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EDITORIAL

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Contents

OCTOBER–DECEMBER 2022 • VOLUME 76, NUMBER 4

Research and review articles

COVER: Pollinators throughout the world are experiencing declines due to habitat degradation, pesticide exposure, disease, and climate change. Although pollinators and the services they provide to agriculture are not the primary focus of carbon farming, numerous carbon storage practices, such as the hedgerows shown here, can be adapted to benefit pollinators without diminishing climate outcomes or economic benefits to farmers (see Sardiñas et al., page 104). *Photo*: Will Suckow.

RESEARCH ARTICLE

Carbon farming can enhance pollinator resources

Carbon farming can help protect bees and other wild pollinators that are essential to California agriculture.

by Hillary S. Sardiñas, Rebecca Ryals and Neal M. Williams

Online: https://doi.org/10.3733/ca.2022a0014

Abstract

Native California bees and other wild pollinators, which are essential to many fruit and vegetable crops, are being threatened by climate change, pesticides and habitat degradation. Carbon farming, a set of practices that sequester carbon in the soil or woody biomass, can create habitat that supports these pollinators. This paper focuses on habitat management and farming practices that both increase carbon sequestration and benefit pollinator communities. By incentivizing and supporting conservation practices that incorporate carbon farming, we can protect wild pollinators and increase the resilience of California agriculture in the face of ongoing climate change.

Climate change is impacting California agriculture in many ways. Climate-associated shifts in ecological regimes, including rising temperatures and increased wildfires, droughts and floods, are negatively affecting populations of beneficial insects, including pollinators, that provide ecosystem services — benefits humans derive from nature — to crops (Giannini et al. 2017). A reduction in pollinator populations could lead to lower crop yields (Allen-Wardell et al. 1998; Rader et al. 2013) as well as less consistent crop production (Pathak et al. 2018; Reilly et al. 2020). As the largest producer of fruits and vegetables in the United States (according to the California Department of Food and Agriculture), it is critical for California agriculture to build resilience to climate change in order to help maintain global food security.

Modest modifications to many carbon storage practices on farms, such as the hedgerows and riparian restoration shown here, can yield large benefits to pollinators without diminishing climate outcomes or economic benefits to farmers. *Photo:* Sam Earnshaw.

Carbon storage, like pollination, is an ecosystem service. Carbon farming is an array of agricultural practices that aim to reduce greenhouse gas (GHG) emissions or increase carbon sequestration (Toensmeier 2016). In rangelands and crop fields, carbon can be stored in aboveground vegetation or in the soil as soil organic matter (SOM) — a combination of roots, dead plant matter, and microbial biomass. SOM improves soil health and productivity, which can decrease inputs including synthetic nutrients and water, and help increase yields in both crop and rangeland systems (Oldfield et al. 2019; Ryals and Silver 2013). However, for pollinated crops, yields may remain low if pollinators are limited (Reilly et al. 2020). Certain carbon farming practices can bolster pollinator populations which, in turn, can help promote pollination to improve crop yield (Albrecht et al. 2020; Garibaldi et al. 2014; Garibaldi et al. 2016).

Pollinators enhance crops

One-third of crops are pollinator-dependent (Aizen et al. 2009), with approximately 75% of fruits and vegetables producing higher yields when pollinated (Klein et al. 2006). Although honey bees provide critical pollination to a vast array of crops, they are negatively impacted by disease (e.g., Traynor et al. 2016) and their pollination effectiveness is projected to decrease as rising temperatures limit their productive periods (Rader et al. 2013). A diverse pollinator community can help minimize and buffer the effects of the projected decline in honey bee availability (Brittain et al. 2013; Garibaldi et al. 2013) because wild native bees tolerate a wider variety of environmental conditions and provide ecological redundancy (Rader et al. 2013), which can contribute to resiliency.

Pollinators throughout the world are experiencing declines (e.g., Goulson 2019). Habitat destruction and degradation, pesticide exposure, disease and climate change contribute to these losses (Kjøhl et al. 2011). Although pollinators and the services they provide to agriculture are not the primary focus of carbon farming, modest modifications to many carbon storage farm practices can yield large benefits to pollinators without diminishing economic benefits to farmers or climate outcomes.

Adapting carbon farming

Numerous carbon farming practices can be adapted to benefit pollinators (fig. 1; table 1). In fact, many are

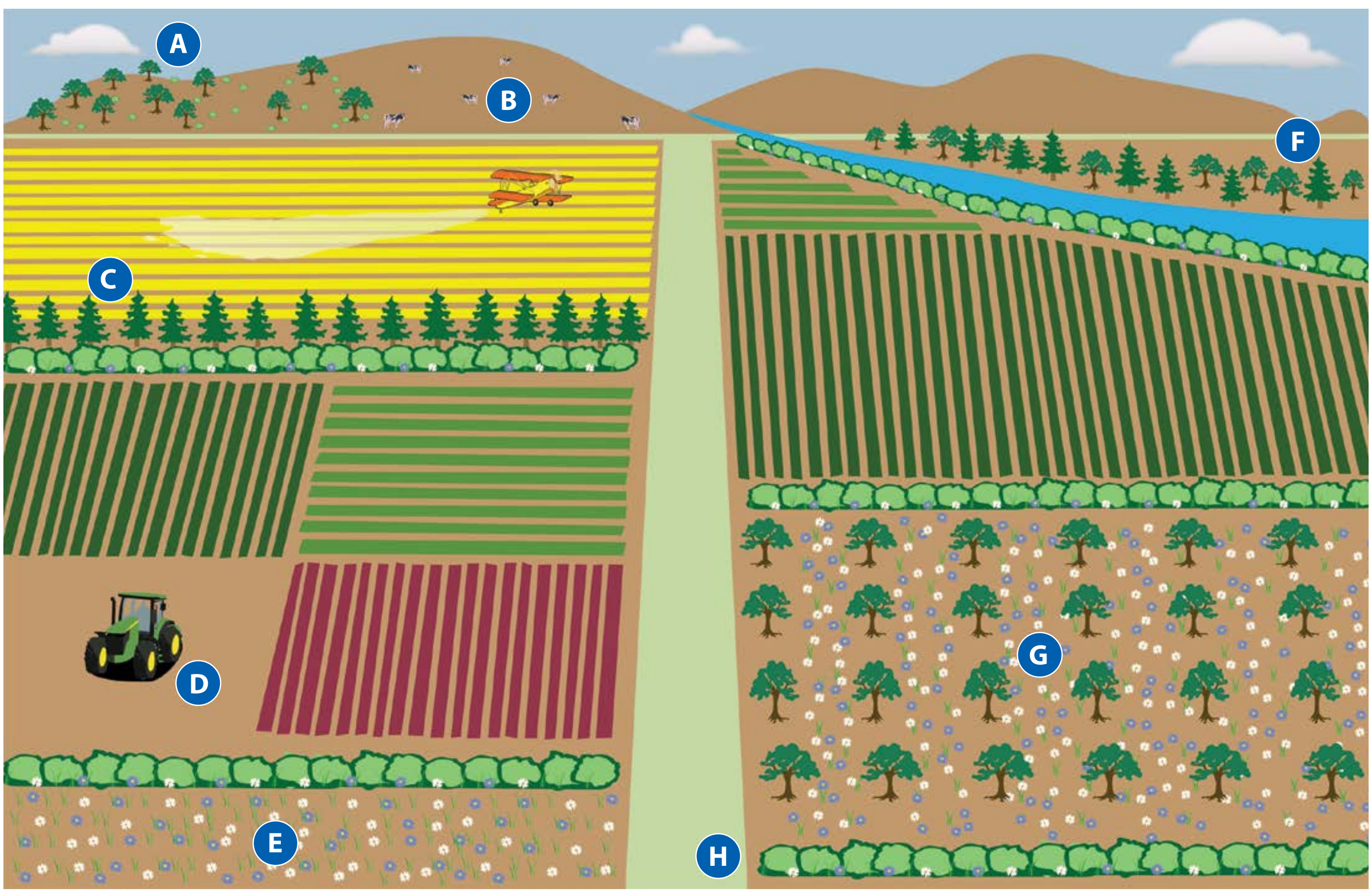

FIG. 1. Potential carbon-beneficial pollinator-friendly practices that can be implemented in agricultural landscapes. (A) Tree/shrub establishment, (B) prescribed grazing, (C) windbreak, (D) reduce/eliminate tillage, (E) field border, (F) riparian planting (woody or herbaceous), (G) cover crops, (H) hedgerow. *Illustration*: Jamie Tibbetts.

TABLE 1. Carbon farm practices approved by CDFA and NRCS that can be adapted to benefit pollinators*

Practice	CPS	Unit	Description	Pollinator-beneficial adaptation	Carbon-sequestration potential	Crop	Orchard/ vineyard	Range
Conservation Cover†	327	ac	Permanent vegetative cover of forbs, grasses and/or legumes.	Plant species that provide floral and nesting resources.	0.6	x	x	
Cover Crops†	340	ac	Temporary plantings during fallow winter or summer periods, or as a seasonal understory in perennial cropping systems.	Plant flowering species and allow them to bloom before terminating.	0.4	x	x	x
Field Border†	390	ac	A strip of permanent vegetation established at the edge of a field.	Plant species that provide floral and nesting resources.	0.9	x	x	
Hedgerow Planting†	422	lf	Establishment of woody vegetation along field edges.	Plant species that provide floral and nesting resources.	0.9	x	x	x
Prescribed Grazing	528	ac	Management of vegetation with grazing and/or browsing animals.	Manage timing, frequency, duration, or intensity of grazing to encourage flowering plants and minimize disturbance of host plants.	< 0.1			x
Range Planting	550	ac	Establishment of perennial or self-sustaining vegetation such as grasses, forbs, legumes, shrubs and trees on rangelands.	Plant flowering native or non-native species.	0.3			x
Residue and Tillage Management – No Till	329	ac	Eliminate soil disturbance and manage plant reside.	Eliminating tillage can help promote ground-nesting bees.	0.2	x		
Residue and Tillage Management – Reduced Till	345	ac	Limit soil disturbance and manage plant reside.	Reducing tillage can help promote ground-nesting bees.	0.1	x		
Riparian Forest Buffer†	391	ac	Permanent woody vegetation along riparian areas.	Plant native tree species that provide habitat or resources for pollinators.	2.0	x	x	x
Riparian Herbaceous Cover†	390	ac	Permanent herbaceous vegetative cover along riparian areas.	Plant species that provide floral and nesting resources.	0.2	x	x	
Tree/Shrub Establishment†	612	ac	Tree or shrub establishment by seeding, planting or natural regeneration.	Plant native trees and shrubs that provide floral and nesting resources.	19.0	x		x
Windbreak/ Shelterbelt Establishment†	380	lf	Single or multiple rows of trees or shrubs to achieve specific benefits.	Include trees, vines or shrubs that that provide pollen and nectar. Alternately, can be used as pesticide drift barriers, in which case, use conifers.	0.9	x	x	x

* Not a full list of the carbon farm practices currently approved by CDFA.

† Supported by CDFA's Pollinator Habitat program.

The carbon-sequestration potential for each conservation practice standard (CPS) was calculated using CDFA's version of COMET-planner. Carbon-sequestration potential, measured in metric tonnes CO_2 per year per unit, was calculated at either the 1-acre (ac) or 500 linear feet (lf) scale depending on the NRCS standard practice unit. The x's indicate whether a practice is applicable to crop, orchard/vineyard, or rangeland production systems.

already utilized to support pollinators. Agricultural practices that help sequester carbon and protect pollinators on farms can be grouped into two general categories: habitat management and farm production practices.

On-farm habitat can consist of perennial or annual vegetation within or along fields to achieve specific agronomic or conservation outcomes. Woody vegetation maximizes carbon-storage potential because woody plants have secondary persistent growth and often achieve greater biomass than herbaceous species (Blaser et al. 2014; De Stefano and Jacobson 2017). As a result, the USDA Natural Resources Conservation Service's (NRCS) Riparian Forest Buffer conservation practice standard (CPS 391), which introduces woody vegetation adjacent to waterways, is estimated to have 10 times the carbon sequestration potential of Riparian Herbaceous Cover (CPS 390) (table 1; Swan et al. 2018).

Carbon-sequestering habitat can be adapted to support pollinators by including species that provide floral resources and nesting or breeding sites for pollinators. Most pollinators exclusively feed on pollen and nectar, though different species vary in seasonal activity and flower preference. Offering numerous flowering species that bloom throughout the year introduces floral resource diversity and continuity to the farmed environment that is capable of supporting an array of pollinating species (Mallinger et al. 2016). Including plants used for nesting (e.g., pithy-stemmed species) creates nest locations that are often lacking in intensively farmed landscapes that contain little remnant vegetation (Forrest et al. 2015).

Some pollinators are trophic specialists, exclusively provisioning pollen to their young from one or a few related plant species. Incorporating these plants into habitat areas can help support selective, often more imperiled, pollinators (Sutter et al. 2017). Other pollinators depend on host plants during immature life stages, such as the reliance of monarch butterfly larvae on milkweed. Some host plants support a wide array of invertebrate pollinators. Oaks (*Quercus* spp.) are among the most effective tree species at sequestering carbon (SFEI 2017); they are also the host plant for many lepidopteran species and provide an important source of pollen for pollinators (Williams et al. 2007; Yourstone et al. 2021), despite being predominantly wind pollinated. Incorporating plant species that have high carbon sequestration potential and serve as an important pollinator resource will increase the multifunctional benefits of habitat. Additional research is needed to identify multi-beneficial plant species in order to streamline project design.

Providing habitat may also help pollinators adapt to climate change by creating structural diversity. Plantings can create varied microclimates that buffer pollinators from the impacts of extreme temperatures (Papanikolaou et al. 2017). For example, monarchs take refuge in shaded areas during periods of high heat (Landis 2014). Access to shade is likely to become increasingly important for bees and other insects as temperatures continue to rise (Sunday et al. 2014).

Managing for pollinators

Farm production management practices, including disking, applying pesticides, and grazing, have both direct and indirect impacts on both pollinators and GHG emissions. Adopting practices that sequester carbon and protect floral and nesting resources is critically important to reduce carbon emissions and conserve pollinators on farms.

Disking and cultivating farm fields mechanically agitates and redistributes soil, impacting soil structure, vegetative cover, root structure, soil microbes, and other soil organisms (Schmidt et al. 2018). Minimizing tillage through conservation tillage practices can increase soil organic carbon, though results vary by soil type (Ogle et al. 2012). Conservation tillage practices can also protect bees that nest within crop fields. Tillage can kill bee larvae in their underground nests. Although the exact depth will vary by bee species, tillage depths >15 inches have been shown to increase larval mortality by up to 50% for squash bees (*Peponapis purinosa*) (Ullmann et al. 2016). By contrast, surface tilling may have a reduced impact. Reducing or eliminating tillage-related disturbance protects underground nests by allowing bees to safely emerge.

Planting herbaceous flowering plants between rows of annual crops can increase pollination within fields. *Photo*: Sam Earnshaw.

Planting summer and winter cover crops that include flowering plants can provide additional floral resources between rows in orchards as well as during crop rotations in annual field crops (Ellis and Barbercheck 2015). On the other hand, weed control practices (e.g., mowing, disking, burning or spraying) on vegetated field borders can remove floral resources, depending on implementation and timing. Timing weed control practices to avoid bloom periods or dividing habitat into sections managed over consecutive years or seasons will help provide refuges for pollinators (Morandin et al. 2014; Sardiñas et al. 2018), especially those that may not be able to relocate nest sites in the absence of floral resources. A more permanent solution would be to replace weedy field edges with native California flowering plants that can outcompete weeds (Wilkerson 2014).

Selective management practices in rangelands can also impact pollinator and climate conservation goals. The rangelands that encircle California's Central Valley function as source habitat, exporting pollinators to crop fields (Chaplin-Kramer et al. 2011). Timing or intensity of grazing can affect the diversity and abundance of both flowering plants (Black et al. 2011) and pollinators (Lázaro et al. 2016; Shapira et al. 2020). Seasonal grazing can limit competition from weedy species and allow persistence of desirable plants (Bartolome et al. 2014). Rotational grazing reduces grazing pressure, helping to increase plant biomass and leaf litter, which in turn increases SOM and carbon sequestration (Gosnell et al. 2020) and can increase the overall productivity of the grassland system.

Integrated pest management (IPM) strategies can also protect pollinators while mitigating climate impacts. Some IPM practices such as planting pest and disease resistant varieties, using crop rotation to break pest-disease cycles, and the use of selective pesticides that protect natural enemies can help reduce pesticide use (Biddinger and Rajotte 2015). This in turn can potentially limit GHG emissions by reducing sprays and volatile organic compounds (VOCs) (Heeb et al. 2019). On-farm habitat can also attract natural enemies of crop pests, including insects and birds that enhance pest control in adjacent fields (Heath and Long 2019; Kross et al. 2016; Morandin et al. 2014), which can further reduce reliance on pesticides. Synergistic effects between pest control and pollination services can increase crop yields (e.g., Lundin et al. 2013; Morandin et al. 2016). Subsequent reductions in crop losses can enhance carbon assimilation by the retained crops (Heeb et al. 2019). Another win-win example is intercropping, which entails planting strips of habitat between crop rows to support natural enemies and pollinators (e.g., Brandmeier et al. 2021). Planting windbreaks composed of non-flowering woody vegetation (e.g., conifers) to shelter habitat and pollinators from pesticide drift also creates benefits to pollinators while increasing carbon sequestering via on-farm woody biomass (Lee-Mäder et al. 2020).

Balancing outcomes

Although promoting multiple ecosystem services from the same practice can amplify benefits, some practices may create neutral or negative outcomes for either pollinators or carbon storage (fig. 2). For example, Prescribed Grazing (CPS 528) can benefit pollinators, but the quantifiable carbon benefits of the practice are low (fig. 2). However, by restoring woody or herbaceous plants in grasslands (e.g., Range Planting CPS 550) a rancher can achieve dual carbon- and pollinator-beneficial outcomes, though this practice must be balanced with a need for forage production.

Alternatively, it may be preferential to limit the maximum potential of each service to ensure some level of each service. For example, many nitrogen-fixing cover crops are mowed or reincorporated into fields before they flower to capture their maximum nitrogen value. However, when terminated before bloom, they cannot provide forage for pollinators. Where it is compatible with management and primary crop phenology, waiting until a cover crop has achieved 50% bloom can benefit pollinators while still benefiting soil nutrients. Perennial crops like orchards and vineyards are more likely to allow for such timing than many annual row crops, although late-seeded crops such as winter squash may also be well suited to this strategy. In any production system, if a flowering cover crop might bloom during a season when regular pesticide applications occur, it may be preferable to terminate the cover crop and force pollinators to find different floral resources

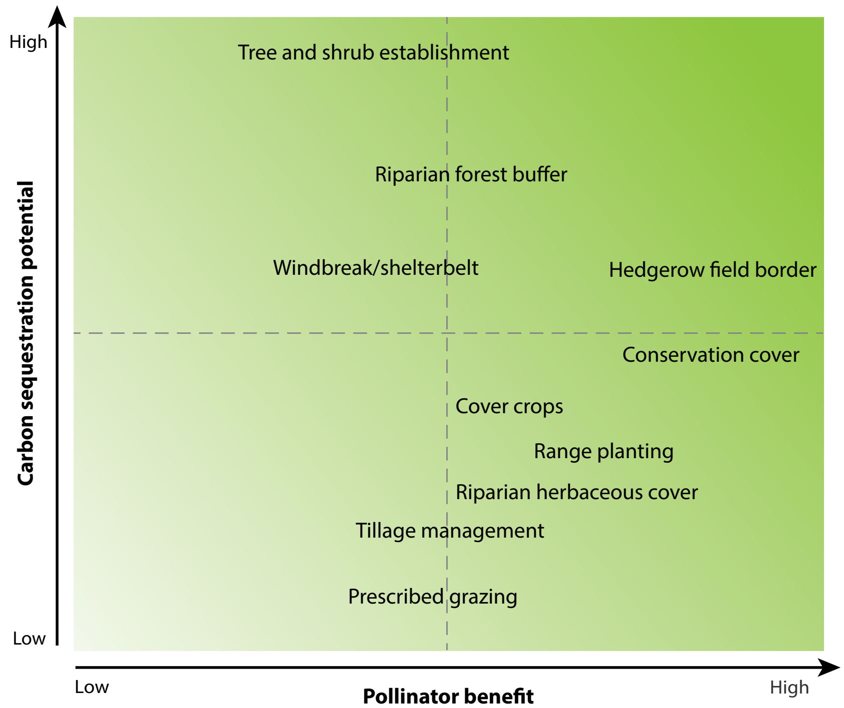

FIG. 2. Four-box model of the relative carbon sequestration potential of individual carbon farm practices compared to the relative pollinator benefit of the same practices. Notice some practices will vary in benefit depending on specific aspects. For example, the pollinator value of tree and shrub plantings for pollinators will vary according to the plant species chosen, thus there is a range of potential benefits associated with pollinator practices instead of a discrete value (corresponding to the width of the text). As the four-box layout emphasizes, certain practices trade off high values in one dimension against the other (top left and lower right regions; e.g., riparian herbaceous cover and tree and shrub establishment, which provide high pollinator benefits but modest carbon storage in the one case versus high carbon storage but moderate pollinator benefits in the other). Other practices (top-right box) afford high function in both dimensions (e.g., hedgerows). Because of complementary habitat needs of pollinators it is also possible the multiple practices in combination could fall into the top right box when either alone does not.

Between row cover crops in vineyards or orchards can provide pollinator resources while improving soil carbon sequestration capacity by improving soil organic matter. *Photo*: Houston Wilson.

instead of exposing bees to pesticides. Almond is an example in which the yearly crop cycle can accommodate cover crops, but regular insecticide applications are generally ramped up in mid-April. In this system, if flowering cover crops are allowed to persist through spring, mowing them prior to spraying would avoid pesticide exposure for resident wild bees and could be incorporated into management activities. As this example illustrates, careful timing of management actions and weighing different production goals can be used to promote multiple benefits.

The location where practices are implemented in a field or region can also impact on-farm ecosystem service delivery as well as emergent benefits. Pollination services predominantly occur at small scales because many pollinator species are non-migratory and have relatively short foraging ranges (Greenleaf et al. 2007), and thus are reliant on nearby floral and nesting resources. Regional-scale pollination benefits can occur when sufficient habitat is created to support a metapopulation of pollinators whose dispersal movements help maintain the resiliency of the overall pollinator community over time (Iles et al. 2018; M'Gonigle et al. 2015). For carbon-sequestering practices, benefits can also accrue at the global scale because the carbon cycle is a global process.

It is important to determine the best location to implement a specific practice at field scale (Faichnie et al. 2021) because this can impact the level of agronomic or economic benefits received by farmers. At the same time, the distribution of practices across the landscape should contribute to regional resiliency (Batáry et al. 2011). Planning habitat-based carbon farm practices at both the farm and landscape level would help optimize benefits (Williams et al. 2018). Incentive programs, discussed below, could vary payment rates to encourage adoption in specific areas to generate a more even distribution of pollinator and climate benefits across agricultural landscapes.

Farm management decisions will vary based on the importance of field-scale goals related to farm economic sustainability. The value of a given practice to a farmer — which is likely to determine whether they adopt the practice — varies in relation to the agricultural system (crops versus livestock, organic versus conventional), crop type, water availability, and economics (Albrecht et al. 2020). A farmer growing pollinator-reliant crops may adopt a different suite of practices than one growing self-fertilizing, wind-pollinated, or non-pollinated crops. Identifying management scenarios for specific sets of practices for different cropping systems will require additional targeted study or modelling to help maximize benefits. Co-management of benefits and tradeoffs will also require clear goal setting and prioritization.

The woody vegetation in this hedgerow maximizes carbon-storage potential because woody plants have secondary persistent growth and often achieve greater biomass than herbaceous species. Hedgerows have also been shown to support robust pollinator populations. *Photo:* Sam Earnshaw.

Incentivizing conservation

Farmers face costs in both adopting new and adapting existing carbon-farming practices to benefit pollinators. To recognize the regional and global value of these on-farm efforts, government-sponsored incentive programs can provide cost-sharing opportunities to offset costs or supplement forgone income. In California, farmers have opportunities to apply for funding from the state government via the California Department of Food and Agriculture's (CDFA) Healthy Soils Program

FIG. 3. Different habitats impact ecosystem service delivery at different scales. Habitat implemented at the local scape (within and along fields) can scale up to have landscape-level pollinator-beneficial effects. *Photos (L-R)*: Houston Wilson, Jessa Kay-Cruz, Sam Earnshaw, Deedee Soto, Kelly Gill.

(HSP) or the Pollinator Habitat Program (PHP) as well as from the federal government through the Natural Resources Conservation Service's Environmental Quality Incentives Programs (EQIP). The HSP is funded by California's Greenhouse Gas Reduction Fund, which is generated from auction proceeds from California's carbon emissions cap-and-trade program, whereas the the PHP is a new program developed by the state legislature (SB 170, Skinner) that was developed in 2021 and rolled out in 2022. EQIP is funded through the Farm Bill.

If an HSP- or EQIP-funded practice provides an added benefit to farms, the cost-share rate is enhanced above the regular reimbursement rate for the same practice. Practices supported by these programs include hedgerow plantings, cover crops, reduced tillage, and range plantings. The PHP notes co-benefits like carbon sequestration are likely outcomes of pollinator-focused projects but does not award additional points during their application process (though past performance in other climate smart programs like HSP may be taken into account during the selection process) nor provide increased rates for projects that create such co-benefits. Increased integration between programs like the HSP and PHP could provide more holistic funding opportunities for growers in California.

Along with financial incentives, demonstration projects help showcase implementation and benefits. Demonstration programs can be particularly effective when they encourage farmer-to-farmer dissemination of information (Garbach and Long 2017). HSP, PHP and EQIP technical assistance programs also provide site-specific support to farmers for planning, implementation and maintenance of pollinator-friendly carbon farming techniques. Technical assistance has also been shown to enhance farmer adoptions rates of conservation practices (Garbach and Long 2017).

Certification programs and voluntary carbon taxes represent consumer-driven avenues that can incentivize farmers to adopt climate-friendly or pollinator-beneficial practices. The nonprofit Zero Foodprint developed an opt-in for restaurants to divert 1% of a customer's bill to a fund that supports planning and implementation of carbon farming practices. Pollinator-focused certifications are a value-added marketing tool. Food companies are increasingly incorporating certified pollinator-beneficial ingredients into their supply chains to address consumer demand for products that protect pollinators. Although existing pollinator-related certification programs such as Bee Better and Bee Friendly require flower-rich habitat, they do not formally recognize the carbon-sequestration co-benefits of the practices they require. To date, carbon-related certifications have focused on emissions (e.g., climate neutral), rather than on-the-ground habitat creation (though a small-scale niche program Fibershed is pioneering a carbon-beneficial certification for wool products). If such programs start to emphasize the dual benefits of their efforts, both pollination and carbon sequestration could benefit.

Carbon farming is a win-win

Carbon farming encompasses a wide range of conservation practices that are readily adaptable to a variety of crops. Although the carbon-sequestration potential of carbon farming practices varies depending on soil type and precipitation levels, implementation of carbon farming practices can enhance wild pollinator populations in agricultural fields. This, in turn, can sustain the production of pollinator-dependent crops and thereby help California remain a top region for global food production. Thus, carbon farming is a critical tool to help support pollinators, which are essential for reliable production of many of California's highest value crops. It is imperative to encourage and incentivize the adoption of the pollinator-beneficial carbon farming strategies outlined here to increase California's agricultural resiliency in the face of ongoing climate change. CA

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References

Aizen MA, Garibaldi LA, Cunningham SA, et al. 2009. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Ann Bot-London 103(9):1579–88. https://doi.org/10.1093/aob/mcp076

Albrecht M, Kleijn D, Williams NM, et al. 2020. The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: A quantitative synthesis. Ecol Lett 23(10):1488–98. https://doi.org/10.1111/ele.13576

Allen-Wardell G, Bernhardt P, Bitner R, et al. 1998. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. Conserv Biol 12(1):8–17. www.jstor.org/stable/2387457

Bartolome JW, Allen-Diaz BH, Barry S, et al. 2014. Grazing for biodiversity in Californian Mediterranean grasslands. Rangelands 36(5):36–43. https://doi.org/10.2111/Rangelands-D-14-00024.1

Batáry P, Baldi A, Kleijn D, Tscharntke T. 2011. Landscape-moderated biodiversity effects of agri-environmental management: A meta-analysis. P Roy Soc B—Biol Sci 278(1713):1894–1902. https://doi.org/10.1098/rspb.2010.1923

Biddinger DJ, Rajotte EG. 2015. Integrated pest and pollinator management—adding a new dimension to an accepted paradigm. Curr Opin Insect Sci 10:204–9. https://doi.org/10.1016/j.cois.2015.05.012

Black SH, Shepherd M, Vaughan M. 2011. Rangeland management for pollinators. Rangelands 33(3):9–13. https://doi.org/10.2111/1551-501X-33.3.9

Blaser WJ, Shanungu GK, Edwards PJ, et al. 2014. Woody encroachment reduces nutrient limitation and promotes soil carbon sequestration. Ecol Evol 4(8):1423–38. https://doi.org/10.1002/ece3.1024

Brandmeier J, Reininghaus H, Pappagallo S, et al. 2021. Intercropping in high input agriculture supports arthropod diversity without risking significant yield losses. Basic Appl Ecol 53:26–38. https://doi.org/10.1016/j.baae.2021.02.011

Brittain C, Williams N, Kremen C, et al. 2013. Synergistic effects of non-Apis bees and honey bees for pollination services. P Roy Soc B—Biol Sci 280(1754):20122767. https://doi.org/10.1098/rspb.2012.2767

Chaplin-Kramer R, Tuxen-Bettman K, Kremen C. 2011. Value of wildland habitat for supplying pollination services to Californian agriculture. Rangelands 33(3):33–41. https://doi.org/10.2111/1551-501X-33.3.33

De Stefano A, Jacobson MG. 2017. Soil carbon sequestration in agroforestry systems: A meta-analysis. Agroforest Syst 92:285–99. https://doi.org/10.1007/s10457-017-0147-9

Ellis KE, Barbercheck ME. 2015. Management of overwintering cover crops influences floral resources and visitation by native bees. Environ Entomol 44(4): 999–1010. https://doi.org/10.1093/ee/nvv086

Faichnie R, Breeze TD, Senapathi D, et al. 2021. Scales matter: Maximising the effectiveness of interventions for pollinators and pollination. In *Advances in Ecological Research Vol 64*. Bohan DJ, Vanbergen AJ (eds.). Academic Press. p. 105–47. https://doi.org/10.1016/bs.aecr.2020.11.003

Flint LE, Flint AL, Stern MA, et al. 2018. Increasing soil organic carbon to mitigate greenhouse gases and increase climate resiliency for California (CCCA4-CNRA-2018-006). California Natural Resources Agency. https://pubs.er.usgs.gov/publication/70199846 (accessed May 19, 2021).

Forrest JR, Thorp RW, Kremen C, et al. 2015. Contrasting patterns in species and functional-trait diversity of bees in an agricultural landscape. J Appl Ecol 52(3):706–15. https://doi.org/10.1111/1365-2664.12433

Garbach K, Long R. 2017. Determinants of field edge habitat restoration on farms in California's Sacramento Valley. J Environ Manage 189:134–41. https://doi.org/10.1016/j.jenvman.2016.12.036

Garibaldi LA, Steffan-Dewenter I, Winfree R, et al. 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science 339(6127):1608–11. https://doi.org/10.1126/science.1230200

Garibaldi LA, Carvalheiro LG, Leonhardt SD, et al. 2014. From research to action: Enhancing crop yield through wild pollinators. Front Ecol Environ 12(8):439–47. https://doi.org/10.1890/130330

Garibaldi LA, Carvalheiro LG, Vaissière BE, et al. 2016. Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. Science 351(6271):388–91. https://doi.org/10.1126/science.aac7287

Giannini TC, Costa WF, Cordeiro GD, et al. 2017. Projected climate change threatens pollinators and crop production in Brazil. PLoS One 12(8):e0182274. https://doi.org/10.1371/journal.pone.0182274

Gosnell H, Charnley S, Stanley P. 2020. Climate change mitigation as a co-benefit of regenerative ranching: Insights from Australia and the United States. Interface Focus 10(5):20200027. https://doi.org/10.1098/rsfs.2020.0027

Goulson D. 2019. The insect apocalypse, and why it matters. Curr Biol 29(19):R967–71. https://doi.org/10.1016/j.cub.2019.06.069

Greenleaf, SS, Williams NM, Winfree R, et al. 2007. Bee foraging ranges and their relationship to body size. Oecologia 153(3):589–96. https://doi.org/10.1007/s00442-007-0752-9

Hartz TK, Mitchell JP, Giannini C. 2000. Nitrogen and carbon mineralization dynamics of manures and composts. HortScience 35(2):209–12. https://doi.org/10.21273/HORTSCI.35.2.209

Heath S, Long RF. 2019. Multiscale habitat mediate pest reduction by birds within intensive agricultural landscape. Ecosphere 10(100):e02884. https://doi.org/10.1002/ecs2.2884

Heeb L, Jenner E, Cock MJ. 2019. Climate-smart pest management: Building resilience of farms and landscapes to changing pest threats. J Pest Sci 92(3):951–69. https://doi.org/10.1007/s10340-019-01083-y

Iles DT, Williams NM, Crone EE. 2018. Source-sink dynamics of bumblebees in rapidly changing landscapes. J Appl Ecol 55(6):2802–11. https://doi.org/10.1111/1365-2664.13175

Kennedy CM, Lonsdorf E, Neel MC, et al. 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecol Lett 16(5):584–99. https://doi.org/10.1111/ele.12082

Klein AM, Vaissiere BE, Cane JH, et al. 2006. Importance of pollinators in changing landscapes for world crops. P Roy Soc B—Biol Sci 274(1608):303–13. https://doi.org/10.1098/rspb.2006.3721

Kjøhl M, Nielsen A, Stenseth NC. 2011. *Potential effects of climate change on crop pollination*. Rome: Food and Agriculture Organization of the United Nations (FAO). 49 p.

Kross SM, Kelsey TR, McColl CJ, et al. 2016. Field-scale habitat complexity enhances avian conservation and avian-mediated pest-control services in an intensive agricultural crop. Agr Ecosyst Environ 225:140–9. https://doi.org/10.1016/j.agee.2016.03.043

Lal R. 2020. Soil organic matter content and crop yield. J Soil Water Conserv 75(2):27A–32A. https://doi.org/10.1002/agj2.20282

Landis TD. 2014. Monarch waystations: Propagating native plants to create travel corridors for migrating monarch butterflies. Native Plants J 15(1):5–16. https:///doi.org/10.3368/npj.15.1.5

Lázaro A, Tscheulin T, Devalez J, et al. 2016. Moderation is best: Effects of grazing intensity on plant–flower visitor networks in Mediterranean communities. Ecol Appl 26(3):796–807. https://doi.org/10.1111/een.12310

Lee-Mäder E, Vaughan M, Goldenetz-Dollar J. 2020. Agroforestry and cover cropping for pollinators. In *Towards Sustainable Crop Pollination Services: Measures at Field, Farm and Landscape Scales*. Rome: Food and Agriculture Organization of the United Nations (FAO). p 105–26. www.apiservices.biz/documents/articles-en/sustainable_crop_pollination_services.pdf (accessed May 19, 2021).

Lundin O, Smith HG, Rundlöf M, et al. 2013. When ecosystem services interact: Crop pollination benefits depend on the level of pest control. P Roy Soc B—Biol Sci 280(1753):20122243. https://doi.org/10.1098/rspb.2012.2243

M'Gonigle LK, Ponisio LC, Cutler K, et al. 2015. Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. Ecol Appl 25(6):1557–65. https://doi.org/10.1890/14-1863.1

Mallinger RE, Gibbs J, Gratton C. 2016. Diverse landscapes have a higher abundance and species richness of spring wild bees by providing complementary floral resources over bees' foraging periods. Landscape Ecol 31(7):1523–35. https://doi.org/10.1007/s10980-015-0332-z

Mola JM, Miller MR, O'Rourke SM, et al. 2020. Wildfire reveals transient changes to individual traits and population responses of a native bumble bee (Bombus vosnesenskii). J Anim Ecol 89(8):1799–1810. https://doi.org/10.1111/1365-2656.13244

Morandin LA, Long RF, Kremen C. 2014. Hedgerows enhance beneficial insects on adjacent tomato fields in an intensive agricultural landscape. Agr Ecosyst Environ 189:164–70. https://doi.org/10.1016/j.agee.2014.03.030

Morandin LA, Long, RF, Kremen C. 2016. Pest control and pollination cost benefit analysis of hedgerow restoration in a simplified agricultural landscape. J Econ Entomol 109(3):1020–7. https://doi.org/10.1093/jee/tow086

Ogle SM, Swan A, Paustian K. 2012. No-till management impacts on crop productivity, carbon input and soil carbon sequestration. Agr Ecosyst Environ 149:37–49. https://doi.org/10.1016/j.agee.2011.12.010

Oldfield EE, Bradford MA, Wood SA. 2019. Global meta-analysis of the relationship between soil organic matter and crop yields. Soil 5(1):15–32. https://doi.org/10.5194/soil-5-15-2019

Papanikolaou AD, Kühn I, Frenzel M, et al. 2017. Semi-natural habitats mitigate the effects of temperature rise on wild bees. J Appl Ecol 54(2):527–36. https://doi.org/10.1111/1365-2664.12763

Pathak TB, Maskey ML, Dahlberg JA, et al. 2018. Climate change trends and impacts on California agriculture: A detailed review. Agronomy 8(3):25. https://doi.org/10.3390/agronomy8030025

Rader R, Reilly J, Bartomeus I, Winfree R. 2013. Native bees buffer the negative impact of climate warming on honey bee pollination of watermelon crops. Glob Change Biol 19(10):3103–10. https://doi.org/10.1111/gcb.12264

Reilly JR, Artz DR, Biddiner D, et al. 2020. Crop production in the USA is frequently limited by a lack of pollinators. P Roy Soc B—Biol Sci 287:20200922. https://doi.org/10.1098/rspb.2020.0922

Ryals R, Silver WL. 2013. Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands. Ecol Appl 23(1):46–59. https://doi.org/10.1890/12-0620.1

[SFEI] San Francisco Estuary Institute. 2017. Re-Oaking Silicon Valley: Building vibrant cities with nature. Publication 825. www.sfei.org/documents/re-oaking-silicon-valley (accessed May 19, 2021).

Sardiñas H, Hopwood J, Cruz JK, et al. 2018. Maintaining diverse stands of wildflowers planted for pollinators: Long-term management of planted wildflower habitat for pollinator conservation. Portland, OR: The Xerces Society for Invertebrate Conservation. https://xerces.org/publications/guidelines/maintaining-diverse-stands-of-wildflowers-planted-pollinators (accessed March 21, 2022).

Schmidt R, Gravuer K, Bossange AV, et al. 2018. Long-term use of cover crops and no-till shift soil microbial community life strategies in agricultural soil. PLoS One 13(2):e0192953. https://doi.org/10.1371/journal.pone.0192953

Shapira T, Henkin Z, Dag A, et al. 2020. Rangeland sharing by cattle and bees: Moderate grazing does not impair bee communities and resource availability. Ecol Appl 30(3):e02066. https://doi.org/10.1002/eap.2066

Sunday JM, Bates AE, Kearney MR, et al. 2014. Thermal-safety margins and the necessity of thermoregulatory behavior across latitude and elevation. P Natl Acad Sci USA 111(15):5610–15. https://doi.org/10.1073/pnas.1316145111

Sutter L, Jeanneret P, Bartual A.M, et al. 2017. Enhancing plant diversity in agricultural landscapes promotes both rare bees and dominant crop-pollinating bees through complementary increase in key floral resources. J Appl Ecol 54(6):1856–64. https://doi.org/10.1111/1365-2664.12907

Swan A, Easter M, Chambers A, et al. 2018. COMET-planner: Carbon and greenhouse gas evaluation for NRCS conservation practice planning. http://comet-planner-cdfahsp.com/ (accessed May 19, 2021).

Toensmeier E. 2016. *The carbon farming solution: A global toolkit of perennial crops and regenerative agriculture practices for climate change mitigation and food security*. Vermont: Chelsea Green Publishing. http://lccn.loc.gov/2015034506

Traynor KS, Rennich K, Forsgren E, et al. 2016. Multiyear survey targeting disease incidence in US honey bees. Apidologie 47(3):325–47. https://doi.org/10.1007/s13592-016-0431-0

Ullmann KS, Meisner MH, Williams NM. 2016. Impact of tillage on the crop pollinating, ground-nesting bee, *Peponapis pruinosa* in California. Agr Ecosyst Environ 232:240–6. https://doi.org/10.1016/j.agee.2016.08.002

Wilkerson ML. 2014. Using hedgerows as model linkages to examine non-native plant patterns. Agr Ecosyst Environ 192:38–46. https://doi.org/10.1016/j.agee.2014.03.044

Williams NM, Kremen C. 2007. Resource distributions among habitats determine solitary bee offspring production in a mosaic landscape. Ecol Appl 17(3):910–21. https://doi.org/10.1890/06-0269

Williams NM, Lonsdorf EV. 2018. Selecting cost-effective plant mixes to support pollinators. Biol Conserv 217:195–202. https://doi.org/10.1016/j.biocon.2017.10.032

Yourstone J, Gunnarsson J, Smith HG, Somanathan H. 2021. High dependency of chilli fruit set on wild pollinators in southern India. J Pollination Ecol 28:65–74. https://doi.org/10.26786/1920-7603(2021)629

RESEARCH ARTICLE

4-H Water Wizards: Lessons learned for effective afterschool science programming

The 4-H Water Wizards project shows the value of ongoing training and support in encouraging afterschool staff to teach hands-on science.

by Marianne Bird and Aarti Subramaniam

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Abstract

The University of California 4-H Youth Development Program created the 4-H Water Wizards project in response to two related issues: the need for high-quality science education programming in afterschool settings, and the desire to foster a citizenry that understands and can make informed decisions about water. In collaboration with afterschool program staff, Sacramento County 4-H implemented the 12-week water education project for children in grades four through six. We evaluated the program over four years (2012–2016) utilizing a pretest-posttest study design and evaluation surveys from participants and program staff. Our findings indicate positive outcomes both for program staff who delivered the project and for the children who participated in the program. Afterschool program staff gained competence in delivering hands-on and inquiry-based science programming. Fourth- and fifth-grade students demonstrated small but significant knowledge gain about water. Students also demonstrated increased awareness about water issues and water conservation behavior. We discuss our findings for both groups and share our insights for promising practices when collaborating with afterschool providers, especially relating to the importance and challenge of science education in afterschool settings.

A function of Cooperative Extension is to develop quality curriculum and outreach programs to communities around the nation. However, many Extension staff have found it challenging to effectively deliver these to the community, including underserved audiences (Davis et al. 1990). One venue for program delivery to school-age children is through school-based afterschool programs, which are well-established throughout the country. Also called Expanded Learning, these programs take advantage of the often-underutilized hours after the school day to enhance student learning. Afterschool programs are free from the constraints of mandated standards, allowing for rich modes of program delivery (Pelcher and Rajan 2016). Because they are flexible, and those who administer them are generally eager to include content-rich learning experiences, afterschool programs are well-suited to host science education programs that reach beyond the scope of the school day (Chi et al. 2008). Despite these advantages, afterschool staff have often found it challenging to deliver science programs effectively.

Samuel Sandoval Solis, Associate Professor and Cooperative Extension Specialist in Water Resources at UC ANR, shares his groundwater model. *Photo:* Marianne Bird.

State and federal funding support afterschool programs in economically disadvantaged communities. Goals for these programs include providing academic support and enrichment to complement what children learn during school hours (Deke et al. 2012). This support and enrichment are especially critical in providing quality science, technology, engineering and math (STEM) programming. As of 2015, only 38% of fourth grade students in the United States scored above average or proficient in science (NAEP 2015). In California, 55% of fifth graders scored proficient in science in 2015 (CDE 2015). The gap in scientific literacy is especially prominent for youth of color (NCES 2018).

Afterschool programs face several challenges. Instructors in afterschool programs are not typically credentialed teachers (Chi et al. 2008). As well, afterschool staff, particularly in low-income communities, often have little background in subject expertise or in training as teachers, especially in science pedagogy, such as inquiry-based exploration (Freeman et al. 2009). Increasing staff competence in understanding content and raising staff confidence in facilitating science learning are important components in providing quality STEM programming (Harlen 1997; Harlen and Holroyd 2007; Miller 2005).

Afterschool programs benefit from science programming that can meet the dual purpose of increasing students' science knowledge while enhancing the staff's ability to effectively deliver science education to students (Smith and Schmitt-McQuitty 2013). To help meet this dual goal, the University of California 4-H Youth Development Program created 4-H Water Wizards in 2006. This project provides water education to children in after school programs, with the long-term goal of fostering a citizenry that understands and can make informed decisions about water. The program also serves to increase afterschool staff competencies in teaching science. It incorporates best practices in STEM education for afterschool settings, including the Experiential Learning Model, staff training strategies and service-learning (see Ripberger and Blalock 2011). We undertook a multi-year study, described here, to determine if the program is effective in meeting its two-pronged goal. We share our lessons learned from implementing this project especially with regard to working with afterschool audiences.

4-H Water Wizards project

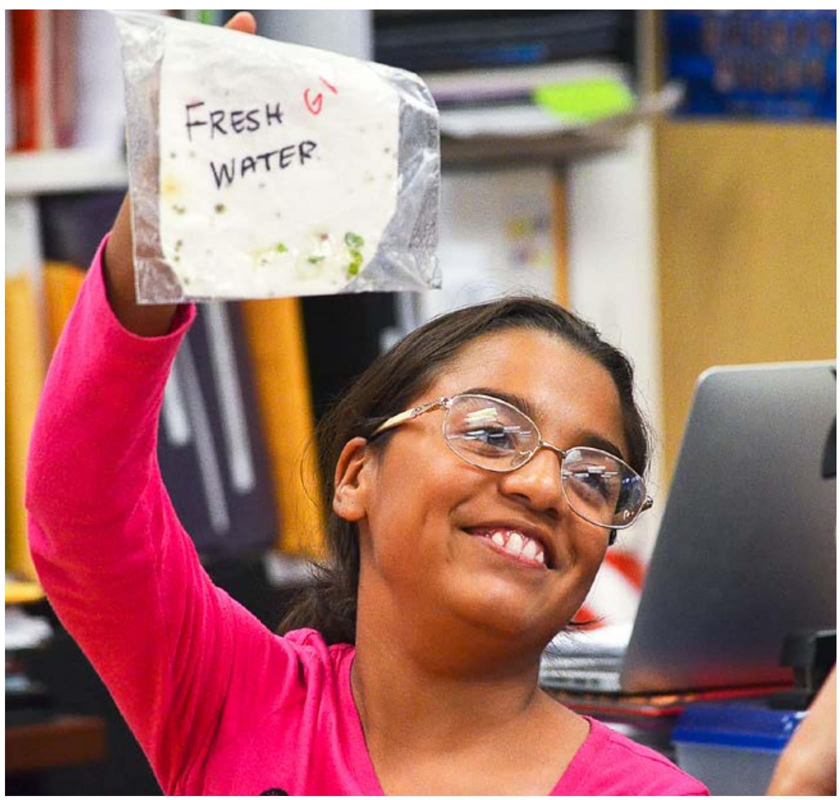
Water has been called California's "new gold," a precious and limited natural resource that is critical to agriculture, communities and the environment. Water is a driver of California's large agricultural economy and is often the center of policy debate. The issues surrounding water are also personal ones; individuals and families increasingly face issues of water conservation and clean waterways (Gregory and Di Leo 2006). Education is the first step in helping children understand and appreciate water and its role in their communities (Gregory and Di Leo 2006). The 4-H Water Wizards project helps foster this understanding and appreciation through three components: community partnerships, curriculum and staff training.

Community partnerships

Sacramento County University of California Cooperative Extension (UCCE) partnered with the City of Sacramento's afterschool program to deliver 4-H Water Wizards. During the years of our study, 2012–2016, 20 afterschool sites participated in the program annually (10 sites in the fall and 10 in the spring) and included a total of 2,039 students in grades four through six. At least 50% of students in participating schools received free or reduced-fee lunches and almost 85% were students of color (table 1). The 143 program staff members leading the project were equally diverse (table 2).

Curriculum

The 4-H Water Wizards curriculum (table 3) consists of 11 weekly sessions, each 45 to 60 minutes long, and encompasses three units: Water and the Environment (the water cycle, watersheds, water pollution and conservation); Water Properties (taste test, salinity, density and hardness); and a Service Learning Project (exploring service learning, planning and delivering a water-related community service project, and project evaluation). The curriculum utilizes guided inquiry, which encourages students to construct knowledge



4-H Water Wizards encourages youth to investigate water through models, experiments, and surveys. Here, a student shares the results of seeds placed on a paper towel dampened with fresh water, which they will compare to a salt water sample. *Photo*: Marianne Bird.

TABLE 1. Ethnicity and gender for total youth enrolled in the 4-H Water Wizards Project, 2012–2016

Program year	Total	Male	Female	White	African American	Native American	Asian	Pacific Islander	Hispanic	Other
2012–2013	447	217	230	89	95	8	85	0	170	0
2013–2014	470	235	235	83	136	2	96	0	148	5
2014–2015	681	332	349	86	152	9	42	63	307	22
2015–2016	441	219	222	67	85	3	84	51	150	1
Total	2039	1003	1036	325	468	22	307	114	775	28
Percentage	100%	49%	51%	16%	23%	1%	15%	6%	38%	1%

TABLE 2. Ethnicity and gender for total afterschool program staff who delivered the 4-H Water Wizards Project, 2012–2016 (duplicates included)

Program year	Total	Male	Female	White	African American	Native American	Asian	Pacific Islander	Hispanic	Other
2012–2013	27	8	19	4	4	4	2	0	11	0
2013–2014	32	10	22	4	4	4	3	1	9	0
2014–2015	63	8	55	10	10	10	3	3	26	0
2015–2016	21	5	16	5	5	5	0	2	4	2
Total	143	31	112	23	23	23	8	6	50	2
Percentage	100%	22%	78%	16%	16%	16%	6%	4%	35%	1%

TABLE 3. Components of the 4-H Water Wizards project

Session	Description
Introduction	Staff are given background information on curriculum content, session organization and discovery through exploration
Water and the Environment	
Session 1: The Water Cycle: Nature's recycling system	Youth work in teams to create and share posters depicting the water cycle, and they do an experiment to investigate evaporation.
Session 2: Watersheds: Where we live	Youth work in teams to build and compare model watersheds.
Session 3: My Community Watershed: Keeping our water clean	Using an Enviroscape model, youth see how pollutants enter the water system.
Session 4: Water Use and Conservation: How much water do we use?	Youth conduct a simple water survey in their homes, compile and compare data and discuss findings.
Water Properties	
Session 5: Water Taste Test: Is bottled water better?	Participating in a blind taste test, youth sample a variety of bottled and tap water, rate their tastes and chart and analyze findings.
Session 6: Exploring Salinity	Youth experiment growing seeds with fresh and salt water, making an egg float and using a hydrometer.
Session 7: Discovering Water Density	Using colored water of differing salinity, youth see how water can be layered, problem-solve which color is saltiest and discuss how this relates to the delta ecosystem.
Session 8: The Science of Soap Suds	Youth conduct a controlled experiment to explore water hardness by observing how soap reacts in different water samples.
Service-Learning Project	
Session 9: Making Our Community a Better Place	Youth explore the concepts of volunteering, community and service, then select a water issue they will address for their community project.
Session 10: Choosing and Planning a Community Service-Learning Project	Youth design a plan to address their chosen water issue.
Session 11: Evaluating and Celebrating Our Project	Identifying what went well and what they would do differently, youth evaluate their service project. They also complete a questionnaire about their 4-H Water Wizards experience.

through investigation. In the project, students engage in hands-on activities that promote exploration, such as experimenting and using models. Encouraging students to construct knowledge is an established science education technique rooted in education philosophy, and it guides contemporary learning practices (Dewey 1916; Russ and Berland 2019). In addition to hands-on activities, students at each afterschool site attended an afternoon field trip to the nearby American River Water Education Center, where they visited the Folsom Lake watershed; learned about the Folsom Dam and its role in water storage and flood control; and discussed the need for water to support agriculture, people and the environment.

Staff training

4-H Water Wizard developers designed staff training to include best practices for science education in urban settings (Ripberger and Blalock 2011). Afterschool program staff attend three, three-hour evening trainings, one before each unit (a total of nine hours). The trainings included an introduction to teaching inquiry-based science, a modeled lesson, the opportunity to practice delivering lessons to each other, and reflections on the material and their experience in delivering the project. This type of incremental training over an extended period of time (as opposed to an episodic workshop) has been shown to be an effective professional development strategy (Smith and Schmitt-McQuitty 2013). Program staff left each session with all the materials they needed to teach the unit for which they had just been trained. 4-H staff were available for additional support, including site visits.

4-H Water Wizards participants gather around an Enviroscape model where afterschool staff facilitate a lesson on non-point source pollution. Students add elements representing car oil, fertilizer and pesticides to the model and note what happens when runoff from rain carries pollutants into waterways such as rivers and lakes. *Photo*: Marianne Bird.

Evaluation of 4-H Water Wizards

Our research question was twofold: Does the 4-H Water Wizards project significantly impact staff confidence in teaching water-related science material? And, does the project increase student knowledge about water and lead to conservation practices? We designed and conducted our multi-year study to assess the project's outcomes. Specifically, we wished to determine if

- afterschool program leaders became more confident leading science activities as a result of delivering 4-H Water Wizards,
- the 4-H Water Wizards project was effective in raising children's knowledge about water and awareness of water issues,
- youth participating in the project changed their behavior related to water usage as a result of participating in the project and
- youth and program leaders enjoyed the project.

We used a one-group, pretest-posttest study design to help us answer these questions (Creswell and Creswell 2017). For four consecutive years, from 2012 through 2016, we collected data from 59 staff members and 469 students from a sample of 21 afterschool sites that implemented 4-H Water Wizards curriculum and opted to be a part of the study. Many sites participated for multiple years.

We present our evaluation as two parts, focusing on staff evaluation and outcomes in the first and student evaluation and outcomes in the second. Following this we discuss our findings and lessons learned from this process.

I. Evaluating staff knowledge and confidence

Sample. The 59 afterschool staff who participated in our study were ethnically diverse, reflecting the diversity of the students, and 78% female. The amount of time that each staff member worked in the afterschool program varied (mean = 2.9 years; range = 1 month to 14 years).

Data collection. We designed two surveys to assess changes in staff knowledge about, and attitudes toward teaching science. The first was a pre- post- questionnaire that assessed changes in the staff's perceived experience, ability and comfort in teaching science. We administered the pre-questionnaire at the first training session, and the post-questionnaire after the final training session — to measure change. In the questionnaires, we asked staff to rate themselves on their experience and understanding of science, comfort level in teaching and their enjoyment of science using a four-point Likert scale (1 = poor to 4 = very good). The questionnaires also contained open-ended questions about why staff were interested in the project (on the pre-questionnaire), what they learned in teaching the project (on the post-questionnaire) and what they considered "important things to do" when teaching science (on both pre- and post-questionnaires).

The second staff survey was an end-of-project evaluation that included a retrospective self-report on knowledge of water information and teaching science. We asked Likert-scale questions concerning training, confidence and enjoyment of the project, and we included open-ended questions to assess experience in delivering the curriculum. The evaluation also included a program checklist where staff indicated which curricular components they completed with their students.

Quantitative analysis. We matched pre- and post-questionnaire data, compiled it in Excel and analyzed it in SPSS (IBM, N.Y.) with paired sample t-tests to check for significant differences in scores. We did the same for the quantitative data we collected through the end-of-project staff evaluations.

Qualitative analysis. We analyzed the short-answer qualitative data for insights into the program staff's experience with, and insights about, the project. We compiled and summarized the responses related to program experience using a grounded-theory framework (Strauss 1987), noting emergent themes. We quantified the qualitative data to understand theme prevalence and changes in staff understanding of important factors in teaching science. Staff provided a checklist of project activities they completed with students, and overall reports showed that, on average, they completed more than 90% of the activities.

Staff outcomes

Growth in competence and confidence. Afterschool staff rated themselves significantly higher ($P = 0.05$) on the posttest questionnaire than they did in the pretest questionnaire in the following areas: Experience teaching science to children, understanding of science, comfort level teaching about water and the environment, and enjoyment of science (fig. 1, table 4). In the end-of-project evaluation retrospective survey (fig. 2), afterschool staff reported increased understanding in both content knowledge (the water cycle, water properties and water issues) and teaching methodology (how to teach science and the importance of inquiry in that process).

The end-of-project evaluation demonstrated two main themes related to what staff had learned: content knowledge (water properties, the water cycle, the value of water and the importance of conservation) and teaching pedagogy (the importance of inquiry and teaching science through learner-centered methods). Staff comments included:

> *I learned more about water and the water cycle. I also learned how to teach and learn about water in a fun and engaging manner.*

> *. . . how valuable water is.*

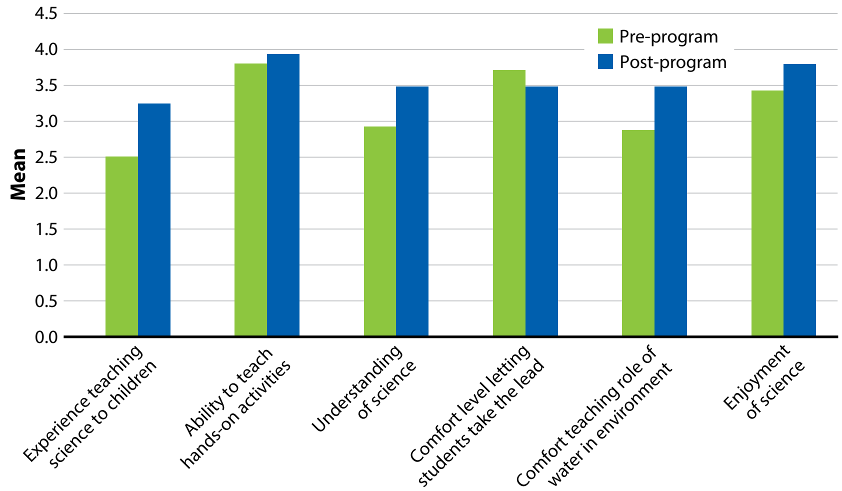


FIG. 1. Afterschool program staff pre-program and post-program scores from the questionnaires rating (1 = poor to 4 = very good) about various skills and attitudes in teaching science ($n = 59$).

TABLE 4. Afterschool program staff pre- and post-program scores rating themselves (1 = poor to 4 = very good) on various skills and attitudes in teaching science ($n = 59$)

Skill or attitude	Pre-program	Post-program
Teaching science	2.3	3.0
Hands-on activities	3.5	3.6
Understanding science	2.6	3.2
Students leading	3.5	3.3
Teaching about water	2.8	3.1
Enjoyment of science	3.1	3.6

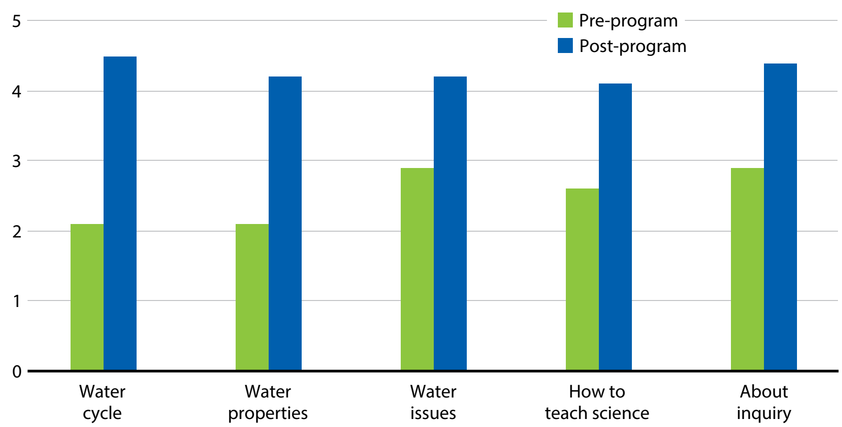


FIG. 2. Afterschool program staff retrospective assessment rating their understanding about water and teaching science prior to and after delivering the project.

I built on my vocabulary and great experiments. Also after the field trip I realized I waste too much water.

As a result of delivering the program, staff members' thoughts shifted regarding what was important when teaching science. Whereas "fun/student engagement" and "being prepared" were typically cited as important in the pre-questionnaire, a greater percentage of staff said in the post-questionnaire and end-of-project evaluation that "encouraging exploration" was important (22% pre-questionnaire to 29% post-questionnaire). This was the most cited response by the end of the program, as expressed in the following comments.

I learned that the children learn more when they're actually doing the project instead of just listening to it.

There is nothing wrong with not knowing an answer in Water Wizards and science in general.

I learned how to be open in questions and the answers so the kids explore further in their thinking instead of cutting their thought off with my own answer.

Engagement and reflection. Almost half (46%) of the afterschool staff cited the curriculum content or learning about water as the reason they chose to participate in 4-H Water Wizards. Most staff (80%) indicated that they would choose to deliver 4-H Water Wizards again, and the remaining 20% said maybe they would. Typical comments included:

Absolutely, important topic, engaging, materials provided.

Yes & No [to doing the project again]. The [training] meetings are inconvenient but I love doing the projects.

Staff cited both "activities" and "hands-on learning" as the best part of the program (38%), followed by the field trip (14%).

Children were engaged in every activity, also were very excited to do hands-on activities.

Hands on activities. Some projects felt like very big undertakings that were better in theory than in practice.

I very much enjoyed everything I did with the children, especially the field trip.

Almost one-third of staff (29%) identified time as the greatest challenge in delivering the project regularly. Other challenges included "holidays and

A community engagement project caps 4-H Water Wizards. Here, a program leader helps youth explore what a community is and what it means to volunteer as they prepare to plan their project. *Photo*: Marianne Bird.

professional development days," "homework and other activities" and ". . . pacing myself so I could get to an activity a week." Fourteen percent said they had challenges with specific activities, while 24% reported no challenges in delivering the project. When asked what would strengthen the project, some staff mentioned changing the time of the training sessions from evenings (after a long program day) or providing more training.

II. Evaluating student knowledge, behavior change and enjoyment

Sample. Our student sample consisted of 496 ethnically diverse elementary school students in fourth through sixth grades from 21 afterschool sites.

Data collection. We designed pretest and posttest questionnaires, based on key curricular concepts, to assess changes in student knowledge and attitudes towards water use and conservation. Both questionnaires included nine multiple-choice and short-answer questions to assess knowledge. An example of a question that appeared on both questionnaires was:

The part of the water cycle where water returns to the air is called

a. waterfall
b. evaporation
c. observation
d. condensation

The posttest questionnaire also contained additional questions to gauge behavior change regarding water conservation. We used these questions, such as the one following, to assess whether students enjoyed 4-H Water Wizards and if they were using less water as a result of participating in the project.

Are you using less water since participating in 4-H Water Wizards? Yes/No

If so, what are you doing to conserve water?

Children received the pretest questionnaire in their afterschool program within the first two weeks of the project. They filled out the follow-up questionnaire at the conclusion of the project. 4-H staff administered the assessments.

Analysis. As we did with the staff data, we matched pretest and posttest quantitative data, compiled it in Excel and analyzed it in SPSS. We conducted paired sample *t*-tests to assess whether the project impacted students' knowledge about, and attitudes toward, water.

Student outcomes

Increased knowledge about water science. Most student participants gained knowledge about water through the 4-H Water Wizards project. Mean post-test scores were significantly higher than pretest scores for all four years combined (mean difference = 0.7, P = 0.05, standard deviation [SD] = 0.39). Posttest scores were also significantly higher for each individual year (P = 0.01), with effect sizes ranging from 0.26 to 0.5. Table 5 and figure 3 show mean pretest and posttest scores for all four years.

There were some variations in pretest and posttest scores by age. While fourth and fifth graders showed significant increase in knowledge (fourth-grade mean difference = 1.0; P = 0.05 and d = 0.49; and fifth-grade mean difference = 1.1; P = 0.01; d = 0.60), sixth graders did not show significant increase in knowledge overall.

Greater awareness of water issues and conservation. Participants who completed the program were more likely to identify two or more water issues in their communities in the posttest questionnaire than they did in the pretest. For instance, while 15% of participants named two water issues in the pretest (e.g., pollution or wasting water), this number increased to 24% in the posttest (a significant difference at P = 0.05). Also, the percentage of participants who cited no issues dropped from 33% in the pretest to 18% in the posttest (P = 0.05). Issues the students cited included "drought in Sacramento," "people are wasting water," "junk in creeks and lakes," "fish are dying" and "running water for pools or leaving water on overnight."

A majority of participants (79%) said they were using less water since participating in the 4-H Water Wizards program. When asked what they were doing to conserve, children most often gave simple, concrete examples like "[taking] shorter showers," "turning water off when brushing my teeth" and "using less water by turning off the faucet when I am washing my hands."

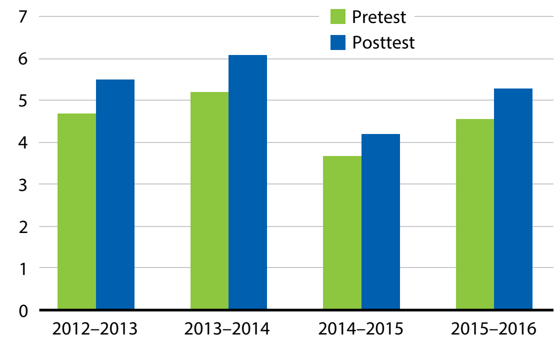


FIG. 3. Mean pretest and posttest scores for student participants, 2012–2016 (n = 469).

Project enjoyment. Overall, a large majority (85%) of the students agreed that they enjoyed the program. Comments from the afterschool staff confirmed this. Staff often commented that children loved the hands-on aspect of the program, that is, that they took advantage of the tools and license to explore activities.

> *Children were engaged in every activity, also were very excited to do hands-on activities.*

> *Kids love hands-on science and learning.*

Promising practices for science education in afterschool programs

Certainly, water is a critical resource that children in California, and throughout the world, need to understand. Afterschool programs can provide a gateway for exploring water science, especially in low-income communities. The 4-H Water Wizards program was designed to increase afterschool staff competency to teach water science to children, and raise children's knowledge and awareness of water. We conducted this four-year evaluation to determine if the program was effective in meeting its goals. In the discussion that follows, we explore the findings from our study and share thoughts about teaching science in the after-school setting.

TABLE 5. Means, SDs and effect size (Cohen's *d*) for 4-H Water Wizards student data 2012–2013, 2013–2014, 2014–2015 and 2015–2016

Program year	Survey items	*n*	Mean pretest	Pretest SD	Mean posttest	Posttest SD	Cohen's *d*
2012–2013	9	147	4.7	1.71	5.5	1.85	0.45
2013–2014	9	124	5.2	1.89	6.1	1.78	0.50
2014–2015	9	129	3.7	1.82	4.2	1.90	0.26
2015–2016	9	69	4.46	1.89	5.29	1.83	0.45

Understanding our findings in the context of afterschool programs

The nature of education in the afterschool setting is decidedly different than it is during in-school hours (Afterschool Alliance 2014). Attendance is not required, children may leave the program early and — having completed a day in the classroom before arriving — a child's attention is not optimal. The environment may be loosely structured, sometimes chaotic. For these reasons, it's a difficult setting for program fidelity, and scholastic outcomes are not always achieved (Deke et al. 2012; James-Burdumy et al. 2007). This may help to explain the average program effect size in our study.

Despite the obstacles, the 4-H Water Wizards project delivered reliable, if small, results. We found that there were consistent knowledge gains about water (with average effect size) overall for the participants of the program in every session. Fourth and fifth grade students showed statically significant gains in learning. The smaller sixth grade sample size, along with higher pretest scores, likely contributed to the non-significant results for this group. The consistency in results is especially significant when taken in the context of afterschool programs, where maintaining program fidelity is often a challenge. How did 4-H Water Wizards achieve consistent, positive program results in both knowledge and enjoyment despite these challenges in the afterschool context?

Expanded Learning (afterschool) program staff learn to measure water salinity using a hydrometer. *Photo*: Marianne Bird.

Integrating training and support

From our experience, when developing science programming for afterschool, creating curriculum and "handing it off" to program staff for implementation serves neither students nor staff. Curricula are most effective not as a stand-alone product but when designed with support for the practitioners (Ripberger and Blalock 2011). In 4-H Water Wizards, this included ongoing training, materials and coaching for afterschool staff.

Training sessions happened not once but three times during the 12-week program, reinforcing and building upon the material the staff was learning. Staff contributed questions and insight during these gatherings. The trainings also allowed participants to experience and deliver the content they would be presenting to students, thus building understanding and confidence in a subject many knew little about. During the training, staff shifted in their thinking about what was important in teaching science to children — from fun to exploration. This shift was likely related to the training, which emphasized science as exploration and investigation. Throughout the three trainings, staff saw demonstrations of inquiry-based teaching and, perhaps more importantly, had opportunities to practice and be coached. It appears that staff had lasting change in this area.

Also helpful was that the project included teaching materials. Program staff left each training session with all the materials needed to deliver content for the following unit. This eliminated the need for last-minute supply purchases or the inability to locate needed items, which might have led to skipped or compromised sessions. In addition, 4-H staff visited afterschool sites one or more times and checked in with afterschool staff to see where they were in the delivery of the project.

When reflecting on their own development throughout the project, afterschool staff articulated the value of student-constructed knowledge based in learn-by-doing experiences, as opposed to teacher-imposed knowledge based on simply telling information to children. Encouraging questions and investigation are foundational points in current methods of teaching science. This framing of how science is taught aligns with the adoption by most states, including California, of the Next Generation Science Standards (NRC 2012), which emphasize reasoning skills and concept development. The 4-H Water Wizards curriculum was written with a focus on inquiry, providing tools for facilitators in guiding learners in the process of discovery.

In 4-H Water Wizards, there is a bold focus on using ideas and energy from the students themselves to address water issues in the students' communities, and staff are trained to help this happen. The service-learning component — where children plan a community water-related project — is designed to help students apply their learning and see themselves as agents for positive change (Billig 2004). Our findings indicate that, prior to implementing 4-H Water Wizards, staff saw themselves at ease in empowering youth to be part of a project design but, when implementing the project, they realized challenges in doing so. This may not be surprising; working in partnership *with* young people is not commonplace in traditional educational settings. Future program design might include more training for staff to successfully integrate youth voices and partnership.

Conclusion

Afterschool programs provide excellent opportunities for nonformal, outside-the-classroom science education (Falk and Dierking 2010). Specific program practices may enhance the effectiveness of teaching science in afterschool, including training, support and program design. Our results suggest that a program design that includes ongoing engagement and collaboration with afterschool staff enhances successful learning outcomes in the afterschool context. Programs that utilize inquiry-based learning especially benefit from professional development that provides instructors with opportunities to experience what they will later replicate with students. This allows practitioners to construct their own understanding of content and process. In this regard, the tailoring of 4-H Water Wizards for afterschool settings is successful.

We do not know how the longer-term project goal — that of fostering concern and stewardship for the environment — plays out as young learners grow. It's a hopeful thought that an 11-session curriculum culminating in a single service-learning project would make a life-long impact on a child's behavior concerning water practices and greater care for the environment. Further study might explore the role of service-learning in cementing learning, changing behavior, encouraging environmental stewardship and developing engaged citizens.

Further research might also investigate if and how afterschool staff transfer inquiry-centered teaching when teaching beyond 4-H Water Wizards. Do afterschool staff transfer the science principles they learn in 4-H Water Wizards to other science activities in afterschool? Do youth retain information they've learned, and do they maintain water conservation practices over time? An exploration of such questions would further inform strategies to create optimal learning environments in afterschool settings. CA

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References

Afterschool Alliance. 2014. *Taking a Deeper Dive into Afterschool: Positive Outcomes and Promising Practices*. Washington, D.C.: Afterschool Alliance. www.afterschoolalliance.org/documents/Deeper_Dive_into_Afterschool.pdf

Billig SH. 2004. Heads, Hearts, Hands: The Research on K–12 Service-Learning. Growing to Greatness 2004. St. Paul, Minn.: National Youth Leadership Council.

[CDE] California Department of Education. 2015. State schools chief Torlakson calls first year of CAASPP results California's starting point toward goal of career and college readiness. Sacramento, Calif.: California Department of Education News release. Sept. 9, 2015. www.powayusd.com/getmedia/29e4226a-ba95-469a-9c4d-53dbc899a58f/pr_08-09-15yr15rel69.aspx

Chi BS, Freeman J, Lee S. 2008. Science in after-school market research study. A final report to the S.D. Bechtel, Jr., Foundation. Berkeley, CA: Lawrence Hall of Science, University of California, Berkeley.

Creswell JW, Creswell JD. 2017. *Research Design: Qualitative, Quantitative and Mixed Method Approaches*. Los Angeles: Sage Publishing. 304 p.

Davis M, Locklear E, Scott H. 1990. Educational needs of after-school care providers. J Ext 28(3):3RIB2. https://archives.joe.org/joe/1990fall/rb2.php

Deke J, Dragoset L, Bogen K. et al. 2012. Impacts of Title I Supplemental Educational Services on Student Achievement (NCEE 2012-4053). Washington, D.C.: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education. https://ies.ed.gov/ncee/pubs/20124053/pdf/20124053.pdf

Dewey J. 1916. *Democracy and Education: An Introduction to the Philosophy of Education*. New York, NY: Macmillan Company. 434 p.

Falk JH, Dierking LD. 2010. The 95 percent solution. Am Sci 98(6):486. https://doi.org/10.1511/2010.87.486

Freeman J, Dorph R, Chi B. 2009 Strengthening After-School STEM Staff Development. Berkeley, CA: Coalition for Science Afterschool, Lawrence Hall of Science, University of California, Berkeley.

Gregory GD, Di Leo M. 2006. Repeated behavior and environmental psychology: The role of personal involvement and habit formation in explaining water consumption. J Appl Soc Psychol 33(6):1261–96. https://doi.org/10.1111/j.1559-1816.2003.tb01949.x

Harlen W. 1997. Primary teachers' understanding of concepts of science and its impact in the classroom. Res Sci Educ 27(3):323. https://doi.org/10.1007/BF02461757

Harlen W, Holroyd C. 2007. Primary teachers' understanding of concepts of science: impact on confidence and teaching. Int J Sci Educ 19(1):93–105. https://doi.org/10.1080/0950069970190107

James-Burdumy S, Dynarski M, Deke J. 2007. When elementary schools stay open late: Results from the national evaluation of the 21st Century Community Learning Centers Program. Educ Eval Policy Anal 29(4):296–318. https://doi.org/10.3102%2F0162373707309077

Miller B. 2005. Pathways to Success for Youth: What Counts in After-School (Massachusetts After-School Research Study (MARS) Report). Boston, MA: United Way of Massachusetts Bay.

[NAEP] National Assessment of Educational Progress. 2015. The Nation's Report Card: Science Results. www.nationsreportcard.gov/science_2015/files/overview.pdf

[NCES] National Center for Education Statistics. 2018. Digest of Education Statistics, 2016 (NCES 2017-094), Chapter 2. Institute of Education Sciences, U.S. Department of Education. https://nces.ed.gov/pubs2017/2017094.pdf

[NRC] National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press. 400 p. https://nap.nationalacademies.org/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

Pelcher A, Rajan S. 2016. Afterschool program implementation in urban environments: Increasing engagement among adolescent youth. J School Health 86(8):585–94. https://doi.org/10.1111/josh.12411

Ripberger C, Blalock LB. 2011. 4-H Science in urban communities: Promising practices guide. Rutgers, NJ: The State University of New Jersey. http://urban4hscience.rutgers.edu

Russ RS, Berland LK. 2019. Invented science: A framework for discussing a persistent problem of practice. J Learn Sci 28(3):279–301. https://doi.org/10.1080/10508406.2018.1517354

Smith M, Schmitt-McQuitty L. 2013. More effective professional development can help 4-H volunteers address need for youth scientific literacy. Calif Agri 67(1):47–53. https://doi.org/10.3733/ca.v067n01p47

RESEARCH ARTICLE

With sustainable use of local inputs, urban agriculture delivers community benefits beyond food

Urban gardens based on sustainable principles help create healthier communities along with healthful food.

by María Teresa Gómez-Villarino and Teresa Briz

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Abstract

Urban agriculture is becoming increasingly important in developed countries, especially in terms of its economic and social benefits. If urban gardens are managed according to agroecological principles – involving the efficient and sustainable use of local resources and inputs – there are many environmental benefits to local communities. We studied urban gardens in Berkeley, California, and Madrid, Spain, to see how agroecology is practiced. Communities such as these that utilize good ecological practices in urban gardens obtain a wide range of valuable ecosystem services – the kinds of services provided by healthy ecosystems, including cultural services such as a place to socialize. These communities can serve as model urban agricultural centers which can contribute to the achievement of the United Nations Sustainable Development Goals, including good health, food security and sustainable cities.

Ever since the domestication of crops and animals began in the Neolithic period, agriculture has made many social contributions beyond simply producing food (Lovell 2010; Poulsen et al. 2017). Urban agriculture (UA), which is the raising of plants and animals within cities, has a long and multifaceted history in both developed countries (Corcoran and Cavin 2018; Surls et al. 2015) and developing countries (Olivier and Heineken 2017). As in all agricultural systems, UA produces a wide range of non-food products and services that contribute to economic growth while bolstering social and cultural systems. Along with the growing interest in UA, recently there has been an increased emphasis on the ecosystem services (ES) provided by urban gardening, which either directly or indirectly improve city dwellers' quality of life (Wilhelm and Smith 2018). Ecosystem services are the benefits that healthy ecosystems provide. They include "provisioning services" (such as providing food), "regulating

A study of urban gardens in Berkeley and Madrid found that applying agroecological principles can be an important source of ecosystem services and can be used to achieve urban sustainability. *Photo*: María Teresa Gómez-Villarino.

services" (such as purifying water), "supporting services" (such as nutrient cycling) and "cultural services" (such as a place to relax and socialize).

Although the effects of agriculture are almost always positive, they can sometimes be negative — water consumption, fertilizer and pesticide runoff, and altered nutrient cycles, among others. However, if UA is managed under agroecological criteria, negative environmental impacts can be avoided, production can improve, and ES can be enhanced (Altieri and Nicholls 2020; Schmutz 2017; Siegner et al. 2020). We call this type of management UA+.

Agroecology is often perceived as more than a production technique: "It is a movement, a science, a political vision and a practice which, alongside agricultural knowledge, endorses specific values and ethics, such as social relations of mutuality and respect [and] a commitment to bring forward more equitable change and land stewardship" (Tornaghi and Hoekstra 2017). Under this perspective, UA+ entails the production, transformation, and circulation of agricultural and livestock products in urban areas, based on the efficient and sustainable use of local resources and inputs, taking advantage of local knowledge and with the desire to rebuild community ties and sustainable food systems (Peredo Parada et al. 2016).

If UA is managed under agroecological criteria, negative environmental impacts can be avoided, production can improve, and ES can be enhanced.

However, agroecological practices in urban gardens have received very little attention, and gardeners face continuous challenges to sustainable food production, including maintenance or improvement of soil quality, efficient water use, and pest control, as well as social concerns (Gregory et al. 2016).

In this study, we compare UA practices and their perceived benefits in Berkeley, California, where UA has been strongly supported for years, and Madrid, Spain, where it has not seen such clear and continuous support, although it is slowly gaining importance. Both locations (fig. 1) share a similar latitude. Also, both have a high economic level, so UA can not only be seen as a food production activity but could also have a social and environmental role. Although recent reviews on UA identified land access as a key limitation for its implementation (Lin et al. 2015; Orsini et al. 2013), access to land did not impede any citizen who wanted to practice this activity in our research setting. This was due to the locations and typology of urban gardens that we selected (university campus gardens, school gardens, and community gardens). Because we were most interested in how agroecological principles are relevant at an urban gardens level and how urban residents perceived the main ecosystem services that flow from urban gardens, we did not want the difficulty of access to land to affect the results. In our study, only one urban garden (a community garden) is currently operating on a privately owned lot, while all the others are operating either on city-owned lots or other publicly owned lots (table 1).

Urban farming principles

The methodological approach was developed in three steps. First, an in-depth literature review was carried out to identify the main agroecological principles and ES theoretically provided by urban gardens. The second step consisted of participant and non-participant observation to identify the agroecological practices and perceived ES provided by the urban gardens that we analyzed. Finally, an assessment questionnaire was conducted to evaluate the use of agroecology and the perceived importance of the ES provided by the urban gardens.

FIG. 1. Location of the cities of Berkeley and Madrid and urban gardens.

During fieldwork (May 2019 to March 2020), while observing the work performed by gardeners, we also participated in informal talks with garden users and garden managers. This helped us increase our understanding of how the activities developed in the garden are related to the provision of ES. This contact ended up turning into participant observation, for example, removing weeds and helping during planting or harvesting. We consider this participant observation essential for the identification of cultural services. Without an open and free conversation, it is not possible to understand what values are enhanced through the activity developed in the garden, the sense of place it awakens, what beliefs it is based on, or what feelings it evokes.

We used the observations developed during the fieldwork to correct the initial list of agroecological principles and ES provided by urban gardeners. Regarding agroecology, we identified the main principles and practices applicable to UA (fig. 2) (Altieri and Nicholls 2018; Wezel et al. 2014). Concerning ES, we identified 18 services divided into four main categories — provisioning, regulating, cultural and supporting (fig. 3) — following the division of ecosystem services

TABLE 1. Main types of urban gardens in Berkeley and Madrid

Name	Definition	Land property		Berkeley	Madrid
		Public	Private		
University campus gardens (UG)	Gardens that function as micro scale food system; offer space for experiential education and for interdisciplinary research; contribute to food literacy; expand opportunities to interact with land and food; adapt urban greening to urban typologies and aesthetics. Undergraduate and graduate students, staff and faculty are involved in their management.	✓		8	6
School gardens (SG)	Gardens within the school grounds or nearby in different forms and sizes, with varying aims but predominantly used by most schools to enhance academic instruction. Families of the students, students, staff and teachers are involved in their management.	✓		9	9
Community gardens (CG)	Gardens managed and operated by members of the local community, producing food or flowers for the personal or common benefit of their members. The members participate in the decision processes and share resources such as space, water and tools. They can take different forms, especially regarding funding, ownership or aims.	✓	✓	12	30

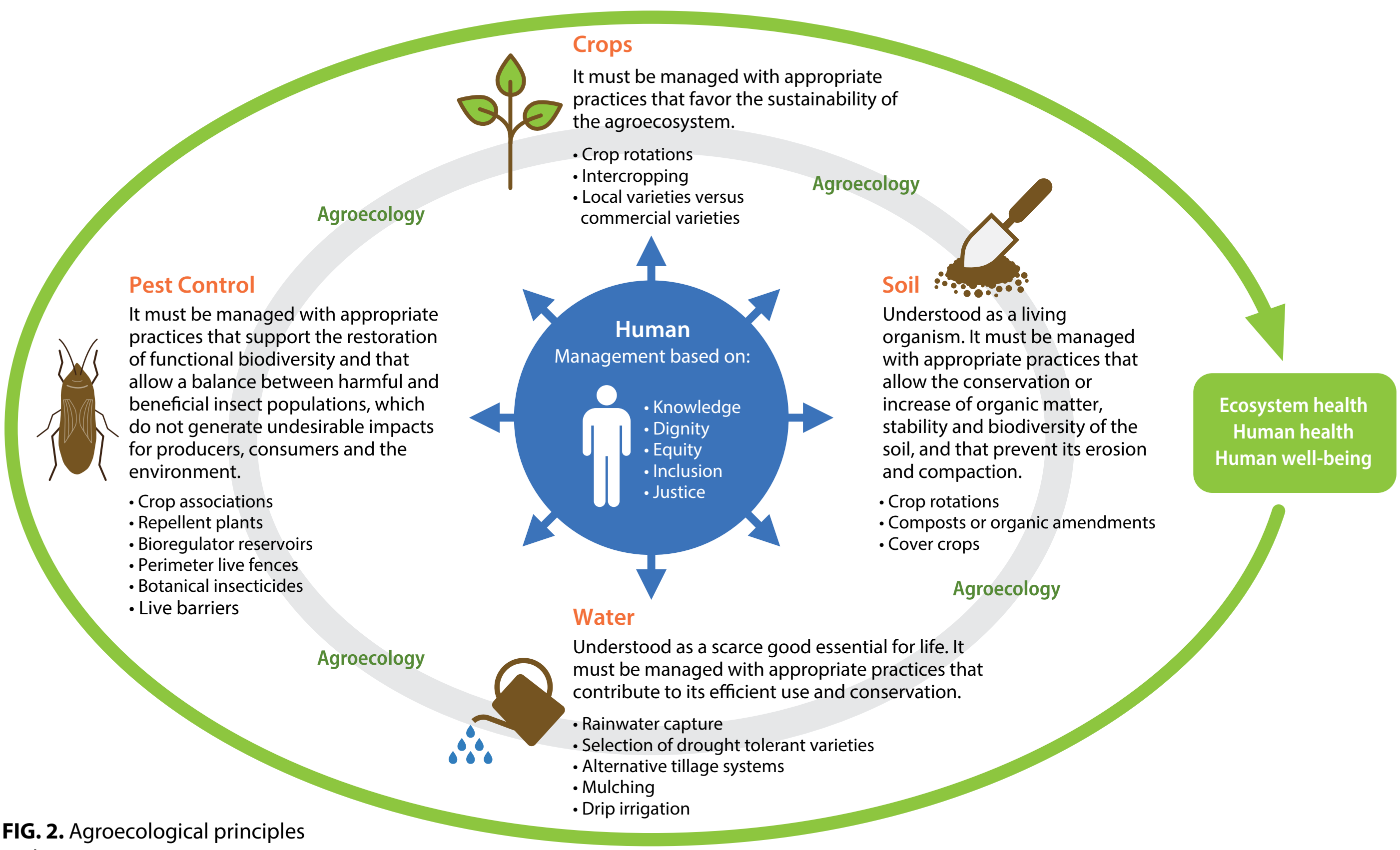

FIG. 2. Agroecological principles and management practices.

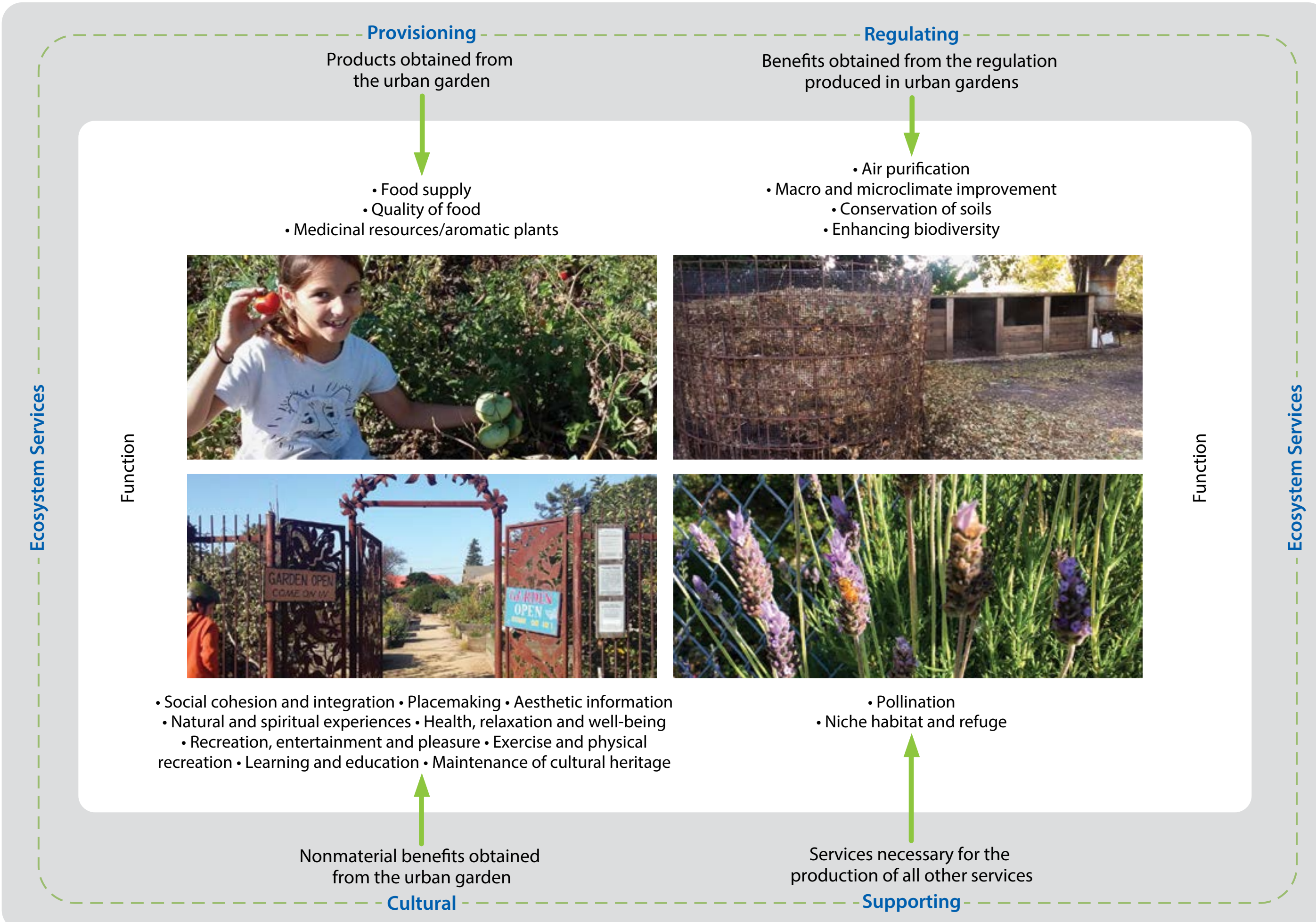

FIG. 3. Ecosystem services provided by UA, organized by functional group. *Photos*: María Teresa Gómez-Villarino.

most commonly used in the bibliography (de Groot et al. 2012; MEA 2005).

The valuation of both practices and ES was based on a survey conducted from October 2019 to February 2020. We administered the survey in English or Spanish to urban garden managers, that is, adults who are knowledgeable about how an urban garden is managed and about the benefits provided by the garden. We surveyed 74 garden managers (29 in Berkeley, 45 in Madrid) from three different types of gardens (university campus gardens, school gardens and community gardens) (table 1).

The survey included three main sections. The first section assessed the profile of the urban garden managers who were responsible for the garden management. To this end, the survey included questions regarding the age, gender, education level, time lived in Berkeley/Madrid, place of origin, people living in the household, and working status. We also asked about their habits and use of the garden, how often they went to the garden, and how much time they spent in it. We used this information to define the profile of the garden managers by means of descriptive statistics.

The second section included a valuation of the agroecological characteristics of the urban garden. The garden manager was asked whether agroecological principles are applied in the urban garden; if so, to which productive factors (soil, water, crops and pest regulation) they are applied; and how they are applied. We also used the averages of the descriptive statistics to assess whether agroecological principles are applied in the urban gardens.

The third section was dedicated to the assessment of the perceived importance of the ES previously identified. For this, a non-economic valuation was chosen, since the purpose of the research was to evaluate the social perception of ecosystem services and their contribution to urban sustainability. We used a Likert scale design, one of the fundamental and most widely used instruments in social science and educational research (Joshi et al. 2015). The questions in this section helped check, first, which of the ES identified as provided by UA is recognized by the respondent, and, second, its importance. For this, the respondent was asked directly whether the urban garden provides a certain ES among the 18 ES previously identified as potentially being provided by urban gardens. If the answer was negative, the respondent did not recognize this value. If the answer was positive, the respondent was asked to evaluate the importance of such ES, using the Likert scale. Responses were recorded on a scale from zero to five, where zero meant total disagreement and five meant full agreement.

Cultural gardening practices

The profile of the urban garden manager was very similar in both locations, and it did not depend on the type of garden they were taking care of. The garden managers are men and women between the ages of 45 and 65, very likely to have completed college, and mostly currently employed. They visit the garden at least twice a week, dedicating two or more hours each time, and show a high level of environmental sensitivity.

The first result to be highlighted is that agroecological principles are applied to the production system in all the gardens (table 2). These agroecological principles integrate four fundamental productive factors — soil, water, crops and pests — and also generate, exchange, and apply the knowledge necessary to improve the management of these factors. This places a strong emphasis on human and social values, such as dignity, equity, inclusion and justice, which benefit both urban ecosystem health and the citizen's health and well-being, and contribute to urban sustainability and a fair food system (fig. 2). This premise has been explicitly recognized by the urban garden managers:

> *Urban agriculture and agroecology bring us together to better understand urban land usage, food and environmental justice principles while using positive practices which benefit both the land and the inhabitants, not to mention the impact on the local economy. — Manager of community garden, Berkeley*

Gardens are irrigated

All gardens in Madrid and 97% in Berkeley are irrigated (table 3). Despite persistent droughts in California and Spain, the irrigation systems use water from the urban supply, with a low percentage of gardens using rainwater harvesting systems. The most commonly used method to reduce water use in Madrid is drip irrigation (95%), whereas, in Berkeley, it is the use of mulch (96%). However, the most noticeable difference between the urban gardens of the two locations is the selection of drought-tolerant varieties, which are widely used in Berkeley (83%) and not so much in Madrid (49%).

Avoiding monoculture

As for crops, the application of agroecological practices is very high, especially in Madrid. Intercropping and the use of local versus commercial (exogenous) varieties are the predominant practices, with high percentages in the two cities. This pattern of intercropping is shared by 100% of university gardens in both cities. Surprisingly, fewer than 50% of university gardens in Berkeley use local varieties rather than commercial ones, although planting local varieties is a very common practice in school gardens (100%) and community gardens (91%). In addition, it is worth mentioning the clear commitment to avoiding monoculture, and to enhancing the biodiversity and healthy state of the soil, water and crop system.

Pest and soil practices

The application of agroecological practices to pest control is also widespread but somewhat below the application to crops in both cities. The prevailing approaches are planting pest-repellent plants and growing two or more plant species in the same space and at the same time in order to obtain better production and pest control. This highlights the sensitivity of garden coordinators and users to biodiversity. However, there is limited use of bioregulator reservoirs — plants or sites in the garden that favor the reproduction of natural enemies of pests, and that do not host organisms that are harmful to crops.

Regarding soil practices, organic fertilization stands out. It is applied in almost all the gardens. In the case of school and university gardens, it reaches 100%. Crop rotation is more widespread in Madrid than in Berkeley, showing a strong tradition in the Mediterranean areas, where many soils have very poor quality.

TABLE 2. Factors on which urban gardens apply agroecological principles

		Berkeley, California (% Yes)	Madrid, Spain (% Yes)
Does this urban garden apply agroecological principles?		100	100
Soil	Are agroecological principles followed in soil management?	90	100
Water	Are agroecological principles followed in water management?	86	91
Crops	Are agroecological principles followed in crops management?	83	96
Pest control	Are agroecological principles followed in pest control management?	76	89

TABLE 3. Agroecological practices implemented by type of urban garden in Berkeley and in Madrid

	Berkeley, California (% Yes)				Madrid, Spain (% Yes)			
	UG	SG	CG	ALL	UG	SG	CG	ALL
Does this urban garden apply agroecological principles?	100	100	100	100	100	100	100	100
Soil								
Are agroecological practices carried out in the urban garden to improve soil health?	88	78	100	90	100	100	100	100
Crop rotations	57	71	83	73	100	56	97	89
Cover cropping	57	71	75	69	100	22	57	62
Applications of compost or organic amendments	100	100	92	96	100	100	97	98
Others	29	14	8	15	33	0	17	20
Water								
Does the garden require water?	100	100	92	97	100	100	100	100
Urban supply	100	100	91	96	83	100	100	98
Sewage water	0	0	9	4	0	0	0	0
Harvested rainwater	13	44	27	29	17	0	27	20
Others	0	11	0	4	17	0	3	4
Are agroecological practices carried out in the urban garden to reduce water consumption?	88	78	91	86	100	56	100	91
Rainwater capture	29	57	30	38	17	20	27	24
Selection of drought tolerant varieties	86	71	90	83	67	20	50	49
Alternative tillage systems	29	14	40	29	67	0	17	24
Mulching	100	86	100	96	100	0	77	71
Drip irrigation	71	57	90	75	100	60	97	95
Others	0	14	30	17	33	0	10	7
Crops								
Are agroecological practices carried out in the urban garden in relation to crops?	63	100	92	86	100	89	97	96
Crop rotations	60	89	73	76	100	63	97	93
Intercropping	100	67	91	84	100	88	90	93
Local varieties versus commercial varieties	40	100	91	84	100	88	87	91
Others	20	0	9	8	50	0	0	7
Pests								
Are agroecological practices carried out for pest control?	75	67	83	76	100	56	97	89
Crop associations	67	33	70	64	100	80	87	90
Repellent plants	67	50	50	59	100	80	87	90
Bioregulator reservoirs	17	0	0	5	0	0	7	5
Perimeter live fences	17	17	10	14	67	0	33	35
Botanical insecticides	50	0	10	18	50	20	13	20
Live barriers	33	67	70	59	100	60	73	78
Others	17	0	20	14	33	0	7	8

CG = community gardens, SG = school gardens, UG = university campus gardens.

Value of ecosystem services

In both locations, ES provided by urban gardens are perceived and highly valued. On a scale of 1 to 5, 83% of the ecosystem services provided by urban gardens obtained a score of over 3, and 33% a very high score with values between 4 and 5 (table 4). As urban gardeners specifically explained:

> *Gardens in cities provide habitat for wildlife, rest and relaxation for humans, food for everyone, space for people to gather, and support education, history and science! We use our garden for art, music, conflict mediation, mindfulness, cooking and nutrition education. We also always grow heirloom varieties and share seeds/plants amongst the other gardens. We also use the garden to teach social education such as stories of immigration, social justice and culture. — Manager of elementary school garden, Berkeley*

> *It is important to have gardens in the city for growing healthy food and to connect with other people. It also spreads values of respect for the environment and educates new generations in a healthy and positive environment. They should make more spaces like this. We should be thankful that community gardens are gradually spreading. — Manager of community garden, Madrid*

> *The community garden is important, but not only for the food it can provide. It is also important [to have a] sense of community and to have the opportunity to work and learn together, appreciate differences, resolve conflicts, to extend a hand towards others, and to receive this benefit as well. [The garden] also provides a shared space for collective leisure and recreation around a shared purpose that is immediately accessible to participants. — Manager of community garden, Berkeley*

In terms of the relative importance of each category of ES, the most highly valued services are cultural (84% Berkeley, 80% Madrid) and supporting services (76% Berkeley, 72% Madrid). On the other hand, the least valued services are regulation (66% Berkeley, 65% Madrid) and provision (68% Berkeley, 49% Madrid). The total valuations obtained in Berkeley and Madrid are very similar but somewhat lower in Madrid. The exception is the provisioning service, which obtained an extraordinarily low value in Madrid.

If we analyze by type of garden, community gardens are those in which the average score of all the ecosystem services reaches the highest value (82% Berkeley, 74% Madrid).

Gardens in both Berkeley and Madrid were committed to using intercropping and local versus commercial plant varieties, and to avoiding monoculture. *Photo*: Evett Kilmartin.

Sustainable urban development

The study highlights that the services provided by urban gardens managed with agroecological principles are not mutually exclusive, but complementary. Therefore, so are the benefits obtained. When the garden managers were questioned about the services provided by the urban garden, all recognized many services, clearly illustrating its multifunctionality. Within this multifunctionality, we would like to draw attention to the key role of the cultural function. The gardens provide a leisure space for recreation, entertainment, and pleasure as well as facilitating the social interaction that derives from community cohesion and integration. Not only is this social interaction established among gardeners, but the gardens also foster social interaction with the non-gardening public, for example through the "open days" organized to introduce gardening and to share experiences, culture, and entertainment. Learning and education have various dimensions. The first is to share knowledge and know-how, not only about gardening practices but also about political and cultural dimensions, mainly at the university gardens. The second, and most frequently mentioned, concerns children. Children's education is mostly mentioned at the school garden, not only to teach about crops, environment, or nutrition, but also to teach social education, such as immigration stories, social justice, and culture. Gardens are also highly valued for their contribution to health, relaxation, and well-being, due to the

TABLE 4. Average score of ecosystem services (range 0–5) by type of urban garden in Berkeley and in Madrid

	Berkeley, California				Madrid, Spain			
	UG	SG	CG	ALL	UG	SG	CG	ALL
Provisioning services								
Food supply	3.25	3.33	4.00	3.59	1.67	1.33	2.47	2.13
Quality of food	3.13	3.44	4.25	3.69	2.67	2.00	3.33	2.98
Medicinal resources/ aromatic plants	3.25	2.11	3.33	2.93	2.33	1.67	2.47	2.29
Average value of provisioning services (range 0–15)	9.63	8.89	11.58	10.21	6.67	5.00	8.27	7.40
Regulating services								
Air purification	2.88	3.44	3.50	3.31	4.00	2.56	3.47	3.36
Microclimate improvement	2.88	3.33	3.67	3.34	4.17	2.67	3.13	3.18
Macroclimate improvement	2.38	3.00	3.33	2.97	4.33	2.22	3.17	3.13
Maintenance of soil fertility	3.63	3.33	3.92	3.66	4.67	1.56	3.57	3.31
Average value of regulating services (range 0–20)	11.75	13.11	14.42	13.28	17.17	9.00	13.33	12.98
Cultural services								
Social cohesion and integration	4.75	4.78	4.75	4.76	4.33	4.22	4.30	4.29
Placemaking (create and rehabilitate spaces)	4.13	3.78	4.67	4.24	3.50	3.11	4.03	3.78
Esthetical and landscape value	3.75	4.11	3.92	3.93	3.33	3.11	3.83	3.62
Natural experiences	4.50	4.78	4.83	4.72	3.33	3.89	4.40	4.16
Health, relax and well-being	4.63	4.33	5.00	4.69	3.83	3.44	4.50	4.20
Recreation, entertainment and pleasure	4.00	4.22	4.33	4.21	3.50	3.56	4.40	4.11
Exercise and physical recreation	2.75	3.78	4.00	3.59	3.50	1.67	3.67	3.24
Learning and education	4.00	4.89	4.75	4.59	3.67	5.00	4.40	4.42
Maintenance of cultural heritage	2.13	3.78	3.58	3.24	4.17	4.44	3.90	4.04
Average value of cultural services (range 0–45)	34.63	38.44	39.83	37.97	33.17	32.44	37.43	35.87
Supporting services								
Pollination	4.00	3.67	3.92	3.86	4.33	2.78	4.07	3.84
Biodiversity, niche habitat and refuge	3.38	3.56	4.25	3.79	4.17	2.00	3.67	3.40
Average value of supporting services (range 0–10)	7.38	7.22	8.17	7.66	8.50	4.78	7.73	7.24
Average value of all services (range 0–90)	**63.38**	**67.67**	**74.00**	**69.10**	**65.50**	**51.22**	**66.77**	**63.49**

CG = community gardens, SG = school gardens, UG = university campus gardens.

healthy food produced as well as the physical exercise, psychological release, and social contact.

Despite the vocational role of agriculture, food production is among the least valued services. However, even if food production is not the main motivation of gardeners, it is an indisputable fact that urban gardens do produce fresh food, generally of good quality. In periods of crisis, these community gardens have served, and continue to serve, to supply food to the population. There are many examples, from older ones such as the "Victory Gardens," which supplied fresh vegetables to the United States during the Second World War (Brown and Jameton 2000), to the current COVID 19 crisis. Although access to gardens was initially limited during lockdowns, access was opened up due to pressure from users, and taking care of gardens was allowed for self-consumption.

Supporting services, such as pollination, were the second most valued category. The gardeners reported the presence of bees, frogs, birds, butterflies, and so on in all urban gardens. This probably explains why their survey responses show the value that they place on supporting services. Further evidence of this recognition is the fact that all the gardens use agroecological practices, including knowledge and general practices, as well as others self-developed in relation to soil, water, crops, and pest management. Regulating services, such as carbon storage, although achieving high ratings, were not perceived as being as important as the other categories.

Gardeners in the study gave high ratings for the cultural services provided by the gardens, including health benefits, education, and social interaction. *Photo*: Elena Zhukova.

The research shows that the application of agroecological practices seems to be the norm for urban gardens in these two developed countries, where the social, environmental, and economic benefits provided by the practice of urban agroecology are recognized and valued. Therefore, urban gardens applying agroecological principles can be an important source of ecosystem services, delivering a high positive impact on the quality of the urban space, as well as on the quality of life of the citizens, and can be used to achieve urban sustainability.

UA within the framework of agroecology becomes a tool that facilitates the creation of diversified, productive, and resilient urban green spaces. UA+ not only allows the adequate management of the nutrients, water, soil, and energy necessary for urban land cultivation but also generates, exchanges, and applies the knowledge necessary to improve such management.

Additionally, agroecology could become a tool for rehabilitate degraded spaces, owing to the existence of thoroughly tested agricultural tools and techniques that ensure the success of plantations and sowings. Thus, agroecology provides solutions for the recovery of the typical degradation of empty lots in the city, which are usually characterized by their compaction, poor organic-matter content, altered moisture characteristics, or contamination with heavy metals (Beniston and Lal 2012; Grewal et al. 2011). Organic amendments stabilize the contaminants in the soil, provide a physical barrier to pollution, improve the overall quality of the soil, increase water-retention capacity, restore microbial communities, and alleviate compaction (Altieri and Nicholls 2018). This also has been recognized by urban gardeners at the sites that we studied:

> *This urban garden used to be a rubbish dump, now it is a wonderful place of flowers and fruits. — Community garden, Madrid*

> *I think there are a lot of places in urban areas where agriculture can be implemented. Most importantly, gardens are a great way to bioremediate degraded soils and be a place for human healing. — University garden, Berkeley*

Therefore, one challenge for the future would be to integrate urban garden projects within a general process of urban ecological rehabilitation, as one more element of urban complexity, and not only as exotic or specific exceptions. UA+ should be included in the

Urban agriculture within the framework of agroecology becomes a tool that facilitates the creation of diversified, productive and resilient urban green spaces.

functioning of the city as an active part of its metabolism, towards a more citizen-oriented city.

Enhancing the quality of life

The United Nations Sustainable Development Goals (SDGs) were designed to promote environmental values while aiming to ensure economic and social stability worldwide by 2030. This is an urgent call to action and one of our greatest global challenges. Enhancing UA+ in cities contributes to the well-being and health of urban dwellers of all ages (SDG 3), specifically by improving the quality of education (SDG 4), biodiversity (SDG 15), and food security and nutrition (SDG 2), which ultimately makes these cities more resilient and sustainable (SDG 11).

In light of these results, we want to conclude this article with a reflection and an open-ended question. Humanity must face the challenge of creating a more environmentally, socially, and economically sustainable world, as is recognized by the UN 2030 Agenda for Sustainable Development. The global problems are wide and complex: water scarcity, environmental degradation, pressure on natural or agricultural land, food insecurity, biodiversity loss, and others. These issues cannot be addressed in isolation. With that in mind, considering the success we have seen in small-scale urban agricultural communities, such as Berkeley and Madrid, we ask the question: Wouldn't the benefits to contemporary society be greater if agroecological practices were applied more widely in urban agriculture on a much larger scale? CA

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References

Altieri MA, Nicholls CI. 2018. Urban agroecology: Designing biodiverse, productive and resilient city farms. Agro Sur 46:49–60. https://doi.org/10.4206/agrosur.2018.v46n2-07

Altieri MA, Nicholls CI. 2020. Agroecology: Challenges and opportunities for farming in the Anthropocene. Environ Ecol Int J Agric Nat Resour 47:204–15. https://doi.org/10.7764/ijanr.v47i3.2281

Beniston J, Lal R. 2012. Improving soil quality for urban agriculture in the north central U.S. In Lal R, Augustin B (eds.). *Carbon Sequestration in Urban Ecosystems*. Springer Netherlands. p 279–313.

Brown KH, Jameton AL. 2000. Public health implications of urban agriculture. J Public Health Pol 21:20–39. https://doi.org/10.2307/3343472

Corcoran MP, Cavin JS. 2018. Introduction: Civil society and urban agriculture in Europe. Nat Cult 13:1–16. https://doi.org/10.3167/nc.2018.130101

de Groot R, Brander L, van der Ploeg S, et al. 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1:50–61. https://doi.org/10.1016/j.ecoser.2012.07.005

Gregory MM, Leslie TW, Drinkwater LE. 2016. Agroecological and social characteristics of New York city community gardens: Contributions to urban food security, ecosystem services, and environmental education. Urban Ecosyst 19:763–94. https://doi.org/10.1007/s11252-015-0505-1

Grewal SS, Cheng Z, Masih S, et al. 2011. An assessment of soil nematode food webs and nutrient pools in community gardens and vacant lots in two post-industrial American cities. Urban Ecosyst 14:181–94. https://doi.org/10.1007/s11252-010-0146-3

Joshi A, Kale S, Chandel S, et al. 2015. Likert scale: Explored and explained. Br J Appl Sci Technol 7:396–403. https://doi.org/10.9734/bjast/2015/14975

Lin BB, Philpott SM, Jha S. 2015. The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. Basic Appl Ecol 16:189–201. https://doi.org/10.1016/j.baae.2015.01.005

Lovell ST. 2010. Multifunctional urban agriculture for sustainable land use planning in the United States. Sustainability 2:2499–2522. https://doi.org/10.3390/su2082499

[MEA] Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Synthesis. Washington, DC: Island Press. World Resources Institute.

Olivier DW, Heinecken L. 2017. Beyond food security: Women's experiences of urban agriculture in Cape Town. Agric Human Values 34:743–55. https://doi.org/10.1007/s10460-017-9773-0

Orsini F, Kahane R, Nono-Womdim R, et al. 2013. Urban agriculture in the developing world: A review. Agron Sustain Dev 33:695–720. https://doi.org/10.1007/s13593-013-0143-z

Peng J, Liu Z, Liu Y, et al. 2015. Multifunctionality assessment of urban agriculture in Beijing City, China. Sci Total Environ 537:343–51. https://doi.org/10.1016/j.scitotenv.2015.07.136

Peredo Parada S, Vela Campoy M, Jiménez Gómez A. 2016. Determination of resilience/vulnerability levels of urban agroecology initiative in the South West of Andalusia. Idesia 34:5–13. https://doi.org/10.4067/S0718-34292016005000003

Poulsen MN, Neff RA, Winch PJ. 2017. The multifunctionality of urban farming: Perceived benefits for neighbourhood improvement. Local Environ 22:1411–27. https://doi.org/10.1080/13549839.2017.1357686

Schmutz U. 2017. Urban agriculture or urban agroecology? Urban Agriculture Magazine. No. 33. p 7. https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/

Siegner AB, Acey C, Sowerwine J. 2020. Producing urban agroecology in the East Bay: From soil health to community empowerment. Agroecol Sustain Food Syst 44:566–93. https://doi.org/10.1080/21683565.2019.1690615

Surls R, Feenstra G, Golden S, et al. 2015. Gearing up to support urban farming in California: Preliminary results of a needs assessment. Renew Agric Food Syst 30:33–42. https://doi.org/10.1017/S1742170514000052

Tornaghi C, Hoekstra F. 2017. Editorial. Urban Agriculture Magazine. No. 33. p 3–4.

Wezel A, Casagrande M, Celette F, et al. 2014. Agroecological practices for sustainable agriculture: A review. Agron Sustain Dev 34:1–20. https://doi.org/10.1007/s13593-013-0180-7

Wilhelm JA, Smith RG. 2018. Ecosystem services and land sparing potential of urban and peri-urban agriculture: A review. Renew Agric Food Syst 33:481–94. https://doi.org/10.1017/S1742170517000205

RESEARCH ARTICLE

Online training for child care providers teaches child nutrition in English and Spanish

Online training is an effective way to communicate about childhood nutritional needs to English- and Spanish-speaking family child care home providers.

by Danielle L. Lee, Abbey Alkon, Ron Strochlic, Deepa Srivastava, Marisa Neelon, Victoria F. Keeton and Lorrene D. Ritchie

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Childhood obesity is a major public health crisis in the United States (Skinner et al. 2018). Thirty percent of children do not consume any vegetables on a daily basis, with up to 15% of their calories coming from foods and beverages with added sugars (Butte et al. 2010; Fox et al. 2010; Weinfield et al. 2019). These unhealthy childhood eating habits contribute to adult health problems such as diabetes and heart disease (Reilly et al. 2011).

Child care is an ideal environment in which to improve young children's eating habits. Over half of young children spend an average of 30 hours per week in child care, where many of them consume the majority of their daily calories (Benjamin-Neelon 2018; Laughlin 2013; Leucking et al. 2020). Because of this, providers serve as influential adults who can shape lifelong healthy eating habits and reinforce them as part of children's daily routines (Deiner and Qiu 2007).

Abstract

Poor nutrition among young children is a national health crisis which contributes to obesity and chronic disease later in life. Since children spend so much time in child care, child care providers can help improve the quality of young children's nutrition and foster lifelong healthy eating habits. However, California's family child care home (FCCH) providers receive little training on *what* and *how* to feed young children. To address this problem, we developed a self-paced online training on child nutrition in English and Spanish for FCCH providers. Our feasibility study evaluated providers' satisfaction with the training and ease of use, using an online survey and a 45-minute interview upon completing the training. Providers rated their training experience as excellent, easy to enroll in, and complete. Most providers reported they were somewhat likely to make changes to what and how they feed infants and toddlers. Many recommended adding printed resources and culturally relevant material for future trainings.

Findings from a UC Cooperative Extension study suggest that online trainings are an effective way for public health educators to convey important nutritional information to family child care home providers. *Photo*: Danielle L. Lee.

Family child care home providers serve as influential adults who can shape lifelong healthy eating habits and reinforce them as part of children's daily routines. *Photo*: Danielle L. Lee.

Family child care homes (FCCH) are a type of licensed child care provided in private homes. Approximately one in five children in the U.S. will attend an FCCH at some point before entering kindergarten (National Association of Child Care Resource and Referral Agencies 2010). FCCHs are typically located in the same neighborhood as the families they serve. They provide longer hours of care and are lower in cost than child care centers. FCCH providers in the U.S. are ethnically diverse and often appeal to underserved families with limited income who may face challenges with healthy eating habits due to systemic social inequities (Min et al. 2018; Whitebook et al. 2006). Evidence suggests that children cared for in FCCHs may be at greater risk of obesity than those cared for in their own home or in child care centers (Ward et al. 2017).

California has over three times the number of licensed FCCHs (about 30,000) as child care centers (Child Care Aware of America 2020). Compared to staff working in centers, FCCH providers experience numerous barriers to providing children with healthy meals and snacks. This is a missed opportunity for FCCH providers to support children's healthy eating habits.

Few nutrition standards apply to licensed FCCHs that are not participating in the federal Child and Adult Care Food Program (CACFP) (Lee et al. 2020). One specific regulatory gap is the California Health and Safety Code, which requires licensed centers but not licensed FCCH providers to adhere to CACFP nutrition standards regardless of program participation (Lee et al. 2020). An attempt to extend this requirement to FCCH providers in 2012 through the Improving Child Care Nutrition Act (CA AB 1872) passed both the California Assembly and Senate but was vetoed by the governor (California Legislative Information 2021). Attempts to mitigate this gap were implemented in 2016 with a California law that requires newly licensed FCCH providers to complete one hour of nutrition training (California Emergency Medical Services Authority 2021). However, this leaves out nearly 30,000 FCCH providers in California licensed prior to 2016 who provide care to over 310,000 children (California Department of Social Services, unpublished data). In general, few nutrition interventions have been conducted in FCCHs (Benjamin-Neelon et al. 2018; Ward et al. 2017).

To address the training needs of FCCH providers, a multi-disciplinary, bilingual team of nutrition and health experts developed an in-person workshop in English and Spanish to share best practices on *what* and *how* to feed young children (Ritchie et al. 2020, 2021). Given that one in 10 FCCH providers in California prefer to speak only Spanish and about one-quarter prefer Spanish in addition to English, a Spanish-language training was essential (Whitebook et al. 2006). The team conducted a three-month pilot study of the workshop and found that, although the FCCH providers adopted many of the recommended feeding practices (Box 1), attending the workshop was challenging due to providers' busy schedules and transportation needs (Ritchie et al. 2020, 2021). To improve accessibility and sustainability, the workshop content was converted to an interactive, online training with a digital teacher avatar named "Laura," which included videos, games and quizzes. The purpose of this feasibility study was to evaluate FCCH provider satisfaction with and ability to complete the self-paced English and Spanish online training.

Interactive online training

The online training was modified into an audio-narrated, interactive training from materials previously developed for the in-person workshop. Content was reviewed by the research team, which included University of California Cooperative Extension (CE) specialists and nutrition, family and consumer sciences advisors.

The in-person training pilot test (Box 2) showed that providers were seldom following certain key recommended practices. These practices were singled out for additional reinforcement via videos, interactive games, and quizzes. The videos were recorded during meals at two FCCH sites, while a registered dietitian developed the quizzes and games. The final content included four 20-minute modules on *what* and *how* to feed infants (0–11 months; two modules) and toddlers (12–36 months; two modules) (figs. 1 and 2).

Materials were translated into Spanish by a bilingual CE translator and converted into online modules. The resulting Spanish materials were reviewed and revised as needed by a CE specialist with expertise in linguistically appropriate nutrition education materials for Spanish-speaking populations. Under guidance

Recommended practices on *what* and *how* to feed young children adopted by family child care home providers after completing a two-hour in-person workshop

Infant feeding recommendations:

- Supporting and encouraging breastfeeding
- Providing adequate refrigeration for storing breastmilk
- Introducing solid foods gradually and waiting 3–5 days before introducing new foods

Toddler feeding recommendations:

- Offering natural cheese no more than 1–2 times per day
- Using only liquid non-tropical vegetable oils
- Providing meals and snacks every 2–3 hours at regularly scheduled times
- Minimizing distractions while eating
- Offering healthy items at celebrations
- Rarely or never offering 100% fruit juice
- Not serving white grains
- Not serving high-salt foods
- Not serving cheese food or cheese spread

Box 1.

Recommended practices on *what* and *how* to feed young children with low or no adherence by family child care home providers after completing a two-hour in-person workshop

Infant feeding recommendations:

- Offering only breastmilk and/or infant formula as beverages (besides water)
- Encouraging older infants to self-feed with their fingers and drink from a cup with assistance
- Feeding younger infants on demand
- Holding infants while bottle-feeding
- Not propping bottles or allowing infants to carry or sleep with bottles
- Including older infants at family-style meals where the provider and children eat together

Toddler feeding recommendations:

- Ensuring water is easily available for self-serve and is actively offered with meals and snacks
- Serving meals family-style and teaching children to serve themselves
- Expecting children to eat a lot at some meals and little at others, to not eat everything offered, change likes and dislikes, be messy, and take time to accept new foods
- Not pressuring children to eat or clean their plates
- Not focusing mealtime conversations on the amount eaten

Box 2.

from the CE specialist, several of the recommended food items were included in the training to ensure cultural inclusivity (e.g., traditionally made whole-grain corn tortillas). Adobe Articulate 360 software was used to create the four interactive modules. Each module was designed to be completed in about 20 minutes. Audio content was narrated in Spanish and English.

Topics covered in the online training were *what* and *how* to feed infants and toddlers. *What* to feed infants and toddlers included recommendations for milk beverages (toddlers only), grains, proteins, other dairy products, fruits, vegetables, sugar and salt. *How* to feed infants and toddlers included recommendations for breastfeeding and bottle feeding (infants only), introducing solid foods (infants only), preventing choking, meal and snack frequency (toddlers only), culturally relevant foods, healthy food at celebrations, the feeding environment, and responsive feeding (which are feeding practices that encourage the child to eat autonomously and in response to physiological and developmental needs (Pérez-Escamilla et al. 2021)).

The training also offered information on *what* not to feed infants and toddlers: juice, soda, sugar-free drinks, juice drinks, coffee, sweet tea, sports drinks, lemonade or aguas frescas, horchata, energy drinks, cow's milk (infants only) and plant-based milks (infants only); white or enriched bread, white rice, flour tortillas, pasta or noodles made from white flour; desserts such as cake, cookies, pie, pastries or donuts; processed meats or deep fried or pre-fried meats, poultry and fish; cheese spreads, imitation cheeses, unpasteurized or raw dairy products; deep fried or pre-fried baked vegetables; canned fruits and vegetables with added salt, sugar or fat; foods with added sugar/sugar equivalents, food with a combination of three or more kinds of sugar/sugar equivalents, low-calorie sweeteners, and honey (infants only); high salt foods (>200 mg sodium for snacks, >480 mg sodium for entrees), or adding salt to food for infants.

The training was made available in an online training portal to facilitate public access (Lee et al. 2022a, 2022b, 2022c, 2022d). Final training modules were exported as Sharable Content Object Reference Model (SCORM) files and uploaded to eXtension Campus, which provides online research-based curricula. Upon logging into the eXtension Campus online portal and enrolling in the online trainings, participants received a welcome message describing what to complete — "Part 1: *What* to Feed" module and "Part 2: *How* to Feed" module — to receive a certificate of completion. When participants clicked on the training module links, they were redirected to a new browser window where the interactive training appeared with a digital teacher avatar named "Laura" to guide them through the content of each module (fig. 1).

Child care is an ideal environment in which to improve young children's eating habits — over half of young children spend an average of 30 hours per week in child care, where many of them consume the majority of their daily calories.

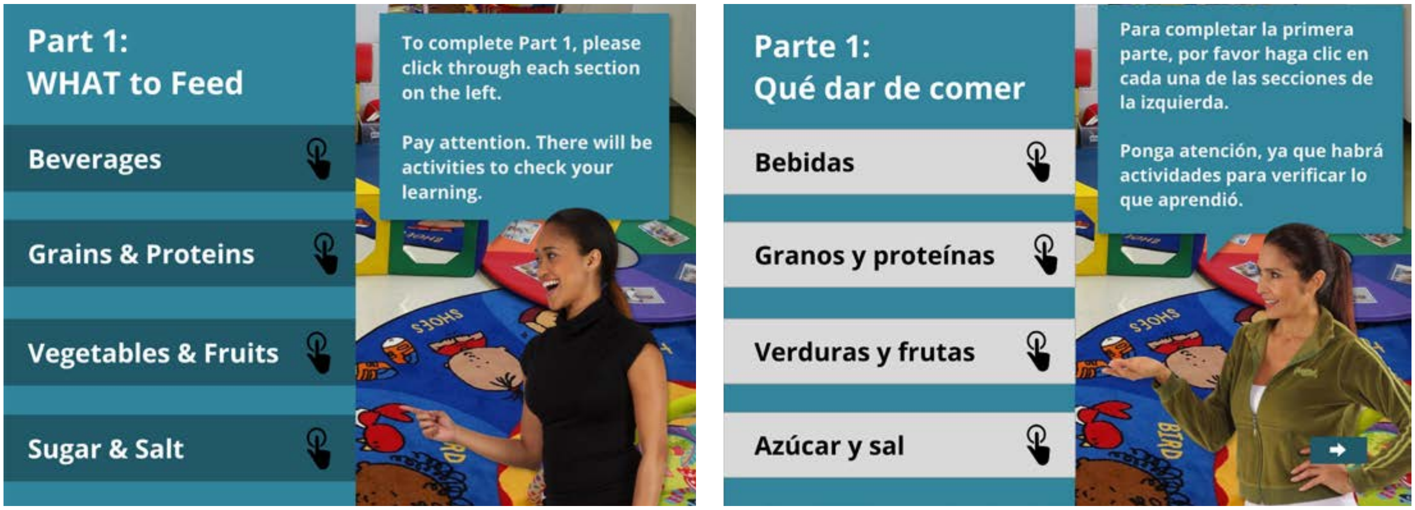

FIG. 1. An interactive menu in the online training. A virtual online training instructor guides students through an interactive menu of sections of the online training that students are required to complete.

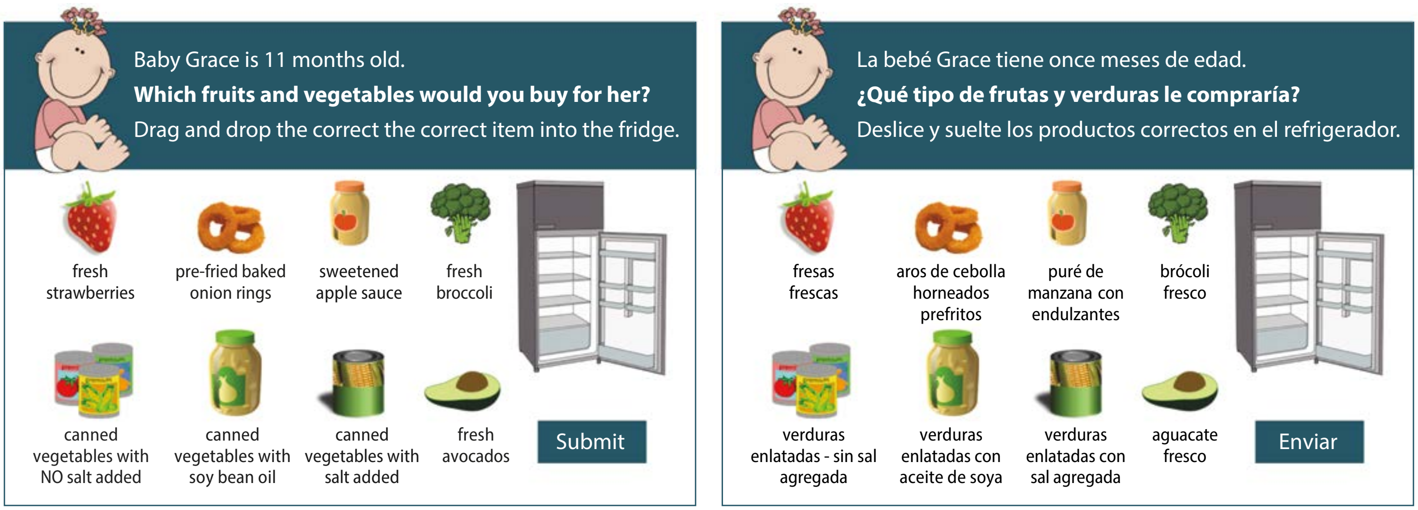

FIG. 2. An interactive game in the online training. Student knowledge is tested throughout the training using interactive quizzes and games similar to this one.

Evaluating the training

FCCH providers (n = 10; half English- and half Spanish-preferring) were recruited using convenience sampling through California CE networks. Recruitment emails and fliers were distributed by local child care resource and referral networks. In the recruitment email, providers were asked to complete a brief online survey to determine whether they were eligible to participate. Eligible providers had to have been in operation for more than one year, care for at least one infant and one toddler age 1–2 years old, provide at least one meal, one snack, and one beverage daily, be able to speak and read English or Spanish, and have access to a computer, laptop, smart phone, or tablet with internet connection. Participation required three hours of each provider's time. Each participant was compensated with a $50 gift card. The University of California, Davis, Committee for the Protection of Human Subjects deemed the study exempt.

Enrolled providers received email instructions to create an account on eXtension Campus and to enroll in the online trainings. After completing the four 20-minute modules, providers were emailed a link to a brief Qualtrics online survey and were scheduled to complete a 45-minute interview via Zoom or by telephone with a bilingual Nutrition Policy Institute researcher.

The main evaluation outcomes measured were: providers' ratings of the online training, what information was helpful or new to them, and if the training promoted changes to *what* and *how* they feed infants and toddlers in their care. We also aimed to understand the unique experiences of providers who took the Spanish version of the online training.

Research team members developed survey questions to evaluate the online training. Providers were asked to rate the training registration, format, clarity, amount and usefulness of information, quality, length, ease of completion, and overall experience. They were also asked about the likelihood of making changes to *what* and *how* they would feed infants and toddlers based on what they learned in the training. Finally, providers were asked if they would recommend the training to other providers and if it would be helpful to have a nutrition educator available to discuss what they learned. The survey (available in the online technical appendix) captured provider demographics, characteristics of the FCCH and the children they cared for, where they received information on nutrition related to their work, and how they shared information with parents.

Research team members developed structured interview questions (available in the technical appendix) to explore providers' experiences with registering for and completing the training. Questions were repeated for each of the four modules to determine what information was new, helpful, not helpful, repetitive, or confusing. Spanish-preferring providers were asked about their country of origin, length of time living in the United States, and questions about the clarity of wording and phrases, ease of following the narrative, training recommendations that they perceived to be relevant or problematic for Spanish-preferring providers and families, and perceptions of Spanish-preferring providers' comfort with an online training.

English and Spanish interviews were recorded and transcribed. English Zoom recordings were transcribed using Zoom's built-in transcription feature. Spanish Zoom recordings were transcribed by a researcher fluent in both Spanish and English. Researchers then reviewed and revised the English Zoom transcriptions and Spanish researcher transcriptions while simultaneously reviewing the audio recordings. Spanish transcriptions were translated into English for analysis.

Survey data were analyzed in Excel (Microsoft Office 2019) using descriptive statistics. Interview data were analyzed using an inductive approach for qualitative evaluation data (Thomas 2006). Interview responses were tabulated by interview question for each participant, then reviewed by two investigators, and coded for themes. One researcher conducted the initial review and developed the original coding scheme; the second researcher conducted the second review using codes developed by the initial reviewer. Disagreements in coding were discussed to reach consensus on final coding. Themes were summarized for each module and key quotes for each theme were extracted.

Providers' training satisfaction

Providers were all women, with an average age of 54. A majority identified as Hispanic and had some college or an associate's degree. Providers cared for an average of nine children, nearly half of whom qualified for child care subsidies (table 1). All providers participated in CACFP; most reported receiving information about nutrition related to their work as child care providers from CACFP, from the families of the children they cared for, and from friends. Providers reported sharing nutrition information with the parents or caregivers primarily via printed handouts or flyers, bulletin boards, text messages, or in-person meetings. The Spanish-preferring providers interviewed were from Nicaragua or Mexico and had lived in the United States for 30–35 years.

The English and Spanish versions of the online training were rated favorably by FCCH providers (table 2). Providers (n = 10) rated the registration for the online training (Mean[SD] 4.4[0.84]), training format (4.2[0.79]), clarity (4.8[0.63]) and amount (4.6[0.52]) of the information, usefulness (4.5[0.85]), quality (4.6[0.52]), length (4.7[0.48]), and overall experience (4.8[0.42]) of the training as good (based on a 5-point scale of 1 = very poor to 5 = excellent). Providers were somewhat likely to make changes to *what* (4.3[1.34]) and *how* (4.3[1.34]) they feed infants and toddlers in their care after completing the training and were very likely (4.8[0.63]) to recommend the online training to other providers (based on a 5-point scale of 1 = very unlikely to 5 = very likely). They found the training easy to complete (4.2[1.14], based on a 5-point scale of 1 = very hard to 5 = very easy). Seventy percent of providers thought it would be helpful to have a nutrition educator available to discuss what they learned after taking the online training.

Evidence suggests that children cared for in family child care homes may be at greater risk of obesity than those cared for in their own home or in child care centers.

Providers indicated in interviews that the English and Spanish versions of the online trainings were well received, that they learned new and helpful information from each of the four modules, and that there was little to no information that was too repetitive or unhelpful. Only one provider, who reported low technical literacy, had difficulty in completing the online course registration and navigating the online training.

Key themes of what information was new and helpful are summarized in table 3. Generally, providers had more to say about the novelty and usefulness of the training content on *how* to feed infants and toddlers compared to *what* to feed them. Many providers said the training was both a good refresher for more experienced FCCH providers and a good resource for new FCCH providers:

> *Right now we are not in many classes and this refreshes us.*
>
> *It would help the people who are starting their business. It's very well explained.*
>
> *I recommend it for new providers who don't maybe know what to feed the kids. I think it's a very good introduction. For me, it was a lot of repeat, but it's good because I don't always have infants all the time. . . . So it was a good refresher.*

TABLE 1. Characteristics of family child care home providers that participated in a feasibility study of a self-paced, online training of *what* and *how* to feed infants and toddlers

Characteristics	English (*n* = 5)		Spanish (*n* = 5)	
	Mean, median or *n*	SD, SE or %	Mean, median or *n*	SD, SE or %
Age (mean, SD)	54.0	7.4	54.4	3.0
Race/ethnicity (*n*,%)*				
Hispanic	2	40%	5	100%
Asian/Pacific Islander	1	20%	0	0%
White	4	80%	2	40%
Highest level of education (*n*, %)				
High school graduate or less	0	0%	2.0	40%
Some college/Associate's degree	3	60%	3	60%
Bachelor's degree or higher	2	40%	0	0%
Maximum no. of children licensed for (*n*,%)				
Up to 8	2	40%	1	20%
9–14	3	60%	4	80%
Children qualifying for subsidies (mean %, SD)	11.8%	31.5%	69.5%	31.5%
No. of children (median, SE)	6	2.1	10	0.5
0–11 months	0	0.6	0	0.4
1–2 years	2	0.4	2	0.5
3–5 years	1	0.9	4	0.5
6+ years	1	1.5	3	0.4
Child's language spoken at home* (mean %, SD)				
English	76.7%	32.5%	40.0%	33.7%
Spanish	10.0%	22.4%	81.0%	32.5%
Other	13.3%	29.8%	0.0%	0.0%
No. of full- and part-time child care providers (median, SE)	2.0	0.6	2.0	0.3
Where providers get information about nutrition related to their work* (*n*, %)				
Child and Adult Care Food Program (CACFP)	4	80%	3	60%
Friends	3	60%	2	40%
Families of the children they care for	3	60%	2	40%
Resource and referral Agency	2	40%	2	40%
Internet	3	60%	1	20%
Other FCCH providers	1	20%	2	40%
National Association for Family Child Care	2	40%	1	20%
Family	1	20%	2	40%
WIC	0	0%	2	40%
How providers share nutrition information with parents/caregivers* (*n*, %)				
Printed handouts or flyers	3	60%	2	40%
Bulletin board	1	20%	4	80%
Text messages	4	80%	1	20%
In-person meetings with parents/caregivers	3	60%	1	20%
Phone calls	2	40%	1	20%
E-mail	2	40%	0	0%
Informational packet provided to families each year	0	0%	1	20%
Social media	1	20%	0	0%
Website	0	0%	1	20%

* More than one response could be selected.

FCCH = family child care home provider; SD = standard deviation; SE = standard error; WIC = Special Supplemental Nutrition Program for Women, Infants, and Children.

TABLE 2. Family child care home providers' evaluation of a self-paced online training on *what* and *how* to feed infants and toddlers

Provider ratings	English training (n = 5)		Spanish training (n = 5)	
	Mean	SD	Mean	SD
Registration*	4.4	0.89	4.4	0.89
Format*	4.2	0.84	4.2	0.84
Clarity*	5.0	0.00	4.6	0.89
Amount of information*	4.4	0.55	4.8	0.45
Usefulness*	4.2	1.10	4.8	0.45
Quality*	4.6	0.55	4.6	0.55
Length*	4.6	0.55	4.8	0.45
Ease of completing training†	4.8	0.45	3.6	1.34
Overall experience*	4.8	0.45	4.8	0.45
Will make changes to *what* infants and toddlers are fed‡	3.8	1.79	4.8	0.45
Will make changes to *how* infants and toddlers are fed‡	3.8	1.79	4.8	0.45
Will recommend training to another provider‡	4.6	0.89	5.0	0.00
Helpful to have a nutrition educator available to discuss online training?	n	%	n	%
Yes	0	0%	3	60%
Maybe	3	60%	1	20%
No	2	40%	0	0%
Don't know	0	0%	1	20%

* Likert scale of 1 = very poor to 5 = excellent. / † Likert scale of 1 = very hard to 5 = very easy. / ‡ Likert scale of 1 = very unlikely to 5 = very likely. / SD = standard deviation.

Interaction is important

Providers expressed appreciation for the interactive aspects of the training, such as quizzes, and recommended including more interactive features in future versions. Additional suggestions included introducing more advanced modules for more experienced FCCH providers and facilitating access for providers with limited technical proficiency. One provider said,

> *You know that's the hardest part about doing this for so long it's finding seminars and classes that aren't really geared for newer providers.*

Providers suggested providing a digital one-page summary of key recommendations to print and post in their home and to share with parents. They noted that their efforts to convey information on child feeding practices to parents are often met with mistrust or skepticism, so they felt that a summary from a trusted source such as the University of California would provide them with much-needed credibility. This indicates that providing support and resources may positively impact parent engagement outcomes and bolster the confidence of FCCH providers to sustain these practices. One provider said,

> *. . . giving [parents] a little referral or a little article or fact sheet from somebody that has a name on it seems to make more impact on them. Summaries, that would have been nice to be able to print that out and then to hand it to my parents.*

Cultural relevance

An additional theme identified during provider interviews was the need for improved cultural relevance and sensitivity of the content of the online trainings. On the topic of food recommendations, one provider said,

> *. . . as I mentioned we are vegetarian, so of course the meat section is definitely not something that I wanted to know about. But the person who eats meat, it's helpful for them. I mean it might be done in such a way that if you don't eat meat at all, you might give an option to skip that section.*

Providers recommended efforts to tailor the Spanish-language version for providers from different regions of Latin America. A Spanish-preferring provider said,

> *We Americans — Central Americans, North Americans, South Americans — are used to giving cow's milk, it's the most common, but [people in] some other places also consume goat's milk. But I know that in other cultures they do not consume cow's milk or goat's milk, only vegetable milk.*

On the topic of utensils, one provider said,

> *Here it says use dishware and utensils that are sized appropriately . . . I mean in India we practice using hands to eat, right. So are you recommending that we should give utensils to infants for them to learn to eat?*

TABLE 3. Themes identified in interviews with family child care home providers about what information was new or helpful for them in a self-paced, online training on *what* and *how* to feed infants and toddlers

Infant feeding recommendations	
***What* to feed:**	***How* to feed:**
Avoiding cereal in bottles*	Appropriate utensil size*
Appropriate type of milk†	Developmental readiness for feeding*
Colorful meals*	Do not allow children to eat/drink while walking†
Grain and protein recommendations†	Encouraging breastfeeding†
Infant age categorization*	Encouraging tactile experience*
Portion sizes	Meal timing*
Sugar recommendations†	Modifying food textures*
When to introduce food, milk and water	Order of food introduction
	Order of texture introduction*
	Preparing expressed breastmilk
	Proper feeding position†
	Provider sits with children at mealtime†
	Responsive feeding
	Self-feeding*
	Slow introduction of foods
Toddler feeding recommendations	
***What* to feed:**	***How* to feed:**
Colorful meals*	Do not allow children to eat/drink while walking†
Food recommendations	Encourage trying new foods†
Information on processed foods†	Having children help with meal prep†
Portion sizes*	Learning during mealtime†
Salt and sugar recommendations	Limit distractions†
	Parents introducing foods first*
	Sitting with children*
	Toddlers serving themselves*

* Theme unique to providers that took the English training.
† Theme unique to Spanish-preferring providers that took the Spanish training.

On the topic of portion sizes, a Spanish-preferring provider said,

> *It seems to me that perhaps we should talk about the portions. It can be cultural. The customs of each country, of each person, affects us a lot.*

Spanish-preferring providers

Themes unique to Spanish-preferring providers' experience of the online training emerged. Data in tables 1 to 3 are presented by training language to highlight experiential differences from those who took the training in English. In general, more Spanish-preferring providers (40% vs. 0%) reported using the federal Special Supplemental Nutrition Program for Women, Infants and Children (WIC) for nutrition information related to their job (table 1). More Spanish-preferring providers reported sharing nutrition information with parents and caregivers using bulletin boards (80% vs. 20%) compared to more technology-based methods (e.g., text messages, phone calls, emails) (table 1). More Spanish-preferring providers (60% vs. 0%) reported it would be helpful to have a nutrition educator available to discuss the online trainings (table 2).

Regarding new or useful information, several unique themes were found from interview responses from Spanish-preferring providers in the training (table 3). Specifically for infant feeding recommendations, Spanish-preferring providers reported the following as new or useful: appropriate milk type; grain, protein, and sugar recommendations; not allowing children to eat or drink while walking; encouraging breastfeeding; proper feeding positions; and sitting with children during mealtimes. Specifically for the toddler feeding recommendations, Spanish-preferring providers reported the following as new or useful: information on processed foods; not allowing children to eat/drink while walking; having children help with meal prep; facilitating learning during mealtime; and limiting distractions during mealtime.

Providers also reported that the Spanish version of the online training was clear, the narrative was easy to follow, and the information and recommendations provided would be particularly relevant for Spanish-preferring providers. One provider said,

> *I think that if it's very well explained and yes they [Spanish-preferring providers] would understand it and it would help the people who are starting their business.*

Spanish-preferring providers highlighted only a few recommendations in the training that might not appeal to other providers. One was the recommendation on whole grains and whole foods, with two providers citing cost as a barrier, in addition to cultural preference.

> *Like whole grains, like brown rice. . . . It's that there are people who prefer to consume white rice because it's what they like... so there is the cultural preference of each one . . .*

> *I know of many Hispanic providers who don't do it because they don't like it. It is not the type of food that they are used to, so there's cultural controversy and also monetary. [They say,] "Don't use that. It's more expensive. The price is higher to consume brown rice than the rice that we can consume as a family of moderate resources."*

> *Some people may not be economically facilitated to have that level and buy that type of food. I'm talking like organic food or whole food. Like whole grains, like brown rice.*

Two providers reported hearing unfamiliar terms in the online training. A provider from Nicaragua noted a lack of familiarity with the Spanish term used for lean meat, while a provider from Mexico reported unfamiliarity with some terms used for fruits. A glossary of terms used in different Spanish-speaking regions may be a useful addition for the online training.

Online training fills a need

FCCH providers reported high levels of satisfaction with the 80-minute online training in both English and Spanish, with most saying they intended to make changes to *what* and *how* they feed infants and toddlers. They said the training taught them new information and also reminded them of old information they had forgotten. These findings and other studies suggest that not only are online trainings a good fit for this population, but are in fact preferred by child care professionals (Ackerman 2017; Cotwright et al. 2020; Lee et al. 2021; Rheingold et al. 2012; Weigel et al. 2012). One study showed that an online training on healthy beverages makes it more likely that FCCH providers will follow these recommendations (Lee et al. 2021).

These online trainings are especially important because they may help fill the gap in California law which does not hold FCCHs to the same nutritional standards as other daycare providers. This online training is publicly available on the eXtension Campus (Lee et al. 2022a, 2022b, 2022c, 2022d) to any FCCH provider who has access to a computer, smart phone, or tablet with internet connection. FCCH providers in California can take the training for free; FCCH providers in other states pay $15.

Despite our attempts to ensure that the online training was culturally sensitive, Spanish-preferring providers suggested making the training more inclusive and culturally relevant to their specific demographic. (Given the brevity of the online training, it is difficult to be inclusive of all cultures.) FCCHs homed in on certain food (specifically whole grains) and beverage items, utensils, and the need to take into account those providers who maintain vegetarian-only FCCHs. Other studies have also suggested similar cultural perceptions around white rice and the unfamiliarity with brown rice and other whole grains in non-white populations (Monge-Rojas et al. 2014). Studies comparing Latinx vs. non-Latinx FCCH providers have found similar differences in nutrition-related attitudes, specifically around *what* and *how* to feed young children (Jiang et al. 2021). Several studies highlight the effectiveness of culturally tailored nutrition guidelines for young children in child care who come from ethnically diverse, low-income families (Gans et al. 2009; Hammons et al. 2019; Kaiser et al. 2015; Looby et al. 2020; Smith et al. 2004). Additionally, over half of Spanish-preferring providers in this study said it would be helpful to have a nutrition educator available to talk to after the online trainings.

One of the big challenges to implementing food recommendations, the providers reported, is higher costs. Studies have shown that the higher cost for more nutritious food is an obstacle for FCCHs (Dev et al. 2020; Earnesty et al. 2022; Lee et al. 2018; Monsivais et al. 2012). (Despite the small financial incentive provided to FCCH providers to participate in our evaluation, we made no attempts to offset the cost of implementing the recommendations.) However, programs such as CACFP have been effective in providing financial support to help FCCHs improve their food and beverage offerings (Gurzo et al. 2020; Lee et al. 2018; Monsivais et al. 2011). Pairing online training with financial assistance for FCCH providers to implement the recommendations proposed in the online training should be explored.

This study has both strengths and limitations. A key strength of the study is the mixed methods approach of gathering both qualitative and quantitative data. Another strength is the online format of the training, which is a convenient option — and possibly the only option — for busy FCCH providers, especially during the COVID-19 pandemic. The principal limitation was the small sample size, the convenience sampling, and the limited representation of non-white or non-Hispanic providers. As a result, these findings may not be representative of all FCCH programs across California or the United States.

The benefits of the self-paced online trainings are that they are easily accessible and provide a conducive environment for supportive learning and reinforcing helpful information. Our findings suggest that these online trainings are an especially effective way for public health educators to convey important nutritional information to FCCHs across a diverse set of ethnic and language groups. Moving forward, future research should evaluate the efficacy of pairing the online training with financial support to encourage FCCH providers to adopt better nutriton practices in order to improve children's health outcomes.

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The online child nutrition trainings are especially important because they may help fill the gap in California law, which does not hold FCCHs to the same nutritional standards as other daycare providers. *Photo*: Danielle L. Lee.

References

Ackerman DJ. 2017. Online child care training in the United States: a preliminary investigation of who participates, what is offered, and on which topics the workforce is focusing. Int J Child Care Educ Policy 11(12). https://doi.org/10.1186/s40723-017-0037-7

Benjamin-Neelon S, Vaughn A, Tovar A, et al. 2018. The family child care home environment and children's diet quality. Appetite 126:108–13. https://doi.org/10.1016/j.appet.2018.03.024

Benjamin-Neelon S. 2018. Position of the Academy of Nutrition and Dietetics: Benchmarks for nutrition in child care. J Acad Nutr Diet 118(7):1291–1300. https://doi.org/10.1016/j.jand.2018.05.001

Butte N, Fox M, Briefel R, et al. 2010. Nutrient intakes of US infants, toddlers, and preschoolers meet or exceed dietary reference intakes. J Am Diet Assoc 110:S27–S37. https://doi.org/10.1016/j.jada.2010.09.004

California Emergency Medical Services Authority. 2021. Child Care Nutrition Information. California. https://emsa.ca.gov/childcare-nutrition/

California Legislative Information. 2021. AB-1872 Child day care facilities: nutrition. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201120120AB1872

Child Care Aware of America. 2020. Child Care in America: 2019 State Fact Sheets, Child Care Aware of America.

Cotwright CJ, Bradley H, Celestin N, et al. 2020. Determining eLearning preferences to inform beverage policy training for early care and education teachers. J Nutr Educ Behav 52(7):732–41. https://doi.org/10.1016/j.jneb.2020.02.020

Deiner P, Qiu W. 2007. Embedding physical activity and nutrition in early care and education programs. Zero to Three 28(1):13–18.

Dev DA, Garcia AS, Dzewaltowski DA, et al. 2020. Provider reported implementation of nutrition-related practices in childcare centers and family childcare homes in rural and urban Nebraska. Prev Med Rep 17:101021. https://doi.org/10.1016/j.pmedr.2019.101021

Earnesty D, Mphwanthe G, Rau K, et al. 2022. A qualitative study: Perceived barriers and facilitators to nutrition standard adherence by in-home childcare providers. J Acad Nutr Diet 122(4):786–96. https://doi.org/10.1016/j.jand.2021.08.104

Fox M, Condon E, Briefel R, et al. 2010. Food consumption patterns of young preschoolers: Are they starting off on the right path? J Am Diet Assoc 110:S52–S59. https://doi.org/10.1016/j.jada.2010.09.002

Gans KM, Risica PM, Strolla LO, et al. 2009. Effectiveness of different methods for delivering tailored nutrition education to low income, ethnically diverse adults. Int J Behav Nutr Phys Act 6(24). https://doi.org/10.1186/1479-5868-6-24

Gurzo K, Lee DL, Ritchie K, et al. 2020. Child care sites participating in the federal Child and Adult Care Food Program provide more nutritious foods and beverages. J Nutr Educ Behav 52(7):697–704. https://doi.org/10.1016/j.jneb.2020.02.009

Hammons AJ, Hannon BA, Teran-Garcia M, et al. 2019. Effects of culturally tailored nutrition education on dietary quality of Hispanic mothers: A randomized control trial. J Nutr Educ Behav 51(10):1168–76. https://doi.org/10.1016/j.jneb.2019.06.017

Jiang Q, Tovar A, Risica PM, et al. 2021. Ethnic differences in family childcare providers' nutrition- and activity-related attitudes and barriers. J Obes 6697006. https://doi.org/10.1155/2021/6697006

Kaiser L, Martinez J, Horowitz M, et al. 2015. Adaptation of a culturally relevant nutrition and physical activity program for low-income, Mexican-origin parents with young children. Prev Chronic Dis 12:140591. https://doi.org/10.5888/pcd12.140591

Laughlin L. 2013. Who's minding the kids? Child care arrangements: Spring 2011. Current Population Reports, P70-135. Washington, DC : U.S. Census Bureau.

Lee DL, Gurzo K, Yoshida S, et al. 2018. Compliance with the New 2017 Child and Adult Care Food Program Standards for Infants and Children before implementation. Child Obes 14(6):393–402. https://doi.org/10.1089/chi.2018.0092

Lee D, Traseira R, Navarro S, et al. 2020. Alignment of state regulations with breastfeeding and beverage best practices for childcare centers and family childcare homes, United States. Public Health Rep 136(1):79–87. https://doi.org/10.1177/0033354920964156

Lee DL, Alkon A, Plank K, et al. 2021. Self-paced online training on healthy beverage policy for child care providers. J Nutr Educ Behav 53(6):457–70. https://doi.org/10.1016/j.jneb.2021.02.007

Lee DL, Keeton V, Alkon A, et al. 2022a. Infant feeding recommendations for family child care home providers. eXtension Campus. https://campus.extension.org/course/view.php?id=1788&lang=en_us

Lee DL, Keeton V, Alkon A, et al. 2022b. Toddler feeding recommendations for family child care home providers. eXtension Campus. https://campus.extension.org/course/view.php?id=1789&lang=en_us

Lee DL, Keeton V, Alkon A, et al. 2022c. Recomendaciones para la alimentación de infantes para proveedores en hogares de cuidado infantil. eXtension Campus. https://campus.extension.org/course/view.php?id=1790&lang=es

Lee DL, Keeton V, Alkon A, et al. 2022d. Recomendaciones para la alimentación de niños pequeños para proveedores en hogares de cuidado infantil. eXtension Campus. https://campus.extension.org/course/view.php?id=1791&lang=es

Leucking C, Mazzucca S, Vaughn A, et al. 2020. Contributions of early care and education programs to diet quality in children aged 3 to 4 years in Central North Carolina. J Acad Nutr Diet 120:386–94. https://doi.org/10.1016/j.jand.2019.09.018

Looby AA, Frost N, Gonzalez-Nahm S, et al. 2020. State regulations to support children's cultural and religious food preferences in early care and education. Matern Child Healt J 24(2):121–6. https://doi.org/10.1007/s10995-019-02833-1

Min J, Wen X, Zue H, et al. 2018. Ethnic disparities in childhood BMI trajectories and obesity and potential causes among 29,250 US children: Findings from the Early Childhood Longitudinal Study–Birth and Kindergarten Cohorts. Int J Obes (Lond) 42(9):1661–70. https://doi.org/10.1038/s41366-018-0091-4

Monge-Rojas R, Mattei J, Fuster T, et al. 2014. Influence of sensory and cultural perceptions of white rice, brown rice and beans by Costa Rican adults in their dietary choices. Appetite 81:200–8. https://doi.org/10.1016/j.appet.2014.06.028

Monsivais P, Kirkpatrick S, Johnson DB. 2011. More nutritious food is served in child-care homes receiving higher federal food subsidies. J Am Diet Assoc 111(5):721–6. https://doi.org/10.1016/j.jada.2011.02.007

Monsivais P, Johnson DB. 2012. Improving nutrition in home child care: Are food costs a barrier? Public Health Nutr 15(2):370–6. https://doi.org/10.1017/S1368980011002382

National Association of Child Care Resource and Referral Agencies. 2010. The economy's impact on parents' choices and perceptions about child care. www.childcareaware.org/wp-content/uploads/2015/10/final_2010_econimpact_poll_report_dec_2010.pdf

Pérez-Escamilla R, Jimenez EY, Dewey KG. 2021. Responsive feeding recommendations: Harmonizing integration into dietary guidelines for infants and young children. Curr Dev Nutr 5(6):nzab076. https://doi.org/ 10.1093/cdn/nzab076

Reilly J, Kelly J. 2011. Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: Systematic review. Int J Obesity 35(7):891–8. https://doi.org/10.1038/ijo.2010.222

Rheingold AA, Zajac K, Patton M. 2012. Feasibility and acceptability of a child sexual abuse prevention program for childcare professionals: Comparison of a web-based and in-person training. J Child Sex Abus 21(4):422–36. https://doi.org/10.1080/10538712.2012.675422

Ritchie LD, Keeton V, Lee DL, et al. 2021. Nutrition standards for infants and young children can be implemented by family child care home providers. Glob Pediatr Health 8:2333794X21989555. https://doi.org/10.1177/2333794X21989555

Ritchie LD, Lee DL, Homel Vitale E, et al. 2020. Transition from breastfeeding and complementary feeding to toddler nutrition in child care settings. Nestle Nutr Inst Workshop Ser 95:54–66. https://doi.org/10.1159/000511517

Skinner A, Ravanbakht S, Skelton J, et al. 2018. Prevalence of obesity and severe obesity in US children, 1999–2016. Pediatrics 141(3):e20173459. https://doi.org/10.1542/peds.2017-3459

Smith M, Nelson JA, Stabuck S, et al. 2004. Selecting foods of children's cultural backgrounds for a preschool menu: A practical solution. J Child Nutr Manag 28(1).

Thomas DR. 2006. A general inductive approach for analyzing qualitative evaluation data. Am J Eval 27(2):237–46. https://doi.org/10.1177/1098214005283748

Ward D, Welker E, Choate A, et al. 2017. Strength of obesity prevention interventions in early care and education settings: A systematic review. Prev Med Rep:S37–S52. https://doi.org/10.1016/j.ypmed.2016.09.033

Weigel DJ, Weiser DA, Bales DW, et al. 2012. Identifying online preferences and needs of early childhood professionals. Early Child Res Practice 14(2).

Weinfield N, Borger C, Zimmerman T, et al. 2019. WIC infant and toddler feeding practices study – 2: Third Year Report. W.U.C.N. AG-3198-K-11-0031. Alexandria, VA: U.S. Department of Agriculture, Food and Nutrition Service.

Whitebook M, Sakai L, Kipnis F et al. 2006. California early care and education workforce study. Licensed Family Child Care Providers. Statewide 2006. Berkeley, CA: Center for the Study of Child Care Employement, Institute of Industrial Relations, University of California at Berkeley and San Francisco, CA: California Child Care Resources and Referral Network.

RESEARCH ARTICLE

Grazing lambs on pastures regrown after wildfires did not significantly alter metal content in meat and wool

Wildfires deposit metals that may be ingested by grazing sheep, but few traces were found in sheep grazing after the 2018 River Fire.

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Abstract

Wildfires can drastically change rangeland by depositing ash contaminated with metals that are not part of normal diets. This can pose health threats to humans and animals. This risk, along with alterations of essential minerals in livestock grazing on regrowth on burnt lands, is not well known. To better understand this, our study investigated metal concentrations in water, soil, plant forage, and meat and wool of sheep grazing on the regrowth of burned lands. We compared metal concentrations in sheep grazed on regrowth to stored meat samples from grazing sheep a year prior to the wildfire. Lead, mercury, arsenic, molybdenum, cadmium, beryllium, cobalt and nickel were not detected above reporting limits in meat, wool or water samples. Contamination from chromium and thallium was detected in three of 26 meat samples from sheep grazed on regrowth. These metals were not detected in 22 stored meat samples from sheep the year before. Copper concentrations found in the meat of animals grazing regrowth was lower than in animals grazing unburned pastures; it is important to monitor copper concentrations in grazing animals to avoid diseases associated with copper deficiency.

Fire has been used to manage grazing lands, control pests, and stimulate new plant growth for centuries. Prescribed grazing is also used for fire prevention. Forage quality and palatability on rangelands may improve following recovery from fires. For example, a four-fold increase has been seen in crude protein concentrations in burned versus unburned regrowth of tall grass on prairies (Allred et al. 2011). Livestock and wildlife may be drawn to graze on the regrowth in post-burn plots of land, because of the improved palatability of new growth forage (Allred et al. 2011). However, increased pressures at the urban-wildland interface, rangeland and woodland management practices, livestock production and other agricultural activities, and structure construction have changed land and thus distorted natural and agricultural burning practices. Globally, human activity has contributed to climate change with longer, hotter, drier fire seasons (Intergovernmental Panel on Climate Change 2014). In 2018, and in subsequent years, California experienced its most destructive wildfire seasons, with

Ewes and lambs graze in February 2021 on a Hopland Research and Extension Center pasture that was burned in the 2018 River Fire. UC Davis researchers analyzed meat, wool, soil, plant and water samples to assess the risk of metal contamination in sheep grazed on recently burned pasture regrowth. *Photo*: Valerie Eviner.

Non-essential metals in the ash and water runoff may be inadvertently ingested by livestock and accumulated in the carcass, and thus represent a potential risk to the health of animals or humans consuming animal-derived foods.

unprecedented damage (Bates 2019). Experts anticipate this trend in California will continue (NASA 2021).

The character and type of ash is a product of what burned and at what temperature (Amiro et al. 1996; Jensen et al. 2017; Panichev et al. 2008; Qi et al. 2017). Lands that have not recently burned might have high concentrations of essential and non-essential metals, particularly mercury, sequestered into vegetation through natural deposits or pollution deposition over decades, and these metals may accumulate in ash after vegetation burns (Giesler et al. 2017), and contaminate surface waters (Abraham et al. 2017). Non-essential metals in the ash and water runoff may be inadvertently ingested by livestock and accumulated in the carcass, and thus represent a potential risk to the health of animals or humans consuming animal-derived foods. Mercury is of particular concern due to its known accumulation in plant biomass, as well as in the muscle tissue of contaminated animals (Castro-González and Méndez-Armenta 2008; Giesler et al. 2017; Jensen et al. 2017; Qi et al. 2017). However, there is a paucity of literature providing evidence-based recommendations regarding the risk of metal contamination in the meat of animals grazed on recently burned lands.

The objective of this study was to investigate non-essential metal contamination and changes in essential trace mineral content in the meat and wool of lambs grazed on recently burned pasture regrowth, compared to samples obtained from animals not grazed on burn regrowth. A secondary objective was to assess the usefulness of wool sampling to estimate meat concentrations of non-essential metals, which could potentially provide a minimally invasive way to test animals for non-essential metal contamination prior to slaughter. Hair analysis has been studied previously as an indicator of non-essential metal contamination in humans, some grazing species, and wildlife, with variable results (Combs 1987; Liang et al. 2017; Roug et al. 2015; Weiss-Penzias et al. 2019).

On July 27, 2018, the River Fire burned approximately two-thirds of the lands at the University of California Agriculture and Natural Resources Hopland Research and Extension Center (UC ANR HREC), including pastures used for grazing approximately 500 cross-bred ewes and their lambs. Hopland's ecosystems include oak woodland, grassland, chaparral and riparian areas, with sheep grazing largely concentrated on grasslands and low-density oak woodlands. We used this natural exposure to compare muscle tissue from lambs that grazed on fire regrowth pastures and were slaughtered in the spring of 2019 to frozen samples from the previous year's 2018 lamb crop, grazed on the same property prior to the wildfire. Additionally, the relationship between metal concentrations in meat and wool samples was evaluated.

We hypothesized that lambs grazed on the first season's regrowth from burned plots of land had greater concentrations of metals in their meat samples compared to stored meat samples obtained from lambs that were not exposed to fire regrowth, which had grazed on the same property the previous year. We also hypothesized that metal concentrations in wool samples from lambs grazed on burn regrowth were correlated with concentrations in meat from matched samples. There is limited data describing metal concentrations in ruminant tissues associated with grazing burn regrowth. Our study aims to generate initial data for further investigations into metal concentrations in grazing ruminants.

A ewe and her lamb in the barn at the Hopland Research and Extension Center. *Photo*: Bret McNabb.

Sampling from animals and land

The non-essential metal of greatest concern for bio-accumulation was mercury; therefore, calculations were based on estimations of mercury contamination. Meat samples from lambs not exposed to burn regrowth are estimated to have mercury concentrations of 0.01 milligram per kilogram (mg/kg) or less on a wet weight basis (Sell et al. 1975), while samples from animals exposed to recent burn regrowth are estimated to contain 0.025 mg/kg or more (a relative risk of 2.5). To obtain results with an 80% chance of detecting results and a 95% confidence interval, at least 20 lambs per group were required. To account for an estimated dropout rate of 25% due to predation, other causes of mortality, or loss of samples at slaughter, a minimum of 25 lambs were enrolled. Commercial statistical software was used to calculate the sample size (JMP Pro v16, SAS Institute, Cary, N.C.).

Frozen neck meat samples from 22 cross-bred lambs that were born in February 2018 and raised at the HREC until routine slaughter were available for analysis as the pre-fire regrowth grazing group (PRE). Neck meat and wool samples from 26 cross-bred lambs born in February 2019 and raised at the HREC until routine slaughter were obtained at the time of slaughter as the post-fire regrowth grazing group (POST). The study was approved by the UC Davis Institutional Animal Care and Use Committee (#21015).

All samples obtained from the PRE group were from lambs grazed together in one group on the same pastures throughout the 2018 grazing season. The PRE group were grazed on the HREC property, prior to any recent burning, finished on a concentrate feed for the final six weeks prior to slaughter, and slaughtered at a U.S. Department of Agriculture (USDA)–approved facility prior to the 2018 River Fire.

All POST lambs and their ewes were turned out to pasture when growth in recently burned pastures was sufficient to graze sheep in late spring 2019. The animals grazing in 2019 were exposed to pastures burned in the 2018 River Fire, as well as prescribed burning that occurred approximately one month prior to the River Fire. Ewe-lamb pairs were grazed in small groups on a combination of pastures, including recently burned as well as non-burned pastures. Each pasture was grazed until the vegetation no longer supported grazing, at which time the animals were moved to the next pasture, as is standard for this grazing operation. The total days of grazing on each pasture were recorded for each animal; burn exposure for each pasture was available for review. All animals were confined in pens and fed a similar type of supplemental concentrate feed from the same mill as the PRE group for the final six weeks prior to slaughter at the same facility in September 2019.

Neck meat from each lamb in both the PRE and POST groups was used for sampling, due to availability of neck meat in the PRE group. This also ensured that each carcass was sampled only once, and from the same anatomic site. Neck meat was obtained after routine slaughter in a USDA-approved sheep slaughter facility. The proximal cervical vertebrae with attached musculature was identified in all frozen PRE and POST samples, and submitted for elemental metal analysis. Both the PRE and POST groups were slaughtered as a single group in their respective years.

A minimum of 5 grams (g) wool sample was obtained from each lamb of the POST group by clipping from the flank region just prior to exposure to grazing on burn regrowth pastures. A second wool sample was obtained at the time of slaughter by clipping wool from an approximately 10 centimeter (cm)–square section of the hide.

Twenty-eight water samples were obtained after completion of 2019 grazing, from all animal drinking water sources available (including natural and man-made) for each pasture grazed by the POST lambs. Water was collected by dipping sterile polypropylene plastic containers directly from the water source where it was available to the sheep, and samples were immediately frozen at −68°F (–20°C) to minimize changes in water content due to biologic activity. Water samples remained frozen until submission for analysis.

A view of Hopland Research and Extension Center in October 2018, after the River Fire, before pasture regrowth. *Photo*: Jennie Lane.

Stored environmental samples of soil and aboveground grassland biomass were available for mineral testing from nine plots within or adjacent to grazing pastures at the Hopland site. These samples were collected after the fire, during the study grazing season. Focal study plots were 50 meters (m) by 20 m, running lengthwise (50 m) downslope to upslope. Soil samples were collected in March 2019 with a 7-cm-diameter auger, to a depth of 20 cm. Two samples were taken per plot (one in the bottom third of the plot, one in the top third of the plot) and bulked. Soil samples were air-dried after collection, and stored at room temperature until analysis. Aboveground plant biomass samples were collected in June 2019 in three locations per plot (bottom third, middle third, top third) and bulked. Each biomass sample was collected from plants rooted within a 15-cm-diameter ring, cut to within 1 cm of the ground surface. Biomass samples were dried at 122°F (50°C) for one week after collection, and stored at room temperature until analysis.

Analyzing metal content

All samples were analyzed at the California Animal Health and Food Safety Laboratory System (CAHFS) for elemental metal analysis, including lead (Pb), mercury (Hg), arsenic (As), thallium (Tl), molybdenum (Mo), copper (Cu), cadmium (Cd), beryllium (Be), cobalt (Co), chromium (Cr), nickel (Ni), manganese (Mn), iron (Fe), zinc (Zn), barium (Ba) and vanadium (V). The method of analysis was inductive coupled plasma optical emission spectrometry (ICP-OES) (iCAP 6500, Thermo Electron North America, Madison, Wis.). Meat samples were also analyzed for water content for dry weight conversion. Preparation of wool samples prior to analysis included filling a 50-milliliter (mL) centrifuge tube with the wool, followed by addition of acetone up to the 40 mL mark. The tube was then capped and was shaken with a tissue grinder (2010 Geno/Grinder, SPEX SamplePrep, Metuchen, N.J.) for 5 minutes. The acetone with residue was then decanted. This washing step was then repeated two more times with acetone and three more times with 18 MΩ water. The cleaned wool was then dried at 185°F (85°C) overnight. For analysis of metals, 1 g of tissue or 0.5 g of wool, soil or biomass were digested with 3 mL of nitric acid at 374°F (190°C). After the digestion was completed, 2 mL of hydrochloric acid was added, and the sample was brought to 10 mL with 18 MΩ water. The sample was then analyzed by ICP-OES. To ensure data quality, a method blank, laboratory control spike, sample over-spike, and a CRM (certified reference material from the National Research Council of Canada) was digested and analyzed with each batch. For every 10 samples, a drift check was also run to ensure the instrument stability throughout the analysis.

Descriptive statistics for grazing data, metal concentrations in the POST group's meat and wool samples, water and environmental samples collected during the 2019 grazing season, and PRE group stored meat samples, were calculated. Metal concentrations data for meat, wool and environmental samples were tested for normality using a Shapiro-Wilk test. Mean and standard deviation were reported when data were normally distributed, whereas median (range) were reported when data were not normally distributed. Metal concentrations between PRE and POST in meat samples or between meat and wool (POST group only) were compared using multivariate analyses of variance (MANOVA). In the MANOVA, group assignment (PRE vs. POST or meat vs wool for POST only) were considered predictor variables and the concentrations of the metals were considered outcome variables. Correlations among metal concentrations was determined using Pearson's (*r*) or Spearman's correlation (*rho*) coefficient. For the POST group only, a Wilcoxon rank-sum test was used to determine differences in the metal concentrations in the wool before and after grazing regrowth pastures. For all analyses, commercial statistical software was used (JMP Pro v16, SAS Institute, Cary, N.C.). $P < 0.05$ was considered significant.

Results of the study

A total of 22 frozen neck meat samples were available from the PRE group of lambs for analysis. A total of 26 neck meat samples, with matching wool samples obtained prior to grazing on burn regrowth pastures, as well as at the time of slaughter, were available for the POST group lambs. Reporting limits are provided in A-table 1 in the online technical appendix.

Grazing data for both the PRE and POST grazing groups is depicted in table 1, demonstrating that the POST group spent 147–158 total days grazing, with 24–46 of those days grazed on pastures burned by either wildfire or prescribed fire.

A total of 28 water samples were obtained, and the metals Mn, Fe, Zn, Ba and V were identified in 7, 5, 2, 23 and 5 of 28 water samples, respectively. No Pb, Hg, As, Mo, Cu, Cd, Be, Co, Cr, Ni or Tl were detected

TABLE 1. Grazing data and metal concentrations in meat and wool

	2018 crop (PRE burn)	2019 (POST burn)	
Grazing data			
Total days grazing	222	154 (147–158)	
Days on unburned pasture	222	118 (111–118)	
Days on wildfire regrowth	0	17 (14–36)	
Days on prescribed fire regrowth	0	11 (7–22)	
Total days on any burn regrowth	0	36 (24–46)	
Neck meat analysis			
Moisture content	0.73 (0.69–0.76)	0.73 (0.67–0.76)	
Mn	0.15* (0.1–0.25)	0.3 ↑ (0.14–4.2)	
Fe	24.5 (15–38)	62 ↑ (28–560)	
Zn	56 (48-75)	56 (13-78)	
Cu	2.75 (0.97–3.4)	1.2 ↓ (0.67–1.6)	
Ba	0.47 (0.18–2.5)	0.34 (0.1–2.4)	
Cr	Not detected	0.78 (NA)†	
Tl	Not detected	1.35 (1.3–1.4)†	
V	0.51 (0.37–0.6)	0.54 (0.42–0.73)	
		2019 crop PRE grazing	**2019 crop POST grazing**
Wool analysis			
Mn	Not sampled from 2018 crop	0.84 (0.42–3)	0.64 (0.31–2.8)
Fe	Not sampled from 2018 crop	20.5 (12–87)	24.5 (12–56)
Zn	Not sampled from 2018 crop	110 (92–130)	115 (97–160)
Cu	Not sampled from 2018 crop	4.6 (3.6–5.5)	4.7 (3.6–6.4)
Ba	Not sampled from 2018 crop	0.66 (0.22–1.5)	0.82 ↑ (0.38–11)
V	Not sampled from 2018 crop	0.96‡ (0.68–1.2)	Not detected

Days spent grazing unburned, prescribed burn, or wildfire burned pastures for 48 sheep over two grazing seasons, before and after grazing lands were burned by wildfire (PRE group $n = 22$ pre-burn grazed as a single group and POST group $n = 26$ total from several smaller groups post-burn). Grazing results presented as median (range) days. Concentrations of metals in neck meat and wool from lambs grazed on PRE fire or POST fire burned pastures. Results reported as median (range) in ppm. No Pb, Hg, As, Mo, Cd, Be, Co, or Ni were detected in any meat or wool samples above the reporting limits. All reported elements were detected in all samples except where otherwise stated. Significant differences between metal concentrations are demarked by ↑ where values are greater after grazing fire regrowth and ↓ when values are lower after grazing fire regrowth.

* Mn not detected above reporting limits in 4 samples.

† Cr was detected in 1 neck meat sample (0.78 ppm) and Tl was detected in 2 additional neck meat samples (1.4 and 1.3 ppm), each in the 2019 grazed group.

‡ V not detected above reporting limits in 7 samples.

above the reporting limits in any water samples (table 2).

Concentration data for Mn, Fe, Zn, Cu, Ba, Cr, Tl and V in meat and wool are depicted in table 1; no Pb, Hg, As, Mo, Cd, Be, Co or Ni were detected above reporting limits in any meat or wool samples.

Differences in metal concentrations in the PRE and POST meat samples were detected ($P < 0.0001$). The POST group had higher concentrations of Mn and Fe compared to the PRE group sheep, whereas the PRE group sheep had higher concentrations of Cu compared to the POST group. There was no difference in Zn, Ba or V in meat samples between the two groups. Positive correlations were detected in concentrations between Fe and Mn, as well as Mn and V. In contrast, Mn and Zn concentrations were negatively correlated. No Pb, Hg, As, Mo, Cd, Be, Co or Ni were detected above reporting limits in meat samples. Chromium was detected in one meat sample (0.78 parts per million [ppm]) and Tl was detected in two meat samples (1.4 and 1.3 ppm). All three of these Cr and Tl detections were in the POST group; however, due to the low number of samples testing positive for Cr and Tl, statistical comparisons were not determined between the groups. No V was detected in wool samples obtained prior to release on burn regrowth, so V could not be compared between groups. Ba concentrations in wool were higher ($P = 0.008$) in post-grazing samples compared to pre-grazing samples. Wool concentrations for Mn ($P = 0.147$), Fe ($P = 0.503$), Zn ($P = 0.129$) and Cu ($P = 0.105$) were not different between pre-grazing and post-grazing time points.

The type of sample (meat or wool) was a significant predictor of metal concentrations ($P < 0.0001$). Concentrations of Fe, Zn and Cu were higher in wool compared to meat samples. Mn concentrations were lower in wool compared to meat samples. There was no difference detected in Ba concentrations between meat and wool samples. The Cr and Tl detected in three meat samples were not detected in any wool samples. Tl, Cr, V and Mo were not statistically compared between meat and wool due to lack of consistent detection in both biologic matrices.

Four study plots were on land that remained unburned in recent prescribed or wild fire, and five study plots were on land that had regrown from recent prescription ($n = 3$) or wildfire ($n = 2$) burning. Concentration data for Pb, Mn, Fe, As, Zn, Cu, Cd, Ba, Be, Co, Cr, Ni and V from nine soil samples and nine biomass samples from the same nine study plot sites are depicted in table 3. No Hg, Mo or Tl were detected above reporting limits in any soil or plant biomass samples. Additionally, no As, Cd, Be or Co were detected in any plant biomass samples.

TABLE 2. Metal concentrations in water

	Mn ($n = 7$)	Fe ($n = 5$)	Zn ($n = 2$)	Ba ($n = 23$)	V ($n = 5$)
Median (range)	0.02 (0.02–0.05)	0.24 (0.12–3)	0.13 (0.05–0.2)	0.03 (0.01–0.09)	0.06 (0.04–0.11)

Median (range) metal concentrations in ppm in drinking water sources ($n = 28$ sources) for grazing sheep following the 2019 grazing season. Number of water samples with detectable concentrations noted below each element. No Cu, Cr, Tl, Pb, Hg, As, Mo, Cd, Be, Co or Ni were detected in any water samples above the reporting limits.

TABLE 3. Metal concentrations in environmental samples

Metal	Soil		Biomass	
	Unburned	Burned	Unburned	Burned
Pb	7.2 (1.8)	6.2 (1.8)	Not detected	Not detected
Mn	780 (358)	896.0 (278.4)	64.8 (40.7)	60.0 (40.8)
Fe	36,250 (17,802)	42,600 (1œ5,453)	35.5 (4.5)	43.8 (27.1)
As	4.7* (0.7)	4.3* (1.1)	Not detected	Not detected
Zn	66.5 (19.3)	72.4 (17.7)	27.5 (11.3)	29.0 (7.7)
Cu	30.3 (10.0)	26.2 (9.1)	7.6 (2.4)	7.2 (4.7)
Cd	1.8 (0.9)	2.2 (1.0)	Not detected	Not detected
Ba	170.0 (34.6)	160.0 (33.2)	47.5 (12.7)	40.0 (20.9)
Be	0.5 (0.1)	0.4 (0.2)	Not detected	Not detected
Co	27.3 (25.5)	36.0 (32.5)	Not detected	Not detected
Cr	169.5 (247.9)	320.8 (473.3)	1.0† (0.5)	1.6‡ (0.1)
Ni	258.3 (402.3)	438.4 (651.7)	6.4§	3.3¶ (2.4)
V	68.5 (48.4)	97.4 (64.4)	3.0 (1.7)	3.6 (1.0)

Mean (SD) metal concentrations in ppm in soil ($n = 9$) and matching biomass ($n = 9$) samples collected from 9 sites (unburned $n = 4$, burned $n = 5$) on the study premises within or adjacent to grazing areas during the 2019 grazing season. No Hg, Mo or Tl were detected above the reporting limits in any environmental samples.

*As not detected above reporting limits in one sample.
† Cr not detected above reporting limits in two samples.
‡ Cr not detected above reporting limits in three samples.
§ Ni detected above reporting limits in one sample only.
¶ Ni not detected above reporting limits in one sample.

Interpretation of findings

The primary objective of this study was to investigate whether non-essential metal contamination occurs in the meat of sheep grazing on pastures on recent regrowth of burnt lands. The essential metals Mn, Fe, Zn, Cu and V were consistently detected in meat and wool samples; this finding is not surprising because these metals have important biological roles in mammalian tissues (Radostits et al. 2007; Rehder 2015). However, differences in these elements between the PRE and POST fire groups were limited to increased Fe and Mn, and decreased Cu in the meat of the POST grazing group.

Copper concentrations

The decrease in copper in the POST group is not of toxicological concern, although copper deficiency can have deleterious health effects in ruminants. The meat

Burn regrowth at the Hopland Research and Extension Center, December 2018. Researchers did not detect lead, mercury, arsenic, molybdenum, cadmium, beryllium, cobalt or nickel above reporting limits in any meat or wool samples. *Photo*: Sarah Depenbrock.

Cu concentrations reported herein (2.75 ppm PRE and 1.2 ppm POST) are both within ranges previously published for sheep (Coleman et al. 1992; Pereira et al. 2021). A summary of Cu concentrations in sheep meat over the last 30 years reported a range of study means of 0.75 to 5.9 mg/kg (ppm), with the only U.S. study reporting a mean of 2.32 mg/kg (ppm) (Pereira et al. 2021). However, muscle Cu concentrations are a poor reflection of total body Cu storage in ruminants, with liver being a more appropriate tissue to monitor deficiencies or excess of Cu. Further investigation into the effects of pasture burning on animal tissue Cu concentrations may be warranted, and attention to Cu concentration screening and species-appropriate supplementation is suggested for grazing livestock.

Watching for toxic metals

Metals of particular toxicological concern, which are not expected to be present in ruminant tissues, include Pb, Hg, As, Cd, Be, Co, Ni, Cr and Tl. The absence of detection of Pb, Hg, As, Mo, Cd, Be, Co or Ni in any of the meat or wool samples obtained in the PRE or POST groups suggests that contamination from these metals did not occur following exposure to burn regrowth for a range of 24–46 of 156 days grazing on this site. However, three meat samples from the POST group contained detectable Cr or Tl. Although there were insufficient numbers of samples in which these metals were detected above reporting limits to analyze differences between the PRE and POST groups, the detection of these potentially toxic metals only in the POST group may suggest that grazing burn regrowth exposes some grazing animals to Cr or Tl. Or, it could be that the exposure to these metals was an unidentified, unrelated event that occurred only in the POST group. Detection of Cr in meat samples from grazing animals has been previously reported (Hassan et al. 2012; Ribeiro et al. 2020). In reindeer, mean Cr concentration reported was at 1.7 µg/100 g (0.017 ppm) wet weight (Hassan et al. 2012). In three sheep breeds on varying diets, mean concentrations of Cr ranged between 1.66 and 2.42 mg/kg, on a dry matter basis (approximately 0.45–0.65 ppm on a wet weight basis if moisture content was similar to our study, at approximately 73%) (Ribeiro et al. 2020). The specific toxicological risk of the concentration of Cr found in our study is unknown and depends on the specific form of Cr. However, a Cr concentration of 0.78 ppm likely would exceed values reported for adequate intake for humans (25 to 35 µg/day) if consumers eat more than approximately 50 g of lamb per day (Trumbo et al. 2001). There is a paucity of literature documenting the detection of Tl in meat of grazing animals; a single review cites a typical value of 0.74 ng/g (0.00074 ppm) in muscle tissue of cattle used as analytical reference material (Karbowska 2016). There is no safe Tl limit published for meat; however, limits for Tl in edible plants range from 0.03 to 0.3 mg/kg (ppm). The concentrations found in our study of 1.3 and 1.4 ppm exceed Tl limits for edible plants, and likely exceed the oral reference dose of 0.056 mg per day if more than approximately 40 g are consumed (Karbowska 2016).

The source of Tl exposure was not identified in our study; no Tl was detected above reporting limits in soil, biomass or water sampled at the site after the fire. However, chromium was identified in soil samples and in some biomass from the site after the fire. Further investigation, specifically into Cr and Tl exposure on grazing lands, and the effect of pasture burning on contamination with these metals, is warranted.

Hg was hypothesized to be the metal most likely to be bio-accumulated and deposited on grazing lands after burning. However, no Hg was detected in any substrate sampled. This is an interesting finding after fire converted much of the nearby biomass, including mature oak trees, into ash, which was distributed across the entire site. However, the pastures are largely dominated by annual herbaceous species with scattered trees, which may not accumulate heavy metals to the extent of woody tissues.

Does wool predict metal in meat?

For all metals evaluated, only Ba had similar concentrations between meat and wool; however, the clinical utility of ante-mortem Ba testing is unknown, because Ba toxicosis is considered an unlikely foodborne risk. Due to the lack of samples with detectable Pb, Hg, As, Mo, Cd, Be, Co and Ni, the correlation between these metal concentrations in wool and meat could not be evaluated. Although not evaluated statistically, the detection of two metals of potential toxicological concern (Cr or Tl) in three meat samples without corresponding detection in any wool samples suggests that wool may not be an appropriate matrix to use for ante-mortem detection of Cr or Tl.

Was water contaminated?

Water samples contained only essential minerals, with no non-essential minerals or minerals of potential toxicological concern. This finding suggests that water contamination with metals of potential toxicological concern from wildfire was below detectable concentrations, or did not remain in water sources throughout the following grazing season on the study premise. These findings likewise suggest that water sources were not a likely source of Cr or Tl contamination. However, the single sampling time point, obtained after the grazing period, may have been insufficient to detect transient water contamination associated with the fire and subsequent runoff.

Room for future studies

Our study was limited to a single wildfire event, and was a longitudinal, semi-prospective study design, with limited sample types and numbers available from the PRE group. Due to animal management needs, there was a lack of prospective grazing on the regrowth of grazing lands from different burn intensities. Therefore, inferences about the effects of grazing pastures regrown from prescribed burn compared to wildfire burn, or regrowth from different burn intensities, could not be made. A full toxicological investigation into the source of Cr and Tl contamination was outside the scope of this study; the source of contamination was not determined. Analysis of all feed and forage was also outside the scope of this study, which limits conclusions based on feed history. Potential confounders when comparing meat and wool samples include the relative dilution of the wool for analysis (0.5 g wool vs. 1 g meat per 10 mL final diluent) and the time delay represented in wool growth relative to meat sampling; mature wool fiber samples inherently represent mineral incorporation during wool development before it grows out enough to sample, whereas concentrations in meat represent the most recent physiologic concentration in tissues. Future investigations would benefit from controlled, prospective, contemporaneously matched grazing assignments on regrowth from different burn intensities and environments, and could be expanded by more robust toxicological investigation. CA

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References

Abraham J, Dowling K, Florentine S. 2017. Risk of post-fire metal mobilization into surface water resources: A review. Sci Total Environ 599–600:1740–55. https://doi.org/10.1016/j.scitotenv.2017.05.096

Allred BW, Fuhlendorf SD, Engle DM, Elmore RD. 2011. Ungulate preference for burned patches reveals strength of fire-grazing interaction. Ecol Evol 1(2):132–44. https://doi.org/10.1002/ece3.12

Amiro BD, Sheppard SC, Johnston FL, et al. 1996. Burning radionuclide question: What happens to iodine, cesium and chlorine in biomass fires? Sci Total Environ 187(2):93–103. https://doi.org/10.1016/0048-9697(96)05125-x

Bates M. 2019. Natural disasters and public health. IEEE pulse 10(2):24–7. https://doi.org/10.1109/MPULS.2019.2899704

Castro-González MI, Méndez-Armenta M. 2008. Heavy metals: Implications associated to fish consumption. Environ Toxicol Phar 26(3):263–71. https://doi.org/10.1016/J.ETAP.2008.06.001

Coleman ME, Elder RS, Basu P, Koppenaal GP. 1992. Trace metals in edible tissues of livestock and poultry. J AOAC Int 75(4):615–25. https://doi.org/10.1093/jaoac/75.4.615

Combs DK. 1987. Hair analysis as an indicator of mineral status of livestock. J Anim Sci 65(6):1753–8. https://doi.org/10.2527/jas1987.6561753x

Giesler R, Klemmensen KE, Wardle DA, et al. 2017. Boreal forests sequester large amounts of mercury over millennial time scales in the absence of wildfire. Environ Sci Technol 51(5):2621–7. https://doi.org/10.1021/acs.est.6b06369

Hassan AA, Sandanger TM, Brustad M. 2012. Selected vitamins and essential elements in meat from semi-domesticated reindeer (Rangifer tarandus tarandus L.) in mid- and northern Norway: Geographical variations and effect of animal population density. Nutrients 4(7):724–39. https://doi.org/10.3390/nu4070724

Intergovernmental Panel on Climate Change. 2014. AR5 Climate Change: Impacts, Adaptation, and Vulnerability. www.ipcc.ch/report/ar5/wg2/ (accessed Dec. 10, 2021).

Jensen AM, Scanlon TM, Riscassi AL. 2017. Emerging investigator series: The effect of wildfire on streamwater mercury and organic carbon in a forested watershed in the southeastern United States. Environ Sci Proc–Imp 19(12):1505–17. https://doi.org/10.1039/c7em00419b

Karbowska B. 2016. Presence of thallium in the environment: Sources of contaminations, distribution and monitoring methods. Environ Monit Assess 188(11):640. https://doi.org/10.1007/s10661-016-5647-y

Liang G, Pan L, Liu X. 2017. Assessment of typical heavy metals in human hair of different age groups and foodstuffs in Beijing, China. Int J Env Res Pub He 14(8):E914. https://doi.org/10.3390/ijerph14080914

[NASA] National Aeronautics and Space Administration. 2021. What's Behind California's Surge of Large Fires? NASA Earth Observatory. https://earthobservatory.nasa.gov/images/148908/whats-behind-californias-surge-of-large-fires (accessed Jan. 7, 2022).

Panichev N, Mabasa W, Ngobeni P, et al. 2008. The oxidation of Cr(III) to Cr(VI) in the environment by atmospheric oxygen during the bush fires. J Hazard Mater 153(3): 937–41. https://doi.org/10.1016/j.jhazmat.2007.09.044

Pereira V, Miranda M, Sierra J, et al. 2021. Toxic and essential trace element concentrations in different tissues of extensively reared sheep in northern Spain. J Food Compos Anal 96:103709. https://doi.org/10.1016/j.jfca.2020.103709

Qi F, Yan Y, Lamb D, et al. 2017. Thermal stability of biochar and its effects on cadmium sorption capacity. Bioresource Technol 246:48–56. https://doi.org/10.1016/j.biortech.2017.07.033

Radostits OM, Gay CC, Hinchcliff KW, Constable PD. 2007. *Veterinary Medicine: A Textbook of the Diseases of Cattle, Sheep, Pigs, Goats, and Horses*. 10th ed. Elsevier Saunders. 2,065 p.

Rehder D. 2015. The role of vanadium in biology. Metallomics 7(5):730–42. https://doi.org/10.1039/c4mt00304g

Ribeiro DM, Scanlon T, Kilminster T, et al. 2020. Mineral profiling of muscle and hepatic tissues of Australian Merino, Damara and Dorper lambs: Effect of weight loss. J Anim Physiol An N 104(3):823–30. https://doi.org/10.1111/jpn.13339

Roug A, Swift PK, Gerstenberg G, et al. 2015. Comparison of trace mineral concentrations in tail hair, body hair, blood, and liver of mule deer (Odocoileus hemionus) in California. J Vet Diagn Invest 27(3):295–305. https://doi.org/10.1177/1040638715577826

Sell JL, Deitz FD, Buchanan ML. 1975. Concentration of mercury in animal products and soils of North Dakota. Arch Environ Con Tox 3(3):278–88.

Trumbo P, Yates AA, Schlicker S, Poos M. 2001. Dietary reference intakes: Vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. J Am Diet Assoc 101(3):294–301. https://doi.org/10.1016/S0002-8223(01)00078-5

Weiss-Penzias PS, Bank MS, Clifford DL, et al. 2019. Marine fog inputs appear to increase methylmercury bioaccumulation in a coastal terrestrial food web. Nature Sci Rep 9(1). https://doi.org/10.1038/s41598-019-54056-7

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UC ANR events and classes

Fairmont 4-H Model Horse Show

https://ucanr.edu/sites/4-H-Fresno/Annual_Events_Page/Model_Horse_Show_103/

Date: February 4, 2023
Time: 8:30 a.m. to 5:00 p.m.
Location: Fairmont Elementary School, 3095 N. Greenwood Ave., Sanger
Contact: Tracy Newton, tlnewton@ucanr.edu

2023 California Plant and Soil Conference

https://calasa.ucdavis.edu/

Date: February 7–8, 2023
Time: 8:30 a.m. to 5:00 p.m.
Location: DoubleTree by Hilton & Fresno Convention Center, Fresno
Contact: ANR Program Support, anrprogramsupport@ucanr.edu

UC California Naturalist UCR Palm Desert Center Course

https://palmdesert.ucr.edu/california-naturalists

Date: February 11–April 22, 2023
Time: Saturdays 9:00 a.m. to 1:00 p.m.
Location: UC Riverside Palm Desert Center, Palm Desert
Contact: palmdesert@ucr.edu