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Ecosystem services of Lake Erie: Spatial distribution and concordance of multiple services

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ABSTRACT

The Laurentian Great Lakes provide a wide range of ecosystem services (ES) whose spatial distribution and extent are largely unquantified, thus limiting our understanding of ES co-occurrence, magnitude of ES supply, and the incorporation of ES into environmental planning. We mapped the spatial distribution of twelve ES in the Lake Erie Basin, including three supporting, three provisioning and six recreational/cultural services at three scales of analysis: sub-basins, counties and natural or urban focal areas. Whether ES are quantified by number of service sites or service delivery, the concordance of services varied among locations. Some ES were found to be spatially correlated, likely due to common function, such as sport fishing, boat launches and marinas, and other ES were co-located according to shared 'human habitat' in or near urban centers, as seen with municipal parks and municipal water supply. Most ES were spatially uncorrelated, and significant associations were almost exclusively positive. Total service delivery varied significantly among locations at both the county and focal area scales, indicating that areas of both high and low overall service delivery were common. Managers may benefit from awareness of the extent of ES delivery for different services in their area of interest, including co-benefit opportunities to improve delivery of multiple services.

Introduction

The Laurentian Great Lakes provide a wide range of human benefits, including municipal and industrial water supply, wildlife and fisheries support, and exceptional opportunities for recreation and nature enjoyment associated with the largest body of surface fresh water on earth (Pearsall et al., 2012; Allan et al., 2015; Angradi et al., 2016). Although the supply of ecosystem services (ES), defined as the benefits that people obtain from ecosystems (Millennium Ecosystem Assessment, MEA, 2005), is frequently cited as the rationale for management and restoration actions, their incorporation into environmental planning has been limited due to a lack of detailed information on their spatial distribution and extent, and of the relationship of services to one another and to environmental stressors (Allan et al., 2013, 2015). Nonetheless, a number of studies have articulated the potential of ES assessment and mapping to improve environmental management and decision-making (De Groot et al., 2010; Chan et al., 2012; Munns et al., 2015; Schaefer et al., 2016; Annis et al., 2017). Because the value of ecosystem services is determined by the location where services are provided and benefits are derived, ES information should be spatially explicit (Tallis and Polasky, 2009).

Much interest in ES has been driven by questions regarding the inter-relationships among services, including potential trade-offs as well as multiple positively correlated ES, often referred to as bundles (Bennett et al., 2009) or hotspots (van Berkel and Verburg, 2012; Queiroz et al., 2015). Trade-offs occur when the quality or quantity of an ES being used by one stakeholder is reduced as the result of other users of that or another ES (Rodríguez et al., 2006). The trade-off between agricultural production and water quality, as seen in the fertilizer-driven algal blooms of western Lake Erie, is a relevant Great Lakes example (Kerr et al., 2016), as is the harvest allocation between recreational vs. commercial fisheries (Gaden et al., 2013). On the other hand, a mix of positively correlated ES may occur together in the same place and at the same time, whether or not a causative relationship exists (Bennett et al., 2009). For example, Great Lakes wetlands provide wildlife habitat, fisheries support and water quality improvement, and potentially provide sediment and nutrient storage and carbon sequestration (Sierszen et al., 2012); thus, wetland protection can be expected to yield co-benefits.

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Studies of the spatial relationship among Great Lakes ES are few. Allan et al. (2015) reported that five recreational services aggregated into spatial units based on county shorelines were significantly positively correlated. Spatial correlations between pairs of 23 biophysical services in the St Louis, MN, estuary were generally low (Angradi et al., 2016). However, that study did find both positive and negative correlations that resulted from the association of particular services with shallow water (wild rice and fish spawning) vs. deep water habitats (power and sailing boats), such that management action affecting water level would generate a trade-off.

Growing interest in Great Lakes ES is evidenced in the scientific literature and in policy documents. An ISI Web of Science literature search using ecosystem services or ecological services and Great Lakes or names of individual lakes found 110 studies since 1999, initially with 0–2 papers published annually but increasing to 8–10 per year by 2010 and doubling to 16–19 annually in 2015–2016. This mirrors the growth of publications in all areas of ES studies (Boerema et al., 2016). Ecosystem services are also referred to within the 2012 Great Lakes Water Quality Agreement (https://binational.net/2012/09/05/2012-glwqa-aqegl/) and the Great Lakes Restoration Initiative's report to Congress (https://www.glri.us/pdfs/21050720-report_to_congress.pdf). Clearly, information regarding ES provisioning of individual services, and whether ES are positively or negatively correlated, can benefit managers and the public in prioritizing lake management actions.

The present study maps the spatial distribution of 12 ES throughout the Lake Erie Basin (LEB) for which location and extent of service provisioning could be estimated or approximated, including 3 supporting, 3 provisioning and 6 recreational/cultural services for both coarse and fine scales of analysis (Table 1 and Fig. 1). These ES represent three of the four commonly distinguished categories of services (MEA, 2005) but do not include regulating services which were not feasible to quantify as these are the result of highly dispersed ecosystem functions. The goals of this study were to (1) quantify the spatial distribution and delivery of 12 ES for the Lake Erie Basin, (2) evaluate spatial concordance of ES at both coarse and fine spatial scales to better understand how services may be inter-related, and (3) interpret the likely causes of spatial patterns and both positive and negative associations among ES. Lastly (4), we examine whether total service delivery varies spatially.

Table 1
Examples of Great Lakes ecosystem services, following the widely used classification of the Millennium Ecosystem Assessment (MEA) (2005), and data layers included in this study.

Service	Great Lakes examples	Included data layers
Provisioning	Commercial fishing, drinking water, water for thermo-electric plant cooling, hydro- and wind power	Commercial fishing - port landings Water withdrawals - municipal Water withdrawals - thermoelectric cooling
Cultural	Recreational experiences, nature and viewscape enjoyment, historical interests, spiritual fulfilment	Sport fishing angler effort Recreational boating Beach use Birding activity Park use – federal and state/provincial Park use – municipal
Supporting	Primary production, nutrient cycling, habitat supporting biodiversity	Coastal terrestrial biodiversity significance Coastal wetland biodiversity significance Important Bird Areas
Regulating	Climate regulation, water purification, nutrient and organic matter processing, resistance to invasion	None

Methods

The Lake Erie Basin

Lake Erie is the smallest, shallowest and most southern Great Lake (GL), and as a result is the warmest of the lakes and has the shortest water retention time. Lake Erie is bordered by New York, Pennsylvania, Ohio, Michigan and Ontario, and a small portion of the Maumee headwaters lies in Indiana. Some 11.6 million people live in the LEB, and about 11 million receive their drinking water from the lake (Pearsall et al., 2012). Lake Erie is considered to be exposed to greater stress from agriculture and urbanization than any of the other GLs (Dolan, 1993; USEPA, 1999).

Lake Erie typically is divided into three basins: a shallow western basin (WB, mean depth 7 m, maximum depth 18.9 m), a large central basin (CB, mean depth 18 m, maximum depth 25 m) deep enough to stratify during summer, and a much deeper eastern basin (EB, mean depth 25 m, maximum depth 64 m). The upper lakes drain into Lake Erie via its upstream connecting river system consisting of the St. Clair River, Lake St. Clair and the Detroit River (St. Clair-Detroit River system, SCDRS); and Lake Erie outflow connects to Lake Ontario via the Niagara River and shipping canals. Consistent with the Lake Erie Lakewide Action and Management Plan (LAMP, USEPA, 2014) this study recognizes four major units: western, central and eastern basins and the SCDRS.

We evaluate service overlap at three spatial scales (Fig. 1): (1) along the shoreline of the four largest sub-units described above (WB, CB, EB and SCDRS); (2) within shoreline polygons defined by U.S. and Ontario counties; and (3) for focal areas defined as natural or urban. Following Allan et al. (2015), shoreline polygons are delineated by the LEB's 22 county units and a 10-km buffer centered on the shoreline. Most biological resources (Vadeboncoeur et al., 2011) and human activities are concentrated along the shoreline, and nearshore influence on water quality attenuates at ~3–5 km (Kelly et al., 2015). Similarly, land-based biological resources are dependent on lake conditions to a distance of ~2–5 km (Pearsall et al., 2012; Bonter et al., 2009). As natural areas we selected national, state and provincial parks bordering Lakes Erie and St. Clair and >2 km^2 in area. We then buffered a 10-km-radius around the centroid of each and dissolved overlap to avoid double-counting of services, identifying 12 units. As urban areas we selected cities with populations >25,000, and again buffered a 10-km-radius around each and dissolved overlapping polygons, identifying 10 units.

Lake Erie ecosystem services

We obtained data from multiple sources to map service distribution (see Electronic Supporting Information [SI] Appendix A for detailed methods and data sources). The scale of available data varies and we use both down- and upscaling for purposes of comparison of individual data layers. Point data are given an approximate location such as the centroid of a beach, a marina or a port for commercial catch landings, and so are accurate at approximately the 1-km^2 scale. Some point data such as municipal water intakes or reported birding hotspots are accurate at a finer scale than 1-km^2, but these services obviously are dependent on some larger, surrounding area and not just the exact point. Management units for reporting sportfishing activity and biodiversity services are represented by polygons of varying size. Data are representative of the 2000–2010 timeframe, with minor differences due to data availability, and water withdrawal data are more recent. Whenever possible we examined time series to determine whether a trend existed, and we averaged over time when no recent trend was obvious in that ten-year period (e.g., commercial fishing) and used the most recent years when a trend was noted (e.g., sport fishing effort is trending down). See SI for further information.

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