The Nature Conservancy
North Carolina

Principles of Low-Impact Solar Siting and Design

Cover: Solar construction © Margaret Fields/TNC
This page: Rooftop solar uses existing structures and requires no additional land development © Cameron Bruns

Solar energy facilities show great potential for providing sustainably sourced electricity and are increasingly playing a larger role in meeting our energy needs. They produce little to no carbon emissions and are an essential component of the effort to mitigate climate change. Currently, North Carolina ranks fourth in the United States in installed solar capacity (after California, Texas, and Florida).[1] Since 2011, more than 650 solar facilities have been built on over 35,000 acres across the state. The Nature Conservancy (TNC) supports replacing fossil fuel electric generation with solar and wind energy and increased implementation of well-sited and designed systems. Aligning this with TNC's core mission of protecting and restoring natural systems and biodiversity requires emphasis on the need to site these facilities in ways that avoid, minimize, and mitigate potential impacts to the environment.

Our preference is for solar panels to be sited on rooftops and in urban environments; a study from the National Renewable Energy Laboratory estimated that 35% of North Carolina's energy demand could be met with rooftop solar from all building types (11.4% from large buildings and 23.5% from small buildings).[2] Slanted roofs on small buildings (totaling 39,560 acres of suitable space) are more efficient for solar panels than the flat roofs of larger buildings (totaling 22,800 acres), but the study also predicts the potential energy provided by large building solar panels will increase over the next few years as innovative racking and module-packing techniques are developed for flat roofs.

Although TNC's preference is to take advantage of roof space and other developed areas for solar panels so that no additional land development is required, there are significant and competitive advantages to large, ground-mounted, utility-scale solar PV projects,[3] and therefore these projects must be designed and developed responsibly.

1 Solar Energy Industries Association (SEIA). Accessed December 2022.
2 Gagnon, P., R. Margolis, J. Melius, C. Phillips, and R. Elmore. 2016. Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment. National Renewable Energy Laboratory Technical Report 6A20-65298.
3 Massachusetts Institute of Technology. 2015. The Future of Solar Energy. Cambridge, MA.

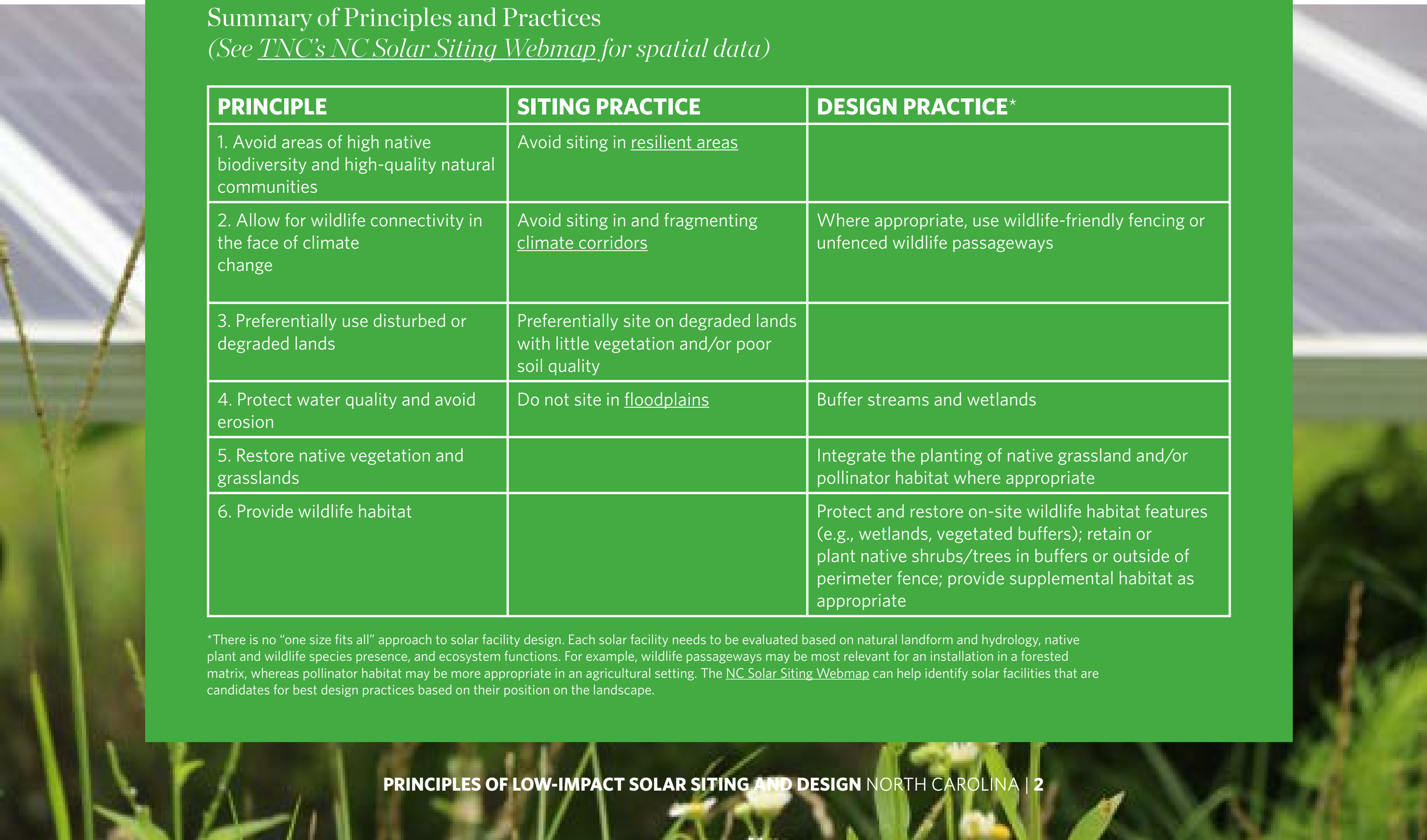
There are various energy sourcing and use scenarios that will allow us to reduce the trajectory of earth's warming through changes to the electric generation sector. These include combinations of reductions in energy use, carbon capture and sequestration technologies, and transition to renewable and other carbon-free electric generation. Solar facilities contribute towards the mitigation of climate change, but if sited improperly, can have negative consequences to biodiversity and natural communities.[4] North Carolina is projected to need an additional 11-35 GW of solar capacity to meet 2050 goals,[5] which on the high end would require ~250,000 of total land for solar development (at 7 acres/MW).[6] Based on TNC's NC siting analysis, it is possible to site this amount of solar in areas that have minimal impact to natural communities and biodiversity. In addition, advances in renewable energy technology are occurring rapidly, allowing for an increase in electricity produced per acre, thus reducing total acreage needed.

The primary purpose of these Principles is to inform and potentially guide solar energy developers, operators, and other stakeholders to site, construct, and operate solar facilities in ways that minimize impacts to natural ecosystems and biodiversity. We understand that siting of solar is a complicated process with many factors and criteria, and TNC is not attempting to address the comprehensive suite of criteria such as electric grid access, social issues, engineering, site topography, permitting requirements, and costs. In addition, utility scale solar projects require approval by state agencies via the NC State Environmental Review Clearinghouse, which should flag any environmental concerns. Thus, rather than duplicating existing processes, the TNC Principles and NC Solar Siting Webmap are intended as resources for solar developers, and the spatial data can be included as an additional, important consideration in developers' existing siting process. We wish to work with solar developers and operators to help implement these Principles to the extent feasible and can provide GIS data for use in the siting process.

4 Oakleaf, J. R., C.M. Kennedy, S. Baruch-Mordo, P.C. West, J.S. Gerber, L. Jarvis, & J. Kiesecker. 2015. A world at risk: Aggregating development trends to forecast global habitat conversion. PLoS ONE, 10(10).

5 Konschnik, K., M. Ross, J. Monast, J. Weiss, and G. Wilson. 2021. Power sector carbon reduction: An evaluation of policies for North Carolina. NI R 21-01. Durham, NC: Duke University.

6 Bolinger, M. and G. Bolinger. 2022. Land requirements for utility-scale PV: An empirical update on power and energy density. IEEE Journal of Photovoltaics 12:2, 589-594.



Summary of Principles and Practices

(See TNC's NC Solar Siting Webmap for spatial data)

PRINCIPLE	SITING PRACTICE	DESIGN PRACTICE*
1. Avoid areas of high native biodiversity and high-quality natural communities	Avoid siting in resilient areas	
2. Allow for wildlife connectivity in the face of climate change	Avoid siting in and fragmenting climate corridors	Where appropriate, use wildlife-friendly fencing or unfenced wildlife passageways
3. Preferentially use disturbed or degraded lands	Preferentially site on degraded lands with little vegetation and/or poor soil quality	
4. Protect water quality and avoid erosion	Do not site in floodplains	Buffer streams and wetlands
5. Restore native vegetation and grasslands		Integrate the planting of native grassland and/or pollinator habitat where appropriate
6. Provide wildlife habitat		Protect and restore on-site wildlife habitat features (e.g., wetlands, vegetated buffers); retain or plant native shrubs/trees in buffers or outside of perimeter fence; provide supplemental habitat as appropriate

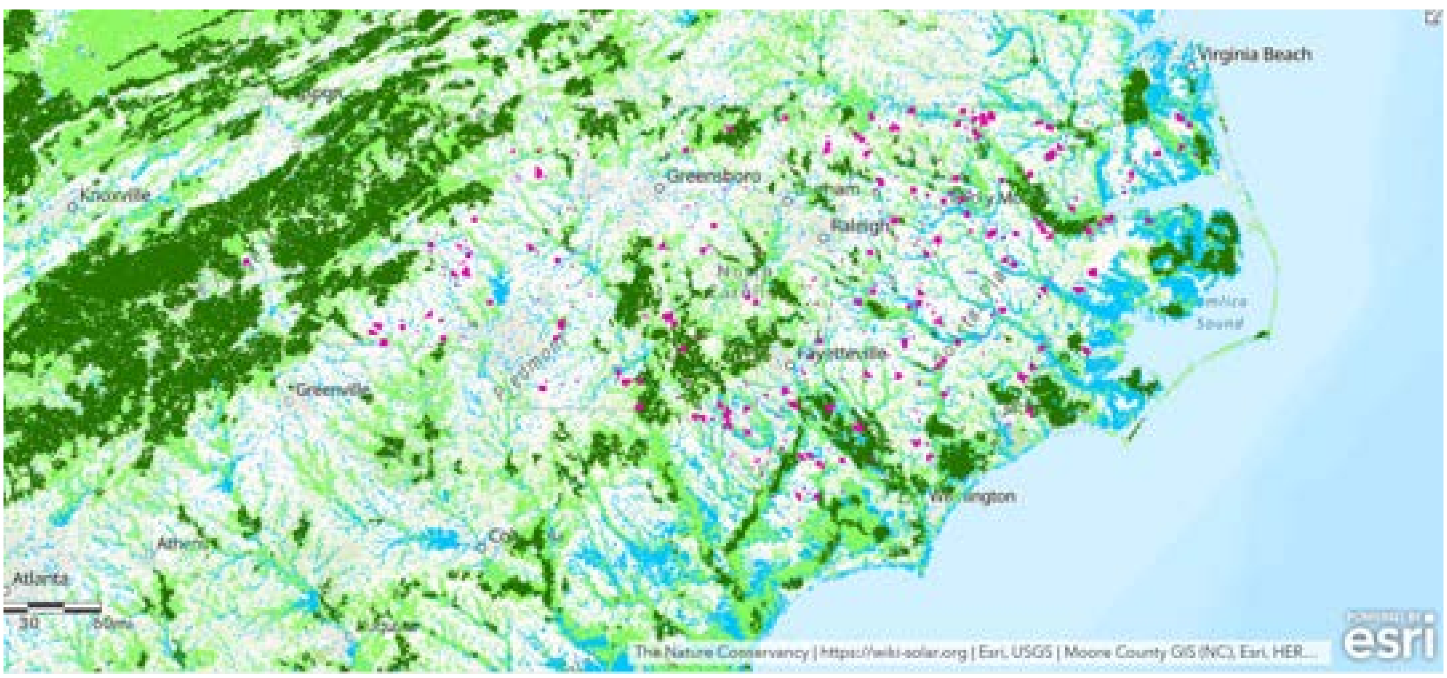
*There is no "one size fits all" approach to solar facility design. Each solar facility needs to be evaluated based on natural landform and hydrology, native plant and wildlife species presence, and ecosystem functions. For example, wildlife passageways may be most relevant for an installation in a forested matrix, whereas pollinator habitat may be more appropriate in an agricultural setting. The NC Solar Siting Webmap can help identify solar facilities that are candidates for best design practices based on their position on the landscape.

1 AVOID AREAS OF HIGH NATIVE BIODIVERSITY AND HIGH-QUALITY NATURAL COMMUNITIES

Avoid siting in the Resilient Connected Network (RCN) resilient areas: Siting solar facilities to avoid areas with high biodiversity is the simplest yet most important step in siting solar. TNC urges developers not to locate facilities in "resilient areas" of the RCN.[7] The NC Solar Siting Webmap identifies resilient areas that contain high levels of landscape diversity and local connectedness that increase resilience to climate change. These areas are likely to have the highest levels of species biodiversity now and in the future and should remain undeveloped. We do not recommend mitigating biodiversity loss by moving sensitive species from a solar site to natural habitat, due to the low success rates associated with these efforts.[8]

Note on permitting: While critical habitat for threatened & endangered species can be considered in siting a solar facility, it does not affect many acres in NC (see USFWS Critical Habitat map); consultation with the USFWS may be required when development might impact a threatened or endangered species. In addition, we recommend the North Carolina Natural Heritage Program as an excellent resource for identifying sensitive plant communities or wildlife species that are present at a site.

7 See Principle 3. If field visits reveal disturbed or degraded habitat then site may be acceptable for solar site development; however, note that even disturbed sites in the RCN could potentially be restored (e.g., a pine plantation) which is preferable.
8 Hernandez, et al. 2014. Environmental impacts of utility-scale solar energy. Renewable and Sustainable Energy Reviews, 29, 766-779.



Screenshot of the online, interactive NC Solar Siting Webmap. Of the 666 established solar facilities in NC, 8 intersect with RCN resilient areas, amounting to 1% of the area solar covers. 144 of them intersect climate corridors, which is 8% of the area covered by solar.

TNC's Resilient and Connected Network (RCN) project is the first study to comprehensively map resilient lands and significant climate corridors across the United States. Released in 2016, the study took eight years to complete, involved 60 scientists, and developed innovative new techniques for mapping climate-driven movements of species. The analysis incorporates areas that are TNC NC chapter conservation priorities and NC Natural Heritage Areas. The NC Solar Siting Webmap contains two layers of the RCN: resilient areas (with confirmed biodiversity) and climate corridors.

2 ALLOW FOR WILDLIFE CONNECTIVITY, NOW AND IN THE FACE OF CLIMATE CHANGE

Avoid siting in and fragmenting RCN climate corridors: In the United States, most research on the environmental impacts of solar facilities has focused on large western installations on public lands. In the Southeast, early solar development favored smaller installations (<100 acres), and later years resulted in the development of larger facilities (>100 acres), all on private lands. The net result is a fragmented landscape, from the standpoint of wildlife movement, which is rarely considered during siting. Little is known about the potential impact of solar facilities on wildlife movement and it varies greatly from site to site and type of wildlife. For example, flying wildlife (e.g., birds and bats) movements are likely minimally impacted by solar development, whereas ground-based wildlife may experience more impact to daily or seasonal movement. Connectivity is also vital to juvenile development, particularly for species that inhabit various ecosystems at different stages of life (e.g., frogs and salamanders). Further, as plant species and wildlife shift their ranges because of climate change, barriers to such shifts could occur and any anthropogenic development, including solar sites, could impede these shifts.[9] We recommend avoiding the construction of solar facilities in RCN "climate corridors" (see NC Solar Siting Webmap).[10] These climate corridors encompass areas that species are likely to use for periodic or seasonal movements and shifts in ranges over time in response to climate change, generally in upward (in elevation) and northward directions across the landscape.

Where appropriate, use wildlife-friendly fencing or unfenced wildlife passageways: Wildlife connectivity and movement may be of greatest concern where there is adjacent wildlife habitat disrupted by the presence of the solar facility (e.g., intact forestland on two or more sides or between two wetlands). Solar facilities generally use fencing that may act as a barrier to larger, ground-based wildlife movement. The NC Solar Siting Webmap can be used to identify solar facilities that are sited within or adjacent to the resilient areas or climate corridors, and thus good candidates for practices that improve wildlife connectivity.

9 Opdam, P. and D. Wascher. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation, 117, 285-297.

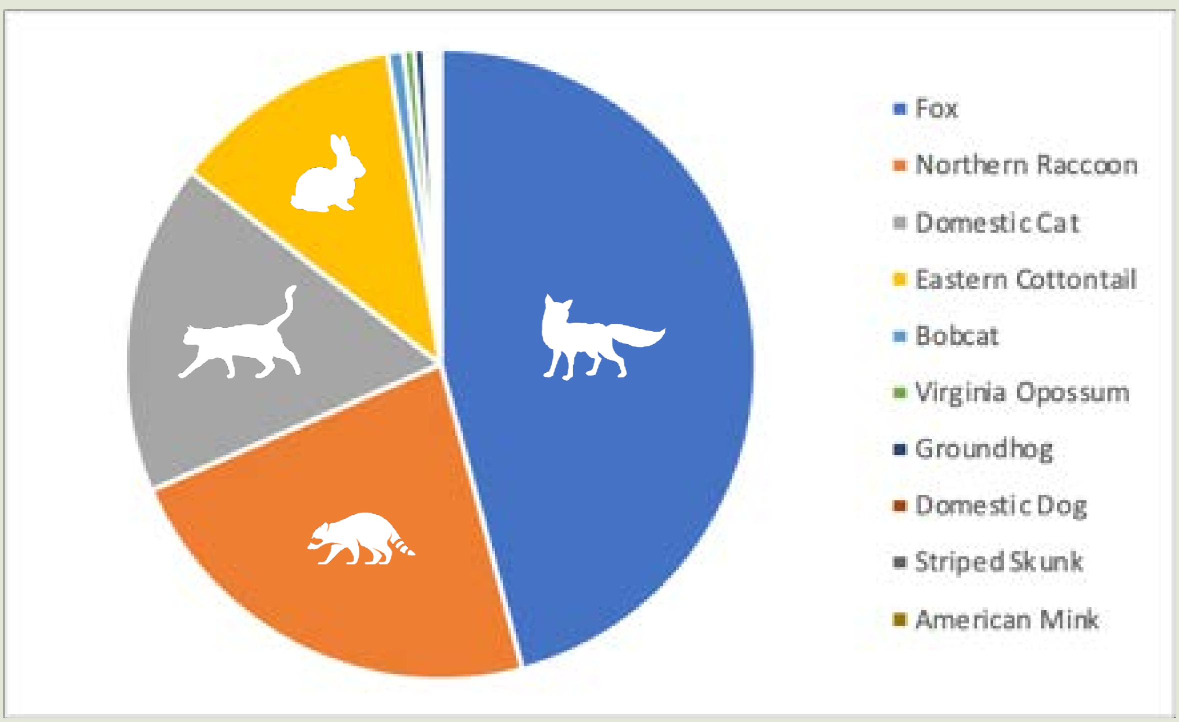
10 See Principle #3. If field visits reveal disturbed or degraded habitat; and/or little to no connectivity, then site may be acceptable for solar site development.

Comparison of a standard chain-link fence (left) with a wildlife-permeable fence (right). © Liz Kalies/TNC

While best management practices for wildlife-friendly fencing are still under research, we recommend using fencing that allows small-to-medium sized animals (e.g., turtles, raccoons, foxes) to pass through (e.g., 6 ft. tall 12.5 gauge Fixed Knot Deer Busters 17/75/6 deer mesh galvanized fence with three strands of 12.5 gauge 4 point barbed wire, Fortress Fencing). We recommend installing the fencing upside-down, such that the bottom section of fence has a vertical wire spaced at least 7 inches apart. TNC has been monitoring this fencing at solar facilities and has determined it is effective in facilitating wildlife movement, particularly for mid-sized mammals (see piechart). Another approach is to provide wildlife passages (8” diameter HDPE pipe) roughly 500’ apart around the site, or raise the fence 6”, but these techniques are untested. When implementing wildlife-permeable fence, equally important is providing on-site vegetation that provides cover for animals when moving through the facility (see Principles #5 and #6).

Monitoring Solar Fencing for Wildlife

Our research at solar facilities using wildlife cameras showed movement of wildlife through wildlife-permeable fencing that otherwise would not be able to enter the facility. The most common wildlife species were foxes, raccoons, and cottontails (species listed in legend from most to least common).



Expert Review of Focal Species

Creating wildlife passageway recommendations began with the development of a list of focal species. These are species that are indicative of essential habitat conditions and ensure protection of a wide range of other species. An initial focal species list was acquired from the "Regional Species of Greatest Conservation Need," report developed by the National Wildlife Federation and the Southeastern Association of Fish and Wildlife Agencies. We then interviewed wildlife experts from conservation NGOs, academia, and state agencies, to choose appropriate focal species for landscapes with solar development, and to determine corresponding habitat needs for passageway design. Thus, our final wildlife passageway recommendations consider a full suite of NC species' needs.

The best method for allowing movement of both large and small animals, and particularly appropriate in large solar installations (i.e., >100 acres), is to retain unfenced wildlife passageways through the solar facility. Key points for implementing wildlife passageways:

Developers omitted this streambed from the solar facility footprint; this can now act as a wildlife passageway through the site. © Google Earth

- Identify focal species and based management on their needs. Passageways in uplands should be a minimum 100 feet wide for ground-dwelling birds (e.g., bobwhite quail) and reptiles (e.g., eastern box turtles), and a maximum of 3,000 feet long. Larger mammals (e.g., bobcats and white-tailed deer) need 150-300-foot-wide passageways but can travel further distances and thus there is no maximum length. Buffer streams by at least 100 feet on each side and buffer wetlands by at least 50 feet. Create passageways between wetlands with a minimum width of 100 feet.
- Ensure habitat quality within passageways. Retain native vegetation in buffers and passageways and restore vegetation as needed.
- Implement shorter and wider passageways instead of longer and thinner ones.
- Consider landscape position of the passageway, and ensure it runs through the entire facility and connects potential wildlife habitat on either side (i.e., do not create passageways that lead animals to human development).

3 PREFERENTIALLY USE DISTURBED OR DEGRADED LANDS

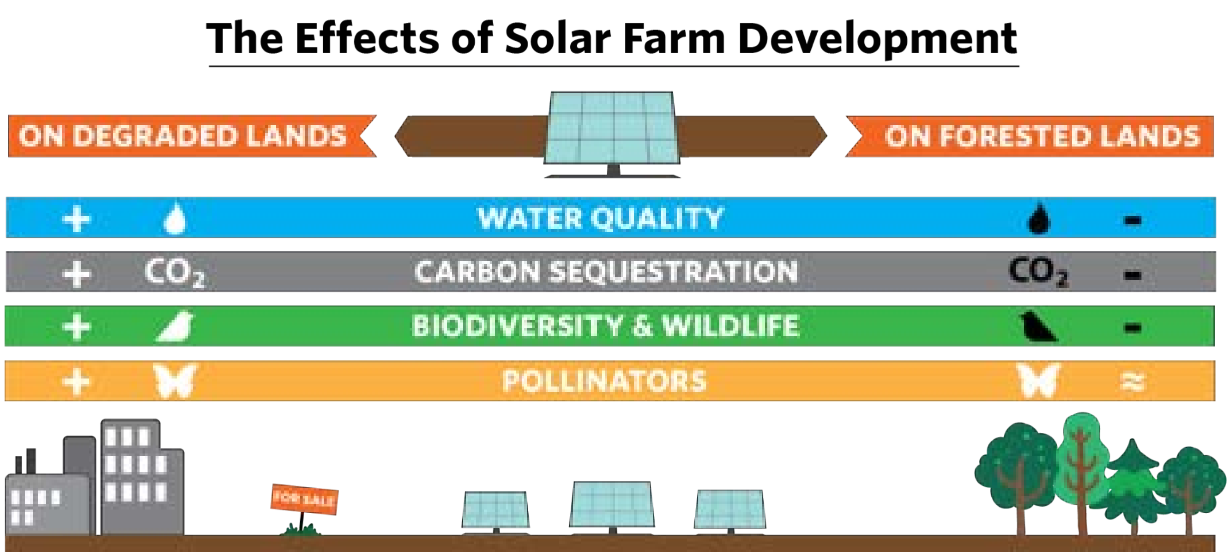
Preferentially site on degraded lands with little vegetation and/or poor soil quality: Choosing the most degraded sites for solar facility development (e.g., Brownfields, sites with prior development, little or no vegetation, poor soil quality, etc.) reduces impacts to wildlife habitat. Clearing native forestland or grasslands should be avoided. It should also be noted that some sites that were previously developed and then abandoned may contain new vegetation and young forest (i.e., early successional vegetation) that can be beneficial to wildlife species. Thus, defining "degraded" requires a site-level evaluation of intact soil, vegetation, and wildlife habitat.

Using degraded sites should reduce the amount of biologically sequestered carbon lost due to solar project construction. Clearing forestland disturbs sequestered carbon, thus reducing the benefits of clean energy production in the short term. While ultimately an acre of PV solar will result in less carbon emissions than the equivalent amount of forestland can sequester,[11] the optimal scenario is when forestland is left intact to continue its role in carbon sequestration and solar is sited elsewhere. Similarly, if an intact grassland is cleared and graded for solar development, it would result in loss of carbon from the soil organic layer, decreased microbial biomass and activity, and additional loss of soil through erosion and runoff.

Developers should preferentially site solar facilities on cleared land with poor soils that are least suitable for agriculture. Farming degraded soils often requires additional use of fertilizer, which can result in nutrient runoff into water systems and disrupt habitats via algal blooms and pollution. Consult with the NC Department of Agriculture & Consumer Services for more guidance on agricultural soil quality or consult the NC Realistic Yield Expectation (RYE) Mapping tool that was developed by NC state agencies.

Principles #1 and #2 and the accompanying spatial data are provided at a coarse scale Principle #3 should be applied at the parcel level to further determine whether a site would be acceptable for development, based on other ecosystem services gained or lost. The following graphic illustrates how the "ecosystem services" nature provides to people are compromised least when solar facilities are sited on degraded lands:

11 Eisenson, M. 2022. Solar panels reduce CO2 emissions more per acre than trees. Columbia Climate School.



© Avery Bond

4 PROTECT WATER QUALITY AND AVOID EROSION

Do not site in floodplains: Not locating solar facilities in these areas is both protective of floodplain ecological function and also guards solar facilities from flooding, especially during extreme weather events, ensuring the resilience and reliability of our energy supply into the future. Avoiding steeply sloped sites that require extensive grading reduces erosion, sedimentation, and runoff, and thus reduces impacts to water quality.

Floodplains are displayed in the NC Solar Siting Webmap and are based on TNC's Active River Area (ARA) data which spatially defines the natural ranges of variability in freshwater and riparian ecosystems in terms of system hydrology, sediment transport, processing and transport of organic materials, and key biotic interactions. The ARA is generally calibrated to approximate the Federal Emergency Management Agency (FEMA) 100-year floodplain but may extend beyond this area as it does not consider flood control infrastructure.

Note on permitting: If the proposed solar facility will cause any disturbance to a stream or wetland, then the developer must apply for a 401 WQC or Isolated and Other Non-404 Jurisdictional Wetland and Waters USACE permit.

Buffer streams and wetlands: Construction of a solar facility usually requires a NC Department of Environmental Quality (DEQ) Stormwater Pollution Prevention Plan (SWPPP) to control and manage erosion and sediment runoff. This SWPPP plan supports a Construction Stormwater permit. The NC Wildlife Resources Commission further recommends a 100-foot buffer on each side of perennial streams and a 50-foot buffer on intermittent streams and jurisdictional wetlands. A developer may also choose to incorporate water features or wetlands into solar facility design (typically in peripheral areas and not under solar arrays) as supplemental habitat (see Principle #6).

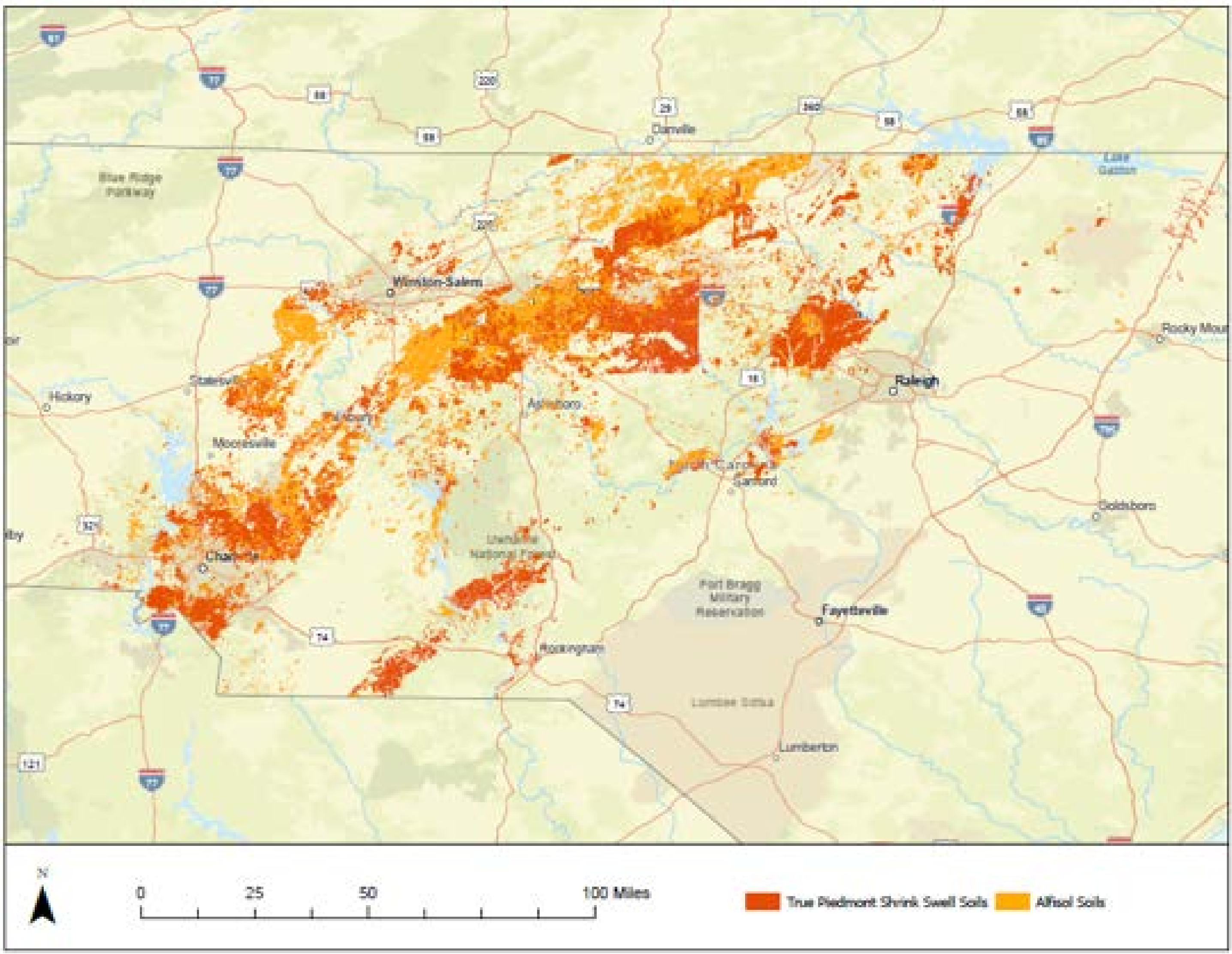
When planning for erosion control, it is advised to avoid the use of nylon or synthetic barriers, as they can impede wildlife movement. These barriers make it nearly impossible for animals to move between areas of vegetation, and those that attempt to cross these barriers (i.e., animals capable of climbing or jumping such as raccoons, foxes, and deer) can easily get ensnared. Animals that cannot climb or jump (e.g., turtles) are especially restricted by these synthetic fences. Instead, we recommend a jute barrier.

Example of a fox struggling to get past a synthetic fence to use the wildlife fencing at a NC facility. © Liz Kalies/TNC

Note on permitting:
NCDEQ's erosion and sediment control plan requires measures designed to provide protection from a rainfall event equivalent in magnitude to the 10-year peak runoff, or in areas where High Quality Waters are a concern, the requirement is for a 25-year storm. Runoff velocities must be controlled so that the peak runoff from the 10-year storm will not damage the receiving stream channel at the discharge point. A sufficient buffer zone along any natural watercourse is required to contain all visible sediment to the first 25% of the buffer strip nearest the disturbed area. An undisturbed 25-foot buffer must be maintained along trout waters. Graded slopes must be vegetated or otherwise stabilized within 21 calendar days of completion of the construction. Off-site sedimentation must be prevented, and a ground cover sufficient to prevent erosion must be provided.

5 RESTORE NATIVE VEGETATION AND GRASSLANDS

Integrate the planting of native and/or pollinator vegetation where appropriate: While one goal may be to reduce impacts of solar facilities on wildlife, another vision is that solar facilities have the potential to produce net wildlife benefits, playing a key role in restoring native grasslands plants and wildlife to the southeastern United States. Native grassland habitats (i.e., Piedmont prairie) were once plentiful in the Southeast, but with development and other changes in land use and management, there is now less than 1% of historical native grassland habitat remaining in the Southeast.[12] Solar facilities represent an opportunity to restore this vegetation to the landscape. Certain soil types (see map below) are conducive to Piedmont prairie development and thus restoration may be easier to attempt at these sites; clearing a forest and creating a prairie is not considered “restoration.”



Piedmont Prairie soils of North Carolina: These soil types are areas that were historically Piedmont prairie and are conducive for establishing native plants. Alfisols have fewer streams, contain more bases (phosphorous and calcium), and produce high quality grasses that historically attracted grazers like bison and deer and thus prevented vegetation succession. Soils with high shrink-swell capacities indicate large differences in water content between seasons, making tree growth difficult.

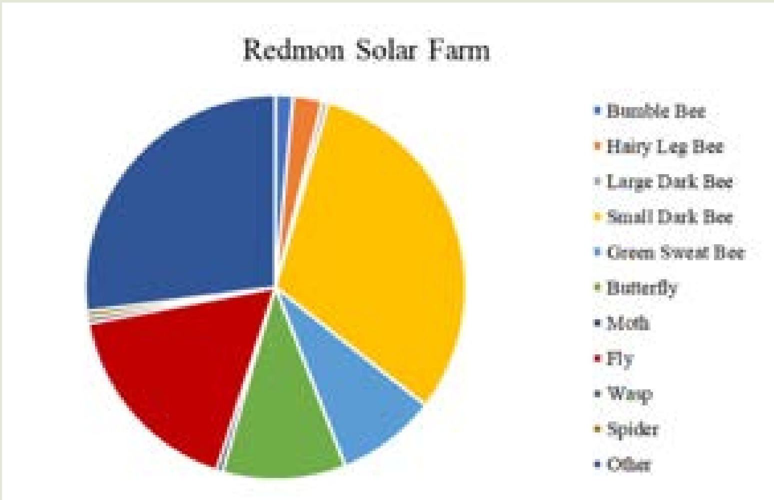
12 Noss, R.F. 2012. Forgotten Grasslands of the South. Island Press, 2nd edition. 336 pp.

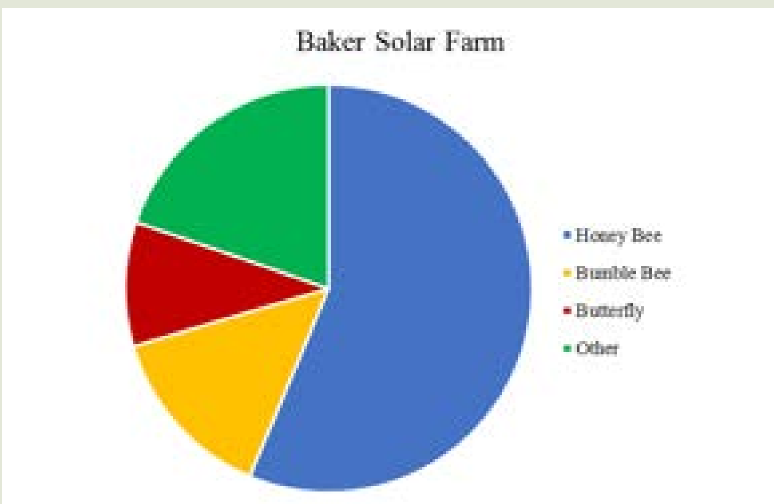
The NC Pollinator Conservation Alliance has developed detailed guidance on how to plant solar facilities with native vegetation, with a focus on attracting pollinators (bees, butterflies, birds), specifically endangered and threatened species found in the state such as the rusty-patched bumble bee (Bombus affinis), yellow-banded bumble bee (Bombus terricola), frosted elfin butterfly (Callophrys irus), and monarch butterfly (Danaus plexippus) in addition to recommendations for management (e.g., avoid summer mowing). We highly recommend using this guidance from the NCPCA when designing solar facilities, as it contains several acceptable approaches as well as detailed lists of possible plant species to include in seed mixes.

Compared to turf grass, the use of native vegetation decreases maintenance costs by way of less mowing and herbicide/pesticide use, minimizes erosion issues, more effectively attenuates the flow of stormwater, provides connectivity and cover to larger wildlife thereby promoting more diverse ecosystems, and increases soil health, carbon sequestration, and pollinator services for local agriculture. We also recognize that restoration with native plants may not always be feasible, in which case non-native, non-invasive pollinator-friendly plants (e.g., clover) can be an acceptable alternative. However, native plants have greater pollinator visitation rates as higher floral abundance over time compared to clover-planted facilities (see below). Pollination is a key service that this practice provides, and thus its implementation may be most relevant for solar facilities located within an agricultural matrix, although natural ecosystems will also benefit from this service.

Quantity and arrangement of pollinator habitat is also important to consider. Insects can use smaller patch sizes than most vertebrate wildlife species. The size of the pollinating insect is positively correlated to the size of the habitat that it uses. Wild or native bees, which are often smaller than honeybees, are more likely to inhabit smaller areas and cannot travel as far as other pollinating insects; foraging patches for native bees cannot be more than 0.6-1.2 miles from the nesting site.[13] It may therefore be necessary to establish vegetation around solar facilities that can provide adequate nesting habitat.

13 Cane, J. (2001). Habitat fragmentation and native bees: A premature verdict? Conservation Ecology, 5(1).





Four years of monitoring vegetation and pollinators at solar facilities: We have been working with several solar developers that have planted either native seed mixes or clover in and around their arrays. Sites that planted wildflower and native seed mixes generally saw higher pollinator diversity and abundance, while also sustaining or even increasing diversity over the entire monitoring period. Sites that were planted with clover had lower counts of pollinators and overall diversity, and these sites generally transitioned from clover to grass and weeds. See monitoring report for details.

Photos © Liz Kalies/TNC

6 PROVIDE WILDLIFE HABITAT

Protect and restore on-site wildlife habitat features (e.g., wetlands, vegetated buffers): If there are special habitat features in or near the proposed solar facility that cannot be avoided via the siting process, the developer can consider incorporating them into site design.

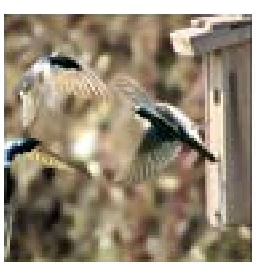
Retain or plant native shrubs/trees in buffers or outside of perimeter fence: Native shrubs and trees can be planted away from the panels to provide food and cover for wildlife and pollinators. Hedgerows can help with visual screening of the site and serve as complex structure for wildlife. In addition, this vegetation serves as a carbon sink which helps further mitigation climate change.

The developer retained a riparian forest and wetland area at this solar facility and allowed a sediment control structure to develop into a pond. © Liz Kalies.

Provide supplemental wildlife habitat as appropriate: Create or restore vegetation on the site (see Principle #5) and focus on native plant species and communities that provide wildlife cover, food (e.g., fruit, mast, pollen), and breeding needs. As practical, the solar site should be designed with open areas spread throughout and planted and maintained with taller plant species. This practice would benefit pollinators, create diversity across the site, and provide needed shelter islands to aid in the movement of small-to-medium sized animals.

Supplemental habitat features can also be added to a site to encourage native wildlife to use and live near or on the site. Determining the best features to include depends on the species of native wildlife in the region that might benefit from additional nesting or foraging structures (e.g., raptor perches to replace cleared trees). While these practices have not been tested on solar facilities, they are successful in a variety of other suburban and urban settings; they include: downed wood, bird perches, bat boxes, bird nesting boxes, and sand piles (for native bees).

DOWNED WOOD



BIRD NESTING BOXES

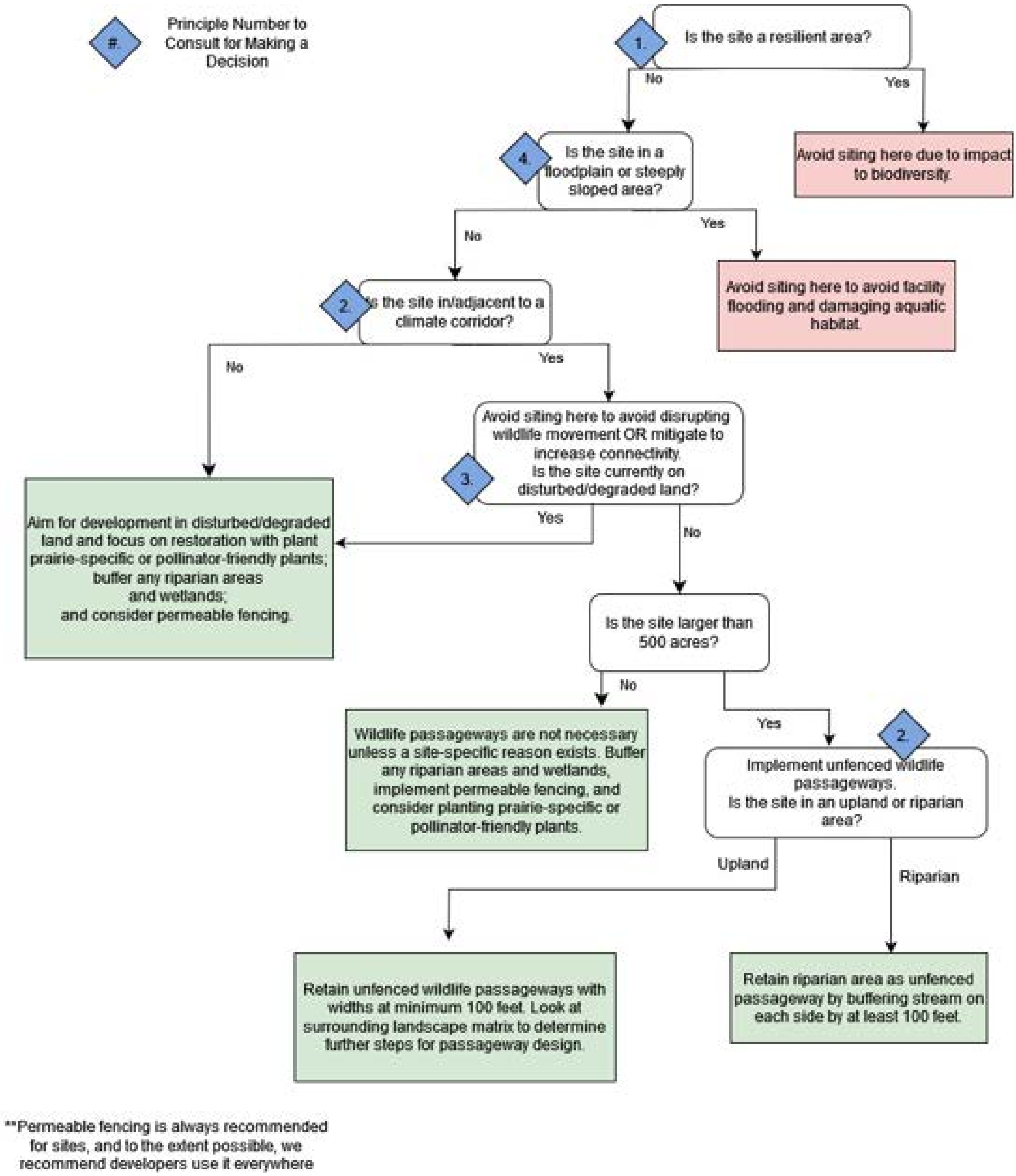
BIRD PERCHES

BAT BOXES

BEE NESTING BOXES

APPENDIX

There is no one size fits all approach to siting solar, and while all six principles are important when planning a new site, they can contribute to the design in different ways. Using the following decision tree can make this process easier:



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