SPECIAL FEATURE: OPINION

Eight simple actions that individuals can take to save insects from global declines

Akito Y. Kawahara[a,b,c,1], Lawrence E. Reeves[c,d], Jesse R. Barber[e], and Scott H. Black[f]

Insects constitute the vast majority of known animal species and are ubiquitous across terrestrial ecosystems, playing key ecological roles. As prey, they are critical to the survival of countless other species, including the majority of bats, birds, and freshwater fishes (1). As herbivores, predators, and parasites, they are major determinants of the distribution and abundance of innumerable plants and animals. The majority of flowering plants, the dominant component of most terrestrial ecosystems, depend on insects for pollination and hence reproduction. As consumers of waste products, insects are essential to the recycling of nutrients. Humans and their agriculture rely heavily on such "ecosystem services" provided by insects (Fig. 1 *A*–*J*), which together have at least an annual value of ~$70 billion (2020 valuation) in the United States (2). Insects also provide humans with honey, silk, wax, dyes, and, in many cultures, food. Insects have become essential subjects in medical and basic biological research. Furthermore, insects are one of the most easily accessible forms of wildlife, with a diversity of morphology, life history, and behavior that seems ready-made for inspiring appreciation of nature and its conservation (Fig. 1 *K*–*T*).

This benign characterization of insects seems self-evident now, but its emergence is historically recent, especially in the United States. In the mostly agricultural 19th century United States, political pressure generated by increasing crop losses to insects led to the creation of a government-supported corps of professional entomologists. Great advances in fundamental knowledge resulted, but entomology became closely tied to the chemical/pesticide industry, which increasingly adopted a strident insects-as-enemy dialogue, broadened to include disease vectors (3). The 1962 publication of *Silent Spring* (4) marked a dramatic turn toward a more balanced view, but the transition has been slow, not least because the challenges of crop pest and disease vector management remain enormous.

Ironically, even as insects gain recognition as essential members of ecosystems, a concern has arisen that their diversity and abundance may be in global decline, owing to habitat degradation and loss, climate change, pollution, and other causes (e.g., 5–8). Although the evidence is as yet fragmentary and controversial (9, 10; see also articles in this issue), there is every reason to suspect that such forces, combined with human population growth and urbanization, are leading to declines among insects and many other organisms (e.g., 11). There is thus abundant justification for trying to slow or mitigate potential ecological catastrophes triggered by biodiversity losses. Multiple proposals exist. For example, Forister *et al.* (12) called for immediate conservation actions at four levels: nations, states, provinces, and cities; working lands; natural areas; and gardens, homes, and other personal property. Others have proposed intermediate and long-term action plans for insect conservation and recovery (e.g., 13, 14). Implementing these plans and actions, especially those that require approval of governments or nations, can take time. Fortunately, at an individual level, people can play a key role with immediate local impacts. In light of the importance of insects to human existence and the negative trends in insect abundance and diversity that have been shown in numerous recent studies, it is vital that people learn how they can take action.

To help individuals broaden participation in the conservation of insects and to promote the adoption of behaviors and habits expected to mitigate insect declines, we propose eight simple actions, most with immediate impact, that many people can undertake on their own, regardless of background, occupation,

[a]Florida Museum of Natural History, University of Florida, Gainesville, FL 32611; [b]Department of Entomology, Smithsonian National Museum of Natural History, Washington, DC 20560; [c]Entomology and Nematology Department, University of Florida, Gainesville, FL 32608; [d]Florida Medical Entomology Laboratory, Institute of Food and Agricultural Sciences, University of Florida, Vero Beach, FL 32962; [e]Department of Biology, Boise State University, Boise, ID 83725; and [f]The Xerces Society for Invertebrate Conservation, Portland, OR 97232

Author contributions: A.Y.K. designed research; A.Y.K., L.E.R., J.R.B., and S.H.B. performed research; A.Y.K., L.E.R., J.R.B., and S.H.B. analyzed data; and A.Y.K., L.E.R., J.R.B., and S.H.B. wrote the paper.

The authors declare no competing interest.

Any opinions, findings, conclusions, or recommendations expressed in this work are those of the authors and have not been endorsed by the National Academy of Sciences.

[1]To whom correspondence may be addressed. Email: kawahara@flmnh.ufl.edu.

This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2002547117/-/DCSupplemental.

Published January 11, 2021.

Fig. 1. Examples of insects that are beneficial to humans (*A–J*), and examples of amazing things that insects do (*K–T*). *A*, Pollinator: Honey bee (*Apis mellifera*). *B*, Bumble bee (*Bombus* sp.). *C*, Decomposer: Dung beetle (Scarabaeidae: Scarabaeinae). *D*, Biocontrol: Ladybird beetle (*Harmonia* sp.). *E*, Ecosystem service: Ants (Formicidae). *F*, Silk production: Silk moth (*Bombyx mori*). *G*, Research: Fruit fly (*Drosophila melanogaster*). *H*, Vaccine development, including coronavirus: Alfalfa looper moth (*Autographa californica*). *I*, Dye production: Cochineal scale insect (*Dactylopius coccus*). *J*, Environmental assessment: Stonefly (Plecoptera). *K*, Visual systems: Dragonflies (e.g., *Neurothemis* sp.) have near 360° vision. *L*, Visual defense: Hawkmoth caterpillars (*Hemeroplanes triptolemus*) scare predators by flipping over and resembling a snake. *M*, Immunity and symbiosis: Parasitic wasps (e.g., *Aleiodes indiscretus*) subdue their host with a virus. *N*, Acoustic defense: Tiger moths (*Bertholdia trigona*) use ultrasound to jam bat sonar. *O*, Biomechanics: Water striders (e.g., Gerridae) walk on water. *P*, Agriculture: Leaf cutter ants (*Atta* sp.) farm fungi. *Q*, Chemical defense: Bombardier beetles (*Brachinus* sp.) blast boiling benzoquinones at predators. *R*, Migration: Monarch butterflies (*Danaus plexippus*) migrate thousands of kilometers. *S*, Longevity: Periodical cicadas (e.g., *Magicicada septemdecim*) live for nearly two decades. *T*, Visual mimicry and luring: Firefly (*Photinus pyralis*) females mimic other firefly light flash signals to lure mate-seeking males and consume them alive. See *SI Appendix* for further information about each insect. Image credits: Fig. 1*A*: Michael J. Raupp (photographer); Fig. 1*B*: Flickr/James Johnstone, licensed under CC BY 2.0; Fig. 1*C*: L.E.R.; Fig. 1*D*: Flickr/John Spooner, licensed under CC BY-NC 2.0; Fig. 1*E*: iNaturalist/Jakob Fahr, licensed under CC BY-NC 4.0; Fig. 1*F*: L.E.R.; Fig. 1*G*: iNaturalist/alexis_orion, licensed under CC BY 4.0; Fig. 1*H*: iNaturalist/Anita Sprungk, licensed under CC BY-NC 4.0; Fig. 1*I*: Wikimedia Commons/Peggy Greb, licensed under CC BY 3.0; Fig. 1*J*: Flickr/USFWS Mountain-Prairie, licensed under CC BY 2.0; Fig. 1*K*: L.E.R.; Fig. 1*L*: André Victor Lucci Frietas (photographer); Fig. 1*M*: Wikimedia Commons/USDA; Fig. 1*N*: Aaron J. Corcoran (photographer); Fig. 1*O*: Flickr/Brad Smith, licensed under CC BY-NC 2.0; Fig. 1*P*: L.E.R.; Fig. 1*Q*: Flickr/Katja Schulz, licensed under CC BY 2.0; Fig. 1*R*: Jeffrey Gage (photographer); Fig. 1*S*: Michael J. Raupp (photographer); and Fig. 1*T*: Flickr/James Jordan, licensed under CC BY-ND 2.0.

or geographic location. The first five of these are aimed at creating more and better insect-friendly habitats, the loss of which is likely a leading cause of insect declines. The remaining three are aimed at adjusting public attitudes toward insects to increase support for conservation actions. Further information on each action item can be found in *SI Appendix*.

The Eight Action Items

Create insect-friendly habitats:

1. Convert lawns into diverse natural habitats. Traditional European or Western lawns are biodiversity deserts (15). There are more than 40 million acres of lawns or turf grass in the United States alone (16), and these groomed/mowed monocultures support few insects and other wildlife. With increasing global fragmentation of natural environments, insects will need quality habitat to be preserved and restored, including travel corridors and stepping stones to allow movement across the landscape (5, 7, 17). Because many insects need little space to survive, even partial conversion of lawns to minimally disturbed natural vegetation—say 10%—could significantly aid insect conservation, while simultaneously lowering the cost of lawn maintenance through reduced watering, and requisite herbicide, fertilizer, and pesticide applications.

If every home, school, and local park in the United States converted 10% of their lawn space into natural habitat, this would increase usable habitat for insects by more than 4 million acres. Converting lawns into natural habitat is relatively easy, and if preexisting turf grass is needed to be removed beforehand, this can be done with a sod cutter or through solarization before seeding. Fallen leaves, twigs, and fruit in this space should be left in place, and vegetation should be minimally trimmed or not trimmed at all, as many insects depend on new growth and complex plant structure. A model effort is the "Thousands of Gardens – Thousands of Species" project in Germany, funded by 2.5 million euros from the German Federal Ministry for the Environment (18).

2. Grow native plants. Although there are exceptions, increasing evidence shows that growing native plants provides more benefits to native insects, on average, than growing nonnative ornamental species. Native insects have tight ecological relationships with native plants that have been shared for millions of years. Many different kinds of insects rely on these plants as a food source or nesting sites. These insects are in turn prey for birds and other wildlife, thus native plants indirectly attract many vertebrates. For example, almost all songbirds (~96%) feed insects to their young (19), and declines in suburban backyard birds have been linked to an increased number of nonnative plants (20). Native plants, being adapted to local climates and rainfall regimes, can also be easier to maintain. If native plants are unavailable, growing a diversity of nonnatives, especially species that produce nectar, can still benefit insects. For homes that lack yards, native plants can be added to balconies, roofs, or between the curb and sidewalk in cities. There are many books on the native flora of particular regions, and additional information on native plants can be obtained from local and mail-order plant nurseries, native plant societies, conservation organizations, and university extension programs (see *SI Appendix*). We argue that the beauty of one's yard should not be determined by how well a lawn is maintained or how uniformly its hedges are trimmed, but instead by the diversity of its native plants.

3. Reduce pesticide and herbicide use. Pesticides often harm nontarget, natural insect populations (reviewed in 5, 7), whereas reduction of their use fosters beneficial arthropods (e.g., 21). Pesticides have been found far from their application source (22) and, in some regions, are more prevalent in urban streams than in those near agricultural lands (23). Many pesticides are applied for cosmetic purposes, that is, aimed only at improving the appearance of nonagricultural green spaces such as lawns, gardens, or parks. Reduction or elimination of cosmetic pesticide use, already legislatively mandated in Nova Scotia and Ontario (24), could greatly benefit both terrestrial and aquatic insect communities.

Mosquito suppression is another frequent motivation for home pesticide use. Pesticide barrier treatments (PBTs), in which pest control companies regularly apply chemicals to vegetation surrounding a home, harm beneficial insects (25) and are thought to promote the development of pesticide resistance in mosquitoes (26). Simple alternative control measures can greatly reduce the need for these chemicals, although judicious use of insecticides is sometimes needed to combat mosquitoes that vector diseases. Nonchemical measures include wearing long sleeves when mosquitoes are active, keeping window screens in good repair, and most importantly, identifying and removing standing water in containers (e.g., buckets, pots, birdbaths, gutters, and old tires), which serve as larval habitat for some mosquito species. Two of the most important pathogen vectors and pest species globally, *Aedes aegypti* and *A. albopictus* mosquitoes, utilize these larval habitats in residential areas. Although not all mosquito species use containers as larval habitats, eliminating standing water in the yard is a free, easy, and ecologically sound method to reduce mosquito abundance.

4. Limit use of exterior lighting. Since the 1990s, nighttime light pollution has increased sharply, even doubling in some of the world's most biodiverse areas (27, 28). The majority of nocturnal insects are attracted to artificial lights, and these lights are powerful sensory traps that can indirectly kill insects via exhaustion or result in predation before sunrise (29). In Europe, nocturnal moths are declining more quickly than moths and butterflies that fly during the day, and this trend is likely attributable to light pollution (30). Artificial light has also been shown to reduce reproductive success in fireflies because these insects use light to attract mates (31). To reduce harm to insects, people should turn off unneeded lights, dim necessary light sources, use motion-activated lighting, shield bulbs, and switch to bulbs that produce amber- or red-colored light, which produce wavelengths that are less attractive to insects (32). UV-blacklight "bug zappers," with a purported function to attract pests such as biting flies, mainly kill harmless, nontarget insects (33). Insect populations will benefit from conservation efforts to protect dark night skies.

5. Lessen soap runoff from washing vehicles and building exteriors, and reduce use of driveway sealants and de-icing salts. Soaps used to wash cars, motorbikes, or the exteriors of buildings often produce significant quantities of pollutants including ammonia, heavy metals, nitrogen, petroleum hydrocarbons, phosphorus, and surfactants that can drain directly into local water systems (34). Natural waterways contain a diversity of aquatic insects, including some of the most threatened animals on Earth (5). As water levels in aquifers precipitously decline globally, we recommend reducing cosmetic and recreational water use and using reclaimed water when possible. Domestic soap usage can be made more environmentally friendly by using biodegradable soaps.

Coal-tar–based sealants, such as polycyclic aromatic hydrocarbons (PAHs), often applied to driveway asphalt, are released as runoff into the soil and the atmosphere, harming both terrestrial and aquatic ecosystems (35). Some states and municipalities have banned their use (36). Alternative soy-based sealants are less toxic. In cold climates, rock salt (halite) is often applied to pavement, including driveways and sidewalks, to prevent icing. However, rock salt is only effective at temperatures above 15°F, and the melted salt can reduce plant growth, cause gastrointestinal disorders in pets, and interfere with insect development, reproduction, and behavior, while damaging concrete (37). Snow blowers, electric snow/ice melt mats, and sand are less harmful, as are salt-free, ice melting chemical formulations such as SafePaw® (safepaw.com).

Increase awareness and appreciation of insects: **6. Counter negative perceptions of insects.** People rarely protect what they do not know and appreciate (38). In many countries, the public is largely unaware of the benefits and services that insects provide, and negative perceptions of insects are widespread (14). Such perceptions can reflect cultural beliefs not grounded in scientific evidence (38) and can be amplified by media sensationalism such as films depicting large, scary insects, or the use of dramatized and misleading headlines.

A concerted effort is needed to counter negative perceptions towards insects. One way to do so is for individuals to know the benefits that insects bring to humankind. These benefits can be easily remembered as the "5Ps": Insects are 1) *pollinators*, 2) *prey*, 3) *physical* decomposers; they 4) help *progress* in science and technology; and they 5) provide *pleasure*. Writing blogs, such as on the "bug of the week" (bugoftheweek.com), and taking photos of insects and writing about them on social media are ways to increase appreciation. Smartphone images can magnify insects and make them more meaningful (14), especially if the images are of high resolution and draw attention. If one's insect pictures are not high quality, spectacular insect macro photos can be found online (e.g., flickr.com, bugshot.net; images taken by others must be credited appropriately). Insect photos can be deposited in web-based biodiversity portals, such as iNaturalist (inaturalist.org), an app that allows participants to document and share their natural history observations in a common social network. The app is an effective outreach tool that can get people quickly interested in nature and counter their negative perception of insects. Although it helps to know the insect species' name when uploading images to iNaturalist, it is not required; unidentified species will be subsequently identified by experts. iNaturalist and other community science (also called citizen science) networks have the potential to generate a wealth of baseline information to understand global insect diversity patterns; iNaturalist has effectively informed many scientific studies on species monitoring, biodiversity patterns, and assessing conservation planning (e.g., 39). Community science efforts that contribute to the monitoring of insects include "Bumble Bee Watch" in North America (bumblebeewatch.org), the "Big Butterfly Count" in Europe (bigbutterflycount.org), and "National Moth Week" worldwide (nationalmothweek.org). These are just a few examples of ways professionals and amateurs can observe, learn, and contribute to insect conservation (see *SI Appendix* for additional examples).

Another means to encourage positive messages about insects is to support and participate in insect-focused public activities. Educational events such as insect fairs, butterfly houses, and live insect zoos exist in Asia, Europe, and North America, and they provide opportunities for participants to handle, learn about, and observe insects (40). Spectacular biological phenomena, such as glowworms in the caves of Australia and New Zealand, migrating monarch butterflies in Mexico, and synchronous fireflies in Malaysia and the United States, all attract thousands of annual visitors (41).

Insect appreciation can also be increased through developing mechanisms that promote insects in culture. An example of a country with prevalent appreciation for insects is Japan. There, insects appear frequently in popular media, animated films, and celebrity quiz shows and are often portrayed as interesting and beneficial (42). Many Japanese insects have approachable common names, and insects appear in anime films and cartoons, often with anthropomorphic traits. Insect enthusiasts in other countries should make efforts to advocate for common names with positive connotations, such as the damselfly "violet dancer" (*Argia fumipennis*) or the orthopteran "rainbow grasshopper" (*Dactylotum bicolor*). There should also be concerted efforts to standardize common names of species that appear often in the media (e.g., Asian giant hornet, *Vespa mandarinia*) and move away from common names with a negative undertone such as "murder hornet." Japan could serve as a model for elevating insect appreciation through celebrity nature advocacy, animation films, and the use of creative common names, as means of improving attitudes toward insects.

7. Become an educator, ambassador, and advocate for insect conservation. An individual's outreach to others, through formal or informal teaching, discussion, etc., is a powerful means for increasing awareness and appreciation of insects, especially when the audience is children (43). The first wild animal a child encounters is likely to be an insect in their immediate surroundings. Positive early experiences can be crucial for the development of an appreciation for nature, given the limited time that children now typically spend outdoors (44, 45). Between the ages of 6 to 12 is when an emotional connection to animals typically peaks (44), and this time is therefore important for natural history education and retention. Professional researchers can contribute to this age group by volunteering to provide interactive insect-themed walks or outdoor activities in schools or through churches, scouts, and other programs serving children. Researchers can also teach from afar through "Skype a Scientist" (skypeascientist.com). There are multiple funding sources for K–12 insect education initiatives, such as the Chrysalis Fund from the Entomological Society of America (entsoc.org/chrysalis-fund). Entomological societies across the world should create similar opportunities. Fostering an appreciation of insects, nature, and the outdoors to children is especially impactful, as they will become the stewards of the natural world.

It is also important to talk to adults about insect conservation, and an excellent place to do so is during outdoor group walks and hikes that allow for hands-on, positive interactions with insects. Engage participants by introducing insects through storytelling and personal experiences that can improve retention and interest, for example by including explanations of how they are beneficial. Facts related to the 5Ps (see above), such as that >90% of temperate bird species feed on insects (46), or that the majority of freshwater fish, including popular gamefish species, rely on insects (47), are examples of messages that will inform the public about the positive benefits that insects provide.

8. Get involved in local politics, support science, and vote. Insect-friendly environmental policies at any level of government will only be adopted if insects are recognized as important. Political advocacy, especially at the local level, can significantly advance insect conservation. For example, landscaping requirements of many homeowners' associations in the United States have led to overuse of pesticides that harm native insects, birds, and other animals. Members of such associations should advocate to make those rules more environmentally friendly and promote neighborhood interest in conservation (action items 1–5) through discussion with their board and the use of yard signage. Citizens can also interact with local parks departments, planning commissions, city councils, and other governing bodies to advocate for evidence-based policies and practices that help insects. Participating in the design and conservation planning of urban landscapes can have an immediate "bottom-up" effect on local politics and species conservation. For example, residents in the United States successfully advocated for the Miami blue butterfly to be listed under the U.S. Endangered Species Act (naba.org/miamiblue.html). Public advocacy focusing on issues that directly and indirectly impact insects and the environment more broadly can contribute to positive changes at the local and national levels. People should attend events that support increased reliance on science in policy-making, such as the "March for Science" (marchforscience.org), and advocate for larger-scale insect- and conservation-friendly changes, such as banning pesticides in towns, and large environmental initiatives, such as the Paris Climate Agreement (unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement) and the Convention on Biological Diversity (cbd.int/). Becoming locally active and voting for evidence-based science can have long-term global impacts to protect insects. Public opinion is a powerful tool for conservation and can compel decision makers to act (14).

Concluding Remarks

We propose eight simple action items by individuals that can create insect-friendly environments and raise public awareness. Preservation and restoration of habitats that support insect diversity, as well as wildlife more broadly, is a critical element in ensuring their conservation. Any or all of our proposed actions can be adopted to slow insect declines. We encourage people to start by picking one of the eight action items discussed above, before adding others. Simple measures, such as being able to recite the 5Ps will help to educate the public about the benefits that insects provide.

It is also important to be mindful of the impacts of our daily actions and decisions. Avoiding some behaviors or adopting others will contribute both directly and indirectly to insect conservation. Further, taking actions that address issues such as climate change can synergistically promote insect diversity. Climate change is increasingly recognized as a primary factor driving local and regional plant and animal extinctions (48), and therefore actions that contribute to reducing one's carbon footprint are critical. The combined impact of millions of people providing direct and indirect contributions is necessary to confront the global issues related to insect declines. See *SI Appendix* for full accreditation for photographs and additional reading materials.

Data Availability. There are no data underlying this work.

Acknowledgments

David Wagner is thanked for inviting the first author to give a presentation on this topic at a symposium at the 2019 Entomological Society of America meeting in St Louis, MO. We thank the editors of PNAS, three anonymous reviewers, and Charles Mitter, all who provided substantial constructive comments. Craig Bateman, Jaret Daniels, Emily Ellis, Jiri Hulcr, Oliver Keller, Ian Kitching, Luc Leblanc, Xuankun Li, Karl Magnacca, Rachel Mallinger, Amanda Markee, Geoff Martin, Matthias Nuss, David Plotkin, Michael Raupp, Adrian Smith, Caroline Storer, and Lisa Taylor provided useful suggestions. Thanks also to the many educators and photographers that continue to inform the public about the importance of insects. Funding sources: NSF DEB #1541500, #1557007, IOS #1920895 to A.Y.K., and NSF IOS #1920936 to J.R.B.

1 E. O. Wilson, The little things that run the world (the importance and conservation of invertebrates). *Conserv. Biol.* **1**, 344–346 (1987).

2 J. E. Losey, M. Vaughan, The economic value of ecological services provided by insects. *Bioscience* **56**, 311–323 (2006).

3 W. C. Sorensen, E. H. Smith, J. R. Smith, D. C. Weber, *Charles Valentine Riley: Founder of modern entomology* (University of Alabama Press, Tuscaloosa, 2019).

4 R. Carson, *Silent spring* (Houghton Mifflin, Boston, 1962).

5 F. Sánchez-Bayo, K. A. G. Wyckhuys, Worldwide decline of the entomofauna: A review of its drivers. *Biol. Conserv.* **232**, 8–27 (2019).

6 S. Seibold *et al.*, Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature* **574**, 671–674 (2019).

7 D. L. Wagner, Insect declines in the Anthropocene. *Annu. Rev. Entomol.* **65**, 457–480 (2020).

8 P. Cardoso *et al.*, Scientists' warning to humanity on insect extinctions. *Biol. Conserv.* **242**, 108426 (2020).

9 R. van Klink *et al.*, Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. *Science* **368**, 417–420 (2020).

10 M. S. Crossley *et al.*, No net insect abundance and diversity declines across US Long Term Ecological Research sites. *Nat. Ecol. Evol.* **4**, 1368–1376 (2020).

11 K. V. Rosenberg *et al.*, Decline of the North American avifauna. *Science* **366**, 120–124 (2019).
12 M. L. Forister, E. M. Pelton, S. H. Black, Declines in insect abundance and diversity: We know enough to act now. *Conserv. Sci. Pract.* **1**, e80 (2019).
13 J. A. Harvey *et al.*, International scientists formulate a roadmap for insect conservation and recovery. *Nat. Ecol. Evol.* **4**, 174–176 (2020).
14 J. P. Simaika, M. J. Samways, Insect conservation psychology. *J. Insect Conserv.* **22**, 635–642 (2018).
15 A. Sturm, S. Frischie, *Mid-Atlantic native meadows: Guidelines for planning, preparation, design, installation, and maintenance* (The Xerces Society for Invertebrate Conservation, Portland, OR, 2020).
16 C. Milesi *et al.*, Mapping and modeling the biogeochemical cycling of turf grasses in the United States. *Environ. Manage.* **36**, 426–438 (2005).
17 S. H. Black, *Insects and climate change: Variable responses will lead to climate winners and losers. Encyclopedia of the Anthropocene* (Oxford University Press, Oxford, 2018).
18. Puppenstuben Gesucht, Thousands of gardens are becoming oases for biological diversity. http://www.schmetterlingswiesen.de/PagesSw/ContentList.aspx?id=2089. Accessed 24 November 2020.
19 M. B. Dickinson, *Field guide to the birds of North America* (National Geographic Society, Washington, D.C., 1999).
20 D. L. Narango, D. W. Tallamy, P. P. Marra, Nonnative plants reduce population growth of an insectivorous bird. *Proc. Natl. Acad. Sci. U.S.A.* **115**, 11549–11554 (2018).
21 G. K. Frampton, J. L. C. M. Dorne, The effects on terrestrial invertebrates of reducing pesticide inputs in arable crop edges: A meta-analysis. *J. Appl. Ecol.* **44**, 362–373 (2007).
22 T. J. Wood, D. Goulson, The environmental risks of neonicotinoid pesticides: A review of the evidence post 2013. *Environ. Sci. Pollut. Res. Int.* **24**, 17285–17325 (2017).
23 U.S. Geological Survey, *Pesticides detected in urban streams during rainstorms and relations to retail sales of pesticides in King County, Washington* (USGS Fact Sheet 097-99). (USGS, Reston, VA, 1999).
24 Canadian Cancer Society, *Cosmetic pesticides: Information brief*. https://www.cancer.ca/~/media/cancer.ca/AB/get%20involved/take%20action/CosmeticPesticides-InformationBrief-AB.pdf (Canadian Cancer Society, Alberta, 2013).
25 T. C. Hoang, R. L. Pryor, G. M. Rand, R. A. Frakes, Use of butterflies as nontarget insect test species and the acute toxicity and hazard of mosquito control insecticides. *Environ. Toxicol. Chem.* **30**, 997–1005 (2011).
26 C. A. Stoops, W. A. Qualls, T. T. Nguyen, S. L. Richards, A review of studies evaluating insecticide barrier treatments for mosquito control from 1944 to 2018. *Environ. Health Insights* **13**, 1178630219859004 (2019).
27 E. L. Koen, C. Minnaar, C. L. Roever, J. G. Boyles, Emerging threat of the 21st century lightscape to global biodiversity. *Glob. Change Biol.* **24**, 2315–2324 (2018).
28 C. C. M. Kyba *et al.*, Artificially lit surface of Earth at night increasing in radiance and extent. *Sci. Adv.* **3**, e1701528 (2017).
29 K. D. Frank, "Effects of artificial night lighting on moths" in *Ecological consequences of artificial night lighting*, C. Rich, T. Longcore, Eds. (Island Press, Washington, D.C., 2006), pp. 305–344.
30 E. Coulthard, J. Norrey, C. Shortall, W. E. Harris, Ecological traits predict population changes in moths. *Biol. Conserv.* **233**, 213–219 (2019).
31 C. Elgert, J. Hopkins, A. Kaitala, U. Candolin, Reproduction under light pollution: maladaptive response to spatial variation in artificial light in a glow-worm. *Proc. Biol. Sci.* **287**, 20200806 (2020).
32 K. Spoelstra *et al.*, Response of bats to light with different spectra: light-shy and agile bat presence is affected by white and green, but not red light. *Proc. Biol. Sci.* **284**, 20170075 (2017).
33 T. B. Frick, D. W. Tallamy, Density and diversity of nontarget insects killed by suburban electric insect traps. *Entomol. News* **107**, 77–82 (1996).
34 M. E. Bakacs, S. E. Yergeau, C. C. Obropta, Assessment of car wash runoff treatment using bioretention mesocosms. *J. Environ. Eng.* **139**, 1132–1136 (2013).
35 P. E. T. Douben, *PAHs: An ecotoxicological perspective* (John Wiley, West Sussex, England, 2003).
36 Minnesota Pollution Control Agency, *Actions to restrict or discontinue the use of coal tar-based sealants in the United States*. https://www.hrwc.org/wp-content/uploads/2014/11/bans.pdf (MPCA, 2014).
37 W. D. Hintz, R. A. Relyea, A review of the species, community, and ecosystem impacts of road salt salinisation in fresh waters. *Freshw. Biol.* **64**, 1081–1097 (2019).
38 R. H. Lemelin, J. Dampier, R. Harper, R. Bowles, D. Balika, Perceptions of insects: A visual analysis. *Soc. Anim.* **25**, 553–572 (2017).
39 M. Theng *et al.*, A comprehensive assessment of diversity loss in a well-documented tropical insect fauna: Almost half of Singapore's butterfly species extirpated in 160 years. *Biol. Conserv.* **242**, 108401 (2020).
40 G. T. Hvenegaard, T. A. Delamere, R. H. Lemelin, K. Brager, A. Auger, "Insect festivals: celebrating and fostering human-insect encounters" in *The management of insects in recreation and tourism*, R. H. Lemelin, Ed. (Cambridge University Press, New York, 2013), pp. 198–216.
41 R. H. Lemelin, "Introduction" in *The management of insects in recreation and tourism*, R. H. Lemelin, Ed. (Cambridge University Press, New York, 2013), pp. 1–19.
42 A. Y. Kawahara, Thirty-foot telescopic nets, bug-collecting videogames, and beetle pets: Entomology in modern Japan. *Am. Entomol. (Lanham Md.)* **53**, 160–172 (2007).
43 S. R. Kellert, Attitudes toward animals: Age-related development among children. *J. Environ. Educ.* **16**, 29–39 (1985).
44 S. R. Kellert, "Experiencing nature: Affective, cognitive, and evaluative development in children" in *Children and nature, psychological, sociocultural, and evolutionary investigations*, P. H. Kahn, S. R. Kellert, Eds. (MIT Press, Cambridge, 2002), pp. 117–151.
45 R. Louv, *Last child in the woods: Saving our children from nature deficit disorder* (Algonquin Books, Chapel Hill, 2005).
46 M. Nyffeler, C. H. Şekercioğlu, C. J. Whelan, Insectivorous birds consume an estimated 400–500 million tons of prey annually. *Naturwissenschaften* **105**, 47 (2018).
47 G. W. Suter II, S. M. Cormier, Why care about aquatic insects: Uses, benefits, and services. *Integr. Environ. Assess. Manag.* **11**, 188–194 (2015).
48 C. A. Halsch *et al.*, Insects and recent climate change. *Proc. Natl. Acad. Sci. USA*, 10.1073/pnas.2002543117 (2021).