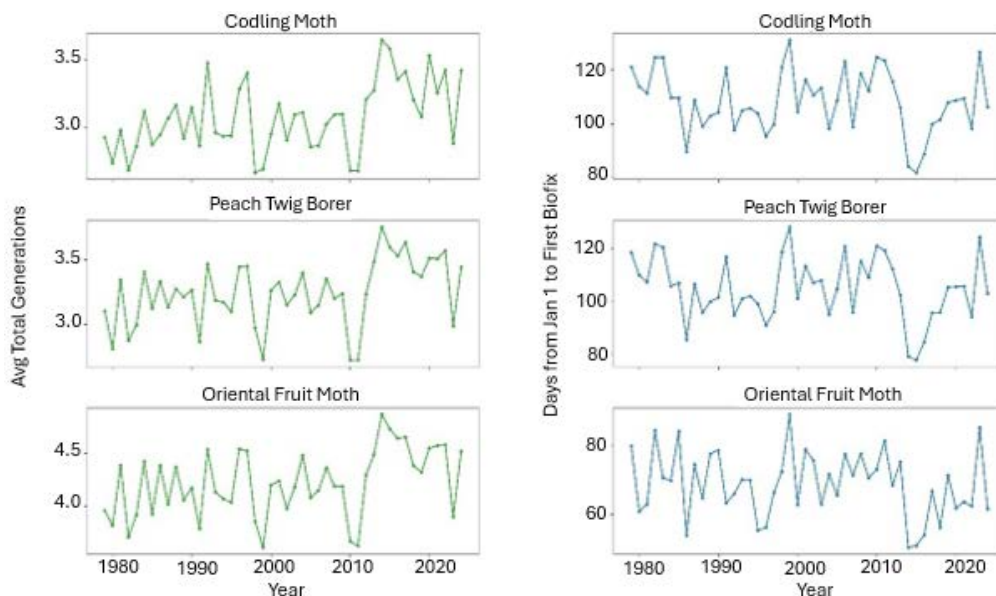


4.6 Fruit and Nut Pest Abundances

Temperature-based estimates suggest that major pests of high-value fruit and nut crops in California (the codling moth, peach twig borer, oriental fruit moth, and navel orangeworm) are developing faster. As temperatures have increased, so too have the average number of generations each year, while the time required for these pests to complete their lifecycles (from eggs to adults) has declined.

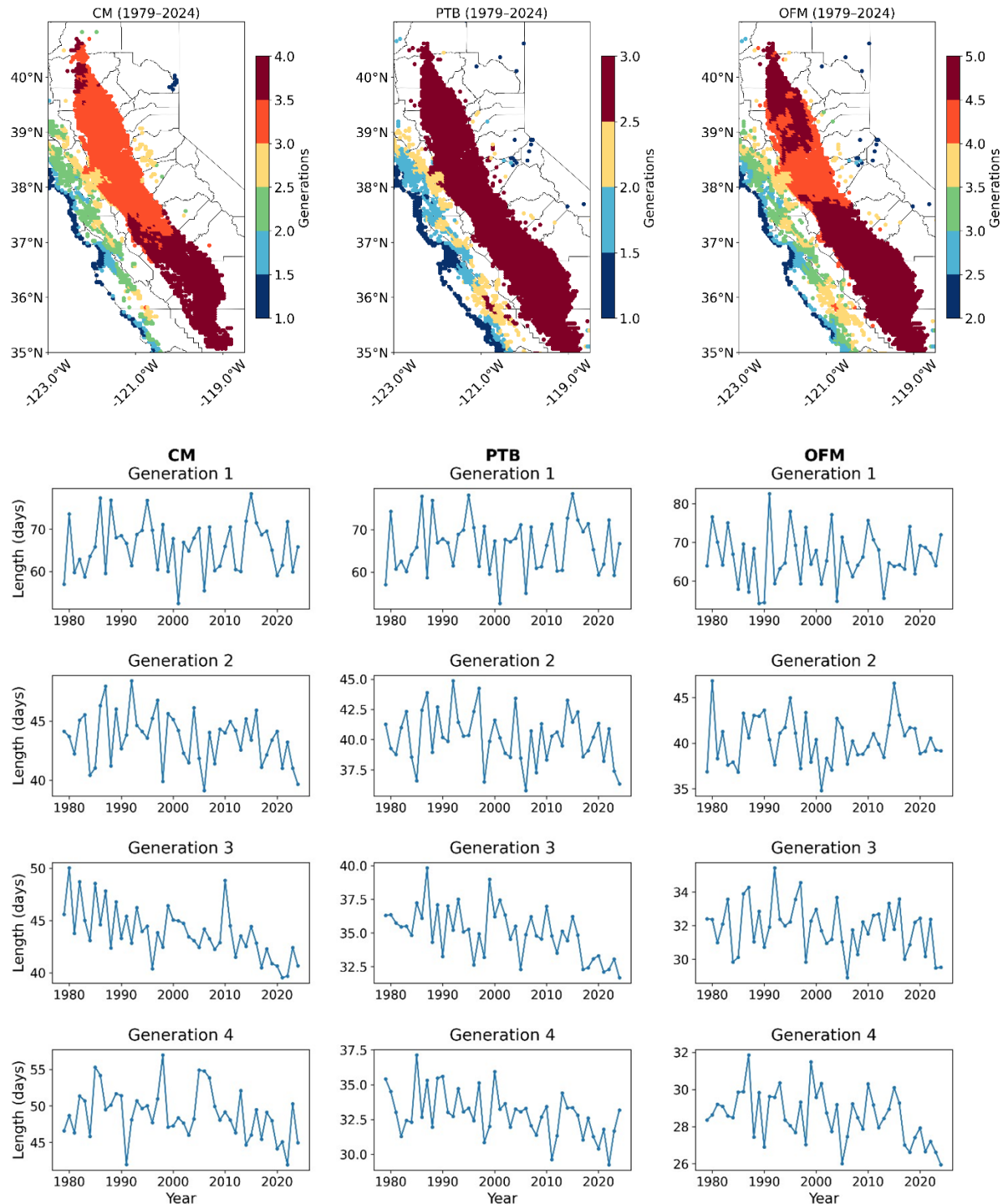
Figure 4.6.1. Estimated Number of Generations and Biofix Length.



The graphs on the left show the annual average number of days from January 1 to the first “biofix” (first adult moth emergence) for the codling moth, peach twig borer, and oriental fruit moth in major agricultural regions of California. The graphs on the right show the annual average total number of generations for each species (each generation represents one lifecycle, from egg to adult). Source: T Pathak/UC Merced, analysis based on metrics published in Jha et al. (2024)



Figure 4.6.2. Trends in the Number and Length of Generations.



The figures show rates of change from 1979 to 2024 in the number and length of generations for the codling moth, peach twig borer, and the oriental fruit moth (labeled CM, PTB, and OFM in the maps and graphs). Source: T Pathak/UC Merced, analysis based on metrics published in Jha et al. (2024)



What does the indicator show?

Lepidopteran (moth) pests, mainly codling moth (*Cydia pomonella*), peach twig borer (*Anarsia lineatella*), oriental fruit moth (*Grapholita molesta*), and navel orangeworm (*Amyelois transitella*), damage walnuts (*Juglans regia*), almonds (*Prunus dulcis*), and peaches (*Prunus persica*) - high-value specialty crops in California with a combined value exceeding \$6 billion (CDFA, 2025; Jha et al., 2024; Pathak et al., 2021).

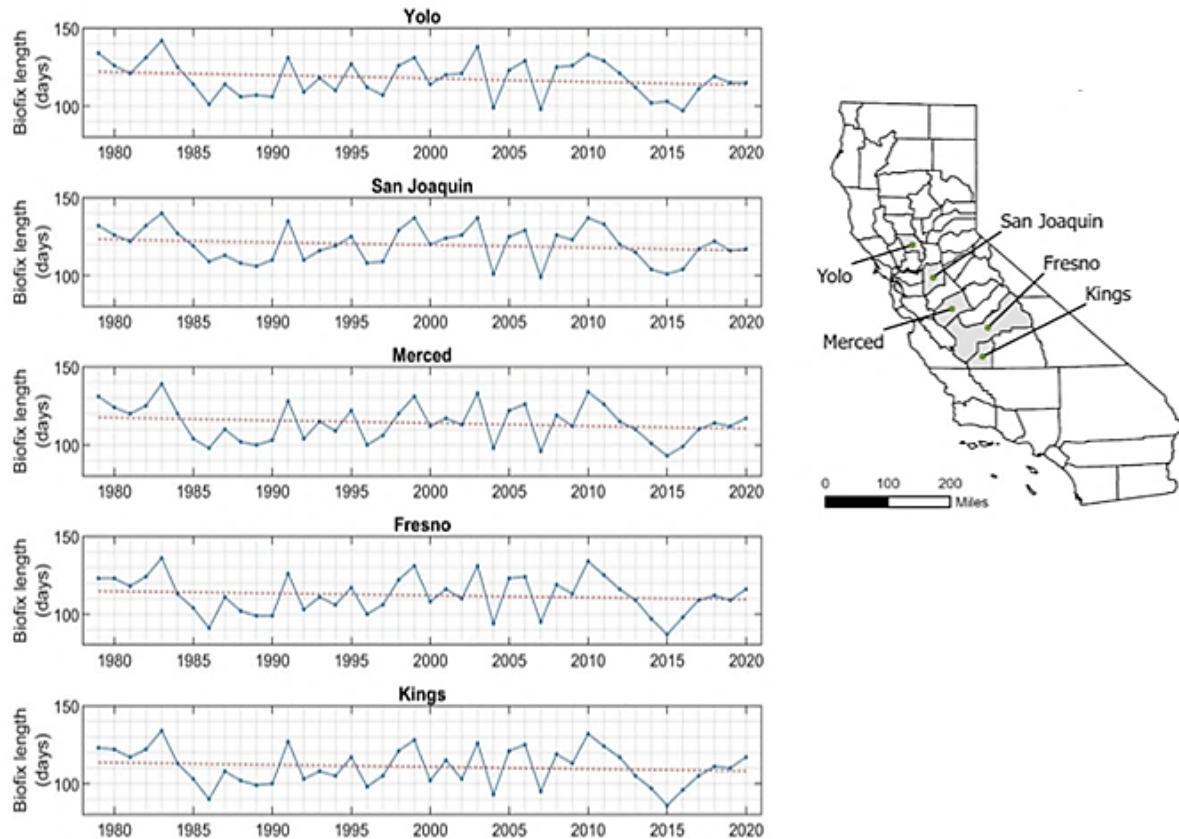
Pest development is tracked using temperature-based “growing degree day” models, which measure heat accumulation over time. Field-based observational data of pest lifecycles in the locations studied were incorporated into the model. Like crops, insects require a certain amount of accumulated heat to reach developmental stages and complete their life cycles. As temperatures rise, these heat thresholds are reached more quickly, accelerating development.

Consistent with warming trends, these pests are developing faster, resulting in shorter life cycles and more generations per year. [Figure 4.6.1](#) shows the number of days from January 1 to first adult emergence (“biofix”, used to calculate growing degree days and to track pest activity during the season). While this timing varies by year, the long-term trend since 1980 shows an annual increase in the number of generations, alongside a decrease in the time required to complete each generation ([Figure 4.6.2](#)). However, these trends do vary by region as changes to pest lifecycles occur more rapidly in the Central Valley than along the coast.

The navel orangeworm, another major pest of walnuts, almonds, and pistachios, shows similar patterns in the Central Valley. Over the past 41 years, the time required to complete each generation has declined ([Figure 4.6.3](#)), with the largest reductions occurring in the third and fourth generations, which develop during the warmest part of the season.



Figure 4.6.3. Estimated Biofix Length of Navel Orangeworm in Almond for Selected Counties in the Central Valley, 1979-2020



The dotted line represents the long-term linear trend. Source: T Pathak/UC Merced, analysis based on metrics published in Pathak et al. (2021)

Why is this indicator important?

Increased number of generations of pests also increases the number of sprays needed to control them, increasing the production cost for growers. A recent economic analysis estimated that the total cost of pest management for nine major crops in California was up to \$36.86 per acre in 2022 with pyrethroid applications (which increased in use from about 3 million acres treated statewide in 2002 to almost 6 million acres in 2022) and even higher with other methods (Goodhue et al., 2026). In 2023, about 176 million pounds of active pesticide ingredients were used in California (DPR, 2025). Plus, more use of insecticides has consequences for beneficial insects, the environment, and



human health. Tracking estimated changes in insect generations informs the agricultural industry about expected crop outcomes and supports investments in making varieties more resilient to these damaging pests. This information can be used to understand patterns in pest life cycles during the growing season for effective pest management. Publicly available decision support tools that integrate this and other important agricultural information to inform agricultural practices include the [CalAgroClimate tool](#).

Almost all walnuts grown in California are susceptible to damage from codling moth (UC IPM, 2023). This pest overwinters as a full-grown larva, whose first flight begins around late March to early April and can complete two or three generations in most places, with fourth generations found in some warmer areas (UC IPM, 2023). Each overwintered female lays about 30 eggs and this number doubles to 60 in later generations. The feeding of the first-generation larvae causes nutlets to drop from the tree, and the later generations feed on the kernels rendering them unsellable.

Damaged nuts, such as from codling moth infestations, serve as a breeding ground for navel orangeworm, which is the most damaging pest across three nut crops – almonds, walnuts and pistachios (Grant et al., 2020; Haviland et al., 2021). Navel orangeworm female moths lay eggs on a naturally split suture of the nuts. The freshly hatched larvae directly feed on the kernel, rendering it unmarketable (**Figure 4.6.4**). The damaged kernels become a preferred target for the saprophytic fungi *Aspergillus* spp., which produce carcinogenic toxins (aflatoxins) (Bentley et al., 2017; Grant et al., 2020; Haviland et al., 2019). Additionally, as damage to crops from navel orangeworms becomes more prevalent, greater use of pest control and pest management techniques will become necessary.



Figure 4.6.4. Damaged Nuts Due to Feeding of Navel Orangeworm Larva.



Source: Wilson et al. (2020)

The peach twig borer (*Anarsia lineatella*) is a major pest of almonds and peaches in California. Female peach twig borers lay eggs on twigs, fruits and leaves. The peach twig borer completes three to four generations each year (UC IPM, 2023). In almonds, larvae feed on both shoots and nuts causing damage to twigs and reducing the quality of kernels. The peach twig borer can attack shoots and fruits of peach as well. It starts attacking peach fruits from the color break stage until harvest and therefore multiple insecticide sprays are needed to minimize economic loss (Hasey et al., 2016).

The oriental fruit moth (*Grapholita molesta*) larvae bore deeper into the shoots of peaches and almonds than the peach twig borer. These pests can typically complete five generations per year, and up to six in years with warm early springs and late falls (UC IPM, 2023). The early generations (first and second) larvae attack peach shoots but as the fruits begin to develop and mature, they prefer to feed on fruit, which makes the fruit unmarketable. The early larval instar enters the fruit, feeds on and grows inside until the advanced larval stage, and then exits the fruit to pupate.

In addition, lifecycle trends may reflect a broader pattern across California of increased generations and faster development of agricultural pests, including invasive species introduced into California and are regulated by the California Department of Food and Agriculture and the U.S. Department of Agriculture to prevent permanent infestations.



These species may expand into previously unsuitable habitats as temperatures continue to rise. Warmer temperatures can also increase overwintering survival and allow some pests to complete more generations per year, increasing the potential for establishment and crop damage (OEHHA, 2022).

What factors influence this indicator?

Temperature directly affects the development of orchard pests, with estimated developmental thresholds ranging from 10°C to 31°C (50°F to 88°F) for codling moth and peach twig borer, 7°C to 32°C (45°F to 90°F) for oriental fruit moth, and 13°C to 35°C (55°F to 95°F) for navel orangeworm (Jha et al., 2024; Pathak et al., 2021). Globally, insect growth rates in tropical regions are expected to decline because current temperatures are already near their optimal range, whereas growth rates for insects in temperate regions (such as those in California) are projected to increase as temperatures continue to rise (Sunil et al., 2023). Humidity, precipitation, and wind affect the body temperature and thus the development of these pests as well (Pathak et al., 2021). Humidity can enhance body temperature, while wind and precipitation can lower it. Orchard sanitization, pesticides, and early harvest are examples of agricultural practices that may reduce their populations (Bentley et al., 2017; Grant et al., 2020; Haviland et al., 2019).

Technical considerations

Data characteristics

The metrics presented for the codling moth, peach twig borer, oriental fruit moth, and navel orangeworm are based on Jha et al. (2024) and Pathak et al. (2021). Gridded temperature data from [gridMET](#) were generated by blending spatially rich data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) with temporally rich data from the North American Land Data Assimilation System Phase 2 (NLDAS-2) using climatically aided interpolation (Abatzoglou, 2011). Daily minimum and maximum temperature data at 4-km spatial resolution from 1979 to 2024 for the codling moth, peach twig borer, and oriental fruit moth, and 1979 to 2020 for the navel orangeworm, were collected and used in this analysis.



A growing degree-days model was used to predict the timing of various life stages of the selected pest species. In this model, growing degree days, which represent daily heat accumulations, were calculated from the minimum and maximum temperatures based on pest species' biological thresholds. Calculations of the number of days required to reach biofix and to complete the life cycle enabled estimates of the total number of generations. Details of the calculations and variables used (e.g., temperature thresholds, growing degree day end dates, generation lengths, etc.) can be found in Jha et al. (2024) and Pathak et al. (2021).

Strengths and limitations of the data

Temperature-based degree-days models to estimate the lifecycle of agricultural pests have been used globally. Zalom et al. (1997) validated the navel orangeworm degree-days model in field conditions. Despite this, uncertainties associated with model parameters and inherent model uncertainties can influence the outputs. Models also do not capture every possible environmental condition, such as mortality due to extreme heat.

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