What if the assumption made in this study of a few homes experiencing defensive actions is incorrect and the defensive actions were more extensive or significant than assumed? For example, while the total number of homes defended might represent a small percentage overall, the significance of these actions for structure survival could be substantial in that they were a primary factor stopping fire spread to downwind surviving structures. Also, the DINS (damage inspections) might underestimate the full extent of defensive actions at this fire. How would the findings of this study change if defensive actions were a significant or the most significant predictor of structure survival as found by a separate study on the Camp Fire (https://www.publish.csiro.au/wf/fulltext/WF21176)?

The DINS data was our source for the percentage of homes experiencing defensive action. Of the 400 homes in our subsample dataset, defensive action was noted for seven (1.6%), with six of those surviving. This relatively low percentage (compared with other wildfires) is corroborated by documents such as the NIST report, the Troy et al. 2022 paper in the link who reported 1.5% of houses experienced defensive action and assumed the other 98.5% did not, fire-fighting contacts who were on the fire, and media reports. Still, it is always possible that the proportion of homes experiencing defensive action was underestimated. The DINS data are imperfect, with defensive action noted after the fact when evidence may no longer be as apparent. Also, DINS data were not collected on undamaged surviving homes, some of which might have been undamaged because of defensive action.

Underestimation of defensive action, or downwind consequences of that action, if any, should have little bearing on our findings. Defensive action would tend to dilute the effects of other variables, like canopy cover, or distance to nearest destroyed structure, because it adds another source of variation. So, if defensive action had been more prevalent than the CAL FIRE DINS data indicate, the fact that these variables came out as strongly in the model as they did would suggest they are even stronger indicators of home survival than we reported.

Whether defensive action was widespread or whether defensive action was a significant predictor or survival are two different questions. The Troy et al. 2022 paper found defensive action to be a highly significant predictor of survival. This is because even though the number of homes defended was small, the effect on survival of those homes was very large – most survived. We did not include defensive action in our statistical models because of missing data and low sample size.

Defensive action is exceedingly important for home survival on many wildfires. For example, on the 2021 Caldor Fire, resources poured into the Tahoe Basin in the days prior to the fire reaching Echo Pass, and massive response, with an engine parked in front of many homes, prevented home loss in Christmas Valley. But in fires like this one, where fire-fighting resources are overwhelmed by the sheer magnitude of the event, a large proportion of homes might go undefended.

Maranghides, A., E. Link, W.R. Mell, S. Hawks, M. Wilson, W. Brewer, C. Brown, B. Vihnaneck, and W.D. Walton. 2021. A case study of the Camp Fire – fire progression timeline. Gaithersburg: National Institute of Standards and Technology.

Is convection a flame spread mechanism worth considering in addition to the other three?

The three examples in Yana's slide were mechanisms by which houses typically catch fire: flame contact, ember ignition, or radiant heat, rather than the three mechanisms of heat transfer – conduction, radiation, and convection. The direct flame contact mechanism might mean anything from a creeping

ground fire to convective heat transfer from a more substantial vegetation fire nearby. Photos from the Camp Fire and other urban conflagrations show that vegetation is often most impacted next to a destroyed house. So, in these urban environments, convective heat transfer from burning houses may impact vegetation just as much or more than convective heat transfer from burning vegetation impacts homes.

Is this fire a good example to say that defensible space via vegetation management isn't as important as we thought it was given that there was virtually no structure protection initiated by firefighters as they focused on rescuing people?

Defensible space is most valuable if there are firefighting resources available to defend. In many wildfires, they are. The Camp Fire was a bit of an anomaly, but seemingly increasingly less so. Because the flaming front was so massive and impacted Paradise so quickly after the fire started, substantial resources were not yet in place. The focus was on getting people out, and not so much on defending, though some defensive action did occur. Defensible space is often very important, but the outcome from this and other recent destructive wildfires highlights that it is ideally done in combination with maintenance and/or retrofitting, to also enhance survival probability in the event firefighting resources are not available to defend the home. Additionally, our societal understanding of defensible space is evolving from creating a place where fire professionals can stage and safely defend the home, to a broader understanding of how to limit building ignitions and transmission pathways. Specifically, in California, we now have a three-zone defensible space system (see the illustration and descriptions below).

Zone 0 (0-5 feet from the structure) reduces the likelihood of structure ignition by reducing the potential for direct ignition of the structure from flame contact, ignition by embers that accumulate at the base of a wall, and/or indirect ignitions when embers ignite vegetation, vegetative debris or other combustible materials located close to the structure.

Zone 1 (5-30 feet) reduces the likelihood of fire burning directly to the structure. This is accomplished by modifying fuels and creating a discontinuity between planting groups that limits the pathways for fire to burn to the structure and reduces the potential for near-to-building ember generation and radiant or convective heat exposures. An additional purpose of this zone is to provide a defendable zone for fire personnel to stage and take direct action.

Zone 2 (30-100 feet or the property line if closer) actions are designed to reduce the potential behavior of an oncoming fire in such a way as to drop an approaching fire from the crown to the ground. Fuel

modification includes removing dead vegetation and reducing living vegetation to eliminate fuel ladders and create vegetation separation between individual or islands of trees or shrubs. These vegetation modification requirements are more significant for those properties with steeper terrain, larger and denser fuels, highly volatile fuels, and areas subject to frequent fires. Additional benefits of Zone 2 include facilitating direct defense actions, as well as improving the function of Zones 0 and 1 by reducing the flame heights and the potential for ember generation and heat exposure to structures.

Is there any evidence (maybe not in Paradise) that a well-designed high-density housing could be more fire resilient than these single-family structures?

Yes. Analyses of Southern CA wildfires have found fewer losses with higher density development. It is possible that vegetation and development pattern differences in S. CA lead to different outcomes than we found in our study. For example, higher density development may have paved over the chaparral that otherwise posed a fire hazard. Live ponderosa pine and black oak forest, such as what was common in Paradise, is different and somewhat less volatile than S. CA chaparral. Paradise is also relatively low density, with larger lot sizes than in many other communities.

High density development is only a problem if one of the houses ignites, but can be a real challenge to manage once ignitions occur, as seen in Coffee Park (Santa Rosa) in the Tubbs Fire. Design and maintenance to minimize ember intrusion or ember ignition might overcome any disadvantage posed by higher structure density.

Syphard, A.D., T.J. Brennan, and J.E. Keeley. 2014. The role of defensible space for residential structure protection during wildfires. International Journal of Wildland Fire 23 (8): 1165–1175. https://doi.org/10.1071/WF13158.

Syphard, A.D., T.J. Brennan, and J.E. Keeley. 2017. The importance of building construction material relative to other factors affecting structure survival during wildfire. International Journal of Disaster Risk Reduction 21: 140–147. https://doi.org/10.1016/j.ijdrr.2016.11.011.

I understand that your 100 m of overstory was not able to consider what understory looked like. Are there efforts to do that kind of research, where understory can be brought into the analysis too?

The challenge in doing so is the difficulty in quantifying understory vegetation and fuels after the fact, when much has been consumed. If such data are collected in a community prior to a fire, the probability of the area actually burning in a subsequent wildfire is very low. (It is also very difficult to estimate where the next fire will be and surface fuel conditions can change rather quickly with annual leaf drop, change in property ownerships, and accumulations of stuff that can act as fuels on a property.) In our study, using imagery rather than data collected by crews on the ground, it was difficult to view the understory due to the relatively high tree canopy cover.

A few questions...1) Can you say more about the updates to the building code in ~2008? Were those changes about the structure AS WELL as the location/siting of the building? Given the effect of year built (which pointed to 1973), what can someone do to harden a home built in 1972.

2) Just as one measures canopy cover within a given radius, did you measure the "housing" cover or cover of buildings within a given radius?
3) What is it about gutters that lead to fire? The gutter material or the content of the gutter?

1. Chapter 7a codes apply to materials used in fire-resistant construction, and not the location/siting of the building. Yana mentioned some retrofit ideas that might improve survival of older homes. The highest priorities are the roof, vents, and near to home defensible space. The goal is to have these features resist ember intrusion. Where buildings are closer together and radiant heat issues may become an issue, use of double-paned windows with one pane of tempered glass can be helpful, as would increasing the fire rating of a wall that may be exposed to radiant heat. More information can be found at https://ucanr.edu/sites/fire/Prepare/Building/
2. We did not measure housing cover, but we did measure housing density (# homes within 100 m), which should be roughly proportional to housing cover.
3. Gutter contents are the issue – the accumulated litter. Embers can easily roll off the roof, into the gutter, and ignite the contents. Metal gutters don't burn, but the fire in the gutter impinges on the roof edge and under roof area giving access to the attic. Vinyl gutters have a relatively low melting point and may detach from the roof. This could be a benefit (it removes the heat source from igniting the roof boards), or a problem if the burning detached gutter contents lands on something else flammable, or causes flames to impinge on the siding. Installation of noncombustible gutter guards are one technique to prevent combustible material from accumulating in the gutter, but keep in mind that they still require maintenance.

One of your slides showed a large diameter tree about 3 feet from a house, but not apparently being a problem for the house. Do you have a sense for whether large diameter trees are actually a problem in that 0-5 ft zone? Clearly it increases the maintenance needed, but what about the large well limbed up trunks themselves?

As you mentioned, the proximity of the tree is mainly a problem because of the litter that tree might produce, which can accumulate on the roof or in gutters. A well-maintained and pruned tree, without low hanging branches, is not a threat if this litter and other downed fuels are cleaned up. Noncombustible gutter guards might also help. The reason homeowners had been discouraged from allowing tree canopies to grow over the roof was not due so much to concerns that the tree would catch fire and threaten the house, but concerns that if the house catches fire, the tree above the roof can torch, sending embers through the neighborhood and igniting other homes. The tree branches should not touch and wear on the roof or be near a chimney.

Trees also provide valuable shade, so it is an important trade off. Many trees have been needlessly cut down because of lack of understanding of the mechanisms.

See: *Gibbons, P., A.M. Gill, N. Shore, M.A. Moritz, S. Dovers, and G.J. Cary. 2018. Options for reducing house-losses during wildfires without clearing trees and shrubs. Landscape and Urban Planning 174: 10–17. https://doi.org/10.1016/j.landurbplan.2018.02.010.*