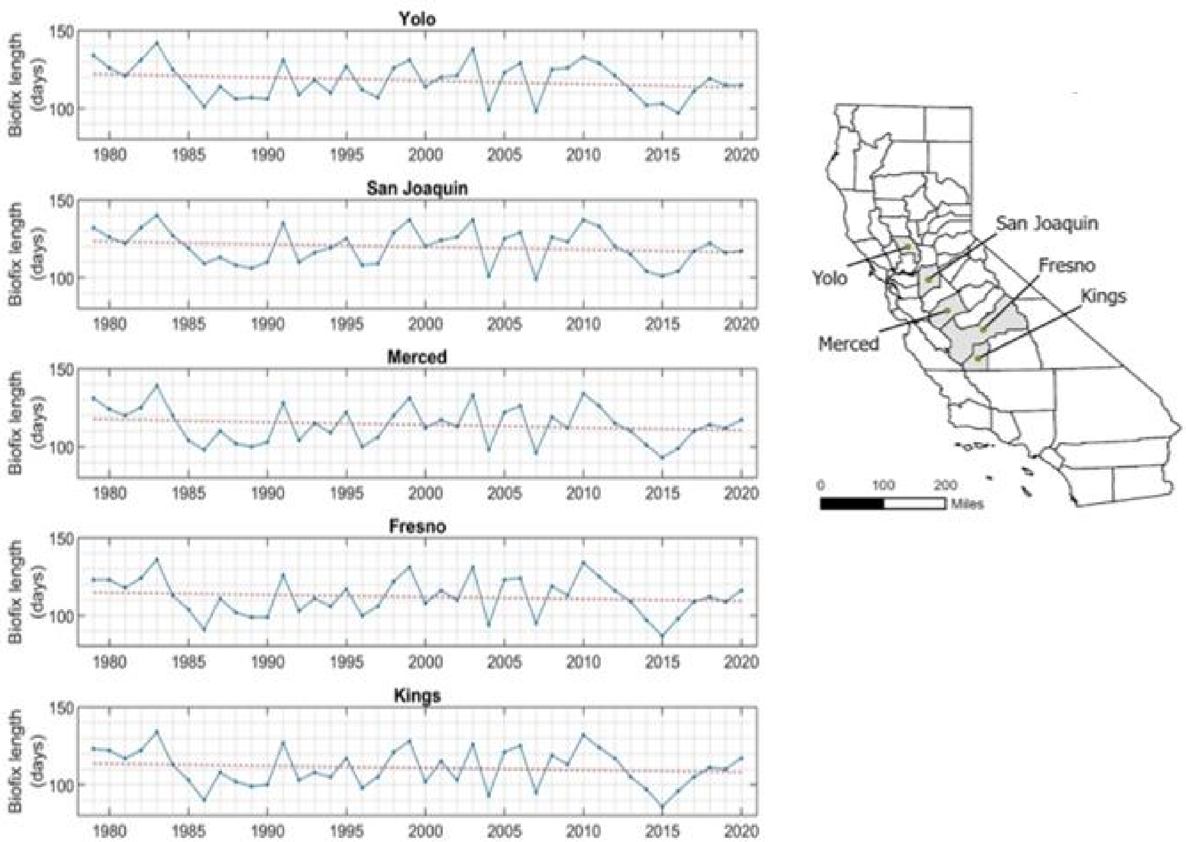
NAVEL ORANGEWORM ABUNDANCE

The navel orangeworm is a temperature-sensitive, highly damaging insect pest of nut crops (walnut, almond, and pistachio). In the Central Valley, temperature-based estimates indicate that the time required for a navel orangeworm to complete its life cycle has declined with warming from 1979 to 2020. The adults (moths) now appear earlier in the season and complete their lifecycles faster. With each successive generation of navel orangeworm, the population of these pests increases.

Figure 1. Estimated length of biofix* of navel orangeworm in almond for selected counties in the Central Valley, 1979-2020



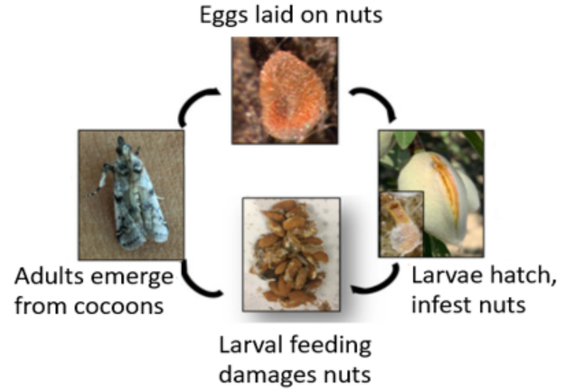
Source: Pathak et al., 2021 (updated)

**The "length of biofix" refers to the estimated number of days from emergence of larvae to the first appearance of the adult moth.*

What does the indicator show?

The navel orangeworm, *Amyelois transitella*, is a major pest of nut crops. Despite its name, the orangeworm is not a significant pest of citrus fruits -- its name comes from when it was first noticed by entomologists in the southwestern United States as it infested citrus fruits (Wilson et al., 2020). Figure 1 presents the estimated length of time (number of days) each year for the adult navel orangeworm to emerge from eggs (see life cycle diagram, Figure 2). This emergence is a biological event referred to as "biofix." A declining trend in the time it takes to reach biofix is evident for the Central Valley counties presented: since 1979, biofix is happening earlier, ranging from almost 9 days earlier in Yolo County to about 5 days in Fresno and Kings Counties (see Table 1). The estimates shown in Figure 1 were obtained using a "growing degree day" model. "Growing degree days" is a widely accepted unit of heat accumulation over time. As with crops (see *Fruit and nut maturation time* indicator), different insects have different heat requirements for development. A sufficient amount of heat – measured as growing degree days – must be accumulated to reach each life stage (such as biofix) and to eventually complete a full life cycle (from egg-laying to adult moth). As temperatures increase, the amount of time it takes for heat units to accumulate and reach these heat requirements decreases.

Figure 2. Lifecycle of the navel orangeworm



Source: Pathak et al., 2021

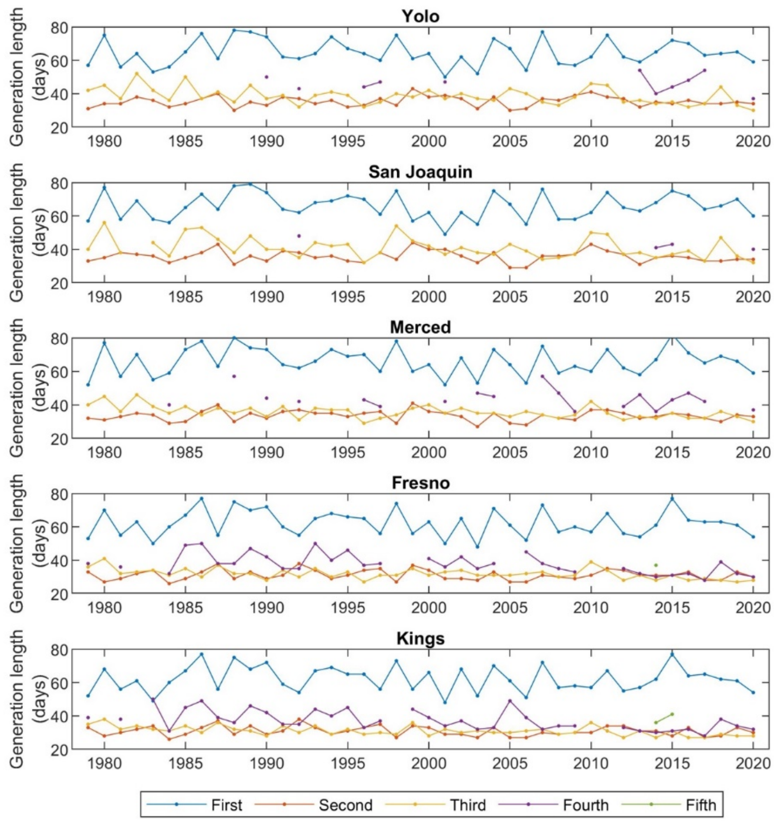
Table 1. Trends (number of days per year) in the duration of biofix and of the 1st through 5th generations of the navel orangeworm in Yolo, San Joaquin, Merced, Fresno, and Kings counties (1979-2020)

	Yolo	San Joaquin	Merced	Fresno	Kings
Biofix	-0.21	-0.18	-0.17	-0.13	-0.13
1st generation	-0.02	-0.01	-0.02	-0.05	-0.03
2nd generation	0.02	-0.03	-0.01	-0.02	-0.04
3rd generation	-0.17	-0.19	-0.16	-0.12	-0.13
4th generation	-0.04	-0.28	-0.12	-0.26	-0.27
5th generation	0	0	0	0.02	5.00

**Red text indicates statistically significant trends ($p < 0.05$).*

Similar to biofix trends, the estimated length of time for the navel orangeworm to complete each generation has also shown declining trends over the past 41 years (Figure 3 and Table 1). As expected with warming temperatures, the navel orangeworm has developed rapidly, resulting in reductions in the duration of the lifecycle for each generation. The duration of the third and fourth generation lifecycles – which occur later in the warm season when temperatures tend to be higher – declined the most.

Figure 3. Generation length of navel orangeworm in almond for selected counties in the Central Valley, 1979-2020



Source: Pathak et al., 2021 (updated)

Generation length refers to the estimated number of days it takes for navel orangeworm to complete one generation (from egg-laying to adult moth).

As a result of the reduced time for each lifecycle, the number of generations of navel orangeworm over the 41-year period has increased. For instance, in Yolo County the navel orangeworm accumulated a maximum of three generations until the late 1990s. However, in recent years, a fourth generation has become more common, suggestive of an upward trend in the number of generations. A fifth may also become more common under future climate conditions if trends toward shorter lifecycle durations and increasing generations continue. With each successive generation of navel orangeworm, the population of these pests increases.

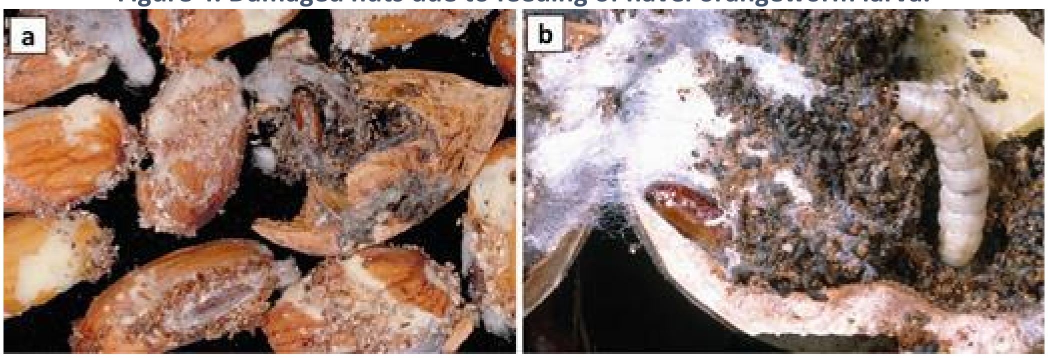
Why is this indicator important?

California is a leading producer of three major nut crops: walnut, almonds, and pistachios. The total cash value of these three crops exceeds $8 billion (CDFA, 2020). The navel orangeworm is considered the most damaging agricultural insect pest for these three important nut crops.

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).

The damaged kernels become a preferred target of the saprophytic fungi, *Aspergillus* spp., which produce carcinogenic toxins (aflatoxins) (Bentley et al., 2017; Grant et al., 2020; Haviland et al., 2019). Therefore, the economic impacts of navel orangeworm come from both the direct feeding damage and the indirect damage caused by contamination of marketable nuts with aflatoxins. 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. Damaged nuts due to feeding of navel orangeworm larva.



Source: Wilson et al., 2020

What factors influence this indicator?

The navel orangeworm is cold-blooded, so the temperature is the main factor in its growth and development. As temperatures continue to rise across California, tracking developmental rates and population dynamics of the orangeworm will become even more critical for strategic planning and minimizing risks associated with this pest. In addition, temporal trends observed with the navel orangeworm might reflect a broader pattern of increased generations and faster lifecycles of other pests in California as temperatures warm (Pathak et al., 2021).

Humidity, precipitation, and wind speed also affect their body temperature and thus their growth and development (Pathak et al., 2020). Factors other than climate that can potentially control the spread of this pest include biological controls, orchard sanitization in winter, timely pesticide applications, and early harvest to decrease risks to nut crops (Bentley et al., 2017; Grant et al., 2020; Haviland et al., 2019).

Technical considerations

Data characteristics

The metrics presented are based on Pathak et al., 2020. In this study, gridded temperature data from gridMET were used. GridMET was 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 updated minimum and maximum temperature data at 4-km spatial resolution from 1979 to 2020 were collected and used in this analysis.

A growing degree-days model was used to predict the timing of various life stages of navel orangeworm. In this model, growing degree days, which represent daily heat accumulations, were calculated from the minimum and maximum temperatures of 12.7 °C and 35 °C (based on the navel orangeworm's biological thresholds). 12.7 °C is the temperature at which orangeworm activity begins in the spring, and 35 °C indicates the temperature above which insect development begins to decrease or stop. The biofix for navel orangeworm occurs at around 148 °C degree days around the central portion of the Central Valley, so the biofix date was set when degree days reached 148 °C. The first generation completes its lifecycle in 565 °C degree-days (Siegel and Bas Kuenen, 2011; Zalom et al., 1997). It takes a fewer number of degree days to complete one generation for subsequent generations due to in-season nuts being nutritionally better in quality than the early season nuts available to the first generation, i.e., 444 °C for almond and walnut and 402 °C for pistachio (Siegel et al., 2010; Siegel and Bas Kuenen, 2011). October 31 was the last day for calculations, as nearly all nut crops are harvested by then, and there is a negligible activity of navel orangeworm due to the significant drop in daily temperatures.

Strengths and limitations of the data

Temperature-based degree-days models to estimate the lifecycle of agricultural pests have been widely used around the world. Zalom et al. (1997) have validated the navel orangeworm degree-days model in field conditions. Despite that, uncertainties associated with parameters and inherent model uncertainties can influence the model outputs. Additionally, pest models are simplified versions of complex systems, and many factors influence the growth and development of these pests. For instance, the degree days model does not account for pest mortalities related to extreme heat events, which may influence the expected pest pressure.

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