**4c. Background and past findings**

Our project seeks to fill major knowledge gaps pertaining to the potential for continuing to conserve wildlife in agricultural landscapes with ongoing climate change (Objective 1) and the potential food-safety impacts of promoting wildlife on farms (Objective 2). Below, we outline the foundational research, as well as our prior work, that has motivated our research questions.

*Objective 1*

Agriculture now occupies ~50% of Earth’s land surface (Mendenhall et al. 2013). Over the past several decades, biologists have thus increasingly turned their attention to conserving biodiversity alongside us in ‘working landscapes’ composed of pastures, crop fields, and forest patches (Kremen and Merenlender 2018, Tamburini et al. 2020). Indeed, early studies suggested that remarkable concentrations of wildlife can often be found on diversified farms— with patches of native vegetation and high crop diversity— compared to intensive monocultures (Daily et al. 2001). For example, using a decadal dataset of >125,000 bird observations in Costa Rica, our work has shown that diversified farms can maintain multiple dimensions of bird diversity, on par with nearby forest reserves (Karp et al. 2011, 2012, Frishkoff et al. 2014). Our work also suggested, however, that the biological communities found in agriculture and forests were distinct, with widespread, dry-adapted species dominating farms (Karp et al. 2015b, 2018, 2019, Frishkoff et al. 2018, Frishkoff and Karp 2019). In contrast, endemic, range-restricted, and wet-associated species were much more restricted to forests. As a result, our models predicted forest species would lose ~60% of their ranges to climate change by 2070 whereas agricultural species would lose <30% (Frishkoff et al. 2016).

These results reflecting the growing scientific consensus that interactions between habitat conversion to agriculture and ongoing climate change will be critical to determining the fate of biodiversity in the Anthropocene (Travis 2003, Brook et al. 2008). Yet the effects of climate change and habitat conversion to agriculture are often analyzed in isolation (Oliver and Morecroft 2014). Thus, the actual mechanisms that underlie how both stressors interact to affect wildlife remain unresolved, impeding efforts to design effective management strategies. One possible mechanism through which climate and land-use change might interact is via altered microclimatic dynamics (Williams and Newbold 2019, Williams et al. 2020a). Many forms of habitat conversion (*e.g.,* agricultural expansion, urbanization) remove insulating tree canopies, thereby reducing local thermal buffering and eliciting temperature spikes (or troughs; (Alkama and Cescatti 2016, De Frenne et al. 2019). Indeed, temperatures on farms are often >10°C hotter than nearby natural sites (Nowakowski et al. 2018). As a result, species that occupy anthropogenic habitats, either agriculture (Frishkoff et al. 2015, Nowakowski et al. 2018, Williams et al. 2019, 2020b, Waldock et al. 2020) or urban heat islands (Piano et al. 2017, Merckx et al. 2018), tend to have broader thermal tolerances than the species restricted to natural habitat.

We might thus expect the effects of climate change on species living in natural and anthropogenic ecosystems to differ (Hendershot et al. 2020), given the vastly different thermal regimes present in each habitat. Birds are particularly suited to understanding the effects of temperature extremes because bird species with altricial young are ectothermic for the first few weeks of life, and low and high temperatures divert large amounts of energy from growth to thermoregulation (Wingfield et al. 2017). Though the effects of cold extremes on avian reproduction are well documented (Winkler et al. 2013, Cox et al. 2019, Shipley et al. 2020), only recently have we begun to realize just how detrimental temperature spikes are for avian reproduction (Conrey et al. 2016, Riddell et al. 2019, Bourne et al. 2020, Marcelino et al. 2020, Schou et al. 2021). Temperature spikes reduce fertility in the southern pied babbler, an arid zone bird (Bourne et al. 2020), and have driven avian community collapse in the Mojave (Riddell et al. 2019). Indeed, our preliminary results indicate that temperature spikes might *increase* reproductive success of birds in forest, while they sharply *decrease* success in agriculture.

Direct thermoregulation challenge for nestlings and reduced food availability are two main mechanisms that likely reduce bird reproductive success in agriculture. Nestlings can survive heat waves by using more energy to thermoregulate, but this diversion of energy may increase stress, decrease growth, and lead to lower survival (Wingfield et al. 2017). Furthermore, heat waves may reduce food provisioning to nestlings, either by forcing adults to spend more energy thermoregulating or by reducing prey availability. For example, warming temperatures are driving lepidopteran declines across the U.S. (a key resource for young birds; Forister et al. 2021). For this project, we propose to investigate the relative contributions of thermoregulation challenge and food provisioning to nestling growth under temperature spikes across four land use types: natural open canopy (grassland), natural closed canopy (riparian forest), agricultural open canopy (row crop), and agricultural closed canopy (orchard).

If the effects of climate change are different among land uses, we might then expect that conservation actions to maintain resilience of biodiversity to climate change might also differ among land uses. Understanding the relative contributions of thermoregulation challenge and reduced food supply to decreased reproductive success under temperature spikes in agriculture and other land uses will provide concrete avenues through which working landscapes could be modified to better accommodate cavity-nesting birds. If the direct effects of heat are more important than food-mediated effects, nest boxes could be modified to reduce their internal temperature. If food-mediated effects predominate, then maintaining patches of non-crop habitats in working landscapes to support food resources may be more effective.

*Objective 2*

The majority of the millions of illnesses caused by foodborne pathogens each year involve three bacteria – *Salmonella* spp., *Campylobacter* spp., *Escherichia coli*– that originate in human, livestock, or wildlife waste (Batz et al. 2012, Havelaar et al. 2015). Because wildlife have been implicated in prior outbreaks involving these pathogens (Jay et al. 2007, Gardner et al. 2011, Langholz and Jay-Russell 2013), growers face increasing market and regulatory pressure to prevent them from entering their farms (Beretti and Stuart 2007, Baur et al. 2016).

Wild birds are of particular concern for several reasons. First, birds carry multiple pathogens, including Shiga-toxin producing *E. coli* (hereafter, STEC), *Salmonella* spp.,and *Campylobacter* spp.(Navarro-Gonzalez et al. 2019, Smith et al. 2020b). Second, birds move long distances, including between cropland and livestock operations (Rivadeneira et al. 2016). Thus, birds could be partially responsible for higher pathogens loads on farms near rangeland (Benjamin et al. 2013, Karp et al. 2015a). Third, excluding birds from farms is difficult. Growers often report that birds habituate to visual or auditory deterrents, whereas more effective methods are very costly (Anderson et al. 2013, Rivadeneira et al. 2018). Finally, birds are ubiquitous in produce fields, defecating in and around crops (Smith et al. 2019, 2020a, Olimpi et al. 2020). For example, after surveying >170 transects for bird feces across 43 farms in California, we found ~50% and ~35% of 1m2 quadrats in strawberry and lettuce fields were contaminated with bird feces.

Nonetheless, it remains unclear whether bird feces in crop fields constitute a meaningful food-safety risk (Smith et al. 2020b). Only one outbreak has been attributed to birds: an outbreak of *Campylobacter* from Sandhill Cranes (*Grus canadensis*) in pea fields (Gardner et al. 2011). Moreover, prior efforts to quantify enteric pathogens in birds have largely focused on only a few species (Langholz and Jay-Russell 2013, Smith et al. 2020b). Indeed, our work suggests that sufficient data existed to precisely calculate STEC, *Salmonella* spp., and *Campylobacter* spp. prevalence in only 5 of 431 (1.2%) North American breeding bird species (Smith et al. 2020b).

To cause foodborne illness, birds must not only carry pathogens but also defecate on or near crops. Yet very few studies link pathogen prevalence estimates among birds with their proclivities to enter farms. We found that only 3.3% of studies in our meta-analysis reported data across the spillover cycle, from pathogen exposure to contact with food to transmission to humans or other hosts (Smith et al. 2020b). To address this gap, we assembled a preliminary dataset of bird surveys across ~350 produce fields in the Western United States. We also collected fecal samples in production areas and attributed them back to bird species via DNA barcoding. Again, we found that livestock-associated birds were more likely to contact crops and defecate on farms. Importantly, however, the frequency at which species contacted crops was not necessarily a good surrogate for how often they defecated, with some species foraging often in crops but rarely defecating and others exhibiting the reverse trend.

Finally, the vast majority of feces that we encountered in crop fields were small, old, and desiccated. Yet very few studies have quantified pathogen survival times in wild bird feces, complicating efforts to assess transmission potential from bird feces to humans via crops. One study inoculated Canada Goose feces with *Salmonella*, placed them in grass, and found it could survive through the full 28 day trial (Feare et al. 1999). Another inoculated goose feces with *Campylobacter* spp., placed them in pastures, and reported shorter survival (*i.e.,* < 1 week), especially during summer (Moriarty et al. 2011). In the lab, STEC was shown to survive in European Starling feces up to 76 days (Kauffman and LeJeune 2011). Another lab study found that STEC and *Salmonella* were undetectable in bird feces by ~60 days; however, *Salmonella* survived through the 130 day experiment when incubated at high humidity (80%; (Fonseca et al. 2020). Finally, a study that inoculated chicken feces with *E. coli* found that the amount of irrigation water dictated *E. coli* survival and transmission to lettuce (Jeamsripong et al. 2019).

Together, these few experiments highlight key gaps in our understanding of pathogen survival in wild bird feces. First, does the substrate on which feces are deposited matter? For example, our prior work suggests that organic soils may host bacteria that can better suppress enteric pathogen survival relative to conventional soils (Devarajan et al. 2021). Pathogens living in feces deposited on plastic mulch may be shielded from these competitive bacteria but may also desiccate faster than if feces were on soil or crops, which may be critical given humidity impacts on pathogens (Fonseca et al. 2020). Second, does survival depend on the bird species? Varying gut microbiomes among species could impact survival. Even more importantly, songbird feces are most common on farms but are unstudied (apart from one lab study on starlings). Songbirds produce small feces with high surface area, making them more prone to desiccation. However, prior experiments have studied fecal samples several orders of magnitude larger in mass than the amount of feces produced by a typical songbird (*e.g.* 5 g vs 0.1g; Jeamsripong et al. 2019).

Estimates of pathogen prevalence and pathogen survival must be combined to understand the risks bird pose. Doing so could help identify species that should be deterred from farms. For example, though our prior analyses identified few species that have both high crop contact rates and *Campylobacter* prevalence, livestock-associated species seem to be most risky along both axes. Such analyses could also help identify opportunities for co-managing farms for conservation and food safety. Because birds consume crop pests, some farmers place nest boxes within their fields to promote birds (Jedlicka et al. 2011, Olimpi et al. 2020). If species associated with nest boxes pose low risks, then conserving birds could be a win-win for birds and farmers. Yet the birds that use nest boxes are poorly represented in the food-safety literature and in our current database. For example, none of the top five species that use nest boxes were tested for *Salmonella* spp.*, Campylobacter* spp., and STEC >10 times.

Finally, it is important to recognize that specific farming contexts, most critically the composition of the surrounding landscape, determines which bird species will be found on the farm (Gonthier et al. 2019, Smith et al. 2019, Olimpi et al. 2020). That is, farms surrounded by rangeland vs. seminatural habitats vs. other farms will likely house different bird communities that present different levels of risk. For example, we found that bird feces were more likely to test positive for *Campylobacter* spp. on farms with higher densities of livestock in the surrounding landscape (Smith et al. 2020a). Conversely, our data from strawberry farms in California and mixed produce farms across the Western U.S. (Smith et al. 2020a) suggest birds are less likely to carry *Campylobacter* spp. on farmers surrounded by seminatural habitats. Understanding which birds are most likely to be present, and if they carry pathogens, could help farmers assess when birds should/should not represent a priority for food-safety management.

Given these knowledge gaps, our second core objective is thus to develop more holistic food-safety risk assessments for wild birds. To do so, we will:

1. We will combine our pathogen database with new *Campylobacter,* *Salmonella*, and STEC tests from field-collected feces. We will focus on under-sampled species that frequent farms, especially species that can be actively managed (*e.g.,* birds that use nest boxes).
2. In the field and in the lab, we will parameterize and compare *E. coli* survival curves in feces from a large bird (*e.g.,* Canada Goose, *Branta canadensis*) and a small songbird (*e.g.,* Western Bluebird, *Sialia mexicana*) placed on four substrates: lettuce plants, conventional soils, organic soils, and plastic mulch. On lettuce plants only, we will also compare *E. coli* survival in feces from 8 more species that carry pathogens and/or are common on farms.
3. We will combine data on pathogen prevalence and pathogen survival to develop holistic risk assessments for multiple farmland birds. We will produce a photo guide to aid farmers in identifying species and farming contexts that present the gravest risks.

**References**

Alkama, R., and A. Cescatti. 2016. Biophysical climate impacts of recent changes in global forest cover. Science 351:600–604.

Anderson, A., C. A. Lindell, K. M. Moxcey, W. F. Siemer, G. M. Linz, P. D. Curtis, J. E. Carroll, C. L. Burrows, J. R. Boulanger, K. M. M. Steensma, and S. A. Shwiff. 2013. Bird damage to select fruit crops: the cost of damage and the benefits of control in five states. Crop Protection 52:103–109.

Batz, M. B., S. Hoffmann, and J. G. Morris. 2012. Ranking the disease burden of 14 pathogens in food sources in the United States using attribution data from outbreak investigations and expert elicitation. Journal of Food Protection 75:1278–1291.

Baur, P., L. Driscoll, S. Gennet, and D. Karp. 2016. Inconsistent food safety pressures complicate environmental conservation for California produce growers. California Agriculture 70:142–151.

Benjamin, L., E. R. Atwill, M. Jay-Russell, M. Cooley, D. Carychao, L. Gorski, and R. E. Mandrell. 2013. Occurrence of generic Escherichia coli, E . coli O157 and Salmonella sp . in water and sediment from leafy green produce farms and streams on the Central California coast. International Journal of Food Microbiology 165:65–76.

Beretti, M., and D. Stuart. 2007. Food safety and environmental quality impose conflicting demands on Central Coast growers. California Agriculture 62:68–73.

Bourne, A. R., S. J. Cunningham, C. N. Spottiswoode, and A. R. Ridley. 2020. High temperatures drive offspring mortality in a cooperatively breeding bird. Proceedings of the Royal Society B: Biological Sciences 287:20201140.

Brook, B. W., N. S. Sodhi, and C. J. A. Bradshaw. 2008. Synergies among extinction drivers under global change. Trends in Ecology and Evolution 23:453–460.

Conrey, R. Y., S. K. Skagen, A. A. Yackel Adams, and A. O. Panjabi. 2016. Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines. Ibis 158:614–629.

Cox, A. R., R. J. Robertson, Á. Z. Lendvai, K. Everitt, and F. Bonier. 2019. Rainy springs linked to poor nestling growth in a declining avian aerial insectivore ( Tachycineta bicolor ). Proceedings of the Royal Society B: Biological Sciences 286:20190018.

Daily, G. C., P. R. Ehrlich, and G. A. Sánchez-Azofeifa. 2001. Countryside biogeography: Use of human-dominated habitats by the avifauna of southern Costa Rica. Ecological Applications 11:1–13.

Devarajan, N., J. A. McGarvey, K. Scow, M. S. Jones, S. Lee, S. Samaddar, R. Schmidt, T. D. Tran, and D. S. Karp. 2021. Cascading effects of composts and cover crops on soil chemistry, bacterial communities and the survival of foodborne pathogens. Journal of Applied Microbiology:1–14.

Feare, C. J., M. F. Sanders, R. Blasco, and J. D. Bishop. 1999. Canada goose (Branta canadensis) droppings as a potential source of pathogenic bacteria. The Journal of the Royal Society for the Promotion of Health 119:146–155.

Fonseca, J. M., S. Ravishankar, C. A. Sanchez, E. Park, and K. D. Nolte. 2020. Assessing the food safety risk posed by birds entering leafy greens fields in the US southwest. International Journal of Environmental Research and Public Health 17:1–16.

Forister, M. L., C. A. Halsch, C. C. Nice, J. A. Fordyce, T. E. Dilts, J. C. Oliver, K. L. Prudic, A. M. Shapiro, J. K. Wilson, and J. Glassberg. 2021. Fewer butterflies seen by community scientists across the warming and drying landscapes of the American West. Science 371:1042–1045.

De Frenne, P., F. Zellweger, F. Rodríguez-Sánchez, B. R. Scheffers, K. Hylander, M. Luoto, M. Vellend, K. Verheyen, and J. Lenoir. 2019. Global buffering of temperatures under forest canopies. Nature Ecology and Evolution 3:744–749.

Frishkoff, L. O., A. Echeverri, K. M. A. Chan, and D. S. Karp. 2018. Do correlated responses to multiple environmental changes exacerbate or mitigate species loss? Oikos 127:1724–1734.

Frishkoff, L. O., E. A. Hadly, and G. C. Daily. 2015. Thermal niche predicts tolerance to habitat conversion in tropical amphibians and reptiles. Global Change Biology 21:3901–3916.

Frishkoff, L. O., and D. S. Karp. 2019. Species‐specific responses to habitat conversion across scales synergistically restructure Neotropical bird communities. Ecological Applications 29:e01910.

Frishkoff, L. O., D. S. Karp, J. R. Flanders, J. Zook, E. A. Hadly, G. C. Daily, and L. K. M’Gonigle. 2016. Climate change and habitat conversion favour the same species. Ecology Letters 19:1081–1090.

Frishkoff, L. O., D. S. Karp, L. K. M’Gonigle, C. D. Mendenhall, J. Zook, C. Kremen, E. A. Hadly, and G. C. Daily. 2014. Loss of avian phylogenetic diversity in neotropical agricutural systems. Science 345:1343–1346.

Gardner, T. J., C. Fitzgerald, C. Xavier, R. Klein, J. Pruckler, S. Stroika, and J. B. Mclaughlin. 2011. Outbreak of Campylobacteriosis associated with consumption of raw peas. Clinical Infectious Diseases 53:26–32.

Gonthier, D., A. R. Sciligo, D. S. Karp, A. Lu, K. Garcia, G. Juarez, T. Chiba, S. Gennet, and C. Kremen. 2019. Bird services and disservices to strawberry farming in Californian agricultural landscapes. Journal of Applied Ecology 56:1948–1959.

Havelaar, A. H., M. D. Kirk, P. R. Torgerson, H. J. Gibb, T. Hald, R. J. Lake, and N. Praet. 2015. World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. PLoS Med 12:e1001923.

Hendershot, J. N., J. R. Smith, C. B. Anderson, A. D. Letten, L. O. Frishkoff, J. R. Zook, T. Fukami, and G. C. Daily. 2020. Intensive farming drives long-term shifts in avian community composition. Nature 579.

Jay, M. T., M. Cooley, D. Carychao, G. W. Wiscomb, R. A. Sweitzer, L. Crawford-miksza, J. A. Farrar, D. K. Lau, J. O. Connell, A. Millington, R. V Asmundson, E. R. Atwill, and R. E. Mandrell. 2007. Escherichia coli in swine near spinach fields and cattle, Central California Coast. Emerging Infectious Diseases 13:1908–1911.

Jeamsripong, S., J. A. Chase, M. T. Jay-Russell, R. L. Buchanan, and E. R. Atwill. 2019. Experimental in-field transfer and survival of escherichia coli from animal feces to romaine lettuce in Salinas valley, California. Microorganisms 7:408.

Jedlicka, J. A., R. Greenberg, and D. K. Letourneau. 2011. Avian conservation practices strengthen ecosystem services in California vineyards. PLoS One 6:e27347.

Karp, D. S., A. Echeverri, J. Zook, P. Juárez, A. Ke, J. Krishnan, K. M. A. Chan, and L. O. Frishkoff. 2019. Remnant forest in Costa Rican working landscapes fosters bird communities that are indistinguishable from protected areas. Journal of Applied Ecology 56:1839–1849.

Karp, D. S., L. O. Frishkoff, A. Echeverri, J. Zook, P. Juárez, and K. M. A. Chan. 2018. Agriculture erases climate-driven β-diversity in Neotropical bird communities. Global Change Biology 24:338–349.

Karp, D. S., S. Gennet, C. Kilonzo, M. Partyka, N. Chaumont, E. R. Atwill, and C. Kremen. 2015a. Comanaging fresh produce for nature conservation and food safety. Proceedings of the National Academy of Sciences 112:11126–11131.

Karp, D. S., C. D. Mendenhall, E. Callaway, L. O. Frishkoff, P. M. Kareiva, and P. R. Ehrlich. 2015b. Confronting and resolving competing values behind conservation objectives. Proceedings of the National Academy of Sciences 112:11132–11137.

Karp, D. S., A. J. Rominger, J. Zook, J. Ranganathan, P. R. Ehrlich, and G. C. Daily. 2012. Intensive agriculture erodes β-diversity at large scales. Ecology Letters 15:963–970.

Karp, D. S., G. Ziv, J. Zook, P. R. Ehrlich, and G. C. Daily. 2011. Resilience and stability in bird guilds across tropical countryside. Proceedings of the National Academy of Sciences 108:21134–21139.

Kauffman, M. D., and J. LeJeune. 2011. European Starlings (Sturnus vulgaris) challenged with Escherichia coli O157 can carry and transmit the human pathogen to cattle. Letters in Applied Microbiology 53:596–601.

Kremen, C., and A. M. Merenlender. 2018. Landscapes that work for biodiversity and people. Science 362:1–9.

Langholz, J. A., and M. T. Jay-Russell. 2013. Potential role of wildlife in pathogenic contamination of fresh produce. Human-Wildlife Interactions 7:140–157.

Marcelino, J., J. P. Silva, J. Gameiro, A. Silva, F. C. Rego, F. Moreira, and I. Catry. 2020. Extreme events are more likely to affect the breeding success of lesser kestrels than average climate change. Scientific Reports 10:7207.

Mendenhall, C. D., C. V Kappel, and P. R. Ehrlich. 2013. Countryside Biogeography. Academic Press.

Merckx, T., C. Souffreau, A. Kaiser, L. F. Baardsen, T. Backeljau, D. Bonte, K. I. Brans, M. Cours, M. Dahirel, N. Debortoli, K. De Wolf, J. M. T. Engelen, D. Fontaneto, A. T. Gianuca, L. Govaert, F. Hendrickx, J. Higuti, L. Lens, K. Martens, H. Matheve, E. Matthysen, E. Piano, R. Sablon, I. Schön, K. Van Doninck, L. De Meester, and H. Van Dyck. 2018. Body-size shifts in aquatic and terrestrial urban communities. Nature 558:113–116.

Moriarty, E. M., N. Karki, M. MacKenzie, L. W. Sinton, D. R. Wood, and B. J. Gilpin. 2011. Faecal indicators and pathogens in selected New Zealand waterfowl. New Zealand Journal of Marine and Freshwater Research 45:679–688.

Navarro-Gonzalez, N., S. Wright, P. Aminabadi, A. Gwinn, T. Suslow, and M. J.- Russell. 2019. Carriage and subtypes of foodborne pathogens identified in wild birds residing near agricultural lands in California: a repeated cross-sectional study. Applied and Environmental Microbiology 86:e01678.

Nowakowski, A. J., J. I. Watling, M. E. Thompson, G. A. Brusch, A. Catenazzi, S. M. Whitfield, D. J. Kurz, Á. Suárez‐Mayorga, A. Aponte‐Gutiérrez, M. A. Donnelly, and B. D. Todd. 2018. Thermal biology mediates responses of amphibians and reptiles to habitat modification. Ecology Letters 21:345–355.

Olimpi, E. M., K. Garcia, D. J. Gonthier, C. Kremen, W. E. Snyder, E. E. Wilson-Rankin, and D. S. Karp. (n.d.). Farmland diversification shapes tradeoffs and synergies in bird-mediated ecosystem services and disservices. Proceedings of the National Academy of Sciences.

Olimpi, E. M., K. Garcia, D. J. Gonthier, K. T. De Master, A. Echeverri, C. Kremen, A. R. Sciligo, W. E. Snyder, E. E. Wilson-Rankin, and D. S. Karp. 2020. Shifts in species interactions and farming contexts mediate net effects of birds in agroecosystems. Ecological Applications 30:1–14.

Oliver, T. H., and M. D. Morecroft. 2014. Interactions between climate change and land use change on biodiversity: Attribution problems, risks, and opportunities. Wiley Interdisciplinary Reviews: Climate Change 5:317–335.

Piano, E., K. De Wolf, F. Bona, D. Bonte, D. E. Bowler, M. Isaia, L. Lens, T. Merckx, D. Mertens, M. van Kerckvoorde, L. De Meester, and F. Hendrickx. 2017. Urbanization drives community shifts towards thermophilic and dispersive species at local and landscape scales. Global Change Biology 23:2554–2564.

Riddell, E. A., K. J. Iknayan, B. O. Wolf, B. Sinervo, and S. R. Beissinger. 2019. Cooling requirements fueled the collapse of a desert bird community from climate change. Proceedings of the National Academy of Sciences 116:21609–21615.

Rivadeneira, P., C. Hilson, A. Justice-Allen, and M. Jay-Russell. 2016. Pathogen risks related to the movement of birds frequenting livestock and fresh produce growing areas in the Southwestern U.S. Proceedings of the Vertebrate Pest Conference 27:258–263.

Rivadeneira, P., S. Kross, N. Navarro-Gonzalez, and M. Jay-Russell. 2018. A Review of Bird Deterrents Used in Agriculture. Proceedings of the Vertebrate Pest Conference 28.

Schou, M. F., M. Bonato, A. Engelbrecht, Z. Brand, E. I. Svensson, J. Melgar, P. T. Muvhali, S. W. P. Cloete, and C. K. Cornwallis. 2021. Extreme temperatures compromise male and female fertility in a large desert bird. Nature Communications 12:666.

Shipley, J. R., C. W. Twining, C. C. Taff, M. N. Vitousek, A. Flack, and D. W. Winkler. 2020. Birds advancing lay dates with warming springs face greater risk of chick mortality. Proceedings of the National Academy of Sciences 117:25590–25594.

Smith, O. M., A. Edworthy, J. M. Taylor, M. S. Jones, A. Tormanen, C. M. Kennedy, Z. Fu, C. E. Latimer, K. A. Cornell, L. A. Michelotti, C. Sato, T. Northfield, W. E. Snyder, and J. P. Owen. 2020a. Agricultural intensification heightens food safety risks posed by wild birds. Journal of Applied Ecology:1–12.

Smith, O. M., C. M. Kennedy, J. P. Owen, T. D. Northfield, C. E. Latimer, and W. E. Snyder. 2019. Highly diversified crop-livestock farming systems reshape wild bird communities. Ecological Applications 30:e02031.

Smith, O. M., W. E. Snyder, and J. P. Owen. 2020b. Are we overestimating risk of enteric pathogen spillover from wild birds to humans? Biological Reviews 95:652–679.

Tamburini, G., R. Bommarco, T. C. Wanger, C. Kremen, M. G. A. van der Heijden, M. Liebman, and S. Hallin. 2020. Agricultural diversification promotes multiple ecosystem services without compromising yield. Science Advances 6.

Travis, J. M. J. 2003. Climate change and habitat destruction: a deadly anthropogenic cocktail. Proceedings of the Royal Society B 270:467–473.

Waldock, C. A., A. De Palma, and P. A. V Borges. 2020. Insect occurrence in agricultural land-uses depends on realized niche and geographic range properties. Ecography 43:1–12.

Williams, J. J., A. E. Bates, and T. Newbold. 2019. Human-dominated land uses favour species affiliated with more extreme climates, especially in the tropics. Ecography:1–15.

Williams, J. J., A. E. Bates, and T. Newbold. 2020a. Human-dominated land uses favour species affiliated with more extreme climates, especially in the tropics. Ecography 43:391–405.

Williams, J. J., A. E. Bates, and T. Newbold. 2020b. Human-dominated land uses favour species affiliated with more extreme climates, especially in the tropics. Ecography 43:391–405.

Williams, J. J., and T. Newbold. 2019. Local climatic changes affect biodiversity responses to land use : A review. Diversity and Distributions:1–17.

Wingfield, J. C., J. H. Pérez, J. S. Krause, K. R. Word, P. L. González-Gómez, S. Lisovski, and H. E. Chmura. 2017. How birds cope physiologically and behaviourally with extreme climatic events. Philosophical Transactions of the Royal Society B: Biological Sciences 372:20160140.

Winkler, D. W., M. K. Luo, and E. Rakhimberdiev. 2013. Temperature effects on food supply and chick mortality in tree swallows (Tachycineta bicolor). Oecologia 173:129–138.