A Study on Microclimate characteristics and energy balance within near-river riparian systems

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Abstract: Riparian microclimate studies are gaining increasing attention due to their close ecological, climatologic and aesthetic interactions with lives in both natural and urban areas. Historically, many researchers studied thermal regimes of rivers and river temperature responses to different management strategies. Near-river microclimate characteristics and relevant energy balance were not fully understood. This review documents recent research on near-river microclimatic features and energy exchanging processes, roles of macroclimate, rivers, riparian vegetation and topography play in microclimate mitigation, their ecological importance in terms of biodiversity support and human thermal comfort promotion. It also emphasizes potentials of studies on integration of rivers and plants, as well as their controls on heat exchanging. This study is hopefully useful for river scholars to strengthen the comprehension for further research, as well as for river designers and managers to make informed decisions of sustainable urban development.

1. Introduction
Riparian areas refer to places extending from the water edge to uplands where vegetation is no longer influenced by elevated water tables, flooding, and soil moisture capacity associated with the water body (Bulliner, 2011). Despite of none science-based criteria and standardized definition of riparian zones (Brooks and Kyker-Snowman, 2009), they are regarded as important biologically transitional zones between aquatic and upland terrestrial systems, since reciprocal exchanges on mass, energy and information occur between them. This allows them exhibit unique microclimatic characteristics and function as suitable habitats with distinctive biotic communities (Bulliner, 2011). Furthermore, urban riverine systems represent one of arenas with increasing relevance for public daily interactions, recreations and engagements (e.g., casual walking, wildlife watching and cycling). Comfortable thermal riparian microclimate prevents individuals, particularly the elders, from extreme heat discomfort or even health problems within a certain distance, promoting both their physical and mental health. However, worldwide riparian microclimate is severely impacted as the agriculture, timber harvesting, channelization or other human modifications. Considering this, it is of great importance to clarify the riparian microclimate features and its key physical parameters, as well as its underlying driving mechanisms, which provides information to city designers, architects, engineers and policy makers regarding sustainable environment (Toparlar and Blocken et al., 2017).
Research on temperatures and thermal dynamics of water environment to explore optimal riparian management strategies has already been well reviewed (Caissie, 2006; Webb and Hannah et al., 2008). Hence, this paper will be targeted on near-river riparian microclimates only, instead of in-river or above-river environment. It is well established that large water bodies could affect surrounding land temperatures by air convection and their thermal dynamic characteristics of the coastal climate are fully understood (Gunawardena and Wells et al., 2017; Moyer and Hawkins, 2017). Research is on-going regarding to the riparian microclimate regimes and heat balance of surrounding land areas along small water bodies, especially rivers and streams.

Therefore, this study is proposed to review studies on microclimate and thermal regimes in terrestrial zones located adjacent to rivers or streams, in order to identify current research interests, achievements and potential research directions. The specific objectives are to 1) clarify riparian microclimate features and underlying heat balance; 2) discuss factors affecting riparian microclimate and thermal balance; 3) explore the ecological importance of unique riparian microclimates, and 4) analyze main methods applied in this field.

2. Riparian microclimate characteristics and energy exchanging

Substantially differed capacities in absorbing radiation, portioning energy and transporting water vapor between aquatic and terrestrial systems mainly come from 1) physical features of water (low albedo, high transmittance and specific heat capacity); 2) river flows transporting heat through convection and evaporation; and 3) “wind channel” favoring by flat surface and less airflow resistance (Gurnell and Lee et al., 2007; Mou, 2013).

2.1. Riparian microclimate characteristics

Relevant studies substantiate the edge effect of water bodies permeating upslope into drier upland areas, forming a river-to-interior gradient of environmental parameters-air temperature (Ta), relative humidity (RH) and wind speed (u), of which Ta and RH are proven to be driven factors of the cooling effect (Gunawardena and Wells et al., 2017). Previous studies explored extents and magnitudes of their cooling effects in either natural or urban riparian areas (Dong and Chen et al., 1998; Anderson and Larson et al., 2007; Rykken and Chan et al., 2007; Syafii and Ichinose et al., 2016). For natural areas, they were mostly focused on undisturbed forests or moorlands. While for urban ones, microclimate in both riparian green space (Yang and Tang et al., 2004; Ji and Zhu et al., 2012; Ji and Zhu et al., 2012; Ji and Zhu et al., 2013; Xin and Kinouchi, 2013) and a larger scale-residential blocks (Endalew and Debaer et al., 2010; Hathway and Sharples, 2012; Park and Lee et al., 2019) were measured. However, Ta and RH are far from enough to indicate riparian microclimate characteristics.

Apart from cooling effect, rivers could offer a source of water vapor, and act as a thermal source during night and cool season. Many studies exhibited the warming effect of urban water bodies (Steeneveld and Koopmans et al., 2014; Moyer and Hawkins, 2017; Tsai and Young et al., 2017). Hathway and Sharples (2012) proposed that cooling near the river was only significant during the day. However, the critical point and counterbalance between cooling and warming effect of urban rivers remains to be further studied. Limited cooling effects at daytime and warming effect at night of small urban waters were also confirmed by (Jacobs and Klok et al., 2020) through simulation, but they focused on the small water body itself, other than the whole river-to riparian environment.

Currently, gradients of aboveground riparian microclimatic indicators were mostly examined horizontally extending from rivers to uplands. Supported by many researchers (Danehy and Kirpes, 2000; Olson and Anderson et al., 2007; Rykken and Chan et al., 2007), trans-riparian gradients of microclimatic parameters (Ta and RH, particularly) were found typically non-linear with sharper changes near-river. But the specific inflection points varied significantly, depending on many factors such as river widths, topographies and vegetations. For example, temperature changes with distances were greatest within 10m of stream center and temperatures were relatively constant beyond 10m (Anderson and Larson et al., 2007), but near-stream RH gradients for riparian areas on the east side of the Cascades were strongest in the first 5m from the stream. Unlike horizontal testing, aboveground
vertical measurements seem to be neglected except Rambo and North (2008) who investigated diurnal and seasonal changes of riparian forest canopy temperature and RH. Considering this, how aboveground factors change from forest canopies to ground surfaces remains to be further studied.

2.2. Heat exchanging process in riparian zones

Energy fluxes, quantifying two basic processes-water vapor cycling and heat exchanges within riparian zones, are fundamental features determining the formation of microclimate. As the primary factor driving heat and water exchanges in soil-air systems, \( R_n \) is the fundamental energy source for all physical processes and phenomenon occurred in riparian zones (Hathway and Sharples, 2012). A series of energy partitioning occurs when it enters earth through air. The extent and magnitude of rivers ameliorating microclimate relay on how radiant energy is partitioned and distributed (Sun and Chen, 2012). Thus, the heat balance of a river is associated to the sensible, radiative and latent heat fluxes between it and the surroundings. Energy exchanging are coupled by water evaporation and vegetation evapotranspiration (Taghvaeian, 2011), that is, water vapor transportation is accompanied with latent heat, while heat balance affects the process of water transportation. The mutual function of turbulent heat exchanging and evapotranspiration in near-river sites makes its microclimate conditions locally wet and cool (Syafii, 2016). Thus, comprehensive understanding processes and influence factors of energy exchanging is the prerequisite of study on mechanism of riparian microclimate formation and alternation.

Currently, observations of water and heat fluxes coupling in the field of riparian ecosystems are surprisingly limited (Zhang et al. 2014), most focused on qualitative analysis (short-term and long-run on-site observation and measurements). Kim and Baik (2004) found that the stream has changed sensible and latent heat flux, thus, mitigating the temperature in Seoul, Korea. Song (2011, 2016) studied the daily and seasonal changes of flux transfer in urban riparian zones of Harbin, China, and regarded solar radiation as principal factors influencing urban riparian microclimate. In natural systems, Garner et al. (2014) provided a unique long-term perspective on riparian microclimate and energy exchanges in semi-natural forest and moorland reaches, and found the role of wind speed and cloud cover on heat exchanging.

Surface energy partitioning in the riparian zones varies daily, seasonally and yearly with the fluctuation of available radiation, temperature, vapor pressure deficit (\( VPD \)), soil moisture and precipitation pattern due to the high climatic variability (Zhang et al. 2014). Guenther et al. (2012) found that riparian zone became more strongly coupled to ambient climatic conditions after forest harvesting as a result of increased ventilation. Hannah et al. (2008) illustrated the seasonal patterns in stream energy budget of mixed woodland, providing a process basis to model stream thermal impact of changes in forest practice. Continued research is needed to fill gaps in heat and water transmission processes as well as their temporal and spatial distributions within near-river sites.

3. Factors affecting near-river microclimate and energy exchanging

Within a smaller scale, scopes of near-river microclimates, the changes of microclimatic gradients and within energy exchanging processes are presumably influenced by alterations and interactions of multiple factors (Anderson and Larson et al., 2007) (Fig. 2), including water body itself (Moore and Spittlehouse et al., 2005), the topographic and geomorphologic features (Rambo and North, 2008), vegetation conditions (Broadmeadow and Nisbet, 2004) and macroclimate of the region (Olson and Anderson et al., 2007).

3.1. Macroclimate conditions

Microclimatic features or thermal exchanging of near-river site along river with various classifications, management levels and land-use types were examined. In one hand, natural headwater or streams of natural sites predominated in temperate zones including North America and Europe (e.g. Rykken and Chan et al., 2007; Seena and Carvalho et al., 2017), indicating an absence of diversity in study locations. Headwater functions as microclimate resources, affecting downstream riparian areas yet particularly vulnerable to harvest disturbance (Rykken, 2005). In the other hand, urban riparian microclimate studies
are getting increasing popularity in mid-latitude areas in northern hemisphere, e.g., Japan (Xin and Kinouchi, 2013), England (Tsai and Young et al., 2017), and China (Du and Song et al., 2016). Comparative measurements along small water bodies with different shapes on their micro-environment were conducted. In the urban context, microclimate was measured mostly during warm season (between June and September) in subtropical climate. Latitude determines the relative position of the Sun which is described by the azimuth angle and the elevation of the Sun, and thus, determining the duration of the whole riparian systems being heated (Roderick and Farquhar et al., 2001). Considering this, regionally specific research at other latitudes is also needed where geophysical and climatological distinctions exist.

Total solar radiation that the site receives varies under different meteorological conditions. Overcast leads to the reduction of solar radiation intensity, the modification of the ratio of diffuse and direct radiation. Currently, near-river microclimate was mostly examined in fair-weather days (days with more than 80% sunshine) (Moriwaki, 2004). It is hard to tell whether and to what extent microclimate regulation does occur in overcast days. Results of relevant studies remain viability due to the differences between geological conditions, research methods and riparian vegetation.

3.2. Rivers
Regarding the river itself, its size (width), depth, flow velocity and channel orientation are found strongly associated with its ability of microclimatic regulation. The size of water bodies exhibits a positive effect on both the range and magnitude of river cooling effects (Du and Song et al., 2016) and wind effect (Zeng and Zhou et al., 2017). This is consistent with Ji et al. (2013) who monitored microclimates of riparian green space along 7 rivers, width of which ranged from 8m to 64m during spring to autumn. In one hand, the expansion of rivers increases the evaporation and convection area of water surface, favoring latent heat exchanging other than sensible heat between water and the air (Zeng and Zhou et al., 2017). In the other hand, wider river absorbs and accumulates more heat, promoting energy flow and water vapor cycling. Yet the quantitative relationship between river depth and riparian microclimate has been rarely studied.

Orientation of the river channel, indicating its relative position to the sun, is important to the amount of riparian vegetation shading and attenuation of wind (Davies-Colley and Payne et al., 2000; Broadmeadow and Nisbet, 2004), thus influencing the key energy and hydrologic fluxes. Sanusi and Johnstone et al. (2016) demonstrated the dominant role of the Sun’s zenith in microclimate effects. Along east-west rivers oriented in the same direction as the Sun’s zenith, a south-facing (north-facing) riparian tree canopy cover could accept solar radiation exposure for much of the daytime in the northern (southern) hemisphere. Whereas, in a north-south river, solar radiation was not able to transmit under tree cover in the early morning or late afternoon. Dignan and Bren (2003) found light penetration at 10m of riparian ash forest in Australia greater for buffers face to the equator than for other directions. Except from interception of solar radiation, the orientation is also related to prevailing wind conditions which will alter the extent and magnitude of riparian microclimatic patterns changing. Cooling effects were shown non-linear with changes of wind directions (Theeuwes et al., 2013), and rivers provided increased cooling in downwind areas (Syafii and Ichinose et al., 2016). This can partially explain why, for instance, downwind cooling studied by Anderson et al. (2007) of the Ota River in Japan reached hundred meters.

3.3. Riparian vegetation
Riparian areas support various development status of vegetation and supply moisture for their transpiration. Its role in microclimate mitigation has been thoroughly studied and reviewed (Salata and Golasi et al., 2017; Topalvar and Blocken et al., 2017). Vegetation modifies microclimate mainly through three ways: 1) shading intercept direct solar radiation; 2) ventilations by reducing lateral airflow and 3) evapotranspiration through physiological activity (Boukhabl and Alkam, 2012; Ghani and Ariffin et al., 2017). The synergistic function on microclimatic mitigation of vegetation and water were stressed by Xu and Wei et al., 2010; Zeng and Zhou et al. (2017).

In studies regarding natural riparian systems, distance-from-river microclimatic gradients and comparison of vegetation types are two principal aspects. It is found that vegetation removal led to a
4.4°C increase in $Ta$ (Bulliner, 2011), while up to 6°C higher in open riparian sites than un-thinned riparian stands was monitored (Anderson et al., 2007). Forest and grassland buffers in North America were studied well (Rykken, 2005), the importance of which was recognized by comparing pre- and post-harvesting strategies. Daily $Ta$ in summer was found higher in clear-cut treatments than riparian forest treatments (Rykken, 2005; Bulliner, 2011; Seena et al., 2017), which was easily understood, given that forested canopies shaded and sheltered riparian forests from direct solar radiation and windiness, and increased humidity, reducing evaporative heat loss (Malcolm and Hannah et al., 2004; Rykken, 2005; Eskelson and Madsen et al., 2011). Short-term measurements were conducted only under typical weather in hot summer (Table 1) when changes of environmental variables could be detected obviously, but all-year-round monitoring were applied as well (e.g., Rambo and North, 2008 and Moyer, 2017). Soykan (2007) found the strength of spatial patterns of microclimate gradients along riparian-upland transitions varied with the time of year in southeastern Arizona, America. Comparisons of vegetation types were also researched, mainly among forests and grassland (Welsh et al., 2005; Garner and Hannah et al., 2014). Microclimate and energy exchange processes in forested canopy were more stable between years, which probably because sheltering produced a more moderated turbulent and radiative heat flux between years (Garner and Malcolm et al., 2014). Considering different roles of vegetation and water play in microclimate regulation at different seasons, a counterbalance between edge effects of riparian forests and stream effect might exist, hence appropriate size and width of riparian plant communities is vital to maintain suitable riparian microclimate (Olson, 2007), which needs to be further explored. Microclimate and energy exchange processes in forested canopy were more stable between years than moorlands in natural riparian systems (Garner and Hannah et al., 2014), probably because sheltering produced a more moderated turbulent and radiative heat flux between years (Garner and Malcolm et al., 2014). Effects of forest structures were yet fully understood, since most natural riparian forests were focused on coniferous reaches (Hannah et al., 2008), rarely in deciduous woodlands.

Table 1. Characteristics of studies conducted in natural riparian forests along headwater systems with on-site monitoring methods.

| References | Measurement Intervals | Duration | Environmental Variables | Monitoring points |
|------------|-----------------------|----------|-------------------------|-------------------|
| (Rambo and North, 2008) | 24min | Whole year | $Ta$ and $RH$ | Horizontally 2,7,5,20,30m to rivers; Vertically 2,5,10,20,30,40m aboveground |
| (Welsh and Jr et al., 2005) | 1h | Summer | $Ta$ and $RH$ | Horizontally 0,10,20,30m to rivers; Vertically 2m aboveground |
| (Rykken and Chan et al., 2007) | 3h | Spring and summer | $Ta$, $Ts$, $RH$ | Horizontally 1,10,20,70m |
| (Kirseps, 2000) | 10min | Summer | $RH$ | Horizontally 0.5,10,20,30m to rivers, Vertically 0.5m aboveground |
| (Scott, 2004) | 30min | Spring, summer and autumn | $Ta$, $RH$, $u$, $Rn$, $Ts$, soil moisture and rainfall | Vertically 0.05, 0.10, 0.20, 0.30, 0.50, 0.70 and 1.0 m belowground |
| (Moyer and Hawkins, 2004) | 1h | Whole year | $Ta$ and $RH$ | Horizontally 86-4742 to rivers, Vertically 1.5m aboveground |
| (Guenther and Moore et al., 2012) | 10min | Spring, summer and autumn | $Ta$, $RH$, and $u$ | Vertically 1.5m above water |
| (Brooks and Kyker-Snowman, 2009) | 1h | Spring, summer and autumn | $Ta$, $Ts$ and water temperature | Horizontally 0.5,15,30m to rivers |
| (Rykken, 2005) | 3h | Spring, summer and autumn | Extreme values of $Ta$, $RH$ and $Ts$ | Horizontally 1,10,20,70m to rivers |
| (Anderson and Larson et al., 2007) | 1h | Summer | VPD (min), $Ta$ (max), $Ts$ (max) and $RH$ (min) | Vertically 1m aboveground; 0.15m below ground |
| (Soykan, 2007) | 10min | Whole year | $Ta$, $RH$, $u$ and $Ts$ | Vertically 1.5m |

Note: $Ta$ means air temperature, $RH$ means relative humidity, $u$ means wind speed, VPD means vapor pressure deficit, $Rn$ means net radiation and $Ts$ means soil temperature.
In urban context, shading provided by high-rise buildings near-water and modified local airflow by urban blocks with complex layouts exert an un-neglected influence on riparian microclimate (Park and Lee et al., 2019). Additionally, the juxtaposition of water body and vegetation, are likely to be spatially compressed due to land requirements, in turn forming a modified riparian microclimate and energy cycling patterns compared with natural systems. Variances in abilities of reducing $T_u$ and increasing $RH$ of different vegetation types, coverage and structures (Ji and Zhu et al., 2012; Wu and Na et al., 2013; Tsai and Young et al., 2017) were examined. Vegetation coverage was positively related to the ability of moderation on temperature and humidity (Wu and Na et al., 2013). This helps to explain the mixture of tree-shrub-herbaceous in riparian areas during summer daytime exhibit stronger microclimate regulation than plant communities of tree-herbaceous, shrub-herbaceous and herbaceous only (Ji and Zhu et al., 2012). However, the influences of vegetation coverage exerting on environmental variables is limited. The threshold of vegetation cover percentage has not yet been determined, and specific values might be depended on vegetation types and community structures.

Trees were strongly related to lowering $T_u$, whereas, shrubs affect $u$ (Zheng and Zhao et al., 2016). However, whether it is consistent with plants near-rivers has not been explored yet. Except from $T_u$ and $RH$, $Ts$ is another indicator of energy exchanges between air, plants and soil in riparian systems. Temperature at top 5cm of the soil was influenced more substantially by plant compositions and structures than that at deeper layers, and annual variations in temperature measured at 5cm were more substantial than those at higher depths. Vegetation types and structures affect $Ts$ by influencing energy reaching to the soil. $Ts$ under conifers was found lower than that under broadleaf trees because of lower under-crown height and thus lesser total solar radiation (Zheng and Zhang, 2016). Unlike above environmental parameters, horizontal and vertical gradients of riparian soil temperature were studied.

Structural patterns and configuration of riparian vegetation communities, including widths, heights, densities, ratios of arbor and shrubs, and canopy structures, influence airflow and leaf evapotranspiration within plant communities, thereby, modifying prevailing wind directing cool air and moist from water bodies into upland areas (Hamada et al., 2013). For example, studies of $T_u$ and $RH$ in riparian vegetation with different widths were examined in Beijing (Ji and Zhu et al., 2013), respectively, both showing a positive response to width of riparian green space. Canopy cover is one of principal structural metrics to evaluate riparian understory microclimate since it determines the level of solar radiation received (Broadmeadow and Nisbet, 2004; Tsai et al., 2017). Plant communities were found to affect the gradient variances of riparian microclimate parameters along distances from rivers (Bulliner, 2011). Several studies have explored riparian-upland gradients in microclimate, which were thought to affect ecological patterns and processes. However, there is limited work, to date, on specific processes and mechanisms by which different riparian plant types structures and configuration affect thermal balance patterns within riparian areas. Additionally, the cooling benefits of the river will be diminished when the riparian site is physically cut off from the water by walls or buildings (Cai and Han et al., 2018). Effects of urban riparian landscape elements (complex mosaic of walking paths,) are supposed to be considered in further studies when monitoring riparian microclimate characteristics and energy exchange patterns.

Relevant studies have traditionally focused on simple summary statistics (e.g., minimum, maximum, coefficient of variation, etc.), with recent attention given to the differences of microclimate patterns and driving factors across spatial and temporal scales. Influences of riparian buffers on energy flux, and thus, microclimate characteristics are highly dependent on the variable and the time of the day and season (Rykken, 2005). Two cyclical periods were studied, namely diurnal and annual cycles (Tabari and Sabzizparvar et al., 2011). Different ecological processes happen at different temporal scales, leading to different dominant factors of microclimate variation. Besides, Zheng and Zhang (2016) discovered five domains of temporal scale with wavelet analysis for $Ts$ in urban riparian zones. Summer monitoring on temporal variance of riparian top soil temperature indicated that variation in daily, ten-day, and twenty-day was mainly resulted from total solar radiation difference, while monthly and seasonal variation was driven by riparian vegetation composition and configuration. But, whether longer temporal scales of soil temperature changes exist in urban riparian zones remains to be a debate. The relative importance of distance-from-river and vegetation structure depends on the microclimate variable under consideration,
time of year, and scale of investigation. Weather conditions under which studies were conducted may differ markedly, and they influence differences in microclimate characteristics of a site within riparian zones but also the comparability between researches.

3.4. Topography

Compared to vegetation, less attention has been put on the influences of riparian topography and terrain. Topographic features of riparian sites including gradients of slopes, elevations and aspects and revetment types, et al., are verified to directly influence the intensity and duration of solar energy received, levels of incident shortwave radiation, the reception, retention, and movement of precipitation, and wind exposure, thus the modifying heat fluxes extent of rivers exerting their effects (Hamada et al., 2013). Although various studies were conducted at multiple sites with different site characteristics, they have not explicitly discussed the influences of site variation in their analyses. Topographic factors were proven to contribute relative humidity gradients by Danehy and Kirpes (2000).

Riparian slope is one of main factors influencing effects of microclimate moderation through incident solar radiation at the stream headwater systems (Ramro and North, 2008). Unsurprisingly, the effect is found maximum at low solar angles (Malcolm and Hannah et al., 2004). Topographic constraints imposed by steep side slopes would narrow riparian zones (Moore and Spittlehouse et al., 2005). Besides, in urban context, revetment is another factor influencing water penetrating towards terrestrial land. They might play a role in water vapor cycling and heat exchanging, yet no specific relationship has been established so far. Liu and Lin (2014) measured summer $T_a$, RH, solar radiation and $u$ along different terrain forms of Suzhou River, finding meadow platform and slope performing better than hard surfaces in terms of $T_a$ and RH, while meadow platform performed best in ventilation.

Aspect is also related to riparian microclimate (Chen and Franklin et al., 1993), since it influences the duration and timing of solar radiation interception according to the sun’s zenith. In the northern hemisphere, north-facing slopes receive less net radiation than horizontal or south-facing slopes (Weeks and Wilson, 2006). Changes on the diurnal patterns of $T_a$, RH and $T_s$ were found associated with aspects of riparian forests (Chen, et al., 1993). However, the interactions between aspects and canopy cover depend on the geographical location. Differences of the insolation between north- and south-facing aspects were found greatest at mid-latitudes and diminishes towards the equator and poles (Holland and Steyn, 1975). The aspect of the riparian zones in the landscape in relation to prevailing winds should be considered in making decisions on the width (Gundersen and Laurén et al., 2010).

4. Potential effects of riparian microclimate

Riparian areas generally encompass a more heterogeneous mosaic of habitats, and consequently tend to support biologically distinctive, productive and diverse organisms (Antvogel and Bonn, 2001; Rykken, 2005), in a large part, attributed to soil-moisture influences of the rivers (Brooks and Kyker-Snowman, 2009). Furthermore, in urban cities, thermal regime of riparian systems makes it of great importance in arena provision for both social activities of residents. To maintain fluvial habitat quality and species biodiversity, as well as for the enjoyment of urban population, it is necessary to clarify the ecological significance of riparian microclimate (habitats provision and human thermal comfort).

4.1. Habitats provision and biodiversity support

Riparian microclimate promotes habitat connectivity and biodiversity conservation, through influencing the biological, physical and ecological processes (plant regeneration and growth, soil respiration, nutrient cycling and wildlife habitat selection) (Brooks and Kyker-Snowman, 2009). Alteration of riparian microclimate leads to the changes of water transportation within plant communities, further affecting directly (through physiological mechanisms) or indirectly (by altering the intensity of biological interactions) habitat types that organisms occupy. Numerous studies reported assemblages of riparian flora and fauna communities -vegetative composition (Hagan and Pealer et al., 2006), invertebrates (Rykken and Chan et al., 2007), amphibians (Crawford and Semlitsch, 2007), birds (Bub and Flaspohler et al., 2004) and small mammals (Ford and Menzel et al., 2006).
Gradients in microclimate generally occur over relatively at small spatial scales (Eskelson and Anderson et al., 2013). \( Ta \) and \( RH \) may directly interact with or even determine physiological and morphological characteristics (e.g., structural characteristics, bio-chemical cycling and other successional processes), and gradients in photosynthetically active radiation were found to influence the development of understory vegetation and its spatial distribution. In natural riparian forests, a variety of species and functional groups, including both generalist plant species and riparian-specialized species were found (MacDonald and Chen et al., 2014). Approximate 20% of native vascular plant species were found in riparian areas of southern California, USA (Rundel and Sturmer, 1998). Similar to riparian microclimate, species composition, phenology, structures and productivity of riparian vegetation may exhibit accordingly seasonal viability.

Compositions, structures and distributions of understory herbaceous communities are affected by light accessibility depending on forest canopy closure (Barbier et al., 2008), since soil moisture and nutrients are likely to be less limited in riparian areas (Rykken et al., 2007). Additionally, they are likely driven by river-riparian-upslope gradients of decreasing soil moisture and \( RH \), especially for the occurrence and recruitment for many moisture-dependent species in the near-river areas (Olson and Anderson et al., 2007; Soykan, 2007). Considering the seasonal variance of riparian vegetation, future work should strive to integrate spatial and temporal patterns of vegetation composition.

### 4.2. Human thermal comfort in riparian zones

Urban rivers might construct and/or maintain pleasant microclimate for urban populations, particularly in summers. Thermal comfort is based on the principle of heat exchanges between the human bodies and their surrounding environment (Xu and Wei et al., 2010). Data could be derived from questionnaires, interviews, survey and observations. It varies from person to person depending on factors such as the person’s age, body types, metabolism and, types of clothing. Relevant studies have rarely been conducted in tropical areas, where impacts of urban riparian thermal comfort is likely to be different from other regions and have specific characteristics (Triyuly and Triyadi et al., 2018), since high temperature and humidity conditions affect the evaporation of sweat, thereby damaging the body’s heat balance and causing sensory discomfort (Burton and Snyder et al., 1955). Continued research is needed to fill this gap. Several indexes have been developed, based on corresponding research objectives and scopes, to indicate human thermal status, such as Predicted Mean Vote (PMV), the Standard Effective Temperature (\( SET \), and Physiological Equivalent Temperature (\( PET \)) (e.g., (Xu and Wei et al., 2010; Gajjar and Jai Devi, 2019)). It has been reported that human thermal comfort improved within 10-20m of a water body during a hot summer in Shanghai, China (Xu and Wei et al., 2010). However, they did not directly take mean radiant temperature, which can impact on daytime thermal comfort into account. In fact, individual responses to microclimate will vary under different weather conditions, even if only subconsciously (Yao and Yang et al., 2018).

### 5. Conclusion

Researches on urban riparian microclimate vary significantly in terms of scales, aims, scopes and point of views. Current studies on riparian microclimate exhibit a lack of comprehensive understanding on theoretical processes of energy exchanging, temporal and spatial distribution patterns and their influencing factors, which will help to comprehensively elucidate the mechanisms of riparian microclimate formation. Of much importance is to put forward the rehabilitation, preservation and management strategies of riparian vegetation communities as well as riparian landscape features to expand the river-influenced area in the process of urbanization to optimize the thermal environment. Relationships between characteristics, structures, functional services of riparian microclimate are supposed to be strengthened to provide water-resource managers and urban designers with improved information and tools to sustainably manage this unique system.

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