Using cultural ecosystem services to inform restoration priorities in the Laurentian Great Lakes

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Ecological restoration programs often attempt to maintain or enhance ecosystem services (ES), but fine-scale maps of multiple ES are rarely available to support prioritization among potential projects. Here we use agency reports, citizen science, and social media as data sources to quantify the spatial distribution of five recreational elements of cultural ES (CES) – sport fishing, recreational boating, birding, beach use, and park visitation – across North America's Laurentian Great Lakes, where current restoration investments exceed US$1.5 billion. These recreational CES are widely yet unevenly distributed, and spatial correlations among all except park visitation indicate that many locations support multiple CES benefits. Collectively, these five service metrics correlate with tourism gross domestic product, indicating that local economies benefit from ecosystem conditions that support CES. However, locations of high recreational CES delivery are often severely affected by environmental stressors, suggesting that either ecosystem condition or human enjoyment of these recreational CES is resilient even to substantial levels of stress. Our analyses show that spatial assessments of recreational CES are an informative complement to ecosystem stress assessments for guiding large-scale restoration efforts.

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Ecosystems provide numerous goods and services to human society, including harvestable fish and timber, water purification, and nutrient recycling, as well as cultural services such as recreational and other non-material benefits (MA 2005). Owing to the societal value of ecosystem services (ES) and their frequent degradation in human-dominated ecosystems, service provision is emerging as an important justification for restoration actions (Palmer and Filoso 2009). Mapping of multiple ES and biodiversity targets to visualize relationships and identify locations of spatial overlap has great potential for benefiting natural resource management and conservation (Tallis and Polasky 2009) but has rarely been applied in restoration planning (but see Benayas *et al.* 2009). Instead, prioritization of restoration relies primarily on qualitative evidence of environmental degradation without explicitly accounting for locations of ES (but see Allan *et al.* 2013). Given that ES represent human benefits that restoration is intended to safeguard or improve, understanding the spatial distribution of multiple services – and the benefits derived from them – can usefully guide prioritization among restoration projects (Kareiva *et al.* 2011).

Cultural ES (CES) refer to a wide range of non-material benefits people receive from ecosystems (Milcu *et al.* 2013). As compared with benefits from other ES, these benefits are often directly experienced by the public, making them a powerful justification for ecosystem restoration and investment (Daniel *et al.* 2012). Categories of CES include recreation and the positive effects of natural landscapes in maintaining mental and physical health, as well as the economic benefits, aesthetic appreciation, spiritual experience, and sense of place associated with nature tourism (TEEB 2010). In the Laurentian Great Lakes (GL) region, recreational activities are among the most important CES supported by the lakes (Pearsall *et al.* 2013), forming the core of a major tourism economy.

The GL currently experience dozens of stressors – ranging from toxic pollution to species invasions to climate change – that degrade ecosystem conditions or alter functioning (Allan *et al.* 2013). Concern over ecosystem impairment has led to the investment of more than US$1.5 billion in restoration projects in recent years (www.greatlakesrestoration.us), in the expectation that improved ecosystem health will result in high economic returns (Austin *et al.* 2008). As restoration efforts continue across this large region, maximizing return on those investments will require systematic analysis of the spatial distribution and local intensity of both stressors and services.

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We quantified spatial variation in five recreational CES (sport fishing, recreational boating, birding, beach use, and park visitation) that underpin economic activity in the GL region (WebPanel 1), and assessed the spatial coincidence of these services and identified locations of high total service delivery. Using gross domestic product (GDP) for tourism and recreation (T&R), we tested the evidence for the economic benefits of service delivery, which represent the most quantifiable summary measure of societal benefit from recreational CES. Finally, we analyzed the spatial intersection of our new estimates of service delivery with prior estimates of ecosystem stress (Allan *et al.* 2013) to explore whether restoration efforts could target stressor alleviation in locations where current service provisioning suggests high potential benefits. Our investigations of the GL region illustrate how joint spatial analysis of ES and stressors can inform large-scale restoration programs that seek to boost the societal benefits flowing from healthy ecosystems.

Methods

We quantified and mapped five recreational CES across the five GL and their connecting waters. Data were obtained from agency reports, citizen-science databases, and social media (WebTable 1) for the years 2000–2010. Variables used in our analyses included the annual average number of visits to major parks, number of visits at birding hotspots, number of user days from geotagged Flickr photographs for beach visitation, number of hours of effort for sport fishing, and number of slips at marinas for recreational boating. We compared alternative proxies for these services, such as quantifying boating activities around boat launches, based on the number of parking spaces allotted for trailers, and found these measures correlated with those presented below. We recognize that many other aspects of CES benefit society in the GL region but are not yet accessible to explicit spatial analysis.

To visualize service distribution and assess spatial overlap among services and with economic data, we defined spatial units by buffering the shorelines of counties adjacent to the GL. County polygons extended 5 km inland and 5 km offshore from GL shorelines, and differed in median shore length between the US (62.2 km) and Canada (180.4 km). We summed point data for four services within county polygons and downscaled sport-fishing data from larger reporting units by assuming that effort in each county was proportional to its share of shoreline length.

We compared our measures of recreational CES to economic activity using 2010 county-level data produced by the National Oceanic and Atmospheric Administration's (NOAA's) Economics: National Ocean Watch (ENOW) (NOAA 2012a,b). We focused specifically on the T&R sector (WebFigure 1), which is the one most likely to be related to the services that we quantify. Because establishments in this sector (eg hotels and restaurants in a metropolitan area) benefit from non-GL-related business, ENOW data for this sector are limited to businesses operating in shoreline zip codes (NOAA 2012a). T&R data were available for 78 coastal US counties.

For comparison of recreational CES to county-level GDP, we created a services delivery index for each county by $\log_{10}(x + 1)$-transforming data, normalizing linearly between the maximum and minimum values to express each service on the same 0 to 1 scale, and then summing normalized service scores across all five services. We used percentiles to make comparisons of the recreational CES index across all counties on a relative scale. Although it is difficult to rate the relative value of these five services, each is highly valued (WebPanel 1), and so we used equal weighting to ensure that a location providing only one service could not have a high overall service index. We assessed coincidence among services per unit shoreline length by computing Spearman rank correlations. To explore the relationship between recreational services and economic activity, we also calculated Spearman rank correlations of T&R-based GDP with each service individually, as well as with the service delivery index.

To evaluate the relationship between recreational services and environmental stress, we plotted the service delivery index against cumulative stress estimated by Allan *et al.* (2013) at the county scale. We defined cumulative stress as the weighted sum of 34 individual stressors that potentially affect ecosystem condition (WebTable 2), which we averaged across all pixels (1 km^2) within county polygons. Specific stressors most likely to hinder service delivery were also identified, including invasive species likely to affect fish stocks and nutrient runoff likely to result in beach closings (Table S3 in Allan *et al.* 2013). To compare counties, we calculated the percentile of ecosystem stress relative to all other counties.

All analyses were performed in R 2.12 (R Development Core Team 2010) and ArcGIS 10.1.

Results

Spatial distribution of services

Each of the five recreational CES occurs widely throughout the GL, showing a mix of concordant and distinctive spatial distributions (Figure 1). For example, Green Bay receives high scores for most services, whereas western Lake Ontario near Toronto is heavily used for beaches and boating but less so for other activities. Sport-fishing angler effort was highest in the US waters of lakes Erie and Ontario and throughout south–central Lake Michigan, and some difference in private versus charter effort was evident (Figure 1, a versus b). Recreational boating was highest in the lower lakes and around urban areas such as Toronto and Chicago (Figure 1c). However, marinas were also abundant in some less populated areas, such as Georgian Bay.

Public-access beaches are widely distributed among the GL (Figure 1d), but there are markedly fewer around Lake Superior and northern Lake Huron. Estimated beach use, based on photo-user-days, is highest near cities, but sub-

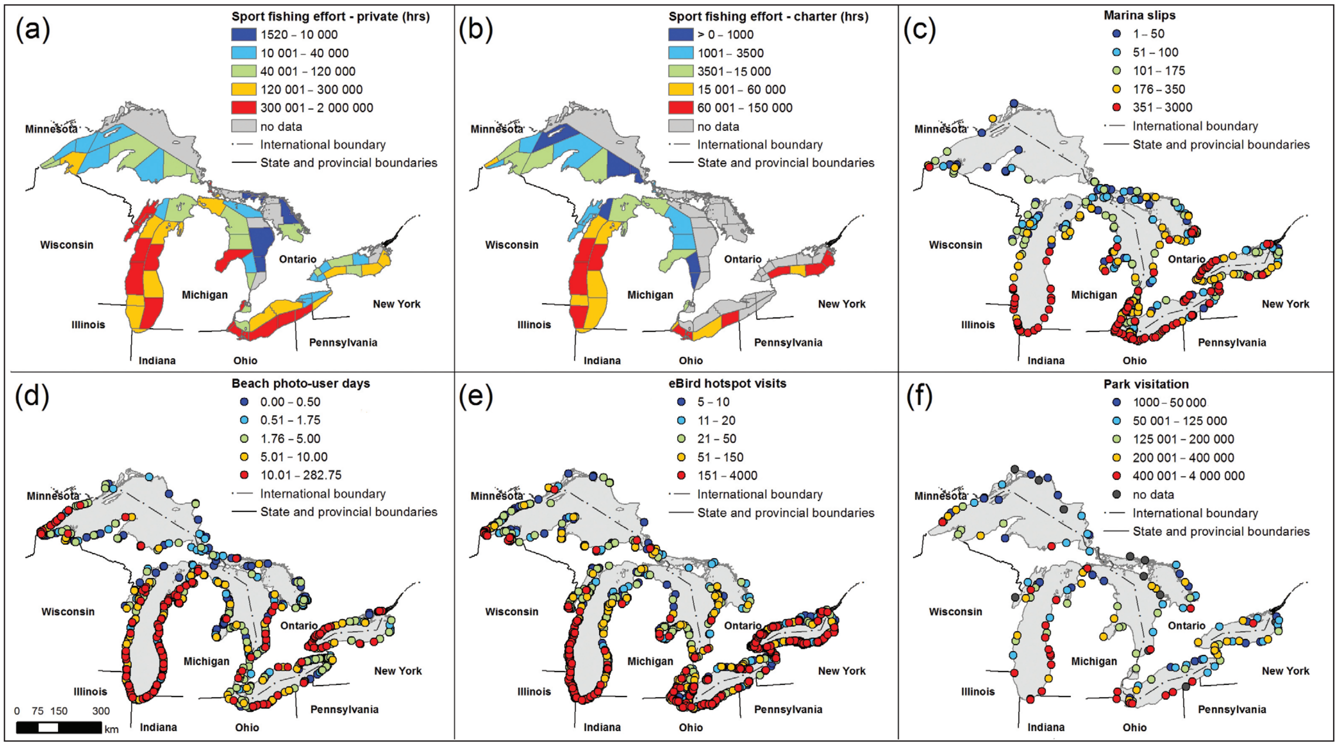

Figure 1. *Delivery of five recreational services in the Laurentian Great Lakes (GL). (a and b) Sport fishing (effort as angler hours) in private boats (a) and in chartered boats (b). Areas lacking data (gray) had low effort. Note the difference in scales between (a) and (b). (c) Recreational boating, based on boat slip counts at 872 individual marinas. Marinas were grouped into 609 locations because multiple marinas shared the same home port. Symbol colors indicate ranges in the number of boat slips per port. (d) The 874 public-access beaches in the GL region, and beach visitation estimated from Flickr photo counts. (e) The 1529 birding "hotspot" sites located within 5 km of GL shorelines and total number of visits, taken from eBird records. (f) The 144 state, provincial, and national parks located within 5 km of GL shorelines.*

stantial lengths of shoreline of all of the GL, with the exception of Lake Superior, have moderate to high values of estimated beach use. Notably, destination beaches, such as Sleeping Bear Dunes National Lakeshore and Warren Dunes State Park in Michigan, have high estimates of usage despite being located in low-population areas.

Highly visited birding locations within 5 km of the shoreline occur around all five GL, indicating that birding is geographically widespread (Figure 1e). Birding sites are abundant around Lake Ontario, most of Lake Erie, and lakes Michigan and Huron, with fewer along the Canadian shores of lakes Huron and Superior, where population is sparser and road access to shorelines is limited.

Annual visitation for the 144 state, provincial, and national parks within 5 km of GL shorelines exceeded 43 million visits (Figure 1f). Highly visited parks occur around all five lakes and in all eight GL states and the Canadian province of Ontario, including sites that are remote from major population centers. Nearly two-thirds of the 25 most visited parks are adjacent to urban populations (>150 000 residents within 30 km of a park), while the remainder are in rural areas (<50 000 residents). Visitation is highly skewed; the top 25% most visited parks host 75% of all visits each year. These high-visitation parks are concentrated along the southern shoreline of Lake Erie and the eastern shoreline of Lake Michigan.

Spatial coincidence of services

Four of our five recreational services were significantly positively correlated with each other (Table 1), whereas park visits were correlated only with beach use. The spatial coincidence of these distinct services suggests high

Table 1. Pairwise correlations among five recreational services for 102 to 107 counties across the Laurentian Great Lakes

	Boating	*Park visitation*	*Birding*	*Beach use*	*Sport fishing*
Boating	1				
Park visitation	NS	1			
Birding	0.688**	NS	1		
Beach use	0.557**	0.230*	0.547**	1	
Sport fishing	0.612**	NS	0.631**	0.357**	1
T&R GDP	0.660**	0.227*	0.684**	0.559**	0.495**

Notes: All values are rescaled to shoreline length and $\log_{10}(x + 1)$-transformed. The bottom row shows the correlation between each service and county GDP (US only, n = 78 counties for most services, but 77 counties for park use) associated with T&R (ie T&R GDP). Rank-based correlations (Spearman's rho) were used in each analysis due to non-conformity to normality assumptions. $^{*}P < 0.05$; $^{**}P < 0.001$; NS = not significant.

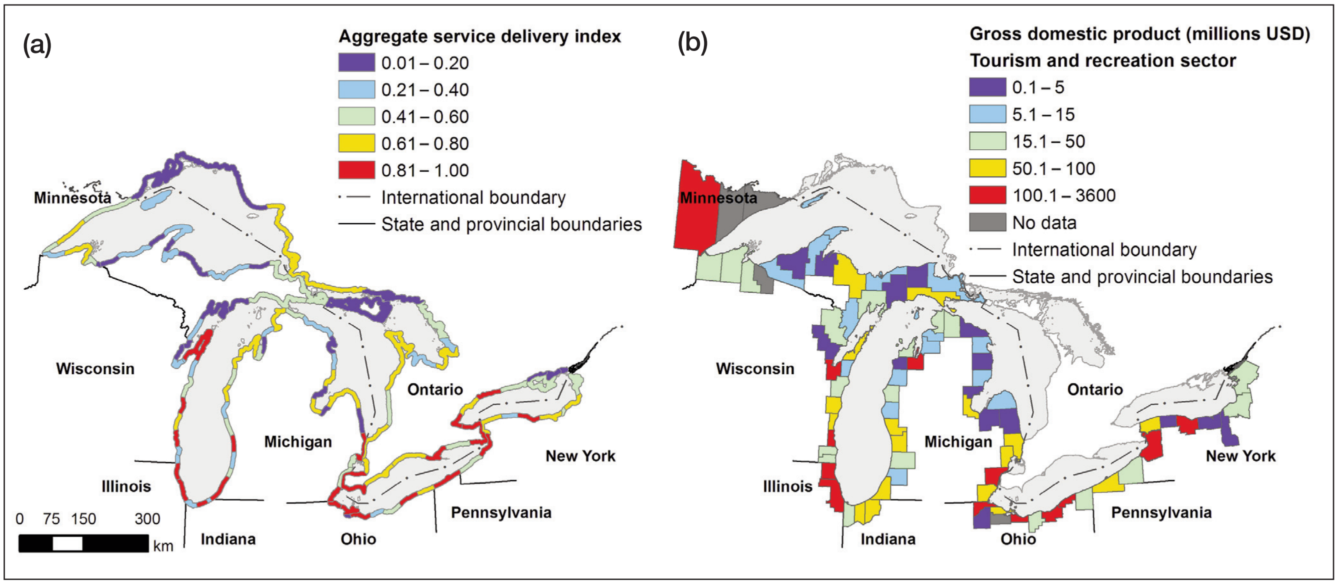

Figure 2. *(a) County-level index of recreational service delivery in the GL, integrating use of five recreational services (sport fishing, recreational boating, birding, beach use, and park visitation). Service delivery is on a percentile scale, ranked relative to all other counties. (b) Gross domestic product for T&R in US counties.*

levels of service delivery at locations where multiple services co-occur. Thus, our service delivery index identifies counties that deliver multiple services to many (Figure 2a), including those found in densely populated areas near Toronto, Chicago, and western Lake Erie, and in more rural recreational destinations, such as Georgian, Green, and Grand Traverse bay.

Coincidence of services with economic activity

In total, US$15.4 billion in GDP was generated within US GL shoreline counties in 2010, based on lake-associated sectors. Tourism and recreation accounted for US$8.3 billion, or 50.2%, of the total, with the remainder attributable mainly to marine transportation (NOAA 2012b). As with service delivery, T&R GDP varied widely among US coastal counties (Figure 2b). Positive relationships between T&R GDP and each of the five cultural services were evident (Table 1), highlighting the economic importance of the GL to shoreline communities. The service delivery index combining all five recreational activities (Figure 2a) was significantly correlated to T&R GDP as well (Spearman correlation, $n = 78$, rho $= 0.64$, $P < 0.001$).

Coincidence of services with environmental stressors

Many possible combinations of environmental stress and recreational service delivery occur in the GL region, as counties high in relative service delivery can be low or high in relative stress (Figure 3a). Locations where both stress and service delivery are above the county medians occur mainly around Lake Erie and Lake Ontario, but high stress/low service and low stress/high service counties also occur around these lakes (Figure 3b). In contrast, all counties bordering Lake Superior experience stress below the median but range widely in relative service delivery. Counties bordering Lake Michigan and western Lake Huron exhibit all combinations of service delivery and stress.

Discussion

Human benefits derived from healthy GL ecosystems, including highly valued recreational CES (WebPanel 1), are the chief rationale for the enormous investments in restoration programs to address food-web disruptions, widespread algal blooms, frequent beach closings, and the much-feared invasion of multiple species of Asian carp (Cyprinidae; Michalak *et al.* 2013; Bunnell *et al.* 2014). As an illustration of the value of recreational visits to lakes, Keeler *et al.* (2015) found that improved water clarity was associated with increased numbers of visits, and that lake users were willing to travel farther and incur greater costs to visit lakes with better water clarity. To date, however, limited understanding of the spatial distribution and coincidence of environmental stressors and CES in the GL has constrained planning for restoration and other conservation actions. Our analyses document extensive spatial variation in individual and aggregate recreational services, and show that T&R GDP values for coastal US counties correlate strongly with our five recreational metrics.

The five direct recreational uses that we have quantified are key motivations for protecting the GL (Austin *et al.* 2008; www.greatlakesrestoration.us) and have high societal value, as is borne out by their correlations with tourism GDP. Yet we also recognize that a wide range of less tangible CES provide benefits to society in the GL

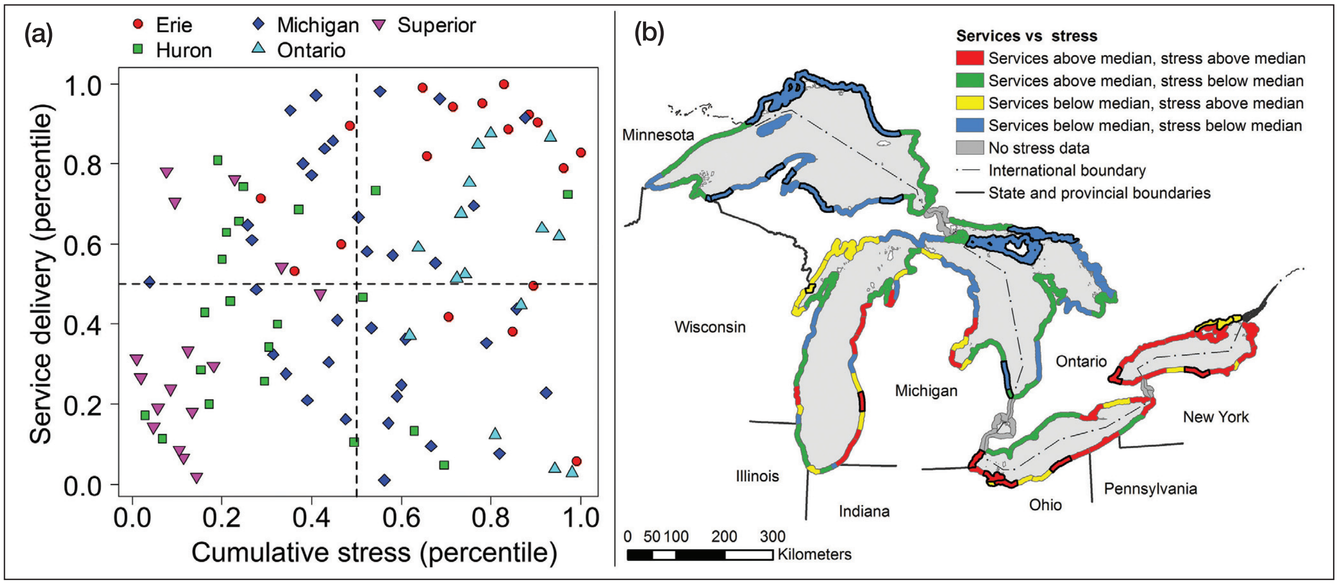

Figure 3. *(a) Aggregate recreational service delivery versus cumulative environmental stress for shore-adjacent counties in the GL (*n *= 105). Both services and stress are shown on a percentile scale, ranked relative to all other counties. Cumulative stress is the weighted sum of 34 environmental stressors (from Allan* et al. *[2013]; see WebTable 2). Each county average incorporates all shore-adjacent pixels (each 1 km^2) to a distance of 5 km offshore. (b) Geographic distribution of combinations of service delivery and cumulative stress, relative to the median of all counties. Counties with the most extreme combinations of services and stress (delineated by highest and lowest quintiles; ie counties from each corner of the plot in panel [a]) have bolded borders. No stress data were available for connecting waters, including the St Clair corridor.*

region, some of which could be integrated into future spatial analysis (eg Alessa *et al.* 2008; van Berkel and Verburg 2014). Our recreational CES metrics also address segments of society with sufficient leisure time and internet access to be accounted for in recreational statistics; hence our results may not account for recreational use by the population as a whole. For instance, data limitations forced us to focus on sport fishing from boats rather than shore-based angling, while our park-visitation metric did not include city and municipal parks, where additional users would be expected to be representative of broader ethnic and cultural diversity. The potential for demographic bias is perhaps especially high for beach use and birding activity. Estimates of beach use derived from digital photographs posted on social media sites may be influenced by user group and the type of recreational experience (Wood *et al.* 2013). However, good correspondence has been found between Flickr photo-user-days and surveyed visits to Minnesota state parks (Wood *et al.* 2013) and recreational visits to lakes (Keeler *et al.* 2015). Although 150 000 unique users of eBird (ebird.org) have submitted 140 million observations in total since eBird's launch in 2002 (Sullivan *et al.* 2014), the majority of data is generated by a smaller subset of users (Wood *et al.* 2011). Thus, while these methods allowed us to acquire comparable data on important recreational CES across the entire GL basin, results must be interpreted in the context of the population segments that they best represent. Overall, we suspect that future ES quantification would not greatly alter our finding that service delivery is greatest in the southern part of the GL region and near population centers. Nevertheless, more northern locations that appear to provide few societal benefits in our analysis might earn high marks for biodiversity maintenance and existence value (Raymond *et al.* 2013).

Our finding of significant positive correlations among services is notable given that trade-offs or no correlation have often been reported from spatial analyses of provisioning and regulating ES (Bennett *et al.* 2009). Trade-offs in ES provisioning occur when one ES is reduced as a consequence of increased use of another (Rodriguez *et al.* 2006) – for instance, the trade-offs in ES between crop production and water quality (Qiu and Turner 2013). Studies have found both strong (Nelson *et al.* 2009) and weak (Chan *et al.* 2006; Naidoo *et al.* 2008) correspondence among individual services, with no emerging consensus. For the provisioning and regulating services analyzed to date, individual services exhibit high spatial heterogeneity and at least moderate spatial independence (Chan *et al.* 2006; Egoh *et al.* 2008), implying that managing for any one service is unlikely to result in benefits to others.

In contrast, recreational and other CES may be less prone to trade-offs than provisioning or regulating services (Rodriguez *et al.* 2006). For instance, preference mapping of landscape features in a region of the Netherlands with a well-developed tourism industry revealed several hotspots due to the coincidence of landscape features, including tree lines, forests, cultural buildings, and animal habitats (van Berkel and Verburg 2014). Cold spots also were evident, and were characterized as locations that lacked visible animal habitat and were dominated by modern, large-scale agricultural operations.

This identification of hotspots and cold spots parallels our finding that some areas provide a multiplicity of services, and others provide few. Indeed, CES have been observed to be more intertwined than other types of ES (Gould *et al.* 2014), and some of the ongoing uncertainty about whether multiple services show similar or opposing spatial distributions may simply derive from comparing different classes of services (Bennett *et al.* 2009).

Relatively strong positive associations among multiple recreational services, resulting in locations with high total service delivery, are partly explained by high usage in populated areas. Services, whether measured by usage or in economic terms, have value primarily when humans are present to derive benefits. Not surprisingly, the greatest delivery of services occurs near population centers and in the southern part of the region; for example, we found high levels of service delivery from around Lake Erie despite popular perceptions of its degraded condition. Moreover, a classification tree analysis of quartiles of service delivery indicates that the highest level of relative delivery was associated with populations greater than 62 000 people per county in shoreline zip codes (WebFigure 2). Some high service delivery was associated with smaller populations but higher proportions of second homes as well – a potential surrogate for preferred vacation destinations. In both cases, much recreational service delivery coincides with locations in populated areas as opposed to more remote locations that lack infrastructure.

Given that many combinations of service delivery and stress rankings exist in the GL region (see also Allan *et al.* 2013), our analysis underscores three challenges in linking restoration efforts to benefits. First, locations characterized by high service delivery are often affected by multiple environmental stressors, making it challenging to identify cause-and-effect relationships with diminishment of service delivery. Second, we lack a means to quantify ecosystem resilience, and thus are uncertain how alleviation of ecosystem stress may or may not enhance ES delivery across locations. Data that quantify temporal trends in both stressors and service delivery following restoration activity would be best suited to establish linkages between stressor amelioration and changes in benefits. Finally, even when ecosystem quality declines near large urban areas, the increased number of beneficiaries may be sufficient to result in an increase in the total value of cultural services that are provided. Each of these considerations, along with assessing which specific stressors most affect individual services, merits further examination as restoration efforts continue.

Spatially explicit evaluation of ES has an essential role to play in strategic planning of restoration efforts by identifying areas where people are most likely to benefit directly from such efforts and by providing a metric of return on investment. As cumulative stress analyses proliferate (eg Danz *et al.* 2007; Allan *et al.* 2013), it is equally important to account for spatial heterogeneity in the benefits provided by healthy ecosystems. This study offers strong evidence that sustaining recreational opportunities in the GL results in economic dividends, and suggests that unifying spatial analyses of ES and stressors will help to target investments to locations with the greatest potential to enhance societal benefits.

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