From: Amanda Bird
To: Great North Road Solar
Subject: EN010162 - Interest party [redacted]
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Attachments: image002.png
Conservat Sci and Prac - 2020 - Chock - Evaluating potential effects of solar power facilities on wildlife from an animal.pdf

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Good Afternoon

Please see attached independent research regarding the effects of solar parks on wildlife. Even though this report took place outside of the UK it is still relevant in many ways with regards to wildlife movement and the effects on many different species. One of my concerns is the restriction of the free movement of deer etc which will inevitably increase road traffic accidents, the over grazing and over populated areas for deer. This will result at some point to reduce the number of deer by a 'humane' cull. It has already been seen with other solar parks and construction sites of deer being trapped in these metal fenced prisons.

Whatever mitigation measures are put in place it will be minimum of 15 years before any difference is seen. This will still not mitigate the park in the Autumn and Winter months. Living in this area we see the effects far more than those who pass through or see the area on a map. Everything is visible, fields, gardens etc. This will lead to the cumulative impact on the area to become far more prevalent. Unless you are completely on a flat surface at the same gradient as the park it will be visible. For example Egmanton Solar Park on Weston road. If you drive past unless going past gate ways it is noticeable but slightly hidden by a hawthorn hedge. Though cross the road where the land slopes upwards and the site sticks out like a sore thumb. From literally every area you stand it is visible and this is 10 years on from its construction and it will never be hidden. As of yet I have not seen one solar park that has been hidden as per the applicants assessments and promises.

The flooding around this area over since I moved here in 2012 continuously gets worse. The digging of a ponds to alleviate the situation only works until the pond is full and if that happens at 2am in the morning it will flow like a river over the top. I know this as we have dug a pond on our land 15m by 10m by 1.5m, this caused a greater issue than just allowing the water to flow down the garden. This is the only time our home was flooded. We have now had to add an overflow pipe to the pond to direct it into the dyke which then causes flooding lower down the road due to blocked drain pipes within the pipe. Which will be another issue when passing places are installed. They may state that they can solve an issue but what happens if it makes it worse, what happens to those affected, to the farmers fields whose crops may be lost to the impact of this huge error, to those who will suffer monetary losses due to insurance increases, loss of revenue etc. Who is going to monitor these drainage issues, who do we contact if and what is the plan if these issues make things worse.

Compulsory purchase for land belonging to others will cause stress, financial issues and also reduces, greatly, the risk of the land never going back to farmland or grassland. This then has to be weighed up against the argument that the land will return to its original state after 40 / 50 years. Therefore if a person does not wish to allow Elements green to use their land they should aspect this and only use the land that is freely offered to them to use. To take farmland from a farmer will leave them in financial troubles. Their fixed costs will be the same and to have land taken from them will effect their income.

Please see below. Again even though this mentions Australia much of it is relevant to the grazing of sheep.

Shards Of Truth: The Compatibility Of Farming And Renewables Projects

Kevin You

- **December 16th, 2023**

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Original Source

The Spectator Australia

In this article, Kevin You contextualises and disseminates the findings of the IPA's research into land use implications of renewable energy targets on prime agricultural land*, conducted as part of the IPA's Net Zero research program.*

All media posted onto the IPA website are directly related to the promotion and dissemination of IPA research.

Up to one-third of Australia's prime agricultural farmland could be destroyed by the industrial-scale solar panels and wind turbines

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Perhaps the biggest mistruth about renewable energy infrastructure is that it can coexist with productive farming practices, such as grazing and cropping.

With recent research by the Institute of Public Affairs estimating that up to one-third of Australia's prime agricultural farmland could be destroyed by the industrial-scale solar panels and wind turbines needed to meet irresponsible Net Zero mandates, establishing the facts around the ability to farm on land carpeted with renewables projects has never been more important.

It has been recently argued that *'the practice of "solar grazing" is well established'*. Based on two solar factories where an elevated layout has allowed for (some) grazing by sheep, it was asserted that 'solar grazing' meant agriculture and solar farms could coexist because sheep can graze around and under the solar panels.

This practice has also been discussed as a method of weed control, whereby livestock is used to weed out undesirable undergrowth beneath solar panels. The impact of weeds and vermin associated with solar factories on neighbouring farms has been a frequent complaint, and renewable industry proponents appear to be responding with an aggressive public relations campaign.

However, just as wind turbines damage native wildlife and the landscape, industrial-scale solar projects pose a real threat to animal welfare.

The BRE (European) National Solar Centre's Agricultural Good Practice Guidance for Solar Farms states:

Larger farm animals such as horses and cattle are considered unsuitable [for solar grazing] since they have the weight and strength to dislodge standard mounting systems, while pigs or goats may cause damage to cabling.

Aside from the harm caused by their contact with exposed electrical wires, animals that graze on solar farms also risk exposure to transformer leakages, which can lead to electrical and fire hazards. There are also the dangers associated with toxic chemicals leaching out from solar panels.

Moreover, in severe weather conditions, any grazing livestock will be vulnerable to shards of broken glass and sharp flying debris. As the UK office of the insurance giant Allianz noted:

In 2021, Storm Arwen wreaked havoc at a solar farm near Wolviston [in the UK], smashing hundreds of glass solar panels and damaging rows and rows of photovoltaics. In extreme weather, solar panels can operate as lifting surfaces making the panels vulnerable to being blown away … Panels are in danger of being smashed by falling debris that's carried by the wind. If solar farms are struck by lightning it can result in damage to modules, cables and electrical equipment.

This is not a scenario in which you would want sheep grazing under solar panels. Besides, there is the issue of sheep being able to chew through the cables that go from the solar panels to batteries, creating a serious hazard to animal welfare.

Even in ideal conditions, solar farms are harmful to animal welfare. Every year hundreds of thousands of birds are killed by solar farms across the globe. Many are water birds that fly into solar panels, deceived by the panels' resemblance to the surface of water. This phenomenon is called the ‘Lake Effect’.

The brightness and intensity of the light coming from solar fields, both during the day and at night (because of night-time security lighting), interferes with the natural habitat of local wildlife.

The mitigation strategies needed to address the harmful effects of solar panels on wildlife and livestock only add to the already mounting cost of renewable energy and – in this case – have introduced additional risks to animal welfare.

Photovoltaic cells contain toxic materials like lead, cadmium, selenium and tellurium which can leach into the natural environment, particularly if damaged in such a way as occurs in a hailstorm or fire. They also need to be properly disposed of at the end of their lifecycles, yet up to 90 per cent of photovoltaic solar panels go straight into landfill at the end of their lives.

Unlike the disposal of nuclear waste, there is no well-established, time-tested, and scientifically informed method of disposing of solar waste in a safe and responsible manner.

Across Australia, local communities and fire brigades are deeply concerned about the limited ability to manage the fire risks associated with solar farms, citing international experience of co-located lithium-ion batteries catching fire and producing large amounts of toxic smoke.

Many of Australia’s largest solar projects are located on viable agricultural land. Shamefully, the value of pre-existing agricultural production of the land on which they sit is condescendingly brushed aside in their environmental impact statements. The list of solar farms and projects taking up agricultural land goes on and is set to grow further.

Across Australia, regional and rural communities are being forced to shoulder the burden of renewables projects demanded by the political class and the inner-city elites.

At a time when the federal government is seeking to ban live animal exports on the spurious grounds of animal welfare, there has been no discussion from policymakers how animals forced to coexist with renewable infrastructure will fare. Put simply this is yet another case of ideology trumping commonsense in the futile race to Net Zero.

Problems with sheep under UK solar panels include poor grass quality/quantity due to shade (requiring lower stocking rates, hindering lamb fattening), potential hazards like chewing cables (needing protection), lack of water access, heat stress, weed/moss issues, logistical challenges (access, dog work), and soil degradation, making it a complex balance between energy and farming. While seen as a dual-use win, operators must mitigate risks to ensure genuine sustainability for sheep welfare.

Nutritional & Forage Issues

- **Reduced Grass Quality:** Shade from panels lowers sunlight, decreasing grass sugar content and nutritional value, forcing farmers to reduce stock or move lambs.
- **Weeds/Moss:** Poor grass leads to more weeds or moss, which sheep won't eat, creating a food deficit and necessitating spraying/topping.
- **Soil Health:** Heat and lack of organic matter can desertify soil, making future grass regrowth difficult even after decommissioning.

Safety & Infrastructure Risks

- **Electrical Hazards:** Sheep can chew through exposed cables, creating electrocution risks, necessitating cable protection.
- **Heat & Debris:** Panels create heat, and in storms, broken glass or flying debris pose dangers.
- **Cabling & Access:** Low panel heights for visual amenity restrict tractor access for maintenance; cables must be protected from chewing and damage.

Management & Welfare Challenges

- **Water:** Many sites lack adequate water access, a major concern for graziers.
- **Dog Work:** The panel layout can hinder sheepdogs, impacting flock management.
- **Reduced Stocking:** Lower grass quality means stocking rates must drop significantly, impacting farm economics.

Potential Solutions & Considerations

- **Protected Infrastructure:** Cables need robust sheathing and protection.
- **Site Design:** Better spacing and panel height design can improve conditions.
- **Contractual Clarity:** Clear contracts placing cable responsibility on the solar operator are crucial.
- **Specialized Stock:** Dry sheep or singles are better suited than ewes with lambs needing high nutrition.

In essence, while solar grazing offers land use synergy, poor planning and design can create significant welfare, nutritional, and safety problems, requiring careful management to avoid being mere "greenwashing".

Kind Regards
Amanda Bird Tech IOSH
Finance Director

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PERSPECTIVES AND NOTES

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Evaluating potential effects of solar power facilities on wildlife from an animal behavior perspective

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Abstract

Solar power is a renewable energy source with great potential to help meet increasing global energy demands and reduce our reliance on fossil fuels. However, research is scarce on how solar facilities affect wildlife. With input from professionals in ecology, conservation, and energy, we conducted a research-prioritization process and identified key questions needed to better understand impacts of solar facilities on wildlife. We focused on animal behavior, which can be used to identify population responses before mortality or other fitness consequences are documented. Behavioral studies can also offer approaches to understand the mechanisms leading to negative interactions (e.g., collision, singeing, avoidance) and provide insight into mitigating effects. Here, we review how behavioral responses to solar facilities,

Rachel Y. Chock, Barbara Clucas, and Elizabeth K. Peterson contributed equally to this study.

including perception, movement, habitat use, and interspecific interactions are priority research areas. Addressing these themes will lead to a more comprehensive understanding of the effects of solar power on wildlife and guide future mitigation.

KEYWORDS

animal behavior, concentrating solar power (CSP), conservation, conservation behavior, photovoltaic (PV) cells, research prioritization process, solar power, utility-scale solar energy (USSE)

1 | INTRODUCTION

As the global human population continues to grow, energy demand increases (IEA, 2019; Pazheri, Othman, & Malik, 2014). Although fossil fuels still dominate energy production, renewable energy sources are a rapidly expanding sector of the global energy market (Islam, Huda, Abdullah, & Saidur, 2018; USEIA, 2019). Renewable resources can help combat climate change, and with falling production costs, serve as an economical alternative to fossil fuels (IRENA, 2019). Most U.S. states now have Renewable Portfolio Standards and other policies that further incentivize production of renewable energy (NCCETC, 2020; NREL, 2019).

The number and size of utility-scale (e.g., >20 MW) solar energy facilities (hereafter solar facilities) have dramatically increased during the past 20 years (Figure 1; Hernandez et al., 2014); for example, the average utility-scale photovoltaic (PV) system installation size increased over 80% from 2010 to 2019 in the United States (NREL, 2020). Solar energy technologies typically fall into two main categories: (a) PV cells that convert sunlight into electrical current (Figures 1a and 2) concentrating solar power (CSP) which uses mirrors to focus sunlight to heat fluids that power steam turbines or generators (Figure 1b,c).

Our current understanding of the impacts of solar facilities on wildlife is limited, despite the pace and scale of its development. Environmental effects, such as soil erosion, changes in water use, and increases in local temperature, are well documented (Barron-Gafford et al., 2016; Hernandez et al., 2014; Moore-O'Leary et al., 2017). A few studies suggest that solar facilities could affect wildlife through exclusionary fencing, habitat destruction or alteration, and direct mortality (Table 1; Northrup & Wittemyer, 2013; Walston, Rollins, LaGory, Smith, & Meyers, 2016), but their relative scarcity highlights the need for additional research (see also Agha, Lovich, Ennen, & Todd, 2020). In particular, studies of wildlife behavioral response to solar facilities have been called for, including by working groups focused on bird interactions with solar facilities (ASCWG, 2020; ASWG, 2020); but such studies are largely still lacking from the literature (Lovich & Ennen, 2011; Northrup & Wittemyer, 2013).

Behavioral responses are often the most visible signs of detrimental effects, as behavioral shifts are usually an animal's first response to environmental change (Dimitri & Longland, 2018; Northrup & Wittemyer, 2013). Although direct mortality is the most obvious sign of negative impacts, large energy facilities may also impact individual fitness, as measured by survival and reproduction (hereafter "fitness"), resulting in population-level impacts that are harder to quantify without long-term demographic studies or using behavioral observations. For example, individuals could decrease mating behavior in response to increased disturbance (Holloran, Kaiser, & Hubert, 2010), stress levels (Lovich & Ennen, 2011), and pollution (Peterson et al., 2017). In addition, behavioral studies can offer approaches to understand the mechanisms leading to negative effects and to provide mitigative strategies. Animal behavior has been successfully utilized by wildlife and natural resource managers to mitigate problems and improve management strategies (Berger-Tal et al., 2011; Dimitri & Longland, 2018). For example, animal behavior has been used to understand and develop approaches to mitigate avian collisions at airports (Blackwell & Fernández-Juricic, 2013). It is imperative for the solar industry to incorporate behavioral research now, in a relatively early stage of the solar boom, to ensure solar power is sustainable for local wildlife populations and to avoid similar developmental and legal pitfalls that plagued the wind industry in its early boom (Brown & Escobar, 2007).

Using a multiphase research-prioritization process (see Supporting Information 1 for detailed methods) we implemented an online survey to ask professionals in the fields of ecology, conservation and energy to identify key behavioral research questions related to potential wildlife conservation issues at solar facilities (see Supporting Information 2 for full survey). We reduced and prioritized these questions at a 2019 workshop held

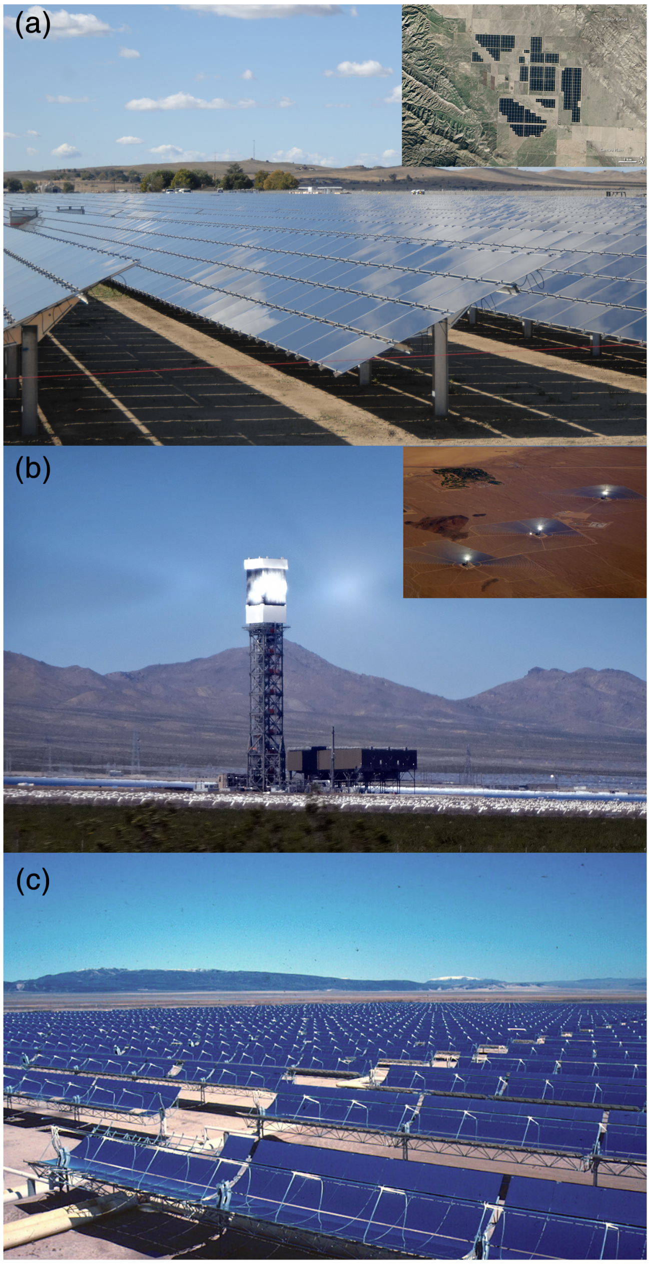

FIGURE 1 (a) An example of photovoltaic (PV) solar panels at topaz solar (550 MW; 4,700 acres). Photo by Pacific Southwest Region from Sacramento, U.S.—Solar Panels at topaz solar 1, Public Domain, https://commons.wikimedia.org/w/index.php?curid=36895794. Inset: aerial photo by Earth Observatory image by Jesse Allen, using EO-1 ALI data provided courtesy of the NASA EO-1 team. Public Domain, https://commons.wikimedia.org/w/index.php?curid=38864327. (b) An example of a concentrating solar power (CSP) tower at Ivanpah Solar Electric Generating System (377 MW; 3,500 acres). Photo by Craig Dietrich—Flickr: Ivanpah Solar Power Facility, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=28676343. Inset: aerial photo by Jllm06—Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=42975801. (c) An example of a CSP parabolic trough at Solar Energy Generating Systems (SEGS; 354 MW; 1,600 acres). Photo by USA.Gov—BLM—Public domain

by the Animal Behavior Society Conservation Committee (Supporting Information 1), and summarize here the emerging themes that resulted from this process (Table 2).

2 | WILDLIFE PERCEPTION OF SOLAR FACILITIES

Solar facilities have the potential to deter, attract, or be imperceptible to individuals, all of which can lead to negative consequences for a variety of species (Kagan et al., 2014; Smith & Dwyer, 2016). Avoidance of solar facilities may lead to use of lower quality habitat or population fragmentation (Hernandez et al., 2014; Saunders, Hobbs, & Margules, 1991) and species attracted to solar facilities might be victims of ecological traps (Robertson & Hutto, 2006). When species attracted to facilities experience low survival or reproduction onsite, regional population dynamics could follow a source-sink pattern, affecting populations beyond site boundaries (Delibes, Gaona, & Ferreras, 2001). Alternatively, solar facilities may attract and provide high quality habitat for non-native or urban adapted species (Hufbauer et al., 2011; Tuomainen & Candolin, 2011). High population density of a few species could have cascading effects, potentially reducing food web integrity (Jessop, Smissen, Scheelings, & Dempster, 2012) or altering species' interactions (see below). Species unable to detect or avoid structures (e.g., power lines, glass windows) are at risk of collision and direct mortality (Bevanger, 1994).

At the core of the problem, we do not fully understand the mechanisms involved in wildlife perception of solar facilities or all the factors that influence avoidance or attraction (but see work by Horváth et al. (2010) and others on aquatic insect attraction to polarized light and solar panels). Individuals deterred by noise pollution might avoid facilities during construction and operation (Halfwerk & Slabbekoorn, 2015) and could also be affected by road noise from traffic associated with them. Individuals might be attracted to these sites because of microclimatic conditions, cover, water availability (e.g., evaporative cooling ponds; Walston et al., 2016), enhanced prey density, lighting, confusion of visual cues, or other potential factors (Dominoni et al., 2020). We also need to know if there is variation in perception and response to solar facilities within and between species and at different temporal scales, both seasonal and daily.

We can identify key behavioral responses by studying how species perceive solar facility structures (Kagan et al., 2014) relative to surrounding landscape elements. Ultimately, this process can allow for manipulation of

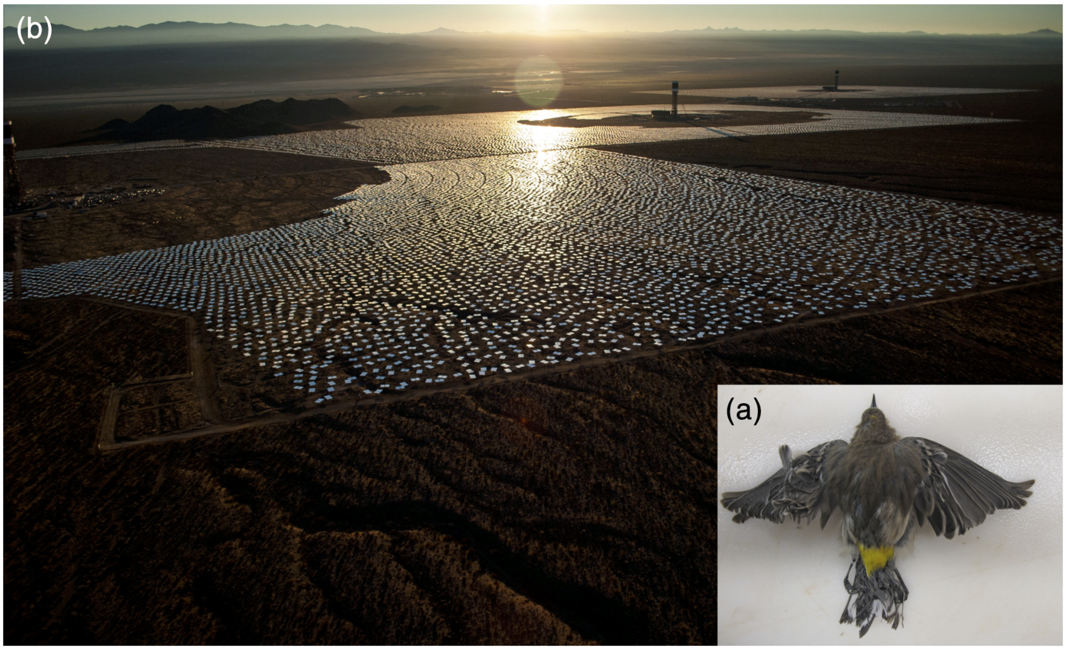

FIGURE 2 (a) Concentrating solar power (CSP) facilities can cause direct mortality to aerial species that fly into solar flare, such as this yellow-rumped warbler burned mid-air at Ivanpah (photograph by U.S. Fish and Wildlife Service, 2013, public domain). (b) CSP or PV facilities can create a "lake effect" (photograph by Kerry Holcomb, used with permission, Ivanpah Solar Electric Generating System, CA); water birds that mistakenly land on the hard surfaces can die on impact, become injured, or are unable to take off from terrestrial surfaces and ultimately die of exposure

TABLE 1 Examples of direct injury and mortality effects, as well as secondary mortality effects, on wildlife species that use the airspace and land covers at solar energy facilities. Noted effects are based on a select number of government and peer-reviewed literature sources, but not a complete survey or synthesis of the current literature

Effect		Taxa affected	Source[1]
Direct injury/ mortality	Solar flux	Birds, insects	2, 3, 4, 6, 7, 8, 9, 10
	Undefined trauma	Birds	8
	Impact trauma	Birds, bats	1, 2, 3, 5, 6, 8, 11
	Electrocution	Birds	6, 8, 11
	Entrapment/drowning in water in-take structures and evaporation ponds	Birds, mammals, insects	4, 6, 7
	Entrapment in soil ruts from vehicle passage	Amphibians, reptiles	10
Secondary mortality	Predation trauma	Amphibians, birds, reptiles	10, 8
	Light pollution	Amphibians, birds, bats, other mammals, insects, reptiles	4, 5, 10
	Electromagnetic field effects	Amphibians, bats, insects, reptiles	4, 10
	Other anthropogenic effects	Amphibians, birds, bats, other mammals, insects, reptiles	5, 7, 8, 10

Note: 1. Costantini, Gustin, Ferrarini, and Dell'Omo (2016); 2. Diehl, Valdez, Preston, Wellik, and Cryan (2016); 3. Ho (2016); 4. Horváth et al. (2010); 5. Huso, Dietsch, and Nicolai (2016); 6. Jeal, Perold, Ralston-Paton, and Ryan (2019); 7. Jeal, Perold, Seymour, Ralston-Paton, and Ryan (2019); 8. Kagan, Viner, Trail, and Espinoza (2014); 9. Loss, Dorning, and Diffendorfer (2019); 10. Lovich and Ennen (2011); 11. McCrary, McKernan, Schreiber, Wagner, and Sciarrotta (1986).

stimuli and associated behavior to reduce mortality (sensu Blackwell et al., 2009 and citations therein). Birds, for example, can experience risk of mortality due to collision (i.e., direct contact with the solar facility), solar-flux (i.e., birds are either burned or singed by exposure to the solar facility; Figure 2a), or become stranded

TABLE 2 Key themes in animal behavior research that could improve our understanding of impacts of solar facilities on wildlife and potential solutions. These themes emerged from a multiphase research prioritization process (see Supporting Information 1) and the final list of priority research questions (Table S4)

Theme	Research areas	Research priority questions	Examples from the literature related to or applicable to solar power facilities
Perception of solar facilities: natural attraction or deterrence?	1. Understand factors involved in wildlife perception of solar facilities 2. Quantify key sensory mechanisms of species with high mortality at facilities 3. Use information in perception models to quantify conspicuousness of facility elements 4. Modify facility elements to enhance or reduce conspicuousness and measure behavioral response	• Do solar facilities attract or deter species? • What are the behavioral/sensory mechanisms involved in creating attraction or deterrence to solar facilities? • What characteristics of solar facilities are attracting and/or deterring certain species? What are the fitness consequences? • How can solar facilities be designed to reduce attraction and reduce negative fitness consequences?	Blackwell, Fernández-Juricic, Seamans, and Dolans (2009), Horváth et al. (2010), Blackwell and Fernández-Juricic (2013), Arnett, Hein, Schirmacher, Huso, and Szewczak (2013), Kagan et al. (2014), Smith and Dwyer (2016), Fernández-Juricic (2016), Száz et al. (2016)
Habitat use in and around solar facilities in resident and migratory species	1. Impacts on resident species a. Home range b. Habitat modification (e.g., fragmentation) 2. Impacts on migratory species a. Habitat connectivity b. Disruption of migratory behavior	• What impact do solar facilities have on habitat use of resident species? • How far do the impacts on behavior extend into habitat? • How is migration behavior impacted by solar facilities? • How does solar facility type affect movement behavior? • Where should solar facilities be built to minimize impacts on behavior and fitness?	Tsoutos, Frantzeskaki, and Gekas (2005), Arnett et al. (2008), Lovich and Ennen (2011), Turney and Fthenakis (2011), DeVault et al. (2014), Hernandez et al. (2014), Grippo, Hayse, and O'Connor (2015), Jeal et al. (2019,b)
Other impacts on fitness associated behavior	1. Behavioral change before and after a. Impacts on foraging b. Impacts on species interactions i Antipredator behavior ii Predation iii Competition c. Impacts on reproduction	• How does behavior (including activity patterns, foraging, predation, antipredator behavior, competition, habitat use, and movement) change before and after solar facility construction? • How do different types of solar facilities impact animal behavior of species directly and indirectly?	Vistnes, Nellemann, Jordhoy, and Strand (2004); Epps et al. (2005); Reimers, Dahle, Eftestøl, Colman, and Gaare (2007); Sawyer, Kauffman, and Nelson (2009); Holloran et al. (2010); Cypher et al. (2019)

(i.e., water birds that cannot take off due to lack of water; ANL & NREL, 2015). It is therefore important to understand how birds and other wildlife perceive solar facilities and why they are attracted, deterred, or fail to detect them. In addition to individual responses to cues generated by solar facilities, vulnerability will vary according to species' ecology and behavior. We discuss below how animal movement, breeding, foraging behavior, and interspecific interactions may influence population level responses to solar facilities.

3 | MOVEMENT AND HABITAT USE IN AND AROUND SOLAR FACILITIES

Many animals, particularly those living in arid environments where solar facilities are more common, are living at their physiological limits; any added movement may thus be costly (Vale & Brito, 2015). Whether and how movements are influenced by a solar facility will be determined by: (a) the trade-off of associated benefits and costs, (b) whether species are attracted or deterred by solar facilities, (c) whether a species is residential or migratory, and (d) the fitness impact of the responses.

3.1 | Resident species

Solar facility construction and operation directly and indirectly alter habitat use via functional habitat fragmentation, dispersal limitations, population isolation, and altered habitat quality (as previously reviewed in Lovich and Ennen (2011)). For example, vegetation at road edges appears to attract Agassiz's desert tortoises (*Gopherus agassizii*) to build burrows there, despite the apparent noise pollution and risk of vehicle collision (Lovich & Daniels, 2000; von Seckendorff Hoff & Marlow, 2002). CSP facilities can include evaporation ponds with chemically treated waters; these polluted waters can kill via drowning, poisoning, egg mortality, or biomagnification (Jeal, Perold, Ralston-Paton, & Ryan, 2019). Electromagnetic fields created by buried and aerial cables transporting energy can affect orientation of some organisms, impairing habitat use and likely causing additional physiological harm (Lovich & Ennen, 2011; Shepherd et al., 2019; Wyszkowska, Shepherd, Sharkh, Jackson, & Newland, 2016). Also, changes in albedo from vegetation removal could cause local increases in temperature and evapotranspiration, which may influence movement patterns, reproductive success, and survival (Barron-Gafford et al., 2016). Although certain habitat modifications could benefit species, such as birds that can exploit solar facility structures for foraging, roosting or nesting (Jeal, Perold, Ralston-Paton, & Ryan, 2019) or prey species that experience reduced predation (Cypher et al., 2019), in most cases, modifications are likely to have negative impacts.

3.2 | Migratory species

Migratory animals are under escalating threat due to growth in human activity (Hardesty-Moore et al., 2018; Wilcove & Wikelski, 2008). Compared to other groups of species, migratory birds appear to suffer disproportionately higher mortality from solar facilities, particularly those located on migration routes and/or near breeding and wintering grounds (Walston et al., 2016). The greater abundance of insect prey attracted by the high structures and light (Diehl et al., 2016) likely attracts aerial insectivores, resulting in a higher risk to burning via solar flux from concentrated solar power (Figure 2a; McCrary et al., 1986; Kagan et al., 2014). Migratory water bird species are also susceptible because solar facilities may be perceived as waterbodies (a hypothesized "lake effect"), attracting them to land and injuring, killing, or stranding them in the process (Figure 2b; Kagan et al., 2014).

3.3 | Facility siting

The effects of solar facilities on wildlife may be exacerbated or mitigated through decisions about where to build them. Models have been developed at regional scales to identify areas that have both high potential for solar energy development and suitability for species of special concern (Phillips & Cypher, 2019), or high species richness (Thomas et al., 2018), representing potential conflict areas that should be avoided. These and other studies also identify priority areas for facility siting that minimizes the loss of high quality habitat (DRECP, 2020; Stoms, Dashiell, & Davis, 2013). While these models provide greatest benefit to resident species, research on migratory routes for aerial and terrestrial wildlife is critical to improve siting recommendations (e.g., Ruegg et al., 2014). The infrastructure necessary to operate solar facilities often extends far into the habitat, and effects of these structures on migratory wildlife have been documented in other energy sectors. For instance, mule deer (*Odocoileus hemionus*) abandoned former migration corridors as a result of oil and gas exploration and moved into suboptimal habitat, resulting in migration bottlenecks with no observed acclimation over several years (Sawyer et al., 2009). Reindeer (*Rangifer tarandus*) actively avoid power lines (Reimers et al., 2007; Vistnes et al., 2004), a behavioral response that could similarly alter migration routes for other ungulates. Gene flow in populations of desert bighorn sheep (*Ovis canadensis nelsoni*) is impeded by the presence of barriers, including roadways and large mining operations, resulting in rapid declines in genetic diversity (Epps et al., 2005). Minimizing these off-site impacts by siting facilities closer to existing infrastructure is important for mitigating effects on wildlife (Stoms et al., 2013).

4 | OTHER FITNESS ASSOCIATED BEHAVIORS: FORAGING AND SPECIES INTERACTIONS

4.1 | Foraging

Foraging involves a complex suite of behaviors, including detection of food sources, perceiving temporal and spatial cues about food availability, and food searching, choice, retrieval, and processing. Solar facilities might alter cues and predation risk assessment or disrupt normal search patterns via habitat change or construction of novel obstacles. Therefore, we must understand a species' trophic level (Fauvelle, Diepstraten, & Jessen, 2017; Moore-O'Leary et al., 2017) and the mechanisms underpinning its foraging decisions (e.g., olfactory cues; Schmitt, Shuttleworth, Ward, & Shrader, 2018) to estimate the impact of landscape alteration caused by solar facilities.

Spatial knowledge, which is critical in foraging behavior, increases individual fitness (Spencer, 2012), and changes in spatial distribution of resources may impact species depending on their capacity to update such information. Assessments on the plasticity of cognitive mapping and role of memory in animal foraging decisions would contribute to our understanding about the impact of solar facilities. For example, bison (*Bison bison*) remembered and used information about location and quality of meadows to make movement decisions, building individual cognitive maps of their environment (Merkle, Fortin, & Morales, 2014). Studies of species affected by solar facilities measuring the effect of changes in the distribution and availability of resources on animal behavior can help predict impacts of development at a population level.

4.2 | Predation, antipredator behavior, and competition

Habitat modification can affect predator–prey dynamics (Dorresteijn et al., 2015; Hawlena, Saltz, Abramsky, & Bouskila, 2010) and competitive interactions between species (Berger-Tal & Saltz, 2019). At solar facilities, reflective surfaces of buildings and PV panels create polarized light pollution that attracts polarotactic organisms, including many insects (Horváth, Kriska, Malik, & Robertson, 2009). Insectivorous species might benefit from the increased availability of prey but trade off potential danger from collisions with reflective surfaces and increased competition for food. In the Mojave Desert, the population of urban-associated common ravens (*Corvus corax*) has increased with development, and they exert high predation pressure on threatened desert tortoise (Kristan & Boarman, 2003), which also face other impacts due to solar development (Lovich & Ennen, 2011).

Alternatively, PV panels or mirrors could serve as shelter for some animals against predators, especially aerial ones, and solar facility buildings and fences can also provide shelter and escape routes for smaller prey by excluding larger terrestrial predators (Cypher et al., 2019). Increased vegetation near structures due to runoff (BLM & DOE, 2012) may be perceived as protective cover from predators (Jacob, 2008), but the vegetation may also make it more difficult to detect predators. Peripheral visibility has been shown to be valued by both mammals (Bednekoff & Blumstein, 2009) and birds (Bednekoff & Lima, 1998); in areas with reduced peripheral visibility, animals perceive a greater risk of predation and may modify their behavior in potentially maladaptive ways, such as increasing time allocated to vigilance over foraging.

5 | FUTURE RESEARCH AND DESIGNING SOLUTIONS

As evidenced by our research and those of others (Agha et al., 2020; Conkling, Loss, Diffendorfer, Duerr, & Katzner, 2020), more studies about the potential impacts of solar facilities on wildlife are needed to develop solutions. Documented efforts to deter wildlife from solar power facilities and other human-made structures include acoustic (Arnett et al., 2013; May, Reitan, Bevanger, Lorentsen, & Nygård, 2015; Swaddle, Moseley, Hinders, & Smith, 2016), visual (Martin, 2011; Goller, Blackwell, DeVault, Baumhardt, & Fernández-Juricic, 2018; Hausberger, Boigné, Lesimple, Belin, & Henry, 2018), and tactile deterrents (Ho, 2016; Seamans, Martin, & Belant, 2013). Evaluation of the effectiveness of such deterrents, however, is often limited or inconclusive (e.g., Dorey, Dickey, & Walker, 2019), and may not address why individuals are attracted to the facilities or collide with facility structures in the first place. A more effective approach may be to understand wildlife perception of solar facilities and minimize features that attract them (e.g., Horváth et al., 2010), or modify features so that wildlife detect them and avoid collisions, burning and singeing. For instance, we can better understand how wildlife visually or otherwise perceive solar facilities by: (a) quantifying key properties of the sensory systems of species that experience high mortality, (b) use this information to quantify the degree of conspicuousness of solar panels and other structures from the species' sensory perspective, then (c) modify the properties of the solar panels to enhance or reduce their conspicuousness, and (d) measure behavioral responses to these modifications (Blackwell & Fernández-Juricic, 2013; Fernández-Juricic, 2016). For example, Horváth et al. (2010) tested the attraction of several aquatic insect species to PV solar panels with various modified features and found that white-framed and white-gridded panels were less attractive than black panels.

Our survey identified several research priorities for designing solutions focusing on where and how solar facilities can be built to minimize influences on behavior and fitness (Table 2 and Supporting Information 1). Another overarching question identified, while not specific to behavior, was whether facility designs should be exclusionary or permeable to wildlife. Some solar facilities are currently evaluating how to co-manage wildlife and PV panels by making them more permeable (e.g., Cypher et al., 2019; Wilkening & Rautenstrauch, 2019). Nevertheless, the answer to this question is likely complex and specific to geography and species (see also Moore-O'Leary et al., 2017).

With regard to assessing and minimizing impacts of solar facilities on wildlife, our workshop identified the need for more purposeful study designs to begin addressing these priority questions (Table 2). Ideally, a before-after control-impact design is desirable; whereby, key behaviors are studied before and after the solar facility is developed, both at the facility location and at control sites (Conkling et al., 2020; Lovich & Ennen, 2011). While this rarely happens (see Agha et al., 2020), such design is the most powerful way to isolate the effects of a solar facility on behavior while controlling for other spatial and temporal variation. Experimental studies assessing impacts of different design features (such as panel height and spacing, corridor placement and size, and vegetation treatment), in addition to studying behavior at different distances from solar facilities, are also necessary to minimize detrimental effects on wildlife.

6 | CONCLUSIONS

Development of utility-scale solar facilities is expected to continue at a rapid pace (USEIA, 2019). There is an urgent need to address how to better locate, design, and operate solar facilities to mitigate potential negative effects on wildlife populations. We have highlighted major research themes addressing how approaches using animal behavior can be utilized to study wildlife-solar facilities interactions and how they could lead to solutions to reduce negative effects. Similar to how those in the wind energy industry have worked with animal behaviorists to reduce wildlife fatalities (e.g., Cryan et al., 2014), finding such solutions will need collaboration across industry, research, and management agencies. This can be achieved by forming working groups that can bring together entities from solar power facilities, wildlife agencies, and academia to determine shared research goals and to facilitate access to solar facilities, research permitting, and research funding opportunities (e.g., Bats and Wind Energy Cooperative, 2020).

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR' CONTRIBUTIONS

Rachel Y. Chock, **Barbara Clucas,** and **Elizabeth K. Peterson**: Organized the workshop that resulted in this study and coordinated the manuscript. All authors participated in the workshop and extensively contributed to the writing and revision of the manuscript.

DATA AVAILABILITY STATEMENT

Survey questionnaire and results from the workshop are freely available and included as Supporting Information.

ETHICS STATEMENT

The survey was approved by the Humboldt State University Institutional Review Board (IRB# 18-161).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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