Monthly river temperature trends across the US confound annual changes

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Abstract

Climate variations and human modifications of the water cycle continue to alter the Earth’s surface water and energy exchanges. It is therefore critical to ascertain how these changes impact water quality and aquatic ecosystem habitat metrics such as river temperatures. Though river temperature trend analyses exist in the literature, studies on seasonal trends in river temperatures across large spatial extents, e.g. the contiguous United States (US), are limited. As we show through both annual and monthly trend analyses for 20 year (n = 138 sites) and 40 year (n = 40 sites) periods, annual temperature trends across the US mask extensive monthly variability. While most sites exhibited annual warming trends, these annual trends obscured sub-annual cooling trends at many sites. Monthly trend anomalies were spatially organized, with persistent regional patterns at both reference and human-impacted sites. The largest warming and cooling anomalies happened at human impacted sites and during summer months. Though our analysis points to coherence in trends as well as the overall impact of human activity in driving these patterns, we did not investigate the impact of river temperature observation accuracy on reported trends, an area needed for future work. Overall, these patterns emphasize the need to consider sub-annual behavior when managing the ecological impacts of river temperature throughout lotic networks.

Keywords

trend analysis; water quality; stream temperature; regulation; water management

1. Introduction

Changing climate, land cover, and water management approaches are fundamentally reshaping pathways of water and heat exchanges around the globe (Jimenez Cisneros et al 2014, Condon et al 2020). Land-based, global mean surface temperatures are warming at historically unprecedented rates (IPCC 2014). Likewise, impervious surface expansions...
in urban areas (Sleeter et al 2013) are altering the timing and rate of water delivery to urban waters (Bhaskar et al 2020), and reducing riparian shading, which increases incoming solar radiation at the air–water interface (Dugdale et al 2018). Water management, including irrigation, dams, and canals, also considerably alters riverine water and heat exchanges (Cai et al 2018). Altogether, these changes are modifying water temperatures now and likely into the future (van Vliet et al 2013, Hannah and Garner 2015, Jackson et al 2018).

Data-driven and model-based studies examining historical river temperature trends around the world demonstrate that riverine river temperatures are warming (Webb 1996, Kaushal et al 2010, Islam et al 2019), though regional cooling has also been observed to a lesser extent (Arismendi et al 2014). Many studies have focused on annual trends. However, temperature-related impacts to hydrology and meteorology—and therefore the aquatic ecosystem—are likely to occur at seasonal and sub-seasonal scales. Quantifying sub-annual trends in river temperatures is particularly important given the strong connections between river temperatures and other sub-annual aquatic dynamics, including stream metabolism, dissolved oxygen reductions, and stream greenhouse gas production (Appling et al 2018, Comer-Warner et al 2018, Song et al 2018). The propagation and mitigation of these impacts demands further investigation of how river temperature trends manifest throughout the year, as this information is necessary to identify likely drivers of these changes.

To address this, we conducted novel monthly trend analyses of river temperatures across the United States (US), comparing monthly results to average annual trends. Overall, we expected the pattern of monthly river temperature trends to mirror the patterns of annual river temperature and air temperature trends across the US. Currently unknown is to what extent seasonal trends in river temperatures are impacted by regulation controls affecting river flow or are organized by physiographic region. We expected monthly trends to be of similar direction (warming/cooling) within physiographic regions except for sites impacted by regulation controls. Our findings provide new insights into sub-annual variations in river temperature trends across a gradient of physiographic regions and human impacts, and the spatial discretization necessary to understand them.

2. Methods

2.1. River and air temperatures

We analyzed trends in monthly-averaged daily maximum and daily minimum river temperature across a 40 year period (1979–2018) and a 20 year period (1999–2018). We assessed maximum and minimum river temperatures, as studies have observed changes to nighttime temperatures are outpacing changes to daytime temperatures (Davy et al 2017). We used the US Geological Survey (USGS) National Water Information System to identify sites with at least 20 years of daily river temperature values, from 1999 through 2018 (United States Geological Survey 2020). Through this process, we identified 138 sites with at least 20 years of observations and 40 sites with at least 40 years of observations (figure 1). Sites were selected to contain no more than 2 years of missing data for 20 year trends and no more than 6 years of missing data for 40 year trends. There were 35 common sites between the two trend periods, as some of the 40 year sites did not meet the more rigorous missing data criteria for 20 year trends. Study sites span the contiguous US and include sites...
that vary in terms of drainage area (minimum: 13 km$^2$, median: 2545 km$^2$, maximum: 240 662 km$^2$) and human impacts (figure 1).

We extracted daily values of maximum and minimum river temperature using the data retrieval package (De Cicco et al 2018) in R (v1.2.5) and averaged them to months. Information on the procedures used by the USGS to generate accurate river temperature measurements can be found in Wilde (2006). As time series for river temperature are notoriously incomplete, we treated months missing more than 50% of daily observations as a missing data value in the analysis. Approximately 129 (of 138) sites were missing less than 12 months of data for analyzing 20 year trends and 28 (of 40) sites were missing fewer than 36 months of data for 40 year trends. Monthly averaged daily maximum and daily minimum air temperature values were also extracted at all relevant sites using the parameter-elevation regressions on independent slopes model (PRISM; PRISM Climate Group 2004, Daly et al 2008). Data was accessed using the R PRISM package (v0.1.0) using R software for all sites (Edmund et al 2020).

2.2. Site classification

We classified sites to enable interpretation of trends in the context of dams and streamflow regulation, urbanization, and agriculture. Each site was classified into one of seven different categories:

- **Reference sites**: sites with limited human impact, as defined by previous work by Falcone et al (2010) and Falcone (2011).
- **Proximally regulated sites**: those within 5 km downstream of a major dam (height of 15 m or greater, or total storage of approximately 6 million m$^3$ or greater; Falcone et al 2010, Falcone 2011) regardless of surrounding land cover.
- **Regulated sites**: those with an upstream dam (but no proximal major dam) and limited developed (<10%) and agricultural (<10%) land cover.
- **Compound stressor sites**: those with an upstream dam (but no proximal major dam) combined with upstream developed (>10%) or agricultural (>10%) land cover.
- **Agri-urban sites**: those with no dam upstream but >20% agricultural and >20% urban land cover.
- **Agricultural sites**: those with no dam upstream but >20% agricultural land cover.
- **Unclassified sites**: sites that were not able to be classified with available information.

At 100 sites, information was drawn from the GAGES II dataset (Falcone et al 2010, Falcone 2011). For these sites, we extracted several calculated metrics, including the distance to nearest dam, distance to nearest major dam, presence of upstream dams, and the percentage of developed, forested, and agricultural land cover. The remaining sites were classified by first delineating each watershed in StreamStats (United States Geological Survey 2021), calculating the distance to the nearest upstream major dam within the National Dams Inventory (United States Army Corps 2019), and extracting developed,
agricultural, and forested land cover percentages (Multi-Resolution Land Characteristics Consortium 2020). StreamStats delineation was not possible for a few sites; in these cases, we identified USGS gages within the GAGES II dataset that are proximal to these sites. We were able to classify all but one site. These classifications are summarized in table S1 (available online at stacks.iop.org/ERL/16/104006/mmedia), with additional classification scheme details described in text S1.

2.3. Statistical analysis

We conducted trend analysis using the nonparametric seasonal Mann–Kendall (seasonal MK) trend test (Hirsch et al 1982). The seasonal MK trend test is a variation of the original MK trend test (Mann 1945) that computes the MK test for each season, and then combines the results to obtain a measure of annual trend significance, direction, and overall strength of the trend (Helsel et al 2020). In our application, a season is equal to 1 month. If strong positive (warming) and negative (cooling) seasonal trends exist in the series, it is possible that these seasonal trends will cancel one another out when aggregating to the annual test statistic. Therefore, little to no trend will be detected at the annual scale, masking important underlying seasonal trends (Helsel et al 2020). As a result, we analyzed both the seasonal MK annual trend results and the trend results for each individual season (i.e. month) (Helsel et al 2020).

We report trends for monthly and annual maximum and minimum river temperatures for a 40 year period, from 1979 to 2018 (n = 40) and a 20 year period, from 1999 to 2018 (n = 138). For sites with 40 years of river temperature observations (n = 40), we also calculated annual and monthly trends for each year from 20 (1999) to 40 years (1979), to investigate how trends change with record length. Trend significance (p-value) is expressed as the probability that the test statistic of the seasonal MK is not significantly different from zero. The strength of the correlation between time and temperature is measured by tau, a measure of correlation that ranges between −1 and 1. Due to the mechanics of its calculation, lower values of tau are equivalent in strength to higher values of the commonly-used Pearson r for linear correlations (Helsel et al 2020). Trend magnitudes are reported as the Sen slope (also known as the Thiel–Sen slope; Helsel et al 2020) in degrees per decade. Trend assessment was performed in Matlab (R2019b; Burkey 2020a, 2020b).

As of 2018, daily river temperature resolution has been 0.1 °C at all sites; however, resolution varied across sites and time given ongoing improvements in sensor technology. To assess whether this shift in resolution impacted annual and monthly trends, we examined a subset of sites (n = 57, 20 years; n = 11, 40 years) for which daily river temperatures were reported consistently at 0.1 °C resolution. For these sites, we rounded daily river temperatures to the nearest 0.5 °C for 1979 through 2007 (40 years) or 1999 through 2007 (20 years), and recomputed all trends. The year 2007 was selected as nearly all sites (87.5%, 40 years; 93.6%, 20 years) contain daily river temperatures at 0.1 °C from this year forward. While the resolution of these observations implies a known accuracy (and shift in accuracy through time), we did not investigate the impact of this accuracy on reported trends.

To explore potential patterns between trends and watershed characteristics, we statistically compared river temperature trends to site drainage area, latitude, and trends in air
temperature (assessed using the same methods for river temperature trends). River
temperature trends were aggregated regionally (following groupings shown in figure 1)
and as a function of site classification (see table S1). Trend distributions aggregated by
watershed drainage area were compared to assess for statistical similarity or difference using
the two-sample Kolmogorov–Smirnov test.

3. Results and discussion

3.1. Similarities and differences amongst annual and seasonal trends

Both significant and non-significant trends in maximum and minimum river temperature
across 138 sites (20 years of record) and 40 sites (40 years of record) overwhelmingly
indicated annual warming (figure 2; figure S1). This was true at 72% (daily maximum)
and 86% (daily minimum) of sites for 20 year trends, and 83% (daily maximum) and 88%
daily minimum) of sites for 40 year trends. We report tau values in table S3. Annual trends
across a subset of sites with long term data were generally static through time (figure S2).
Our measurement accuracy test confirmed similar annual and monthly trend results when
coarsening data from 0.1 °C resolution to 0.5 °C resolution (figures S3 and S4).

Annual 20 year trends were significant ($p$-value <0.05) at more than 40% of sites for
maximum and minimum river temperature observations (table S2). The majority of these
significant trends were positive (81%, maximum; 94% minimum). For 40 year trends, 58%
(maximum) and 68% (minimum) of trends were significant. Again, a large percentage of
these significant trends were positive (83% maximum; 89% minimum). The percentages of
sites with significant warming and cooling trends mirror the percentages found for the entire
dataset.

Twenty-year trends revealed warming river temperatures in most seasons (figure 3; tables
S4 and S5). In aggregate, warming trends in monthly-averaged daily maximum river
temperatures were observed at more than 50% of sites in all but 3 months (April, August,
and November). The same was true for monthly trends in daily minimum river temperatures
except in November. For each month, more than 50% of sites displayed positive monthly
40 year trends (table S6). One caveat to our analysis is that many sites reach or approach
0 °C during winter months. These sites are problematic for annual and monthly trend
analysis because they are more likely to warm than to cool. For instance, many sites display
positive trends during winter months, and especially for the 40 years trend period (figure
3). Regardless, these findings are in line with several studies from the US and around the
world that have shown historical annual and monthly river temperatures have warmed over
the recent past (Kaushal et al 2010, Hannah and Garner 2015, Michel et al 2020, Hare et al
2021).

While aggregated river temperature trends suggest annual and monthly warming is the
dominant pattern across all sites, this relationship did not hold when examining the
persistence of warming trends at individual sites. Few sites unilaterally warmed across
all seasons (figures 2 and S1, table S7). For example, 20 year trends in monthly-averaged
maximum river temperatures increased in all seasons at only two sites. Likewise, only
six sites were found to be warming in all months for monthly-averaged minimum river

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temperature trends. While 40 year trends examined a smaller number of sites ($n = 40$), only two (daily maximum) and three sites (daily minimum) displayed warming trends across all months (figure 3; table S8).

Magnitudes of annual river temperature trends were muted compared to those of monthly warming and cooling trends (figure 2). For example, more than 90% of sites registered annual 20 year trends between $\pm 0.5 \degree C \text{ dec}^{-1}$, yet monthly-averaged maximum and river temperature trends exceeded $0.5 \degree C \text{ dec}^{-1}$ and fell below $-0.5 \degree C \text{ dec}^{-1}$ in at least 1 month at more than 90% of sites. Large magnitude cooling trends were especially pronounced in early spring (April) and late fall (November), and large magnitude warming trends commonly occurred in summer and fall months. While probability would dictate annual trends are muted compared to seasonal responses, these US-wide results underscore the importance of managing water quality impacts at both annual and seasonal scales.

### 3.2. Seasonal trends: patterns and anomalies

Persistent patterns in warming and cooling were observed for nearly all regions for 20 year trends. Though containing only 18 sites, we note that river temperature cooling in 20 year trends occurred for a majority of CA sites in May and December. Likewise, across a small number of sites in the Arid West ($n = 19$), cooling trends for the 20 year period were observed during winter and spring months (excepting March). This is notable because these regions typically receive the majority of annual precipitation during winter months, with May (depending on site elevation) often corresponding to the spring snowmelt season. In reference rivers, there is potential that shifting the timing of snowmelt may alter the timing and temperature of water feeding streamflow (Yan et al 2021). In regulated areas, dam operation likely reflects this shift in inter-annual conditions (Steimke et al 2018). River temperature cooling trends persisted in April, August, and November in the Midwest, April and November in the Northeast, and November in the Southeast. The majority of 40 year monthly trends were positive, though summer cooling persisted during summer at sites in the eastern US (figure 3).

We observed two primary anomalous patterns in seasonal river temperature trends across sites and regions: large magnitude anomalies that were unique to individual sites (figure 2), and anomalies (i.e. large magnitude deviations from zero trend) that were associated with individual sites (figures 3 and S5). For example, while we found general patterns in the direction of trend, many sites uniquely exhibited statistically significant and large magnitude cooling or warming trends for the 20 year record and 40 year record within different regions (figure 4; table S5). The majority of statistically significant trends occurred between late spring and mid-fall and were largest during the summer months for both the 20 year and 40 year record.

Statistically significant anomalies tended to occur at human-impacted sites as opposed to reference sites (figure 4). Across these sites, we hypothesize that the major driver of such anomalous warming and cooling trends is likely streamflow regulation. The mere presence of upstream regulation would not generate a trend; instead, this suggests that changes to dam operation—either as a function of the magnitude and timing of water release or location of water release—are likely generating the observed trends. As reservoirs are thermally...
stratified, the location of dam release may either be hypolimnetic (cold) or epilimnetic (warm) (Olden and Naiman 2010). Additional complexity is introduced because many of these river systems contain multiple dams (e.g. O’Keeffe et al 1990) and experience additional influence from upstream tributaries. Finally, the impact of upstream regulation cannot be truly regarded as independent from climate and weather, as both short-term (a week or less) and seasonal weather forecasts (weeks to months) are regularly used in reservoir operations (Block 2011, Nayak et al 2018).

3.3. River temperature versus air temperature trends

Trends in river temperature are often linked to trends in air temperature, as net solar radiation is a major driver of land surface and river temperatures (Caissie 2006). However, our results demonstrate that while several regions showed apparent correspondence between air temperature and river temperature trends (figure 3), monthly river temperature trend magnitudes did not closely mirror those of air temperatures in most instances. For example, sites in CA and the Midwest displayed deviation from these patterns. In these regions, reference sites were rare, and nearly all sites are classified as impacted by regulation or regulation combined with other land cover impacts.

We found that 20 year trends in river temperature regularly exceeded trends in air temperature, demonstrating that river temperatures are warming at greater rates than air temperatures in many seasons (table S8). We do note that trends in air temperature are expected to deviate from trends in river temperature during winter months for sites with river temperatures at or near 0 °C; in these locations and under these conditions, air and water temperatures are disconnected (Mohseni et al 1998). During summer (June–August), trends in river temperatures (both maximum and minimum) both exceeded or fell below air temperature trend magnitudes, depending on location.

The finding that trends in air and water temperatures differ in magnitude is in many ways unsurprising, as numerous studies have established that the slope of relationships between monthly and annual air and water temperatures are rarely one-to-one (Webb and Nobilis 1997, Erickson and Stefan 2000) and that relationships between air and water temperatures are nonstationary through time (Arismendi et al 2014). The strength of the air–river temperature relationship is modified by a host of site-specific factors, including riparian shading, groundwater buffering, and upstream regulation, among others, as well as evaporation that can cool warm water temperatures as air temperatures continue to rise (Mohseni et al 1998). However, our findings suggest that warming in rivers is outpacing warming at the land surface (vis-à-vis air temperature trends) during unexpected periods of the year—winter, spring, and fall. The differences between the behavior of air temperature and river temperatures may be attributed to the effect of multiple interactive, short-term dynamics superimposed onto longer term variations in streamflow (as well as sources of water to the stream) and human modifications to the upstream or riparian environment. These processes reflect the propagation of a changing climate and other human impacts on the magnitude and timing of hydrologic processes, which thereby impart complex energy exchanges along rivers (Poole and Berman 2001).
3.4. Spatial organization, river size, and human impacts

How do we discern important drivers of the trends we present? This overarching goal of all trend studies remains a challenge. Annual river temperature trend magnitudes at both 20 year and 40 year periods did not appear to be spatially organized (figures S6 and S7), and displayed no strong linear or nonlinear relationships with latitude or drainage area (tables S9 and S10). However, distributions of sites with low (<100 km$^2$) and moderate (100–2000 km$^2$) drainage areas had higher average magnitude trends than those of large drainage area sites (>2000 km$^2$; figure S8). The distributions of trends at sites with small drainage areas versus large drainage areas were statistically significantly different (according to the two-sample Kolmogorov–Smirnov test with a 5% significance level). This empirically suggests that large rivers may be less impacted by climate change than small or moderately sized rivers, or that flow regulations or multiple human impacts, which commonly occur and compound on large rivers, are modulating this warming. This is supported by work that has shown variance in river temperatures (as well as streamflow) are dampened for increasing drainage areas (Caissie 2006). However, given the limited coverage of our sites, more work is needed before this can be definitively concluded. In addition, ascribing causes of such change, in terms of trend magnitude and significance, is challenged by the accuracy of stream temperature datasets. We caution that, due to limited information, our analysis did not investigate the impact of river temperature observation accuracy on annual and monthly trends. The USGS is known to produce data of exceptional quality, though accuracy of observations has likely increased through time, with unknown implications for the trends reported herein.

While human modification of the water cycle is likely to have strong cascading impacts on long-term water quality, we show that distinguishing drivers of these trends can be challenging. Regardless of classification, trends support a common message regarding the response of river temperatures to changing climate and other associated impacts. When trends were organized regionally, patterns in warming and cooling persisted regardless of the type of human impact (figures 3 and S5). This suggests that while magnitudes of trends may differ at regional to national scales, rivers are likely warming and cooling in response to similar drivers (i.e. weather and climate, modulated by reach and watershed form and water management). Likewise, though few of our sites fell into the reference category ($n = 17, 20$ years; $n = 5, 40$ years), reference sites tended to have fewer statistically-significant seasonal trend anomalies and lower magnitude trends as compared to human-impacted sites (figure 4).

Given that a majority of sites with long-term temperature data for analysis are human-impacted, located along large rivers, or both, it is likely that observed trends are a composite of changing climate mixed with human modification of the water cycle, including flow regulation, forest loss, the growing presence of impervious surfaces, varying water withdrawals, changing magnitudes and temperatures of hydrological exchange flows along the river network, and removal of riparian vegetation (Lessard and Hayes 2003, Drummond and Loveland 2010). Many of the anthropogenically impacted sites within our analysis had already experienced modification by 1970, the start of our trend analysis period. Climate change may also impart diverse effects on river temperatures indirectly via its influences on
aquatic energy exchanges, including shifting the timing and magnitude of snowmelt (Dudley et al 2017), changing fractions of precipitation falling as rain versus snow (Berghuis et al 2014), increasing the frequency of floods, droughts, and heatwaves (Armstrong et al 2012, Dai 2013), and changing the frequency and magnitude of precipitation (Mallakpour and Villarini 2017). Further, across long time scales (multiple decades), climate teleconnections can impact river temperature trends (Islam et al 2019).

The potentially large number of interacting drivers affecting river temperature trends spell unclear outcomes regarding the magnitude of changes into the future. Research is needed to quantitatively discern these diverse drivers across sites and especially within reference settings (e.g. Arismendi et al 2012), as the patterns we and others have detected are the complex result of multiple competing factors that may sometimes augment and other times dampen impacts on river water quality.

4. Conclusions

Our findings corroborate that river temperatures in rivers are warming at annual timescales within the US (e.g. Kaushal et al 2010) and add to global documentation of river warming (Hannah and Garner 2015, Michel et al 2020). However, our results uniquely emphasize that focusing on annual trends in river temperature warming alone may obscure complex sub-annual warming and cooling variations occurring in rivers across the US. Given the strong association between water temperature and other measures of water quality, monthly river temperature trends are likely to confer sub-annual shifts in other water quality signals and aquatic ecosystem health undetected by annual analyses.

Around the world, rivers are expected to warm under future climate change (van Vliet et al 2013, Ficklin et al 2014). For this reason, identifying locations in the landscape that are prone to warming over long (e.g. decadal) and short (e.g. heatwaves; Piccolroaz et al 2018) timescales will be of key importance. For example, mountain environments may be buffered against changing climate, potentially because of microclimates in dense riparian cover, contributions from groundwater, and both direct and indirect impacts from snowfields (Isaak et al 2016). However, streams with shallow groundwater signatures are showing higher proportions of warming than those with deeper groundwater signatures presumably due to buffering from these and other factors (Hare et al 2021).

Given data-driven analyses may inaccurately estimate responses of rivers to climate warming (Arismendi et al 2014, Leach and Moore 2019), mechanistic modeling approaches that account for energy exchange alongside hydrological processes are needed to enable future predictions (Dugdale et al 2017). Recent developments in modeling capabilities at global scales are making such simulations possible along larger rivers (Wanders et al 2019), though more work is needed to understand how river temperatures in smaller watersheds will respond, given the complex heat budgets in these areas. Overall, these uncertainties suggest that process-based insight is needed for hindcasting and projecting future outcomes. Such insights will help to identify how complex interactions in the subsurface, at Earth’s surface, and in Earth’s atmosphere can be parsed to interpret historical trends and to predict likely impacts on future river temperatures.
Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability statement

All data and trend analysis codes are publicly available.

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.4211/hs.b3773518e38b454780492d79e3a3f050 (Kelleher et al 2021).

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Figure 1.
Sites assessed for 20 year and 40 year trends in river temperature. Regions shown in this figure are used for grouping and analyzing results (see figures 2 and 3).
Figure 2.
Regional annual and monthly river temperature trends. (A) Annual trends assessed via the MK trend test and monthly 20 year trends assessed via the seasonal MK trend test for monthly averaged daily maximum river temperature shown for six regions. (B) Annual and monthly 40 year trends are shown for eastern and western sites. Monthly trends are shown as line plots, while annual trends are aggregated into box plots (on right-side of panels). Line colors indicate whether annual trends are positive (red) or negative (blue). Numbers within boxplots indicate the number of positive and negative trends, excluding trends equal to zero.
Numbers in boxplot parentheses indicate the number of trends that were significant ($p < 0.05$). Note two sites had annual trends equal to zero. Results for monthly-averaged daily minimum river temperatures are shown in figure S1.
Figure 3.
River temperature trend signs organized by region and human impact. Monthly 20 year (top) and 40 year (bottom) trends for monthly-averaged daily maximum river temperatures (determined via MK) showing the number of sites with positive (Sen > 0) or negative (Sen < 0) trends. While 20 year trends span the conterminous US (figure 1), 40 year trends were only concentrated in the west and eastern US. Black lines indicate the proportion of sites with positive monthly air temperature trends. Fill indicates site classification. Results for monthly-averaged minimum river temperature trends are shown in figure S5. Class ‘other’ compasses one agri-urban site, two agriculture sites, and one unclassified site.
Figure 4. Statistically significant monthly, 20 year Sen slopes organized by site class. Sen slopes are shown for monthly-averaged daily maximum river temperatures. We report the number of sites with statistically-significant trends during any month, with the total number of sites within each class shown next to this number in parentheses. Results for four sites (one agri-urban site, two agriculture sites, one unclassified site) were omitted from the figure.