Reading Excerpts:

1. Determinants of emissions pathways in the coupled climate–social system

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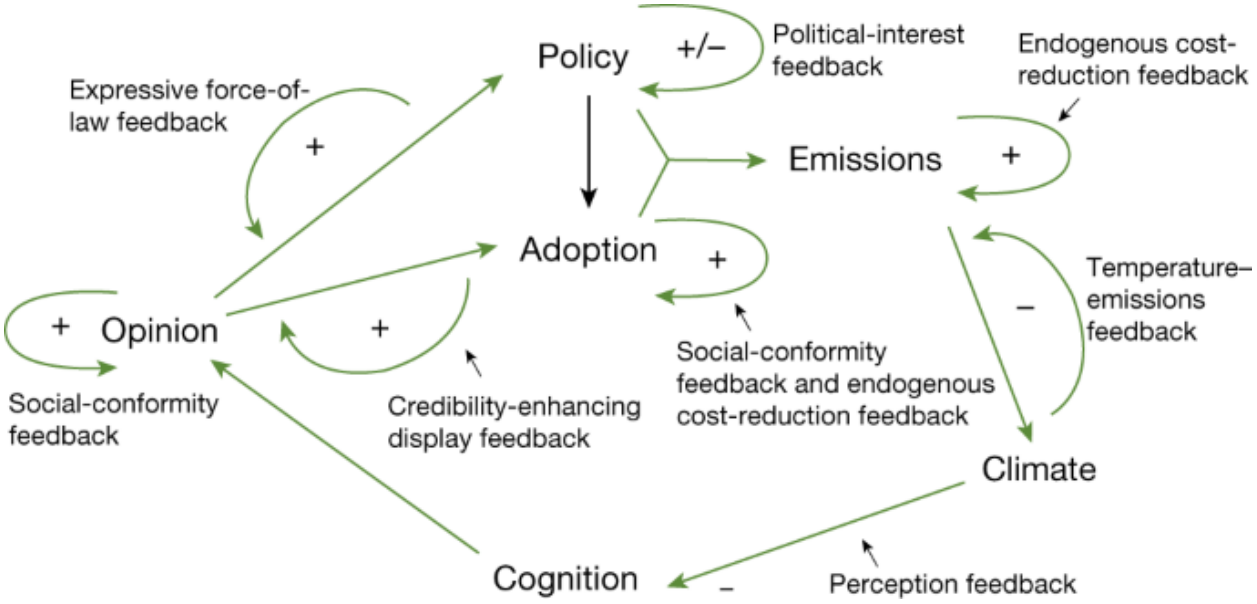
Feedback and model structure

The positive and negative feedback processes operating within the coupled climate–social system are critical to understanding system behavior and dynamics. The feedback processes that are represented in the model were identified in a two-step process. First, potentially relevant system feedback processes were described during a four-day interdisciplinary workshop. Second, targeted searches were conducted across relevant literatures in psychology, economics, sociology, law, political science and engineering to evaluate the evidentiary literature for or against candidate feedback processes, resulting in eight key feedback processes being included in the final model. This section briefly describes each feedback process, and Table 1 and Fig. 1 describe how these feedback processes are coupled together in the model and the model structure.

Table 1 Description of the climate–social model components and key parameters

Fig. 1: The climate–social model components and feedback processes.



Components are shown in black and the model feedback processes in green. Feedback processes are identified as positive (+) (that is, reinforcing) or negative (−) (that is, dampening). The black arrow shows a connection between components (policy-adoption effect) that is not directly part of a particular feedback process. Descriptions of the components and key parameters governing both feedback strength and component behavior are given in Table 1.

Social-conformity feedback

The social networks in which individuals are embedded at home, work, school or leisure have a strong influence on opinions and behavior (30 - 31). Social norms (that is, representations of the dominant or acceptable practices or opinions within a social group) are costly for individuals to violate and, over the long term, can shape individual identities, habits and world-views (32, 33). Studies in the USA have shown that perceived social consensus, that is, the degree to which individuals believe a particular opinion or action is dominant within their social group, can partially explain belief in climate change and support for climate policies34. A large body of literature has also shown that social norms are one important determinant of the probability that an individual engages in pro-environmental behavior, such as conserving energy or adopting solar panels (35,36,37). A tendency towards social conformity can lead to tipping-point-type dynamics in which a system transitions suddenly from a previously stable state given a sufficient critical mass of proponents of the alternate norm (24,38). The model includes the social conformity effect in two ways: formation of public opinion regarding climate policy and individual decisions on adopting pro-climate behavior (Fig. 1).

Climate change perception feedback

The anthropogenic influence on the Earth's climate system is increasingly apparent (39,40,41). Assessments of the contribution of anthropogenic warming to the probability of particular extreme events are increasingly routine (42). It has been hypothesized that this emerging signal of climate change in people's everyday experience of weather might lead to widespread acknowledgement of the existence of global warming and possibly, by extension, support for mitigation policy43. A large number of studies have connected stated belief in global warming with local temperature anomalies: people appear to be able to identify local warming (44,45) and are more likely to report believing in climate change if the weather is (or is perceived to be) unusually warm (46,47,48,49). In effect, people appear to be using their personal experience of weather as evidence informing their belief in climate change49.

However, this so-called 'local warming effect' is complicated (50). Several papers have found evidence that interpretations of weather events are filtered through pre-existing partisan identities or ideologies (45,51,52). This suggests the presence of motivated reasoning (that is, the rejection of new information that contradicts pre-existing beliefs) in the processing of climate-change-related information (53,54). Moreover, the perception of weather anomalies might well be complicated by a 'shifting-baselines' effect in which people's perception of normal conditions is quickly updated on the basis of recent experience of weather (55).

Credibility-enhancing display feedback

Although the ability of individuals to alter the trajectory of greenhouse gas emissions is limited, individual adoption of pro-environmental behaviors can have spillover effects to the larger social network. Changing behavior to better align one's consumption or practices with how one believes society ought to function can strengthen this moral identity and send a normative signal to other community members about desirable collective outcomes (59,60). Engaging in costly personal actions aligned with collective goals can act as 'credibility enhancing displays', increasing the persuasiveness of the actor. Kraft-Todd et al.61 use this framework to explain why community ambassadors promoting solar panel installation were more effective if they had installed solar themselves. For climate change more generally, Attari, Krantz and Weber (62,63) found that the personal carbon footprints of researchers advocating climate policy affects their credibility and the impact of their message.

Expressive force of law feedback

To the extent legal or judicial institutions are perceived as legitimate, changes in laws coming out of them can provide information about desirable or common attitudes within the population, feeding back to reinforce the attitudes or behavior of the society that produced them. Tankard and Paluck (64) identify signals from governing institutions as one of three sources of information about community norms. Legal scholars have developed the theory of the 'expressive function' of law—the idea that law and regulation work on society not only by punishing undesirable behavior but also by signalling what kind of behavior is praiseworthy and what is reprehensible (65,66,67). This signal is particularly important if individuals have imperfect information about the distribution of attitudes or behavior within a reference population (67,68). Several papers have found evidence for feedback from changes in laws and regulations to the perception of social norms, attitudes or behaviour, including the legalization of gay marriage (69,70), smoking bans (71) and the COVID-19 lockdowns (72

Endogenous cost-reduction feedback

New energy technologies are often expensive, but also tend to exhibit price declines with installed capacity. This 'learning-by-doing' effect has been widely documented in the energy systems literature and is incorporated into some energy system models (73). Falling costs are attributed to the combination of economies of scale, lower input costs and efficiencies in the production process and design (74). This is a reinforcing feedback process, where small initial deployments, possibly driven by subsidies or regulatory requirements, lower costs and enable further deployment. Rubin et al. (75) reviewed estimated learning rates (that is, the fractional reduction in cost for a doubling of installed capacity) for 11 generation technologies and found ranges between −11% and 47% with many estimates falling in the 2% to 20% range.

2. **Insights into human-wildlife interactions in cities from bird sightings recorded online**

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Abstract
Interactions with nature can improve the wellbeing of urban residents and increase their interest in biodiversity. Many places within cities offer opportunities for people to interact with wildlife, including open space and residential yards and gardens, but little is known about which places within a city people use to observe wildlife. In this study, we used publicly available spatial data on people's observations of birds from three online platforms—eBird, iNaturalist, and Flickr—to determine where people observe birds within the city of Chicago, Illinois (USA). Specifically, we investigated whether land use or neighborhood demographics explained where people observe birds. We expected that more observations would occur in open spaces, and especially conservation areas, than land uses where people tend to spend more time, but biodiversity is often lower (e.g., residential land). We also expected that more populated neighborhoods and those with higher median age and income of residents would have more bird observations recorded online. We found that bird observations occurred more often in open spaces than in residential areas, with high proportions of observations in recreation areas. In addition, a linear regression model showed that neighborhoods with higher median incomes, those with larger populations, and those located closer to Lake Michigan had more bird observations recorded online. These results have implications for conservation and environmental education efforts in Chicago and demonstrate the potential for social media and citizen science data to provide insight into urban human-wildlife interactions.

Advances in internet technology are opening new opportunities for research on human-wildlife interactions. For example, some data on where people observe birds are now publicly available, in the form of spatially explicit bird observations that people record on the internet. eBird is a prominent example of an online platform where thousands of people record observations of birds for the purposes of personal record keeping, enhancing scientific understanding of bird species dynamics, and contributing to conservation efforts (Wood, Sullivan, Iliff, Fink, & Kelling, 2011). In addition to eBird, other platforms for recording biodiversity observations online have emerged in recent years. One of the largest is iNaturalist, a social networking site where individuals upload photographs of the organisms they observe and can outsource species identification to their network of followers. Some other social networking sites that are not explicitly aimed at biodiversity records, such as the photo-sharing platform Flickr, also contain biodiversity observations. Scientists have recently recognized the potential for these various online platforms, including social networking sites such as Flickr and Twitter, to supplement more traditional sources of data for biodiversity science and conservation (Daume, 2016, Hausmann et al., 2017, Roberge, 2014, Tenkanen et al., 2017), such as information on wildlife viewing (Mancini, Coghill, & Lusseau, 2018a). However, to our knowledge, no study has made use of these data sources for identifying sites of human-wildlife interactions in cities.

Introduction

In this paper, we examined human-wildlife interactions in Chicago, Illinois (USA), using data on bird observations from eBird, iNaturalist, and Flickr to ask where these observations occur. First, we were interested in determining which land uses are most important for providing opportunities for people to observe birds in the city. We compared land uses that likely differ in their perceived conservation value and levels of accessibility: conservation areas, other types of open space (e.g., golf courses, cemeteries), residential areas, water bodies, and roadways and rights-of-way. We expected that the majority of people would observe birds in open space, and especially in conservation areas such as nature reserves, where there tends to be higher bird diversity (Ortega-Álvarez & MacGregor-Fors, 2009) and where people may specifically go to see birds. In contrast, we expected that fewer people would observe birds in land uses where people generally spend more time but tend to have lower bird diversity, such as residential areas. Second, we examined differences in the number of bird observations made in different neighborhoods in relation to neighborhood characteristics, including socioeconomic factors. We expected that more populated neighborhoods and those with higher median age and income of residents would have more bird observations recorded online, because older and wealthier individuals are more likely to participate in birdwatching (Carson, 2013). This study provides information on popular locations and gaps of bird observations in Chicago, with implications for conservation and education efforts.

Discussion

We found evidence that people are observing birds in a wide range of land uses and neighborhoods across Chicago. Open spaces, especially recreation areas, appear to be important locations for bird observation in Chicago (Fig. 2). However, other land uses such as water and roadways also provided opportunities for people to observe birds, suggesting that incidental observations could be an important mechanism for human-wildlife interaction in cities (Cosquer et al., 2012, Cox et al., 2017). We also observed spatial patterns in bird observations across neighborhoods, with fewer observations in low-income community areas and those with less open space, as well as those farther from Lake Michigan (Fig. 4). These results suggest some potential opportunities for increasing positive human-wildlife interactions, which we discuss below.

The importance of open space for bird observations in our dataset, particularly in comparison to residential areas, suggests that more people make bird observations while out in the city than at home. However, there are several reasons why residential areas may be underrepresented in our dataset. First, while residential land use is extensive, it provides less green space in which to observe birds than other land uses with fewer built surfaces. Second, our method for filtering the bird observation data to one observation per person per location removed some observations of birds at single-family residences (mostly recorded on eBird; Appendix E). Finally, some iNaturalist observations in residential areas had obscured locations—likely due to privacy concerns by its users—and so were excluded from our analyses. Thus, the data suggest that residential areas can be very important locations for urban bird observation for some individuals, such as those who regularly monitor birds on their property, but are less important than open space for providing bird-observing opportunities for many people.

The use of open space for observing birds was also evident at the neighborhood scale, with more observations recorded in community areas with more open space. Neighborhoods with more open space may attract more birdwatchers, or may host more birds or more diverse bird communities (Loss, Ruiz, & Brawn, 2009). The importance of accessible open space for interactions with nature suggests that maintaining open spaces across neighborhoods, and creating open spaces in neighborhoods lacking them, can increase human-nature interactions and possibly residents' wellbeing (Barbosa et al., 2007, Colléony et al., 2017, Soga et al., 2015). It is particularly important to increase the accessibility of green spaces and create equitable opportunities for people to recreate and experience nature close to where they live and work (Pham et al., 2012, Rigolon, 2016). In Chicago, low- to mid-income Hispanic neighborhoods tend to have less access to open space, tree cover, and bird biodiversity than other neighborhoods, suggesting that lack of access to open space could constitute an environmental justice issue (Davis et al., 2012). In addition to creating open space, "greening" programs to promote native species and provide wildlife habitat on private lands are another potential mechanism for providing more equitable opportunities for nature experiences in cities (Shanahan et al., 2014).

Notably, most of the observations in open space occurred in recreation areas rather than conservation areas or other types of open space considered to have conservation value, such as cemeteries (Lussenhop, 1977, Smith & Minor, 2019). Conservation areas are likely a strong draw for people specifically looking to see birds, especially particular species that are uncommon in densely populated areas (Kolstoe & Cameron, 2017). In general, however, the relative accessibility of recreation areas may account for their higher usage for observing birds. In Chicago in particular, many recreation areas are located close to the downtown area and Lake Michigan (Fig. 1), accessible by public transportation, and frequented by tourists. Recreation areas also provide opportunities for people to observe birds casually while participating in other activities, such as meeting friends, visiting a tourist attraction (e.g., the 'bean' statue at Millennium Park), or attending a concert or other event. Incidental nature observations, such as hearing birdsong, can have positive effects on mental well-being (Bakolis et al., 2018, Keniger et al., 2013) and green infrastructure design can incorporate key elements to enhance these incidental interactions and associated benefits (Beery et al., 2017).

We found that fewer bird observations were recorded in lower-income community areas, perhaps because wealthier people have more leisure time and access to equipment for viewing and photographing birds, as well as technology for recording observations on online platforms. Different communities within a city may also engage differently with birds and with urban nature and green spaces more broadly. Indeed, several studies have pointed out that different urban populations often use parks differently (Lin et al., 2014, Sasidharan et al., 2005) and that projects aimed at increasing open space in neighborhoods should thus consider how local communities use green space (Kabisch and

Haase, 2014, Soga et al., 2015). Nevertheless, these results point to some potential opportunities for education and outreach to make people more aware of the biodiversity in their neighborhoods. People's orientations towards or connection to nature is often an important factor influencing whether and how people use green space, whether they notice and appreciate biodiversity, and their participation in conservation behaviors (Gunnarsson et al., 2017, Lin et al., 2014, Nisbet et al., 2009).

Environmental education and outreach have the potential to enhance these qualities by increasing people's knowledge and appreciation of nature, including their ability to notice species they encounter (Cosquer et al., 2012, Pollock et al., 2015). This is especially true for those with limited prior exposure to nature (White, Eberstein, & Scott, 2018). Thus, targeting traditionally underserved areas for outreach efforts, as some programs in Chicago (e.g., Project Exploration, https://projectexploration.org/) are currently doing, could help to "close the gap" in bird observations we documented. As we found that people observe birds in various land uses across the city, there is clear potential for environmental education to take place in residential areas and other land uses (such as commercial areas) as well as open spaces. Citizen science projects, including those focused on residential areas such as backyard bird monitoring programs (e.g., Project Feederwatch, https://feederwatch.org/; Neighborhood Nestwatch, https://nationalzoo-si-edu.proxy-um.researchport.umd.edu/migratory-birds/about-neighborhood-nestwatch), can help to engage urban citizens with nature and potentially form stronger connections between people and their environment (Schuttler, Sorensen, Jordan, Cooper, & Shwartz, 2018). By offering a way to learn new species using only a smartphone, apps like iNaturalist can also be a useful tool for increasing engagement in observing birds and other organisms in various places throughout a city.