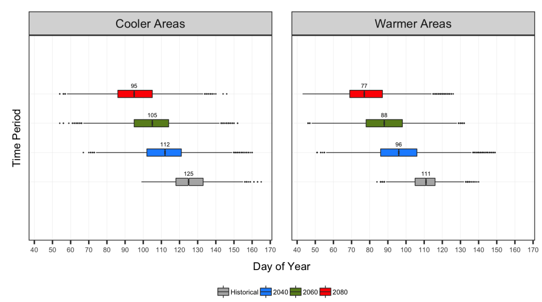
(a) Eggs hatching (rcp 4.5)



(b) Eggs hatching (rcp 8.5)



(c) Adult first flight (rcp 4.5)

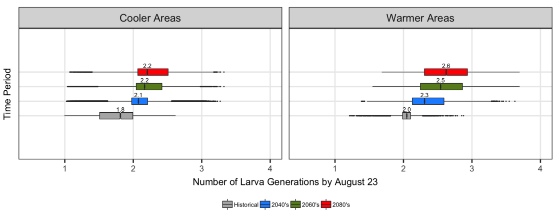


(d) Adult first flight (rcp 8.5)

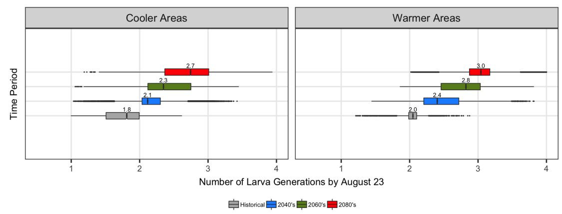
Figure 2: Critical Events

4.3 Changes in the number of generations of the pest

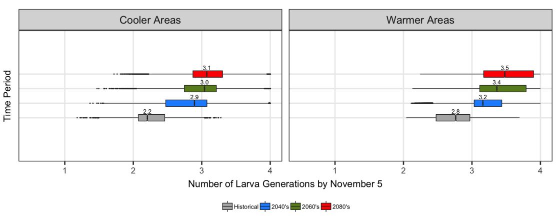
Show this for the larval stage. Show for August 23 and Nov 5.



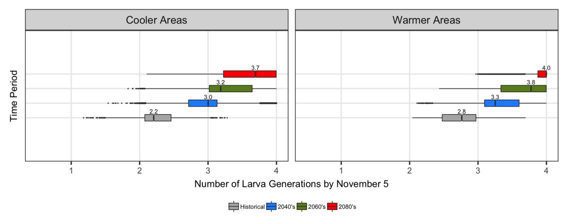
(a) Larva Gen. by Aug. (rcp 4.5)



(b) Larva Gen. by Aug. (rcp 8.5)



(c) Larva Gen. by Nov. (rcp 4.5)

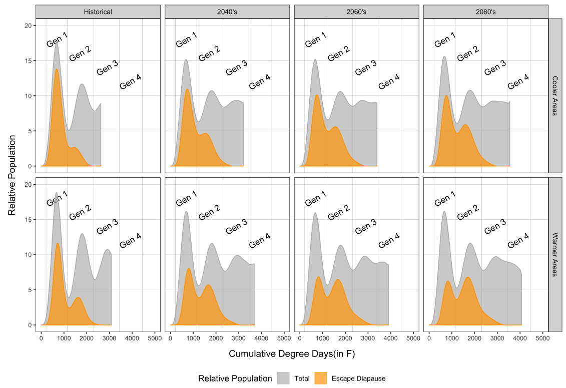


(d) Larva Gen. by Nov. (rcp 8.5)

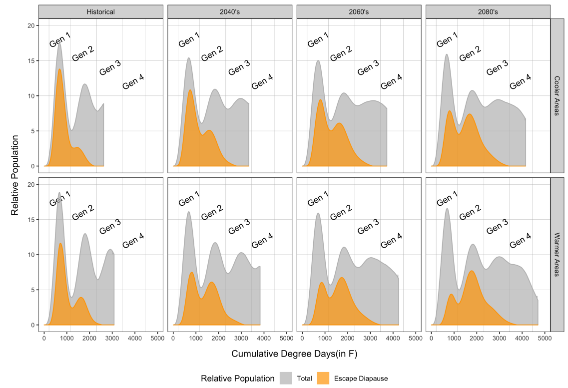
Figure 3: Changes in the number of generations of the pest

4.4 Relative fraction of larvae escaping diapause induction

Some text has to go here.



(a) Relative fraction of escaped larvae (rcp 4.5)



(b) Relative fraction of escaped larvae (rcp 8.5)

Figure 4: Relative fraction of larvae escaping diapause induction

4.5 Changes in potential for successful overwintering (need to create)

4.6 Changes in the window of opportunity for pest control (need to create)

Create bar plots related to the number of calendar days it takes for specific growth stages and show that it is reducing.

4.7 Effectiveness of pest control alternatives (Kirti to check with Vince)

Figures similar to the new ones Vince created comparing “No control”, “Spray only”, “Spray plus Mating Disruption”

4.8 Spatial variability in results

Select a few maps

4.9 Sensitivity analysis to moderations by indirect CO_2 effects?

Can add diapause to photoperiod sensitivity as well if needed? For a few select grids. (Added this section based on some lit review I found and added to the discussion section.)

5 Discussion (Kirti, Vince)

The timing of all codling moth growth stages shift to earlier in the year. In addition, a reduced time to complete each growth stage and longer season of higher temperatures both allow for a higher number of generations of the codling moth. This increased pest pressure is consistent with results focused on other parts of the United States and world [13, 15, 19] (Luedeling et al., 2011). This potentially implies the need for additional pesticide sprays and larger range of chemicals, which translates to increased cost of pest control. It also implies increased pesticide resistance risks. Given shifts in the relative fraction of larvae escaping diapause induction, the second generation of the codling moth is likely to be larger problem than has been in the past, and require more control.

There is limited discussion in the literature of potential management implications as a result of changing pest pressures due to warming. With accelerated completion of growth stages, the window of opportunity for pest control is reduced. Therefore if the ideal spray timing is missed even by a day, a larger number of codling moth escape control and cause damage. This underscores the importance of weather-based decision support products to forecast spray timing. On the flip side, if the timing is captured right, control mechanisms can be more effective under warming. For a given pesticide residual time or mating delay, a larger proportion of pests pass through susceptible growth stages and can be controlled. Although there is potential for more pest generations under warming, if the first generation of the pest is effectively controlled, the risk of damage from additional generations is minimal. A control program solely based on pesticides is not as effective and it is critical to include non-pesticide control mechanisms such as mating disruption in the mix. Something about mating disruption not being as sensitive to getting the application timing right because they have longer residual lives? California is already using...The longer season length might require availability of pheromone products that have a longer residual life than currently available. ***This section needs to be corrected and expanded.****

Multiple factors outside of what has been considered in this work can affect pest pressures and management implications under warming. Shifts in tree fruit phenology (harvest timing), and its intersection with shifts in insect phenology can have implications in terms of availability of food for larvae. Earlier fruit maturity under accelerated growing degree day accumulation, and resulting lack/unavailability of food for larvae could/can constrain development of additional pest generations postharvest. In this case, our pest pressure results would be an overestimate. However, from a practical orchard management perspective, apples left on the ground postharvest can act as a food source for CM larvae. Also increased pest pressures in backyard gardens - which are not well managed in comparison to commercial orchards - will continue to be an issue for commercial orchards bordering urban boundaries. Additionally, accelerated maturity in crops is typically associated with decreases in yields [16] , and as an adaptation response to address yield decreases, crop breeding technologies may provide slower maturing crop varieties. So food availability may not necessarily moderate potential increases in pest pressures to the extent expected.

Our results do not consider the effect of elevated CO2 levels on CM pressures and management because there are no critical direct effects on insect physiology and phenology [14]. However, elevated CO2 levels have a direct effect on the pest's host plant [14] by increasing the carbon to nitrogen ratio (less relative nitrogen which is a limiting factor for insect performance), and therefore there are potential indirect effects for pests: larvae need to eat more, delayed larval growth [18], and elevated mortality rates to stressors such as heat [17]. By not considering these indirect effects, we may be overestimating pest pressures.

Empirical models designed for historical conditions are extrapolated into the future. This assumes a continued linear response of insect phenology and physiology to elevated temperatures, while temperature responses are often non-linear and empirical models likely need adjustment to better represent responses to conditions outside of what they they were developed for [3] (Luedeling et al., 2011). Non-linearity and increased mortality of high temperatures, likely implies that pest pressures are overestimated. However, there is also experimental evidence that the codling moth has demonstrated ability to adjust to high temperatures [8]. Should we add some discussion of upper thresholds of the model, how often we exceed them etc., to show the model seems relevant until we go well into the future.

Based on field experiments at a limited number of locations for a limited number years, our model for the codling moth's diapause induction in Washington state is a function of just the photoperiod. In Mexico - at a lower latitude with higher average temperatures than Washington state - diapause induction has been modeled as a photothermic response [9], where it is dependent of photoperiod and temperature. The magnitude of pest pressure changes is highly sensitive to assumptions related to diapause induction [19], and there is very little we know about this aspect. Other studies related to impacts of climate change on codling moth pest pressures have either not considered the diapause induction aspect [13] (Luedeling et al., 2011), or assumed that diapause induction will evolve as a response to climate change [19]. Given that .....Vince to add something about why we believe this evolution does not seem likely in the time frames we are interested in.... , we extend our historical diapause induction model into the future. However, this is a critical aspect of uncertainty in characterizing impacts of climate change to the codling moth and pests in general.

Warmer winter, mortality in field. Higher survival in overwintering. Insufficient chilling unit distort time. Not synchronised emergence and spread out more. Male versus female effects. Effective numbers of males versus females are not synchronised. Males tend to come out early. Higher overwintering generations.

6 Conclusions (Vince, Kirti)

Consistent with other related work, there are signs of increased codling moth pressures under higher future temperature projections. However, it is likely that transformational changes in management would not be necessary. Multiple factors contribute to this. First, the first generation population that escapes diapause induction is likely lower, and if this first generation pest is controlled well, future increased potential number of generations are less of an issue. Second, if timed right, control mechanisms such as pesticides and mating disruption tend to be more effective under warmer temperatures. Third there is potential for a higher mortality rate under warming; however, the codling moth has shown strong adaptive capacity to this in experiments, and it may not be a moderating factor. Fourth, other factors such as indirect effect of elevated CO2 levels moderate temperature related increases in pest pressures, through delayed pest development. Although delayed development of pest reduces pest pressure in terms of the potential number generations of pest, it also potentially negates increases in effectiveness of pest control mechanisms. Knowledge gaps related to our understanding of pest response to warming - such as diapause induction, non-linearity in pest response to temperatures beyond the historical range, and pest/host interactions - lead to uncertainty in future projects of codling moth management. Many of the responses are competing in nature and negate each other. Therefore, while climate change impacts on codling moth pest pressures are largely negative when temperature effects are considered in isolation, multiple factors point to the possibility of a less severe net effect of climate change on codling moth pest pressures, and pest management unlikely to need major transformative changes.

7 Figures and Tables (Min, Giridhar)

8 Kirti's compiled list of potential references and summary notes

(Harrington et al., 2001) Discusses the question: Can climate change impacts on insects be predicted? Notes that with climate change there are implications for effectiveness of pest control mechanisms as well. This is however not discussed in the way we do it. More in terms of dryer future implying more suitable days for spraying. Can use as reference for noting implications for effectiveness of pest control measures. (Fleming & Tatchell, 1995) and (Zhou et al., 1996)

There is evidence for impacts in historical records as well. Historical long term records of aphids and advancement in phenology of 10 days over a period of 21 year for across several latitudes.

(Stoeckli et al., 2012) climate change impacts in a few regions in Switzerland. Assumes there will be adaptation in photoperiod requirements for diapause induction and does a sensitivity analysis. No detailed discussions on management implications. (Chidawanyika & Terblanche, 2011) We do not consider mortality rate under elevated temperatures. Can this be used as evidence that CM has demonstrated ability to adjust to it? (Luedeling et al., 2011) CM in Walnuts in California (currently 2 to 4 generations) Well written paper.

(Steinberg et al., 1988) Higher pre-diapause temperatures caused earlier diapause induction. Immature fruit delayed diapause induction. (Jacobo-Cuellar et al., 2005) Diapause induction as a function of photoperiod and temperature. (Maiorano et al., 2012) Discusses the fact that empirical models assume linear temp responses to continue in the same way, while in reality the responses are typically non-linear and level off. There is the heat stress aspect as well. So it may be not be appropriate to extrapolate these into the future. Perhaps briefly mention this as a potential limitation. We can reference Luedling et al. 2011 as well. (Patterson et al., 1999) Climate-change weeds, insects......

(Cossentine et al., 2004) Discusses something about CO2 in relation to fumigation of apple packing boxes. Don't think this is is applicable, but adding it just in case. (Gregory et al., 2009) Importance of integrating pests into the climate change/food security debate. Has useful references we could add. (Zvereva & Kozlov, 2006; Stiling & Cornelissen, 2007)

Zvereva Elevated Temp positively affects insect performance while Co2 negatively effects and when considering them simultaneous the effects are negated. Stiling note that under elevated CO2 there were considerable reductions in leaf miner consumption rate, total consumption, development rate etc.

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