CHAPTER 18

Odonata assemblages in human-modified landscapes

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Overview

Human activities such as logging, agriculture, and urbanization can drastically change and limit Odonata species distributions in aquatic and terrestrial environments. These modifications may culminate in extirpations of rare and resident species and homogenization of community composition across space. This chapter reviews how human land use is (re)shaping odonate assemblages and focuses on the impacts from logging, agriculture, and urbanization. Deeper appreciation and analysis of regulatory mechanisms (e.g. vulnerability traits, species interactions, phylogenetic niche conservatism) and background "noise" (e.g. natural heterogeneity, climate change, historical context) will be important in understanding and predicting odonate community responses to ongoing and future landscape alteration.

18.1 Introduction

Defining landscapes is subjective and because there is no all-encompassing ("one-size-fits-all") perspective and scale, a key challenge is attempting to capture environmental space as perceived by the organisms we study (Chapter 13; Wiens and Milne 1989). Bounding a landscape by geographical extent matters immensely in conceptualizing and interpreting community size (Figure 18.1), composition, and spatial structure. Likewise, bounding a community depends greatly on scale (Figure 18.1), for example defining the assemblage locally at a groundwater spring or regionally among a network of springs connected by dispersal (i.e. metacommunity; Chapter 17).

To study diversity in human-modified landscapes, we must be clear about the geographical extent and ensure that our definitions of landscapes and communities make biological sense rather than being of mere research convenience. When capturing "disturbance" one should consider how land-use changes through time have shaped community assembly (Figure 18.2), that is, legacy effects and not just recent human activity (Ball-Damerow et al., 2014; Assandri 2021; Smith and Patten 2021).

This chapter considers a few of the ways that human activities can change landscapes and, in turn, affect odonates. It begins with a brief overview of the main practical challenges and approaches for studying community changes (Section 18.2). The bulk of the chapter is divided into two broad categories, non-urban (Section 18.3) and urban (Section 18.4). First it examines odonate assemblages with respect to logging (Section 18.3.1), agriculture (Section 18.3.2), and non-urban secondary habitats (Section 18.3.3), and then reviews odonate assemblages in urban aquatic ecosystems (Section 18.4.1), urban heat islands (UHIs, Section 18.4.2), and urban ecological traps (Section 18.4.3). It ends by discussing some background challenges and future directions for studying odonate communities in human-modified landscapes (Section 18.5).

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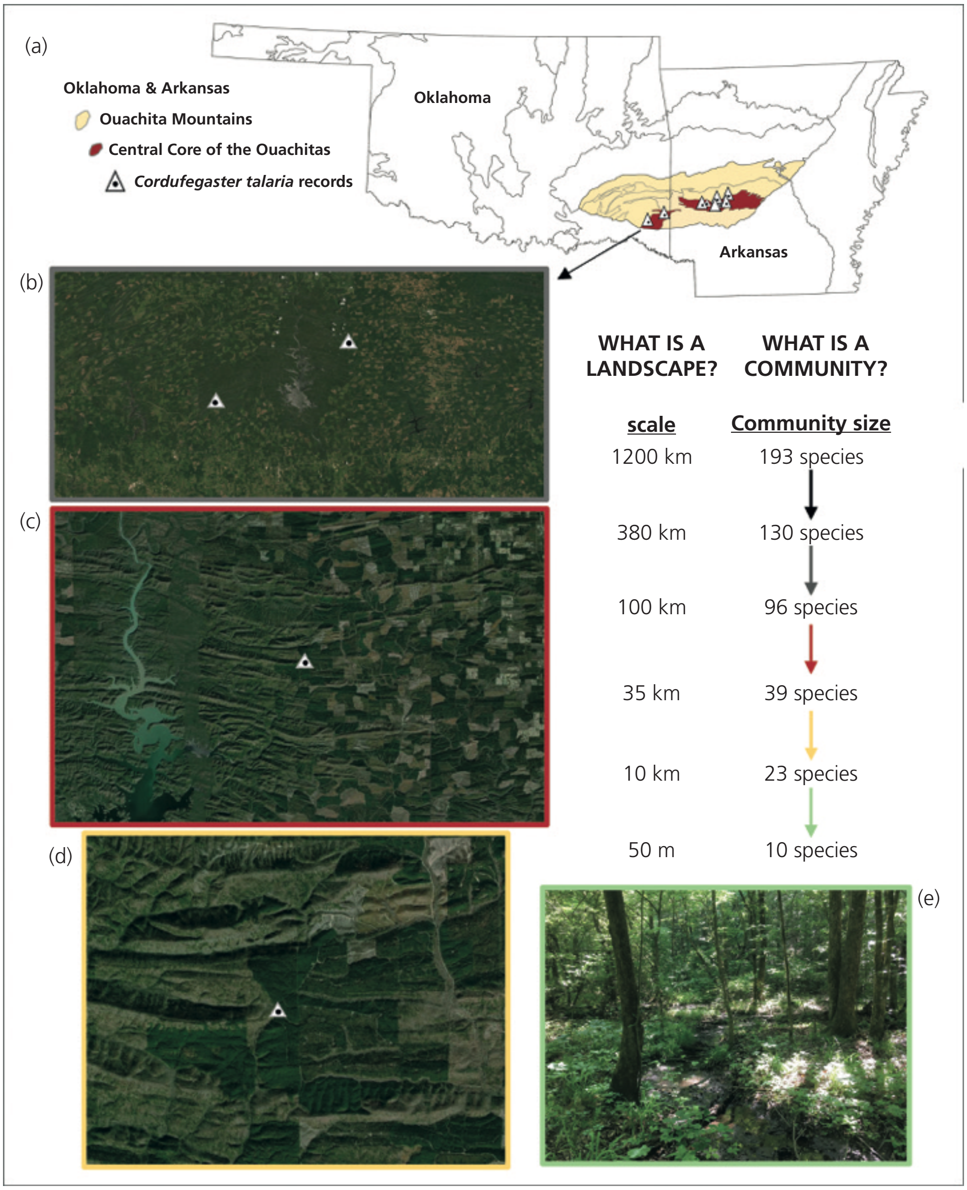

Figure 18.1 At what geographic scale do ecologies of landscapes and communities interact? Take for example, the scaling of *Cordulegaster talaria* distribution. The species is found in only two US states: Arkansas and Oklahoma, an area ≈ 1200 km west to east, within which it is confined to the Ouachita Mts. (≈ 380 km wide) (a). Are these spatial scales where one would examine this species' community? Perhaps a scale of (b) 100 km, (c) 35 km, or (d) 10 km (where we could more clearly visualize the fractured landscape due to logging) would be more appropriate in which to bound the associated community? However, all of those scales look at landscapes from a human perspective. Perhaps the landscape most relevant is that viewed from the species' perspective, that is, (e) the isolated seep complex in which it lives?

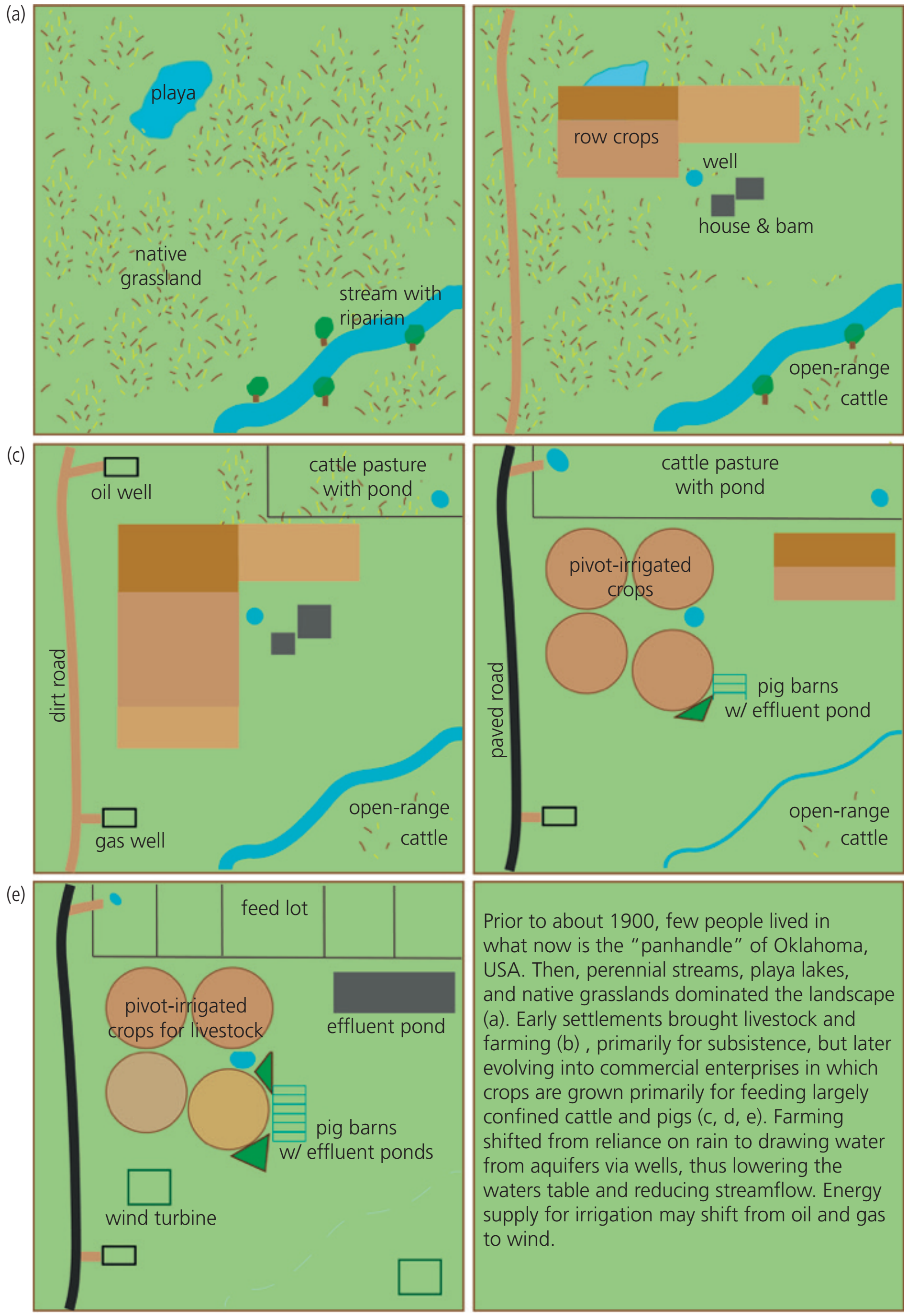

Figure 18.2 A landscape can be broadly characterized as "agricultural" but, as with urban areas, intensity matters both temporally and spatially. Transformation of a natural landscape (a) by agricultural conversion and intensification over time (b–e) can make it one inhabited solely by generalist odonates. Consideration of concurrent intensification is problematic if disparate intensities are treated as having equal impact on odonates.

18.2 General challenges and methods

Attributing odonate community changes to human activity is often challenging and may require dynamic approaches (Kietzka et al., 2017). Since historical maps are available from at least some areas of the world and satellite images from the 1970s onwards, this should, theoretically, be possible. A major obstacle is the limited availability of historical distribution records and standardized surveys covering entire assemblages for long periods, say 10–20 years or more (Chapter 26; Shiffer and White 2014; Dalzochio et al., 2020).

Comparison of past and present communities within specific discrete time frames may compensate, at least partially, for the lack of long-term monitoring data. Few studies have compared opportunistic historical data derived from scientific collections and faunistic inventories with re-surveys conducted at the same sites. Although limited by low-resolution historical data, this approach still can provide a coarse assessment of long-term effects of landscape transformations on odonates (e.g. Ball-Damerow et al., 2014; Rapacciuolo et al., 2017; Assandri 2021; Smith and Patten 2021).

However, long-term monitoring remains essential in order to follow odonate diversity trends and detect irreversible transitions between community states driven by human activities (Rodrigues et al., 2016; Dalzochio et al., 2020). Citizen science may greatly help to obtain data and assess trends over extensive geographical areas (Chapters 26 and 29). Although these data generally lack standardization and mostly focus on adult occurrence, recording sex-specific abundance (standardized by search area or time) and evidence of reproduction could greatly increase the scientific value of citizen-science records (Patten et al., 2015, 2019).

18.3 Logging, agriculture, and non-urban secondary habitats

Dozens of land-use activities result in habitat loss and deforestation, impacts to aquatic and riparian systems, and altered odonate diversity. This section focuses on two activities of widespread concern (logging and agriculture) and changes occurring within non-urban secondary habitats.

18.3.1 Logging

Logging is a key global driver of odonate habitat alteration and loss of odonate diversity. Selective logging, the targeted removal of individual trees from a natural stand of forest, is relatively benign because it does not result in deforestation. Modern mechanized extraction, however, can clear large swaths of forest and damage trees left behind. For example, Veríssimo and colleagues (1992) found that a logging operation in the Brazilian Amazon resulted in a loss of almost twice the volume of targeted trees removed. When complete deforestation occurs, cleared areas can then be used for agriculture or be replanted with stands of other trees, typically as monocultures (e.g. oil palm or pine plantations). Timber plantations are repeatedly clearcut, allowing little time for establishment of odonate communities. Studies reviewed by Sahlén (2006) revealed that plantations negatively affected populations and that within the first decade after deforestation, partivoltine species richness (often specialists) decreased while univoltine (often generalists) remained unchanged.

Logging and its associated activities (e.g. road construction, staging areas) are linked with hydrological changes and stress, release of greenhouse gases, increased fire hazards, and loss in soil productivity (Fearnside 2005). These factors and others can directly or indirectly negatively impact aquatic biodiversity, including odonates (Sahlén 2006). Implementation of best-management practices can help reduce the ecological footprint (Calvão et al., 2016, 2018; Luke et al., 2017; Prudente et al., 2017; Cardoso et al., 2018; Mendes et al., 2021), for example, the creation of riparian buffers; however, what constitutes an adequate buffer for odonates requires tailored investigation. Carvalho and colleagues (2018) found that 30-meter zones were ineffective at buffering negative impacts of oil palm plantations to streams and odonate communities. They further observed how reducing riparian zones bordered by pasture shifted odonate composition and decreased richness and abundance, especially of zygopterans. Similarly, Luke and colleagues (2017) recorded fewer adult zygopteran species with increasing forest disturbance around tropical streams. Although oil palm streams with riparian buffers contained depauperate larval assemblages compared to streams in selectively logged forests, they concluded that odonate communities will benefit overall from preservation of riparian buffers within oil palm plantation landscapes. These studies and others indicate that conserving forested riparian zones and determining extent and composition of adequate buffers are key to persistence of forest-specialist odonate assemblages.

Figure 18.3 Examples of features of human-dominated non-urban landscapes. (a) Logging and "slash and burn" clearing of rainforest at a site near the eastern boundary of Palenque National Park, Chiapas, Mexico. (b) Fen meadows were maintained for centuries in Europe by traditional low-intensive mowing practices but are now largely abandoned. (c) Pasture with effectively non–functioning farm pond, Venezuela. (d) Agriculture landscape showing livestock watering trough (foreground) and field (background), Tolfa Mountains, near Rome, Italy. (e) Agricultural field abutting degraded forest in Volcanoes National Park, Rwanda.
Photos (a, c, e) © Brenda D. Smith, (b) © Giacomo Assandri, (d) © Francesco Cerini.

18.3.2 Agriculture

Modern agriculture continues to disrupt and convert native ecosystems and natural landcover such as forests, grasslands, and wetlands (Figures 18.2 and 18.3). Agriculture consists of many land-consuming activities such as farming of crops for human consumption or to feed livestock, along with animal husbandry/ranching activities and associated infrastructure such as farm roads, fencing, slaughterhouses, and storage facilities. Impacts on odonates can come from intensification of agricultural practices as well as their abandonment (Figures 18.2 and 18.3; Kadoya et al., 2009; Reece and McIntyre 2009).

Agricultural fragmentation along with water pollution, drainage, damming, and diversion can severely impoverish odonate habitats and shift odonate assemblages to more generalist species (Delpon et al., 2019; Renner et al., 2018; Giuliano and Bogliani 2019). The most acute problems for odonates include:

1. Extraction of water for irrigation and livestock needs, which affects hydroperiod and surface/subsurface water levels and flow (Clausnitzer et al., 2012).

2. Use of fertilizers and pesticides, which can be toxic directly or cause eutrophication, oxygen depletion (hypoxia), and excessive macrophyte or algal growth (Hinojosa-Garro et al., 2010; Rosset et al., 2014; Castillo et al., 2006; Nakanishi et al., 2018; Ito et al., 2020).
3. Overuse of soils and overgrazing that can lead to erosion and siltation of surface waters (Epele and Miserendino 2016; Assandri et al., 2020).

Studies on the effects of agricultural abandonment on odonates are rare; however, secondary odonate habitats (e.g. European traditionally-managed wet meadows; see also Section 18.3.3) that were once maintained by agricultural practices deteriorate after abandonment (Figure 18.3), leading to the collapse of odonate assemblages that may include threatened species (Bernard and Wildermuth 2005; Assandri 2021). Among the few reported positive effects of agriculture on odonate communities is creation of farm ponds (for irrigation or cattle-rearing). When allowed to mimic natural states, they can be valuable odonate habitat (Lee Foote and Rice 2005; Raebel et al., 2012; Briggs et al., 2019; Huikkonen et al., 2020), but when overused, they become denuded and have high turbidity and heavy fecal loads. Watering troughs or "cattle tanks" are found in many rural (sometimes urban) areas. These cattle drinking stations are above-ground enclosures (e.g. Figure 18.3) that appear to benefit many rapidly colonizing organisms, including odonates, by near-absence of top predators (e.g. fish), constant water supply, and habitat compensation when built where natural waterbodies are lacking (Stoch 1983; Buono et al., 2019; Cerini et al., 2019, 2020). Primary threats to odonates in troughs are sporadic cleaning (emptying; chemical washing) and modern agriculture making them obsolete (Garcia-Gonzalez and Garcia-Vazquez 2011).

18.3.3 Non-urban secondary habitats

Recent studies have highlighted the importance of previously overlooked man-made (secondary) habitats for harboring diverse odonate assemblages (e.g. Dolný and Harabiš 2012; Harabiš and Dolný 2010; Vilenica et al., 2016a; Tropek et al., 2010). Following the discussion in Section 18.3.2 of agricultural secondary habitats, this section focuses on human-modified waterways and reservoirs, which have proliferated worldwide (Zarfl et al., 2015; Huđek et al., 2020).

By obstructing and regulating flow, dams dramatically alter the "waterscape" (dispersal-connected hydrological landscape for active and passive species) by changing or all-together stopping streamflow and inundating formerly terrestrial landscapes. Prolonged inundation generally limits the cover, diversity, and structure of shoreline and littoral macrophyte beds (Geest et al., 2005). Because macrophyte structure is important for adult and larval activity and required for life-cycle completion in many Odonata species (Corbet 1999), it is not surprising that reservoirs with high daily or seasonal water level fluctuations have lower odonate diversity than those with limited fluctuations and well-developed riparian zones and macrophyte beds (Figure 18.4; Balzan 2012; Vilenica et al., 2016a, 2020a).

Debate exists as to whether reservoirs can mimic natural lakes in ecological structure and function. There are clear hydrogeomorphological differences between the two that drive different states and trajectories in aquatic community structure (Samways 1989; Clark and Samways 1996; Wetzel 2001; Irz et al., 2006; Balzan 2012; Vilenica et al., 2016b, 2020a). When constructed in areas with few or no natural lakes, as they often are, reservoirs can bring about drastic species turnover (Suhling et al., 2006; Smith and Patten 2021).

Reservoirs built on rivers are inhabited predominantly by lentic species, especially widespread and abundant generalists (Khrokalo and Prokopov 2009), although lotic species that can reproduce in well-oxygenated lentic systems can also occur (Vilenica et al., 2020a), particularly at the river's inlet into the reservoir. A mixture of lentic and lotic odonate species is often present below dams along outflows. Odonates can be negatively affected by channelization and flow regulation, along with effluents such as pesticides, pharmaceuticals, sewage, and industrial and domestic waste (Previšić et al., 2020, 2021; Vilenica et al., 2020b; see also Chapter 26). Occasionally, anthropogenically altered streams, including reservoir drainage channels, can be important habitats for threatened lotic species (Chapter 28; Harabiš and Dolný 2015).

18.4 Urban landscapes

For the first time in history, over half of all humans reside in urban areas (Grimm et al., 2008). From even a cursory examination of aerial views of these landscapes it is evident that they have a large ecological footprint and are homogenous environments with little "green space" and limited resources for breeding odonates (Figure 18.5). Thus, odonate taxonomic diversity is constrained locally and across sites, promoting disturbance-tolerant and generalist species (e.g. Willigalla and Fartmann 2012; Ball-Damerow et al., 2014; Goertzen and Suhling 2019). In some cases, species of conservation concern are present (e.g. Goertzen and

Figure 18.4 Suitable (left column) and unsuitable (right column) man-made lentic habitat for odonates. Croatian non-urban reservoirs: a) Ponikve reservoir, in the Dinaric western Balkan ecoregion; b) Čakovec reservoir, in the Pannonian lowland ecoregion. Urban recreational/ornamental reservoirs in Croatia: c) Jarun lake, in Zagreb City; d) Šoderica lake, near Koprivnica Town. Two stormwater retention ponds located in Canada: e) 36-year-old pond; f) 1-year-old pond.
Photos (a, b, c, d) © Natalija Vučković; (e, f) © Mary Ann C. Perron.

Suhling 2013; Simaika et al., 2016) but they may not successfully reproduce (see Section 18.4.3). Monitoring urban and suburban odonate assemblages over time is important as changes in species composition can reflect habitat quality and status (e.g. source vs. sink) and indicate biotic homogenization (Powney et al., 2015).

18.4.1 Water in urban landscapes

Although not able to replace natural habitats, man-made aquatic features can provide unique opportunities for promoting biodiversity within cities. Some urban waterbody creation is even motivated by and designed specifically for dragonflies (see Chapter 29). However, urban water bodies are usually created for ornamental or recreational purposes and feature heavily landscaped or otherwise managed surroundings and homogeneous built shorelines (Figure 18.4). The composition and structure of aquatic and terrestrial vegetation plays a significant role in maintaining odonate diversity across the urban landscape (Goertzen and Suhling 2013; Jeanmougin et al., 2014; Perron et al., 2021). An overall lack of vegetation and environmental heterogeneity may filter Odonata assemblages to mainly generalist species (Villalobos-Jiménez et al., 2016; Vilenica et al., 2020a,b). Furthermore, the highly fragmented urban matrix poses significant barriers to dispersal that, depending on amount and connectivity of green space and surface water, may isolate odonate populations (Sato

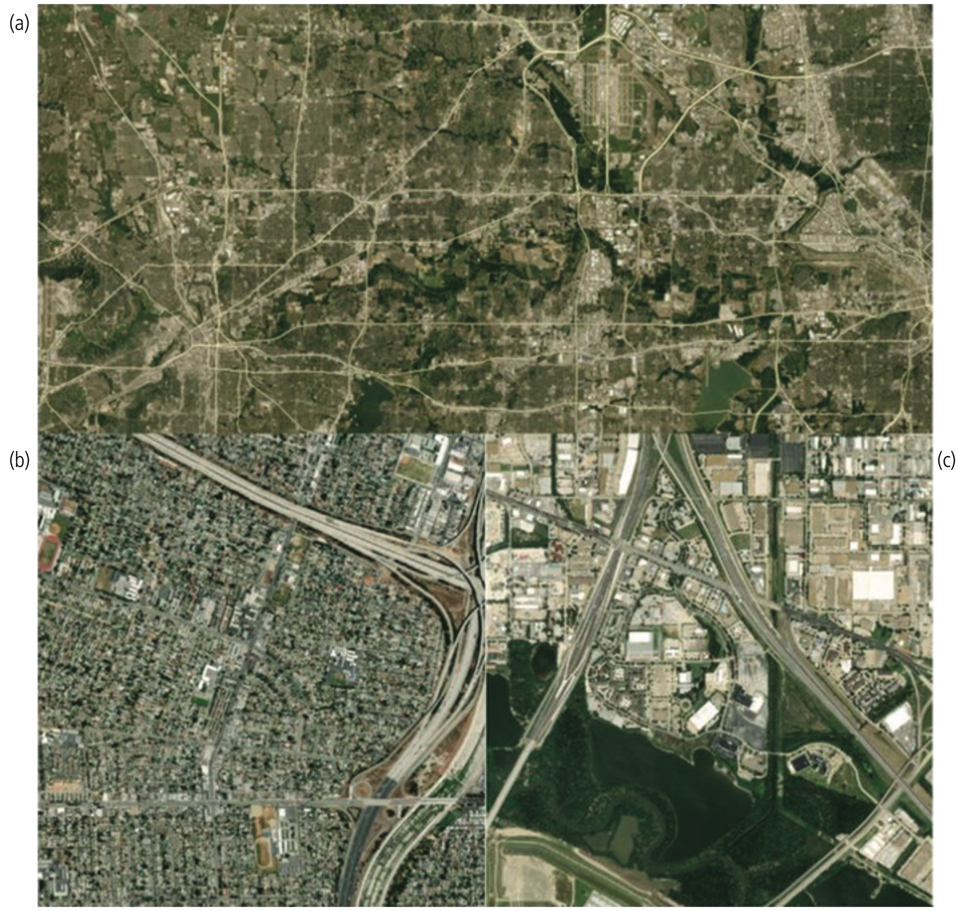

Figure 18.5 Where does the urban landscape end and the non-urban begin? Furthermore, what is a "green" space? (a) Some biodiversity studies of urban landscapes examine spaces that lie within cities themselves, whereas others will include or focus on infrastructure that lies beyond central urban cores (such as highways). Therefore, caution must be used when comparing "urban" studies. Likewise, comparison of homogenous versus heterogenous urban areas, that is, those (b) without and (c) with green spaces, is like comparing apples to oranges. Even in cities with "green" space, one must take special consideration of aquatic-dependent species such as odonates and the water available within green spaces.
Scale: (a) 1:250,000; (b, c) 1:20,000.

et al., 2008; Hassall 2014; Lorenzo-Carballa et al., 2015; Deacon and Samways 2021).

Urban ponds specifically designed for collecting urban runoff and mitigating floods in cities, known as stormwater ponds, can be important habitats for Odonata. Stormwater ponds are often ubiquitous in cities across North America, Europe, and other geographical regions. Initial design significantly affects habitat quality for Odonata, with some able to attract and sustain diverse assemblages and provide for life-cycle completion (Hassall and Anderson 2015; Johansson et al., 2019; Perron and Pick 2020a). The diversity and structural complexity of urban pond macrophytes is a major determinant of adult and larval odonate community structure, often overriding the influence of water quality and surrounding land cover (Johansson et al., 2019; Perron et al., 2021). Permanent stormwater ponds, known as retention ponds (Figure 18.4), are readily colonized by a suite of adult odonates (Perron and Pick 2020a), whereas temporary stormwater ponds, known as detention ponds due to their periodic drying, are generally limited to species with fast-developing larvae.

Aquatic features in urban landscapes are generally more polluted than their rural counterparts (Frost et al., 2015; Perron and Pick 2020b). Surface runoff in urban environments affects water quality and introduces pollutants (fertilizers, pesticides, household chemicals, antibiotics, hormones, trace metals, nutrients, etc.) harmful to odonates. Urbanization tends to increase water temperature and pH and decrease dissolved oxygen concentrations, stressing larval development and limiting diversity (Corbet 1999; Rychla et al., 2011; Suhling et al., 2015). Nitrate, a common urban contaminant often sourced from fertilizers and wastewater, was negatively associated with odonate larval richness and abundance in wetlands across southern Brazil (Maltchik et al., 2010). Urbanization-related pesticides and polycyclic aromatic hydrocarbons have reportedly caused physiological stress and DNA damage in odonates (Villalobos-Jimenez et al., 2016; Meland et al., 2019). High chloride concentrations, often derived from road salts in temperate cities, can alter odonate species composition and abundances and decrease their immune response (Mangahas et al., 2019; Perron and Pick 2020b).

There is some evidence that urban populations of larval odonates can adapt to contaminant levels (Tüzün et al., 2015), and odonate larvae are considered at least moderately tolerant of metal toxicity and poor water quality in general (Hilsenhoff 1987; Heier et al., 2013; Tippler et al., 2018; Buczynska and Buczynski 2019). However, odonates can accumulate trace metals and contribute to biomagnification (Chapter 26; Nasirian and Irvine 2017), and interactions among contaminants may amplify their negative effects on odonates (Heier et al., 2013). Moreover, tolerance of pollution and other human disturbance varies widely across odonate species, and indeed their broad range of environmental sensitivity is one of the main justifications for using odonates as bioindicators (Chapter 26) and management indicators (Chapter 28).

18.4.2 Urban heat island (UHI) effect

A special consideration in urban environments is the urban heat island (UHI) effect characterized by increased environmental temperature in cities compared to rural surroundings due to anthropogenic heat emission (from buildings, transportation, etc.) and land cover changes (less vegetation cover and more impervious surfaces that decrease albedo). Although explicit studies of UHI and odonates are limited, effects of thermal stress are well documented (Chapter 8) and research interest in phenological, physiological, and behavioral responses is growing. For example, Villalobos-Jiménez and Hassall (2017) found community-level flight period advances and contractions in urban areas compared to rural surroundings. Phenological responses of species differed according to life history traits such as emergence timing and egg diapause—spring species and lack of egg diapause produce an early emergence in response to increased temperatures, whereas summer species and species with obligate egg diapause respond to UHI by contracting the flight period (Villalobos-Jiménez and Hassall 2017). Community changes in traits linked to body size, though not yet shown for Odonata, have been observed for other taxa in urban heat islands (Merckx et al., 2018).

Eventually odonates may adapt to UHIs. Tüzün and colleagues (2017) compared the thermal performance curves (TPCs) of growth rate and survival between urban and rural populations of *Coenagrion puella* and found differences in response to UHI. The TPCs for growth rate shifted vertically, which corresponds to the faster-slower theoretical model where cold-adapted rural larvae grew faster than the warm-adapted urban larvae (other studies are contrary, e.g. Suhling and Suhling 2013). Similarly, urban larvae showed a higher survival, most likely due to the costs of rapid growth. Considering this was a result of a common-garden rearing experiment, TPC differences suggest that UHI imposes a strong selective pressure upon urban populations and may drive life history evolution in urban-rural landscape gradients.

18.4.3 Urban ecological traps

Cities have abundant ecological traps for odonates, partly because these environments undergo rapid change, leaving odonates with insufficient time to adapt. Ecological traps are low-quality habitats that fail to meet species' requirements for life-cycle completion yet are mistakenly perceived as more "attractive" than high-quality habitats (Schlaepfer et al., 2002). Reproductively mature adults may arrive, but offspring survival and fitness are jeopardized (Sievers et al., 2018). Odonates select reproductive habitats based on various visual cues including degree of horizontally polarized light (HPL) reflectance. In urban areas, various dark reflective surfaces resemble HPL cues for oviposition, such as cars, parking lots, sidewalks, solar panels, glass, and polished gravestones (e.g. Horváth and Csabai 2014). Although ecological traps for odonates have been documented in agricultural landscapes (Šigutová et al., 2015), further studies are needed to determine the ecological trap potential of common urban aquatic features (e.g. stormwater ponds) for odonates.

18.5 Challenges and future directions

Investigations of community responses to natural vs. anthropogenic environmental heterogeneity are still needed for odonates. Variations in environmental gradients (e.g. climate, pH, hydrology) have caused range shifts and changes in community structure (Simaika et al., 2016; Oliveira-Junior et al., 2019; Dalzochio et al., 2020; Li and Park 2020; Barzoki et al., 2021), probably in conjunction with often ignored factors such as biotic interactions, phenotypic plasticity, and colonization–extinction processes (Chapter 17). Unraveling the effects of human activity from background (natural) variation, while also paying attention to life stages and spatial scale, will continue to be a challenge into the future.

Odonata functional traits may be indicative of modified landscapes, for example, species with smaller body sizes, endophytic oviposition, and longer pre-reproductive phases appearing more sensitive to landscape fragmentation and physical alteration (Kadoya et al., 2008; Pereira et al., 2019). Trait-based community ecology offers possibilities to predict relative extinction risk among species and examine whole community responses to environmental change (Chapter 24; Start et al., 2018). Using trait-based and phylogenetically controlled methods to model odonate assemblage patterns and dynamics in response to landscape degradation is a challenge for the future.

How Odonata respond to climate change has rightfully received a lot of attention in recent years (Chapter 27), but other environmental "noise" may also be obscuring odonate community responses in human-modified landscapes, such as historical context. Few studies look beyond the past one or two decades of land-use history. This is a major omission in need of remedy, especially considering how feasible historical landscape and odonate assemblage reconstruction now is. We have powerful tools and extensive data at our disposal to provide deeper and more dynamical understanding of how the interplay between past and present land use continues to shape odonate communities.

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