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Ecosystem Services

Methodological innovations within the RAWES framework for use in development scenarios

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Abstract

Built development changes the nature of land and its ecosystems, with diverse ramifications for human well-being and the resilience of the socioecological system. Robust and replicable approaches are required to assess ecosystem services generated by sites both predevelopment and for evaluation of postdevelopment options, to assess change and to support a paradigm shift from a "do less harm" to a "regenerative" approach. The Rapid Assessment of Wetland Ecosystem Services (RAWES) approach provides an internationally recognized methodology for systemic assessment of the ecosystem services generated by a site, taking account of all ecosystem services and service categories across multiple spatial scales. The RAWES assessments of constituent ecosystem services can be combined into Ecosystem Service Index scores. This article outlines innovations in RAWES methods to assess changes in ecosystem services likely to result from differing development scenarios in the context of a case study site in eastern England. These adaptations of the RAWES approach include revised methods for the analysis of ecosystem service beneficiaries across multiple spatial scales, the establishment of a common baseline against which to compare likely ecosystem service outcomes under a range of development scenarios, and a standardized method for accounting for supporting services through their contributions to other more directly exploited services. *Integr Environ Assess Manag* 2024;20:189–200. © 2023 The Authors. *Integrated Environmental Assessment and Management* published by Wiley Periodicals LLC on behalf of Society of Environmental Toxicology & Chemistry (SETAC).

KEYWORDS: Built development; Ecosystem services; Ecosystem service assessment; Environmental net gain; RAWES

INTRODUCTION

A central premise of sustainable development, as articulated by the World Commission on Environment and Development (WCED) (1987), the Millennium Ecosystem Assessment (2005), and as reflected in the interlinkage of the 17 UN Sustainable Development Goals (United Nations, 2015), is that social and economic progress are interdependent, with continued ecosystem integrity and functioning. A wider variety of redefinitions of sustainable development have occurred since the seminal WCED (1987) "Brundtland definition," many of these serving the interests of the authors of those definitions (Johnston et al., 2007). While there is wide acceptance of the three interlinked elements of sustainable development—social, economic, and environmental—policy and practical implementation have often regarded them as quasi-autonomous with sustainability recognized where they converge, for example, with the perspectives of consumers and entrepreneurs shaping the prioritization of these "triple bottom line" elements in corporate social responsibility strategies (González-Rodríguez et al., 2015).

This perspective of sustainable development comprising three quasi-independent elements is at odds with a growing recognition that humanity is wholly dependent upon supporting ecosystems, despite societal behaviors overlooking this reality (Washington, 2012), and that economic markets are human-created mechanisms dependent upon but also feeding back into socioecological systems (Everard & Quinn, 2015). Just as human rights and social justice have to be set in the context of equitable exposure to environmental good and harm (Wolch et al., 2014), so too truly sustainable economic development can only occur when undertaken within the finite carrying capacity of supporting ecosystems and respecting a wide spectrum of societal needs.

Built development inevitably creates a regime change in the character and functioning of the ecosystems that it replaces. This change occurs not just on the land being developed but spatially and temporally across the socio-ecological system (Reed, 2007). The metabolism of the built development throughout its operational life—including, for

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example, imports of water, food, and energy; exports of waste to all environmental media; and perturbation of groundwater infiltration and surface water flows—also has ecosystem service implications both within and beyond the development footprint. These ecosystem service implications have been often overlooked (Rosa & Sánchez, 2015) or are expressed through a predominantly economic framing (Small et al., 2017). There have been increasing attempts to mitigate ecological harm, for example, through species and habitat relocation, more sympathetic building methods (Reed, 2007), or the development of compensatory habitat beyond the redline boundary of the development site (Defra, 2018).

However, Orova and Reith (2021) describe a recent paradigm shift within new development away from a focus on damage limitation to a broader focus on regenerative sustainability. Examples of this shift include policies such as mandatory biodiversity net gain for development projects being included in the UK Environment Act (HM Government, 2021) and the commitment in the UK Government's 25-year Environment Plan (Defra, 2018) to move toward greater environmental net gain (though it is worth noting neither policy achieves regenerative development in isolation). Progress toward a new, regenerative paradigm requires consistent and replicable approaches for assessment of the predevelopment functioning of a site against which different development scenarios can be compared in terms of their potential minimization of damage and, ideally, improvement or regeneration of environmental condition, functioning, and services. Such approaches necessarily need to go beyond simply counting assets—numbers of trees, bats, landscape features, and so forth—to address the overall linked socioecological functioning of the site through the assessment of ecosystem services.

Ecosystem services describe discrete flows of benefits to society. As all services are elements of an interlinked system, any change in management to exploit any one service (such as the conversion of natural habitat for crop production) has inevitable feedback affecting and potentially ultimately jeopardizing the stability of the system as a whole (Balvanera et al., 2013). A myopic focus on a single discipline, or a limited number of services, overlooks the systemic nature of problems, potential solutions, and their interlinked ramifications (Bradshaw et al., 2021). As such, there is a strong need to consider human interactions with the natural world in a systemic context (Everard, 2020; Kass, 2020; Pedersen Zari & Hecht, 2020). There are many valid criticisms of the ecosystem services concept (see Bekessy et al., 2018; Lele et al., 2013), in particular, the concept of assigning economic value to different elements of the natural system (McCauley, 2006). However, many of these criticisms oversimplistically assume that this is about "valuing nature" as a set of physical assets when the reality is that recognition of ecosystem services enables the valuation of the generally overlooked diversity of supportive functions flowing from nature to humanity (Everard, 2022). Furthermore, Mace (2014, p. 1560) argues that "if the benefits provided by nature are assigned no value, they are treated as having no value, and current trends in the decline and deterioration of natural systems will continue." It is therefore vital to recognize and value all ecosystem services as connected and interdependent parts of the socioecological system.

To be useful operationally, ecosystem assessment must be relevant, rapid, and not onerously expensive. The Rapid Assessment of Wetland Ecosystem Services (RAWES) approach was developed to fulfill the criterion of operational assessment of wetlands (Ramsar Regional Center-East Asia [RRC-EA], 2020) and was adopted as a global standard approach by a 2018 Resolution of the intergovernmental Convention on Wetlands (Ramsar Convention, 2018). Although RAWES was developed for the assessment of diverse global wetland types, it is based on methods previously and subsequently applied to many other ecosystem types across a range of biogeographic regions including, for example, in deserts (Everard & West, 2021) and mountains (Everard et al., 2020).

This article addresses adaptations to the RAWES approach for the assessment of changes in ecosystem services, tested in the context of a proposed building and site development in eastern England.

MATERIALS AND METHODS

The RAWES approach

The RAWES approach (RRC-EA, 2020, 2021) was developed explicitly to support wetland ecosystem service assessment recognizing practical time and resource limitations faced by operational staff (McInnes et al., 2017), being both genuinely rapid and cost-effective. Rapid Assessment of Wetland Ecosystem Services takes a semiquantitative approach, integrating qualitatively different types of evidence on a systemic basis across the full spectrum of ecosystem services spanning the four Millennium Ecosystem Assessment (2005) categories (provisioning, regulating, cultural, and supporting) (McInnes & Everard, 2017a).

A RAWES assessment aims to provide a systemic overview of the range and importance of ecosystem services that a defined site is providing. The RAWES approach does not provide quantitative or monetary values for individual ecosystem services and is not prescriptive, with no specific thresholds and no facility for a site to pass or fail. Instead, RAWES assessors agree on these thresholds, both for the magnitude of the service and the scale at which benefits are realized, on a context-dependent basis before conducting the assessment. The RAWES approach evaluates ecosystem services generated within a local context and with regard to identifiable beneficiaries at wider geographical scales, and was designed to facilitate thinking about how the system functions (RRC-EA, 2020, 2021).

As RAWES can be used for a variety of applications (RRC-EA, 2021), it is first essential to determine the purpose for which the assessment is being conducted. In Cianchi et al. (2023), RAWES was used to establish a baseline level of ecosystem service provision on the case study site, providing a baseline against which to compare predicted ecosystem service outcomes under a range of postdevelopment scenarios. The RAWES assessment was undertaken by the authors, who have pre-existing experience in applying the RAWES system across multiple different countries and socioecological systems. The RAWES assessments are generally performed with some desk-based preparation and then through site visits including consultation with local stakeholders. However, Dickenson's Field assessment was carried out using precollected site data, including postdevelopment plans (Denizen Works, 2021) with decisions backed up by literature evidence.

Assessors assign each ecosystem service a score from (++) for a significant positive contribution to (−−) for a significant negative contribution (see Table 1), based on the relative number of beneficiaries of the service and whether the service is a significant part of the ecological character of the site. Assessors also record the geographical scale or scales at which service benefits are realized. The geographical scales used at Dickenson's Field are described in Table 2. These assessments are not based on specific quantitative metrics such as the number of trees or millimeters of rainfall, but instead use a mix of semiquantitative and qualitative data such as observations, questions, and the incorporation of local and Indigenous knowledge relevant to the context of the assessment in order to avoid overlooking services that may be important but lack or evade robust quantification (RRC-EA, 2020).

The simplified scoring system can then be numerically transformed into semiquantitative Ecosystem Service Index (ESI) values ranging from −1 for a significantly negative outcome to +1 for a service with a significantly positive outcome (see Table 1). An ESI score can be generated for each Millennium Ecosystem Assessment service category (provisioning, regulating, cultural, and supporting), or for all services combined, based on summing the scores for each service and dividing by the number of relevant services. Cianchi et al. (2023) generated ESI scores for the site baseline and for postdevelopment scenarios to semiquantify overall net gain or loss of ecosystem services over the development process.

The field site and its aspirations for development

Dickenson's Field is an approximately 2.2-ha greenfield site within the county of Rutland, England. The planned development was to build an ecological training center on a small proportion of the site (0.26 ha). The development included plans to enhance the biological diversity and educational value of the site by creating additional habitat parcels and enhancing the condition of the current habitat. The development aimed to meet advice supplied by Natural England (the statutory body in charge of the natural environment in England) concerning habitat selection, in addition to local biodiversity targets. The RAWES methodology (RRC-EA, 2020) was applied to the site (as part of a larger study; see Cianchi et al. [2023]) to test likely net gain or loss of ecosystem services between a predevelopment baseline and postdevelopment scenarios.

Application of RAWES to the case study site revealed aspects requiring adaptation of the published methodology (RRC-EA, 2020) to better support scenario testing. Methods were developed to alleviate these problems, forming an updated RAWES+ methodology. RAWES+ was then tested in its application to the Dickenson's Field development project.

RESULTS AND DISCUSSION

Table 3 summarizes the RAWES scores for each ecosystem service in the Dickenson's Field baseline and postdevelopment scenarios (the details of the assessment and supporting evidence are available as Supporting Information Digital Material). Ecosystem Service Index scores are shown in Figure 1. While ESI scores increased across all service categories, some challenges were identified with measuring net gain or loss of ecosystem services between pre- and postdevelopment using the published RAWES methodology. An outline of these challenges and the resultant necessary adaptations of the published RAWES methodology is documented below.

Service provision across spatial scales

The benefits, or potential disbenefits, of ecosystem services can be realized across multiple spatial scales and the level of benefits (or disbenefits) can also vary across these scales (Small et al., 2017). For example, Everard (2020) gives multiple examples of water usage conflicts between upstream and downstream consumers, where the positive utilization of a service at one spatial scale leads to disbenefits at another.

The published RAWES guidance (RRC-EA, 2020) specifies that importance scores (from ++ to −− or? as outlined in Table 1) are assigned to each service and that the spatial scales at which benefit is realized are recorded. However, this method of scoring does not reflect different importance

TABLE 1 Assignment of RAWES importance scores and their transposition to ESI values

Assigned importance	Significantly positive	Positive	Neutral/no importance	Negative	Significantly negative	Not relevant/ unknown
RAWES importance score	++	+	0	−	−−	xx/?
Numerical value for ESI calculation (V)	1.0	0.5	0.0	−0.5	−1.0	Remove from analysis

Abbreviations: ESI, Ecosystem Service Index; RAWES, Rapid Assessment of Wetland Ecosystem Services.
Source: Modified from RRC-EA (2020).

TABLE 2 Geographical scale (of service provision) categories used in the assessment of Dickenson's Field

Scale category	Description	Justification
Site	Within the redline boundary of the development site.	Within the redline boundary is the physical area that will be altered by the development.
Local	Outside the redline boundary of the development site, but within the county of Rutland.	The county of Rutland is the administrative area controlled by the local planning authority that will make decisions over development on the site.
National	Outside the county of Rutland but within the United Kingdom.	Many services, such as education, spill beyond the administrative boundaries of Rutland into other parts of the country.
Global	Globally, but outside the United Kingdom.	Many services, such as global climate regulation, occur across and beyond national boundaries.

scores for each service at each spatial scale, nor are these different benefits across spatial scales reflected in summative ESIs.

In the predevelopment baseline at Dickenson's Field, the "noise and visual buffering" regulating service is rated "positive" (+) at a site scale and therefore is assigned a numerical value of 0.5 for ESI calculation. The "education and research" cultural service is rated positive at the site, local, and national scales and also receives a numerical value of 0.5. As such, there is no difference in the data between a service that is being utilized exclusively on-site and one that is being utilized across multiple spatial scales. Furthermore, while not relevant in our case study, any conflicts between service provisions over different spatial scales would not show up in the index data.

Both of these points are particularly important in the context of conducting pre- and postdevelopment assessments on the same site. Using the current RAWES ESI methodology, the data would not show an improvement in ecosystem service provision from a site where a service had changed from being significant on one spatial scale to being significant on several (over the course of the development). For example, at Dickenson's Field, both the "pest regulation" and "local climate regulation" services are positive on a site scale in the predevelopment baseline and become positive both at site and local scales in the postdevelopment scenario. Despite the increased scales of service provision, "pest regulation" and "local climate regulation" are given numerical values of 0.5 for both baseline and postdevelopment scenarios. As such, the changes in spatial provision would not be recognized in the calculation of pre- and postdevelopment ESI scores. Similarly, currently published methods would not recognize where, in providing a service at one spatial scale, the service benefit was diminished or converted into a disbenefit at another spatial scale, for example, overabstraction or impoundment of water locally depleting flows downstream.

These potential limitations in the RAWES approach were addressed by assigning each ecosystem service a discrete significance numerical value at each spatial scale, rather than an overall scale-independent score for the service. These individual numerical values were then summed to calculate the overall numerical value for each service. To stay within the +1 to −1 boundaries of the index, the maximum (+1) and minimum (−1) numerical values were divided by the number of spatial scales that ecosystem services were being assessed over (in this example 4), giving maximum and minimum values of 0.25 and −0.25 for each service at each scale. Therefore, if a service was significantly positive over all four spatial scales, it would have a value of 1. If the service was significantly positive on two spatial scales and significantly negative on a third, it would have a value of 0.25. For services that were positive, or negative (rather than significantly so), the values were set at 0.1 and −0.1, respectively. These values were chosen to ensure that positive scores at two spatial scales could not outweigh a significantly negative score at another spatial scale (see Table 4).

In Dickenson's Field example, the proposed "RAWES+" methodology shows an increased service provision across both "pest regulation" and "local climate regulation" services as shown in Table 5.

As preassessment agreement about appropriate spatial scales is undertaken between RAWES assessors, there may, in some scenarios, be a requirement for more, or fewer, than the four spatial scales illustrated here. If this is the case, numerical values assigned to each significance level for ESI calculation would have to be adjusted (following the formula below) so that a significantly positive provision across all spatial scales adds to a total of one, and that positive provisioning across two spatial scales would not outweigh significantly negative provisioning at a single scale.

$$SPV = \frac{1}{nSS}$$

$$PV = SPV \times 0.4,$$

where *SPV* is the significantly positive value, *PV* the positive value, and *SS* the spatial scales.

There are arguments in favor of assigning different maximum or minimum values to different spatial scales, for example, assigning greater importance to a global rather than a local benefit. However, this approach was rejected by the authors as it was considered that it would likely lead to the undervaluation of local services that may be highly significant, such as the provision of unique local habitats or

TABLE 3 Summary of RAWES scores for ecosystem service provision on Dickenson's Field pre- and postdevelopment

	Predevelopment baseline		Postdevelopment scenario	
Ecosystem services	Importance	Scale	Importance	Scale
Provisioning				
Fresh water	0		+	S
Food production	0		+	S, L
Fiber and/or fuel production	+	L	+	L
Genetic resources	xx		+	L, N
Biochemicals, etc.	xx		xx	
Ornamental resources	xx		xx	
Harvesting of clay, mineral, aggregates, etc.	xx		xx	
Waste disposal	xx		xx	
Energy harvesting	xx		++	S
Regulating				
Air quality	+	S	+	S
Local climate and/or microclimate	+	S	+	S, L
Global climate	+	G	+	G
Water and/or hydrology	+	S, L	+	S, L
Natural hazard	+	S, L	+	S, L
Pest regulation	+	S	+	S, L
Disease—human	0		0	
Disease—stock	0		0	
Erosion regulation	+	S	++	S
Water purification and/or waste treatment	0		+	S, L
Pollination	+	S	++	S, L
Salinity regulation	xx		xx	
Fire regulation	xx		xx	
Noise and visual buffering	+	S	++	S
Cultural				
Cultural heritage	xx		+	S, L, N
Recreation and/or tourism	xx		xx	
Esthetic value	xx		+	S, L
Spiritual and/or religious value	xx		xx	
Inspiration of art, folklore, etc.	xx		xx	
Social relations	0		+	L, N
Education and/or research	+	S, L, N	++	S, L, N
Nature targets	+	S, L	+	S, L, N
Supporting				
Soil formation	+	S	+	S, L
Primary production	+	S	+	S

(*Continued*)

TABLE 3 (*Continued*)

Ecosystem services	Predevelopment baseline		Postdevelopment scenario	
	Importance	Scale	Importance	Scale
Nutrient cycling	+	S	+	S
Water recycling	0		+	S
Photosynthesis (O_2 production)	+	S	+	S
Provision of habitat	+	S, L	++	S, L, N

Note: The following letters are used to denote geographical scales S = site, L = local, N = national, G = global (see Table 2).
Abbreviation: RAWES, Rapid Assessment of Wetland Ecosystem Services.

other services critical for supporting local livelihoods, belief systems, or traditions. Furthermore, in a built environment context, decisions are usually taken at a local level; therefore, it is crucial to ensure that locally relevant services are not overshadowed by national and global service utilization in local planning decisions.

A consistent baseline for comparison

The RAWES Practitioners Guide (RRC-EA, 2020) calculates the ESI by summing the value of all positive and negative ecosystem service scores and dividing the total by the number of relevant ecosystem services as shown in the equation below (edited from the original in RRC-EA [2020] for clarity).

$$ESI = \frac{\Sigma(SP, P, SN, N)}{ns},$$

where *SP* is the significantly positive scores, *P* the positive scores, *SN* the significantly negative scores, *N* the negative scores, *s* the for relevant ecosystem services, and *n* the number.

This method requires adaptation for comparison of pre- and postdevelopment scenarios on the same site to ensure that the same suite of ecosystem services forms the basis for comparison. For example, if a site before development had provided five services at the positive (+) level and no other services, it would have had a total value of 2.5 which, when divided by the number of relevant services (5), would give an ESI score of 0.5. If, after the development process, the site then had seven services at the positive level, giving a numerical value of 3.5, this would give the same ESI score of 0.5 when divided by the number of relevant services (7). As such, it is possible within the "relevant services" methodology set out in RRC-EA (2020) to miss improvements or deteriorations in site quality through the addition or loss of ecosystem services. For example, applying the RRC-EA (2020) methodology:

- The single positive (0.5) provisioning service of "fiber and fuel" was recognized at Dickenson's Field, yielding a total ESI for provisioning services of 0.5 (excluding two services initially labeled as neutral—see the explanation below).

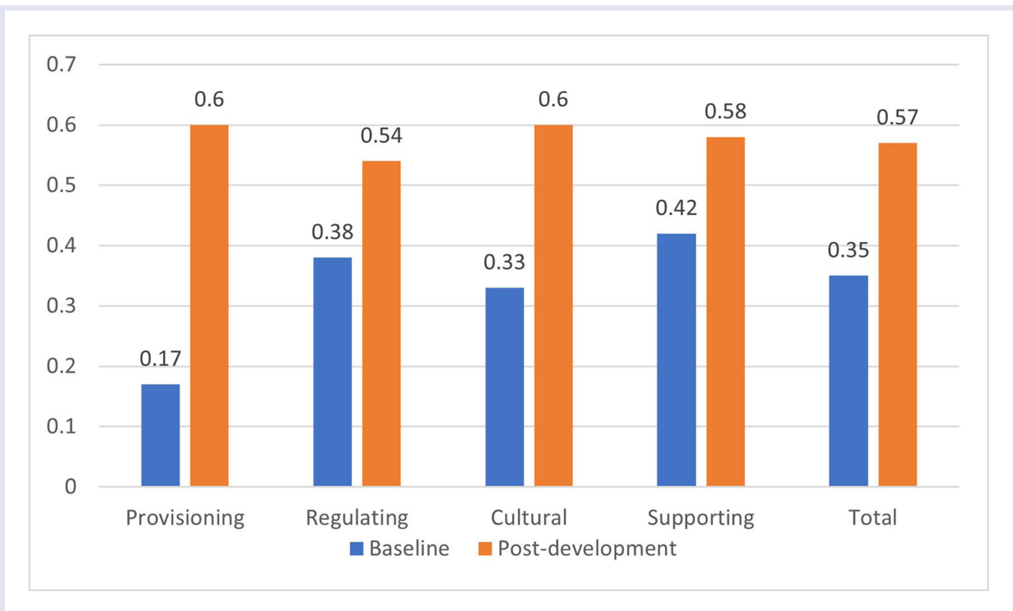

FIGURE 1 Ecosystem Service Index scores across each ecosystem service category at Dickenson's Field in the predevelopment baseline and postdevelopment scenario

TABLE 4 Assignment of RAWES+ importance scores and their transposition to ESI values

Assigned importance	Significantly positive	Positive	Negative	Significantly negative	Unknown
RAWES importance score	++	+	–	––	?
Numerical value for ESI calculation (*V*)	0.25	0.1	–0.1	–0.25	Remove from analysis

Abbreviations: ESI, Ecosystem Service Index; RAWES, Rapid Assessment of Wetland Ecosystem Services.

- In the postdevelopment scenario, the provisioning services of "fresh water," "food production," "fiber and fuel," and "genetic resources" were all scored as positive (values totaling 2.0) and "energy harvesting" was rated significantly positive (value of 1.0), these values totaling 3.0. The RRC-EA (2020) methodology yields an ESI of 0.6 when divided by the number of services (5). This is only marginally greater than the predevelopment ESI for provisioning services and without the contribution of the significantly positive score for "energy harvesting," the ESI would remain at 0.5 in the postdevelopment scenario, disregarding the addition of three new ecosystem services.

It is therefore necessary for comparative purposes to include all relevant scoring services for valid comparison of predevelopment and postdevelopment scenarios to account for service additions and enhancements or losses and reductions.

Recognizing qualifying services

When assessing ecosystem services, especially in complex comparative scenarios, it can become unclear as to whether an ecosystem service should be assessed as having "negligible contribution/no impact" (assigned a score of "0" on the basis that there are "no obvious beneficiaries or benefits" and it is "not an important part of the wetlands ecological character"; see Table 1), versus whether the service should be considered "not relevant." If a service is not relevant, that is, does not occur at all (for, e.g., the "harvesting of clay, mineral, aggregates, etc.," on an arable field), it is not given a score and removed from the analysis. When calculating ESI scores, services classified as having no impact are still considered relevant services. This means that they are included in the total number of services that the summed positive and negative ecosystem service values are divided by to derive an ESI score.

As ecosystem services are defined as benefits to people, no service is provided if no linked beneficiaries can be identified (Everard, 2020, 2022; Millenium Ecosystem Asessment, 2005; RRC-EA, 2020). Therefore, if a service is not being realized by a beneficiary (for, e.g., the "negligible/no impact" services), there is no service. This distinction is significant as whether a 0 score is assigned for any service (negligible/no impact), or if the service is disregarded (not relevant), can skew total ESI scores depending upon which category assessors have assigned, as it changes the number of relevant services that totals are divided by to derive the ESI. For example, the baseline ESI score for cultural services at the Dickenson's Field site is 0.25. This score is made up of the positive (0.5) value assigned to the "education and research" service, divided by two to take into account that the "social relations" service has been assigned a 0 value for no impact. If this nonscoring service had been assigned "not relevant" rather than no impact classifications, it would not have been included in the ESI calculation and therefore the total ESI for baseline cultural services would be 0.5 rather than 0.25.

A novel "distinct services" approach addressing consistency of baseline and qualifying services

A revised "distinct services" adaptation of how services are scored and combined into ESIs is proposed to overcome the dual challenges of consistency of baseline and qualifying services. Application of the adapted methodology to Dickenson's Field is demonstrated.

To ensure that services lost or gained over the development process show up in the ESI scores when making pre- and postdevelopment comparisons, the same number of relevant services need to be accounted for in the calculation of both pre- and postdevelopment assessments.

It is also necessary to be consistent (between assessors and between assessments) about which services are

TABLE 5 RAWES and RAWES+ numerical values for pest regulation and local climate regulation services at Dickenson's Field

Service	RAWES		RAWES+	
	Baseline	Postdevelopment	Baseline	Postdevelopment
Pest regulation	0.5	0.5	0.1	0.2
Local climate regulation	0.5	0.5	0.1	0.2

Abbreviation: RAWES, Rapid Assessment of Wetland Ecosystem Services.

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deemed relevant or not. One option is to divide by all potential services (36 in the basic RAWES suite derived from the Millennium Ecosystem Assessment classification: MA, 2005a), though this would lead to many very low ESI scores as many may not be locally or geographically relevant. Using a full suite of 36 services would also reduce discrimination between pre- and post-development ESI scores. Furthermore, this could remove some of the flexibility of the RAWES system to add context-specific local services, for example, the subdivision of different types of locally significant food types harvested from the coast of the Yellow Sea (McInnes & Everard, 2017b).

The "distinct services" methodology instead creates the baseline for ESI calculation only after both pre- and post-development RAWES assessments have been completed. The baseline is the total number of distinct ecosystem services from pre- and postdevelopment assessments, that is, the number of relevant services that occur in either, or both, of the pre- and postdevelopment scenarios, wherein each service that occurs is only counted once, even if it occurs in both the pre- and postdevelopment assessments. This methodology (described in the formulae below) gives a consistent baseline against which to assess both pre- and postdevelopment scenarios, meaning that the postdevelopment scenario is assessed against any services that were in the predevelopment assessment and have been lost and is also given the extra score if services that did not occur in the predevelopment assessment have been added. The ambiguity between "relevant" services with "no impact" and "not relevant" services was also clarified as the "negligible/no impact" services category was removed, meaning that only services that could be linked to identifiable beneficiaries were counted in any analysis.

$$ESI^a = \frac{\Sigma(vs^a)}{n\theta s^{ab}} \quad ESI^b = \frac{\Sigma(vs^b)}{n\theta s^{ab}},$$

where a is the predevelopment baseline, b the post-development plan, s the relevant ecosystem services, s^{ab} the relevant ecosystem services from a and b (fresh water^a, fresh water^b, food^a, pollination^b, etc.), θs^{ab} the distinct ecosystem services from a and b (fresh water, food, pollination, etc.), $n\theta s^{ab}$ the number of distinct ecosystem services from a and b (3), and v the value.

It is also possible to use an extension of this formula (shown below) to compare multiple postdevelopment scenarios while maintaining flexibility and a consistent baseline. The fluctuating nature of the baseline, depending on the number of relevant services on each site, does mean that this formula for ESI calculation can only be used to compare different scenarios on the same site, with comparison between different sites only approached with caution and further adaptation to account for the sum total of relevant services across all comparator sites.

$$ESI^a = \frac{\Sigma(vs^a)}{n\theta s^{abc}} \quad ESI^b = \frac{\Sigma(vs^b)}{n\theta s^{abc}} \quad ESI^c = \frac{\Sigma(vs^c)}{n\theta s^{abc}},$$

where c is the postdevelopment scenario 2.

This new relevant baseline methodology (without the inclusion of spatial scales) would give provisioning services at Dickenson's Field a predevelopment ESI of 0.1 and a postdevelopment ESI of 0.6, in comparison to the 0.17 and 0.6 of the original methodology.

Incorporation of supporting services

One of the differences between RAWES and many other ecosystem services methodologies (such as The Economics of Ecosystems and Biodiversity [2010], the CICES [2016], UK National Ecosystem Assessment [2011], or The Environmental Benefits of Nature Tool [Smith et al., 2021]) is that RAWES includes supporting services in addition to provisioning, regulating, and cultural services.

In the RAWES Practitioners Guide (RRC-EA, 2020), supporting services are defined as "the services that are necessary for maintenance of ecosystem integrity, functioning and resilience, and for production of all other ecosystem services." The Millennium Ecosystem Assessment (2005, p. 40) notes that "supporting services are not directly consumed and as such are harder to link to a particular beneficiary or group of beneficiaries." As an ecosystem service is only considered a service if it is linked to a beneficiary, this lack of direct connection to beneficiary groups can make it difficult to justify the level (++, +, −, −−) and spatial scale (for e.g., site, regional, national, global) of individual supporting services. However, as an understanding of supporting services on a site is crucial to understanding the functioning and resilience of the system, it is essential to assess supporting services to ensure that their contributions are recognized and factored into policy thinking and practical management (Everard, 2022).

Application of the RRC-EA (2020) RAWES methodology, under which supporting service scores were assigned based on the knowledge and understanding of the surveyors, works well for experienced professionals and practitioners but could be confusing for less experienced users who may not appreciate the often nuanced relationships between supporting services and other services. Furthermore, the reliance on interpretation could lead to conflicts between stakeholders and assessors. Therefore, a standardized approach to assigning value and spatial scale to supporting services linked to beneficiaries within the RAWES framework has been developed. We calculate the significance of service provision of each supporting service within a proposed RAWES+ assessment through direct linkage to services (from within the provisioning, regulating, and cultural ecosystem service categories) that are supported by the supporting service. A set of conditions have been devised (see Supporting Information: Section S1 and Table 1), using literature evidence and expert knowledge, to assist the assessor in unambiguously assigning linkages between

TABLE 6 Conditions for the assessment of the level and scale of supporting services within RAWES+

Level or scale	Conditions
Positive (+)	Supports another ecosystem service that is rated as providing a "positive contribution" (+).
Significantly positive (++)	Supports another ecosystem service that is rated as providing a "significantly positive contribution" (++) or three or more ecosystem services that are rated as providing a "positive contribution" (+).
Negative (–) and significantly negative (––)	Supporting services cannot go negative. If they support services at other levels that are providing disbenefits, then the ecosystem service box would be left blank as there are no ultimate beneficiaries of this service.
Site	Supports another ecosystem service that is used within the redline boundary of the site.
Local	Supports another ecosystem service that is used beyond the redline boundary of the site but within a specified local boundary.
National	Supports another ecosystem service that is used beyond the local boundary but within a national boundary.
Global	Supports another ecosystem service that is used globally beyond the specified national boundary.

Abbreviation: RAWES, Rapid Assessment of Wetland Ecosystem Services.

supporting services and the more directly beneficial services to which they contribute.

Fundamentally, all linkages have an "IF" condition that requires demonstration/evidence that the listed supporting service is genuinely contributing to the active service in the specific case being assessed. This "IF" condition and the requirement for evidence of a linkage with other more directly beneficial services increases the legitimacy of assignment of scores to supporting services.

Once it has been established which supporting services produced by the site contribute to services with identifiable beneficiaries, the significance level and geographical scale of the supporting service can be established, and an ESI score can be calculated. Table 6 describes the conditions for assigning significance and scale to supporting services. A theoretical example is also given below based on the Dickenson's Field example.

In a theoretical example, if the provisioning service "food production" was given a "significantly positive" score on a site level and "positive" on a local level, then all supporting services associated with food production, for which the "IF" conditions have been satisfied, would also be given "significantly positive" (++) on a site level and "positive" (+) on a local level. If one of those supporting services (for e.g., soil formation) was also associated with two or more other services that are given "positive" (+) at a local level, then soil formation would be upgraded to "significantly positive" (++) at the local level. Under these innovations, the "provision of habitat" supporting service in the postdevelopment scenario at Dickenson's Field is rated "significantly positive" at the site, local, and national scales. At the site and local scales, this is due to its evidenced support of the "education and research" cultural service, which is significantly positive at both site and local levels. At the national scale, this is due to

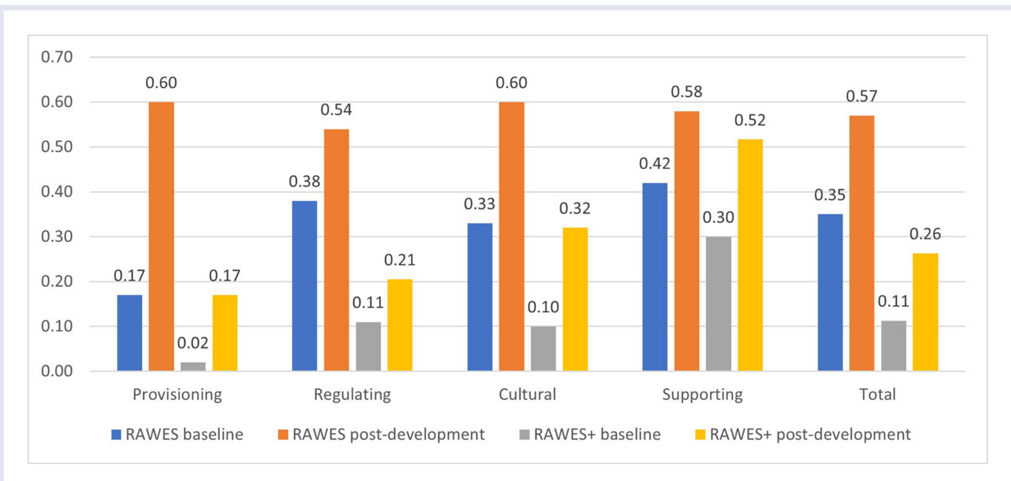

FIGURE 2 Ecosystem Service Index score by service category at Dickenson's Field across RAWES and RAWES+ methodologies. RAWES, Rapid Assessment of Wetland Ecosystem Services

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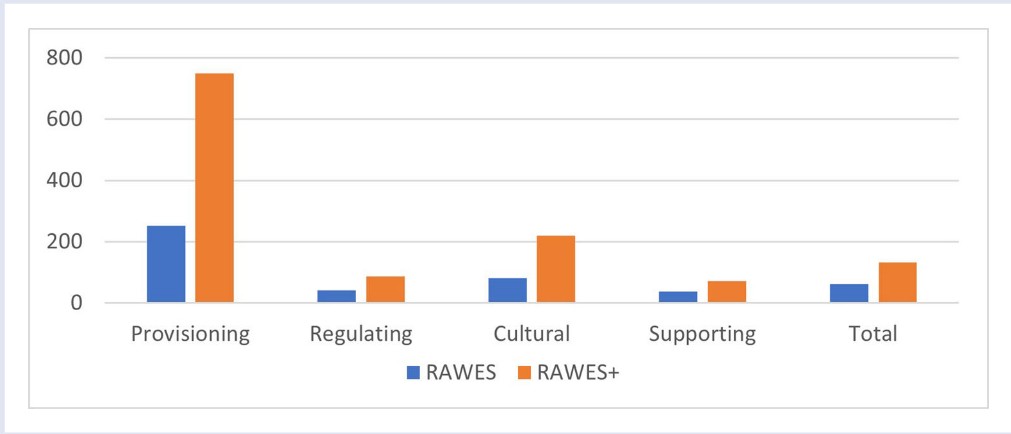

FIGURE 3 Percentage change in the ESI score between pre- and postdevelopment scenarios at Dickenson's Field per service category across RAWES and RAWES+ methodologies. ESI, Ecosystem Service Index; RAWES, Rapid Assessment of Wetland Ecosystem Services

its evidenced support of the "nature targets" (see Cianchi et al., 2023), "education and research," and "cultural heritage" services, which are all classified as positive at the national scale.

RAWES versus RAWES+

The use of the ESI to express ecosystem service gain (or loss) has highlighted some methodological issues. The RAWES+ approach has been developed to address these issues. While not all of the alterations proposed in the RAWES+ methodology were relevant in the Dickenson's Field case study, there are still clear differences between the results of applying the RAWES and RAWES+ methods.

The application of the RAWES+ approach does not fundamentally change the overall outcomes of the pre- and postdevelopment assessments of ecosystem services at Dickenson's Field, as both methodologies identified a wide range of ecosystem services linked to beneficiaries at a variety of scales and both demonstrate increased ESIs across all four ecosystem service categories. However, Figure 2 illustrates that application of the RRC-EA (2020) iteration of RAWES generates higher ESI scores across all ecosystem service categories compared with those calculated for RAWES+. This can in large part be explained by the lowering of significance values in the RAWES+ methodology (see Table 4) to accommodate multiple spatial scales. As no single ecosystem service was scored as "significantly positive" across all four spatial scales, no service achieved the top ESI value of 1 in the revised RAWES+ system, although this top ESI value was achieved multiple times in the RAWES assessment skewed by "significantly positive" scoring on just one spatial scale. As such, the resulting ESI scores under RAWES+ were inevitably lower than those for unrevised RAWES.

One of the potential strengths of applying the updated RAWES+ approach is that it also proved to be more discriminating about change between baseline and postdevelopment ESI scores compared to scoring under the original RAWES approach (Figure 3). This demonstrates the discriminative capability of adapted RAWES+ methods to identify the provision of new services (or loss of services), as well as changes in the spatial scales within a specific development or regime change.

CONCLUSION

This article examined the practicability of applying the RAWES methodology to assess ecosystem service change in a built development context and proposed adaptations to better support comparative pre- and postdevelopment analyses.

The RAWES approach provides great utility in its ability to assess a full suite of ecosystem services, including supporting services and context-specific services, and to link services to beneficiaries at a range of scales. Furthermore, the approach provided insight into the spatial scales across which benefits were realized, which was particularly relevant for the "education" service that was likely to be utilized by schools from outside the immediate vicinity, or local council area, of the site. The intuitive and readily applicable systemic assessment enabled by the RAWES approach, with adaptations identified in this article, has utility for measuring net gain or loss of ecosystem services between pre- and postdevelopment scenarios, providing necessary understanding for sustainable and regenerative development.

However, four key challenges with applying methods published in the RAWES Practitioners' Guide (RRC-EA, 2020) to assess net ecosystem service change between pre- and postdevelopment scenarios were identified. Methodological innovations from the RAWES to RAWES+ assessment approaches were developed to address each of these challenges:

1. Rapid Assessment of Wetland Ecosystem Services ESI generation methods do not incorporate different significances of service provision over different spatial scales, meaning that services with different scales of provision are treated equally and, consequently, the gain or loss of services at these multiple scales is not

considered when comparing different scenarios. RAWES+ removes this challenge by incorporating assessment of ecosystem service significance independently at each spatial scale.

2. Ramsar Regional Center-East Asia (2020) methods do not present a consistent baseline over which to calculate ESI scores for different scenarios on the same site. This can lead to inconsistent outcomes where services that are added or lost in a scenario are assigned the same average value as those present in the baseline and therefore have no impact on the calculation of ESI scores. Within the RAWES+ proposals, the total number of services recognized across pre- and postdevelopment scenarios is used as a consistent denominator for ESI calculations to account for ecosystem service loss, degradation, gain, or enhancement.
3. Calculation of ESI within the RRC-EA (2020) methodology can be ambiguous, depending on whether an ecosystem service has been defined as having "no impact" (a score of 0) or is considered "not relevant" (excluded). As a service with no impact is treated differently from a service that is not relevant for the purposes of ESI calculation, this ambiguity can lead to inconsistent results. Within the RAWES+ adaptations, "no impact services" are removed from assessment, leading to greater consistency in calculated ESIs.
4. Assignment of scores for supporting services under the RRC-EA (2020) methodology relies heavily upon the knowledge and experience of the surveyors, and is therefore open to a degree of subjectivity and potential conflict between different stakeholders. The RAWES+ proposes a structured approach to recognize the contributions of supporting services to provisioning, regulating, and cultural services, aiding consistent assignment of RAWES scores. Furthermore, in a built development context, this explicit recognition of the links between supporting services and "active" ecosystem services ensures that the importance of these services for maintaining ecosystem structure, functioning, and resilience is included in the decision-making process for every development, regardless of whether the site exists within a designated area or contains protected species.

Taken together, these adaptations to the RAWES approach, described here as "RAWES+," add robustness, replicability, and new utility to the RAWES approach, particularly in the context of use as a comparative means to assess the outcomes of a range of development, management, or policy scenarios at a site. The data generated by this approach allow developers, communities, and stakeholders to optimize the site on an ongoing basis, by considering services and spatial scales in their planning that may not have been significant predevelopment. This is particularly relevant in the built environment context of regime change and "environmental net gain," better supporting a paradigm shift toward a regenerative development approach.

AUTHOR CONTRIBUTION

Ben Cianchi: Conceptualization; data curation; formal analysis; investigation; methodology; visualization; writing—original draft. **Mark Everard**: Funding acquisition; methodology; project administration; supervision; validation; writing—review and editing. **Rob McInnes**: Methodology; validation; writing—review and editing. **Rob Cooke**: Funding acquisition; supervision; writing—review and editing.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data and associated metadata and calculation tools for this research are available, upon request, from the authors.

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SUPPORTING INFORMATION

Table 1: "Conditions to guide an assessor into the links between the active and supporting services."

The RAWES field assessment sheet for the case study.

The RAWES+ field assessment sheet for the case study.

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