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This paper proposes both a theoretical framework and an empirical approach to build ecosystem service-specific price deflators for natural capital assets, consistent with standard national accounting practices. We focus on two key freshwater related ecosystem services in England, water provisioning and water-based recreation and tourism, constructing individual deflators for each service as well as a composite deflator. We acknowledge that this only partially cover the range of fundamental ecosystem, services provided by freshwater ecosystems. However, the framework is readily extendable to other ecosystem services and natural assets, offering a principled alternative to the use of the GDP deflator for natural capital valuation.

Keywords: Natural capital accounting, System of National Accounts, water, ecosystem services, deflator

JEL classification: Q21, Q25, Q56

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Abstract

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1. Introduction

The System of Environmental - Economic Accounting - Ecosystem accounting (SEEA EA) is a statistical and spatial framework developed by the United Nations to complement the System of National Accounts (SNA) by considering the value of ecosystems and the services they provide. To highlight the role of ecosystems in society and the economy, the SEEA EA provides a set of ecosystem accounts, which are distinguished into stock and flow accounts as well as physical and monetary accounts (United Nations et al., 2024).

Stock accounts record the extent (quantity) and condition (quality) of each ecosystem asset (e.g., forest) within a specific ecosystem accounting area (typically a country, although it may also be defined at larger or smaller spatial scales) as well as their changes over time. Flow accounts record ecosystem services (ESs) (e.g., timber provision or recreation) supplied by each ecosystem asset in physical and monetary terms. Finally, the monetary asset account records the value of the ecosystem asset as the net present value of the sum of the ecosystem services it provides, calculated assuming a reasonable asset life and an appropriate discount rate (United Nations et al., 2024).

One of the main strengths of the SEEA EA lies in its compatibility with the SNA, which records market-based economic transactions within an economy (Hein et al., 2020). In particular, the SEEA EA adopts an exchange value concept consistent with SNA principles (Edens and Hein, 2013). This allows the derivation of measures that are (i) directly comparable with standard macroeconomic indicators, such as Gross Domestic Product (GDP), and (ii) readily interpretable by policymakers and the general public.

Over the past decade, increasing attention has been devoted to the limitations of the SNA in capturing wellbeing and sustainability, as well as to the inadequacy of Gross Domestic Product (GDP) as a comprehensive measure of welfare (Dasgupta, 2021; Stiglitz, Sen and Fitoussi, 2009). The 2025 revision of the SNA aims to address several of these shortcomings. For example, it explicitly recognises the SEEA as a framework that is complementary to and aligned with the SNA. Furthermore, the updated SNA places greater emphasis on net income measures, acknowledging that they are more informative than their gross counterparts for capturing environmental sustainability considerations (United Nations et al., 2025).

However, incorporating natural capital into an accounting framework remains challenging (Obst et al., 2016), particularly with respect to the measurement of prices and quantities associated with ESs. To avoid double counting, it is important to distinguish between benefits generated by ecosystem services that are recorded within the SNA production boundary and those that fall outside it. These non-SNA benefits are typically linked with nonmarket ecosystem services (e.g., air or water filtration), for which both physical measurement and monetary valuation continue to pose significant methodological challenges. Some ecosystem assets generate a certain number of ESs, some of which are already included in the SNA production boundary and some that are not. Recreation, for example, involves observable market expenditures, such as travel costs or entrance fees, that fall within the SNA boundary, while also generating non-market benefits, including improvements in mental health and wellbeing.

Against this background and the growing emphasis on integrating natural capital within the SNA, this paper proposes a theoretical and empirical approach to construct a deflator for natural capital. In line with standard practices in traditional national accounting, we show that it is possible to construct time series of price indices that can serve as deflators for specific types of natural assets.

To illustrate the procedure, we focus on freshwater ecosystems and consider two key ESs, water provisioning and water-based recreation and tourism, while acknowledging that these represent only a partial measure of the total value of all ecosystem services provided by freshwater ecosystems, such as water purification and flood mitigation. Nevertheless, this approach provides a framework that can be readily extended to incorporate additional ESs. Our empirical illustration focuses on England only, as the data used to assess the water provisioning service in both physical and monetary terms are available for England only.

The rest of the paper is structured as follows. Section 2 presents the theoretical framework underlying the construction of a natural capital deflator. Section 3 describes the empirical application, using the selected ecosystem services as illustrative examples. Section 4 reports the results, and Section 5 concludes with a discussion of the main findings and their implications.

2. Methods for ecosystem services deflator

The valuation of ecosystem services has two important functions. First, it allows for the comparison of heterogeneous ESs using a common metric. Consider two services provided by water in a given period t. The first service is the volume of water extracted by the economy, measured in cubic metres. The second service is the recreational service provided by water, measured by the number of visits during the same period. Despite being expressed in fundamentally different physical units, valuation enables these services to be compared within a unified analytical framework.

These services cannot be directly aggregated, not least because they are measured in different physical units. However, suppose that appropriate valuation methods exist that enable the monetary value of a unit of each service to be estimated. Let p_{1t} and p_{2t} denote the monetary value per unit (price) of services 1 and 2 at time t, respectively, and let q_{1t} and q_{2t} denote the quantities of these services consumed. The monetary value of each service in period t is then given by $p_{1t}q_{1t}$ and $p_{2t}q_{2t}$. Because both values are expressed in a common currency, they can be summed to obtain the aggregate value of the services provided by water in period t[1]. Denoting this aggregate value by V_t, we have:

$$V_t = p_{1t}q_{1t} + p_{2t}q_{2t}. \tag{1}$$

This aggregate value can be computed for any period t for which data are available. Accordingly, changes in the aggregate monetary value of water services over time can be examined by comparing V_1, V_2, V_3, and so forth. While such comparisons are informative to some extent, they do not distinguish between changes arising from variations in prices and those resulting from changes in the underlying quantities, or "volumes," of ecosystem services. To make this distinction, it is necessary to apply a deflator that removes the effects

[1] This assumes that the monetary values of the two services are based on a consistent valuation concept. In the present application, both services are valued using exchange values, in line with SEEA EA principles, which provides a common basis for aggregation.

of price changes, thereby isolating changes in real service provision. The ability to assign monetary values to heterogeneous ESs is therefore essential not only for aggregation, but also for decomposing changes in value into price and quantity components. This constitutes the second key function of ESs' valuation.

In the national accounts, gross domestic product (GDP) is aggregated from its components using a Laspeyres volume index. The algebraically consistent price index corresponding to this aggregation is a Paasche price index. 2025 SNA Chapter 18 defines the Paasche Index (PI) as follows:

$$PI_t = \frac{\sum_i p_{it}\, q_{it}}{\sum_i p_{i0}\, q_{it}} \tag{2}$$

where p and q indicate the price and the quantity of service i, with $i = \{1,2\}$ in our case, t indicates the current year and 0 is the selected base year. If we define the deflator in period t as D_t then the Paasche formula gives us:

$$D_t = \frac{p_{1t}q_{1t} + p_{2t}q_{2t}}{p_{10}q_{1t} + p_{20}q_{2t}} \tag{3}$$

A deflator can be calculated for any period t, with the base-period deflator D_0 conventionally normalised to unity. If, for some subsequent period m, the deflator D_m is estimated to be 1.4 on this indexed basis, this implies that prices have risen by 40 per cent relative to the base period.

Suppose that the aggregate monetary value of water services in period m, V_m, has increased by 50 per cent relative to V_0. The observed change in value can then be decomposed into a price component and a quantity (or volume) component. Since the relationship between value, prices, and quantities is multiplicative, the real change in the volume of services is obtained by deflating the nominal change in value. Specifically, dividing the 50 per cent increase in value (a factor of 1.5) by the 40 per cent increase in prices (a factor of 1.4) yields a volume increase of approximately 7.14 per cent (=1.5/1.4=1.0714).

Accordingly, if we compute the series $V_0/D_0, V_1/D_1, V_2/D_2$, and so on, we obtain a volume series. This series no longer measures services in their original physical units, such as cubic metres of water or numbers of recreational visits. Instead, it represents the volume of ecosystem services provided, expressed in constant period-0 prices.

To derive value and volume indices, we first express the value series as an index normalised to 1 in the base year. This value index reflects the evolution of the nominal monetary value of ecosystem services relative to the base period. The volume index is then obtained by dividing the value index by the corresponding price deflator, thereby isolating changes in the real volume of ecosystem services provided over time.

The above illustration assumed that water provides only two ecosystem services. However, the underlying algebra can be straightforwardly generalised to accommodate any number of services, not just from water but from other ecosystem assets, too. The procedure is also consistent with the way goods and services within the SNA boundary are deflated.

3. Empirical illustration

This section illustrates the empirical construction of deflators for water provisioning, indicated by the subscript 1, water recreation, indicated by the subscript 2, and their aggregate. Data availability differs across ESs: estimates are available for water provisioning for the period 2009–2018, while recreation estimates are available for 2011–2023.

3.1. Valuation of water provisioning ecosystem service

The value of the water provisioning service at time t is given by:

$$V_{1t} = p_{1t}q_{1t} \tag{4}$$

where t runs from 2009 to 2018, p_{1t} indicates the unit price for the service in year t, and q_{1t} denotes the volume of water abstracted in the same period, measured in cubic metres. Such volumes are derived from Department for Environment, Food & Rural Affairs (Defra) water abstraction statistics, available up to 2018[2]. These statistics provide information on water abstracted across various economic sectors in England (agricultural and spray, electricity, fishery, public supply, private supply, other) and types of water sources (tidal surface water, non-tidal surface water and groundwater).

The unit price p_{1t} is defined using abstraction prices derived from the Environment Agency's Annual Report and Accounts for the financial years 2009-2018[3]. From each report, we extracted the table titled "Income" and exported it into an Excel file. We then divided abstraction charges for the years 2009–2018 by the corresponding physical flow volumes to obtain unit prices.

3.2. Valuation of recreation and tourism ecosystem service

The value of the water recreation and tourism service is given by:

$$V_{2t} = p_{2t}q_{2t} \tag{5}$$

where t runs from 2011 to 2023, p_{2t} denotes the unit exchange price per visit and q_{2t} indicates the number of visits in year t.

Estimates of both visits and unit prices are obtained from the ONS Natural Capital Accounts (ONS, 2025a), focusing on the summary tables for "freshwater, wetlands and floodplains"

[2] https://www.gov.uk/government/statistics/water-abstraction-estimates, accessed October 2025.

[3] Available at: https://webarchive.nationalarchives.gov.uk/ukgwa/20230911175815/https://www.gov.uk/government/collections/environment-agency-annual-reports-and-accounts.

recreation and tourism expenditure. Such estimates are based on expenditures associated with visits to the natural environment, including transport costs, car parking and entrance fees. The account combines tourism estimates, which include day visits longer than three hours, overnight trips and visits from international travellers, and recreation estimates, which include only day visits of three hours or less. The underlying data for recreation estimates are derived from Natural England's Monitor of Engagement with the Natural Environment (MENE) survey (2009–2019) and the People and Nature Survey (PaNS) (2020 onwards). For tourism, additional data sources are used, including VisitBritain's Great Britain Day Visits Survey and Great Britain Tourism Survey, as well as the International Passenger Survey run by ONS.

To ensure consistency with the provisioning service, for which abstraction statistics are available for England only, we use only estimates for England relating to freshwater ecosystems. The ONS provides monetary values in constant 2024 prices. Therefore, these prices are converted into current (year-specific) prices using CPI-based conversion factors from the Bank of England inflation calculator. Following this adjustment, annual values are recomputed as the product of the adjusted unit price and the number of visits.

3.3. Aggregate value

The aggregate value of water-related ecosystem services in year t is given by:

$$V_t = V_{1t} + V_{2t} \tag{6}$$

where V_{1t} denotes the value of the water provisioning service, and $V_{2t}$the value of recreation and tourism in year t. The aggregate value is computed for each year t over the period 2011–2018, as these represent the years for which estimates for both selected services are available.

3.4. Deflators

Price deflators are first constructed separately for each service. These single-service deflators allow changes in prices and volumes to be examined at the level of individual ecosystem services.

While price deflators are commonly used to derive volume measures from current-price values, in the present application the physical quantities are directly observable. The price index is therefore used in the reverse direction, i.e., to derive monetary values from observed physical quantities. Equivalently, the procedure can be understood as aggregating physical quantities using base-period unit values as weights.

For the provisioning service the deflator is given by:

$$D_{1t} = \frac{p_{1t}q_{1t}}{p_{10}q_{1t}} \tag{7}$$

while for recreation and tourism, it is given by:

$$D_{2t} = \frac{p_{2t}q_{2t}}{p_{20}q_{2t}}. \tag{8}$$

The composite deflator is then constructed over the two services considered: water provisioning (ES 1) and recreation and tourism (ES 2).

$$D_t = \frac{p_{1t}q_{1t} + p_{2t}q_{2t}}{p_{10}q_{1t} + p_{20}q_{2t}}. \tag{9}$$

Equivalently, the aggregate deflator D_t can be expressed as a weighted harmonic mean of the individual ecosystem-service deflators D_{1t} and D_{2t}. The weighted harmonic mean with value share weights is defined as:

$$H_t = \frac{v_{1t} + v_{2t}}{v_{1t}/D_{1t} + v_{2t}/D_{2t}} \tag{10}$$

where $v_{it} = (p_{it}\ q_{it})/(p_{1t}\ q_{1t} + p_{2t}q_{2t})$ is the value share of service *i* in period *t* is, with *i* equal to 1 or 2 and $v_{1t} + v_{2t} = 1$. Substituting v_{it} and $D_{it} = p_{it}q_{it}/p_{i0}q_{it}$ into equation (10):

$$H_t = \frac{p_{1t}q_{1t}/V_t + \ p_{2t}q_{2t}/V_t}{\frac{p_{1t}q_{1t}/V_t}{p_{1t}q_{1t}/p_{10}q_{1t}} + \frac{p_{2t}q_{2t}/V_t}{p_{2t}q_{2t}/p_{20}q_{2t}}} \tag{11}$$

Where $V_t = p_{1t}q_{1t} + p_{2t}q_{2t}$. Simplifying the denominator terms by cancelling $p_{it}q_{it}$:

$$H_t = \frac{p_{1t}q_{1t}/V_t + \ p_{2t}q_{2t}/V_t}{p_{10}q_{1t}/V_t + p_{20}q_{2t}/V_t} \tag{12}$$

Since $1/V_t$appears in every term of both numerator and denominator, it cancels, giving:

$$H_t = \frac{p_{1t}q_{1t} + \ p_{2t}q_{2t}}{p_{10}q_{1t} + p_{20}q_{2t}} = \ D_t \tag{13}$$

which establishes that the aggregate deflator D_t defined in equation (9) is indeed the weighted harmonic mean of D_{1t} and D_{2t}, with value shares as weights.

Finally, volume series are obtained by deflating current-price values using the corresponding estimated deflators, both at the level of individual ecosystem services and for aggregate ecosystem services. Volume and value indexes are presented at the aggregated level for each year t over the period 2011–2018.

4. Results

4.1. Provisioning service

Table 1 reports, for the water provisioning service over the period 2009–2018, water abstraction prices, the corresponding deflator, current-price values and the corresponding value index, quantities, volume series, and volume index. The volume series is obtained by deflating current-price values using the estimated deflator and expresses the volume of the service in constant 2011 prices. This base year is applied consistently across both services, as it marks the starting point from which recreation and tourism service estimates are available. The value index normalises the value series to 1 in 2011, providing a measure of how the nominal monetary value of the service changes relative to the base period. Finally, the volume index is derived by dividing the value index by the price deflator, capturing changes in the real volume of the ecosystem service over time. Figures 1a, 1b and 1c summarise the same information and illustrate the evolution of prices, water abstraction volumes and values, while Figure 1d presents the corresponding price deflator, value and volume indices.

Over the period 2009–2018, the water provisioning service is characterised by relatively stable physical volumes and abstraction prices. Abstracted quantities range from 15,000–17,000 Mm^3, a 13% difference (2/15) over the period (Figure 1b). Unit prices also remain relatively stable, ranging between £0.0072 and £0.0084 per m^3, a 17% difference (12/72) over the period, with a slight decline observed between 2012 and 2013 and between 2015 and 2016 (Figure 1a). As a result, current-price values range from £112 to £141 million, a 26% (29/112) difference (Figure 1c).

Figure 1d shows that, over the period considered, the deflator and value index move closely together, following a similar downward trajectory from 2012 onwards, both falling notably in 2013 and reaching their lowest point in 2016. The volume index, by contrast, remains consistently above both the deflator and value index throughout the period, staying close to or above unity even in years when the other two indices dip significantly. This divergence indicates that, while the nominal value of the service declined in those years, the real volume of water provisioning did not, suggesting that the decline in value is mainly price-related rather than a reduction in actual service provision.

Table 1: Water provisioning service unit prices, the corresponding deflator, values, (million £), quantities (Mm^3), volume series (million £ 2011 prices), and volume index (2009-2018).

Year	Price (£/m3)	Deflator	Values (M£)	Value index	Quantity (Mm3)	Volume (M£2011 prices)	Volume index
2009	0.0082	0.98	134.80	1.00	16,445	137.56	1.02
2010	0.0080	0.96	131.60	0.98	16,437	137.49	1.02
2011	0.0084	1.00	134.49	1.00	16,078	134.49	1.00
2012	0.0083	0.99	140.60	1.05	17,038	142.52	1.06
2013	0.0075	0.90	118.40	0.88	15,699	131.32	0.98
2014	0.0079	0.95	116.10	0.86	14,682	122.81	0.91
2015	0.0082	0.98	120.50	0.90	14,729	123.21	0.92

2016	0.0072	0.86	112.30	0.83	15,633	130.77	0.97
2017	0.0073	0.87	118.30	0.88	16,301	136.36	1.01
2018	0.0077	0.92	124.20	0.92	16,226	135.73	1.01

Note: Minor discrepancies may occur due to rounding, as calculations are based on unrounded values while reported figures are rounded for readability.

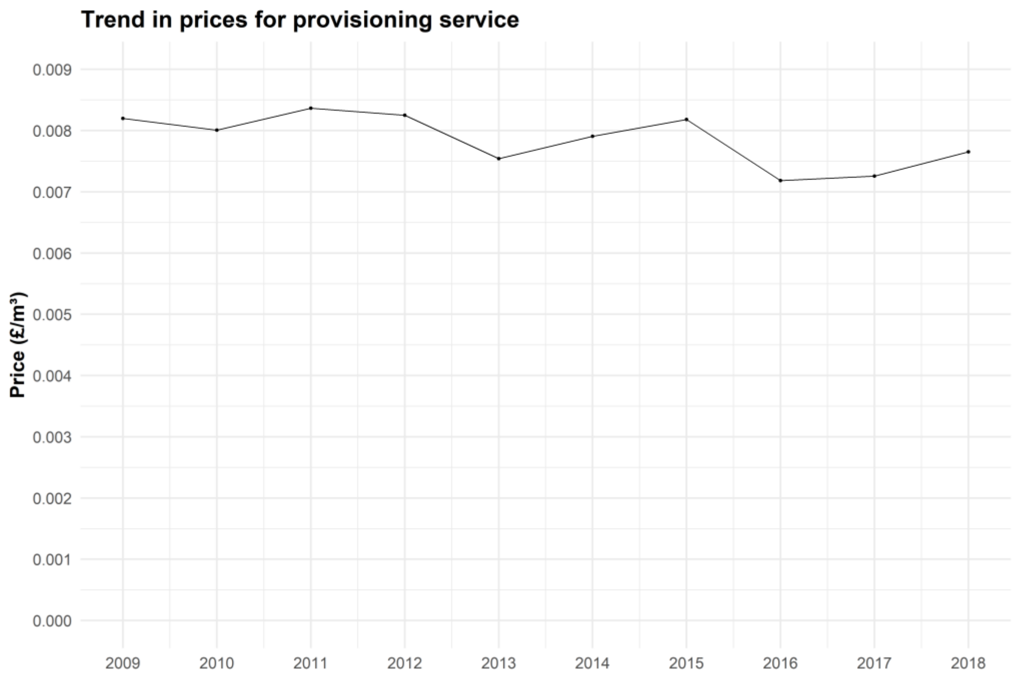

Figure 1a: The trend of abstraction prices over the years 2009-2018.

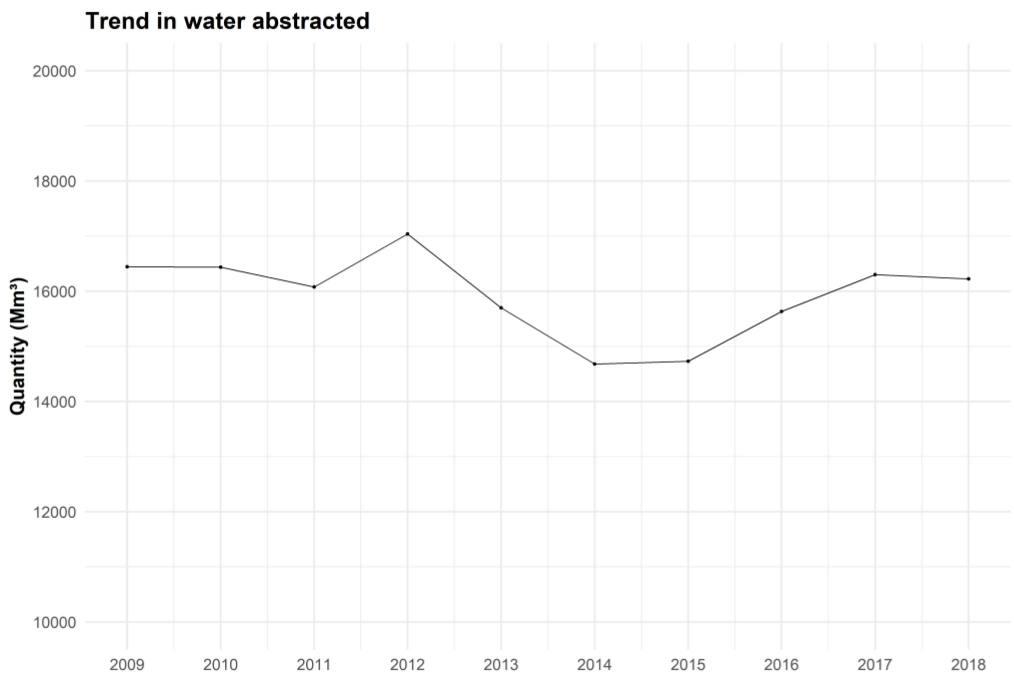

Figure 1b: Water provisioning abstracted volumes (million cubic meters) over the years 2009-2018.

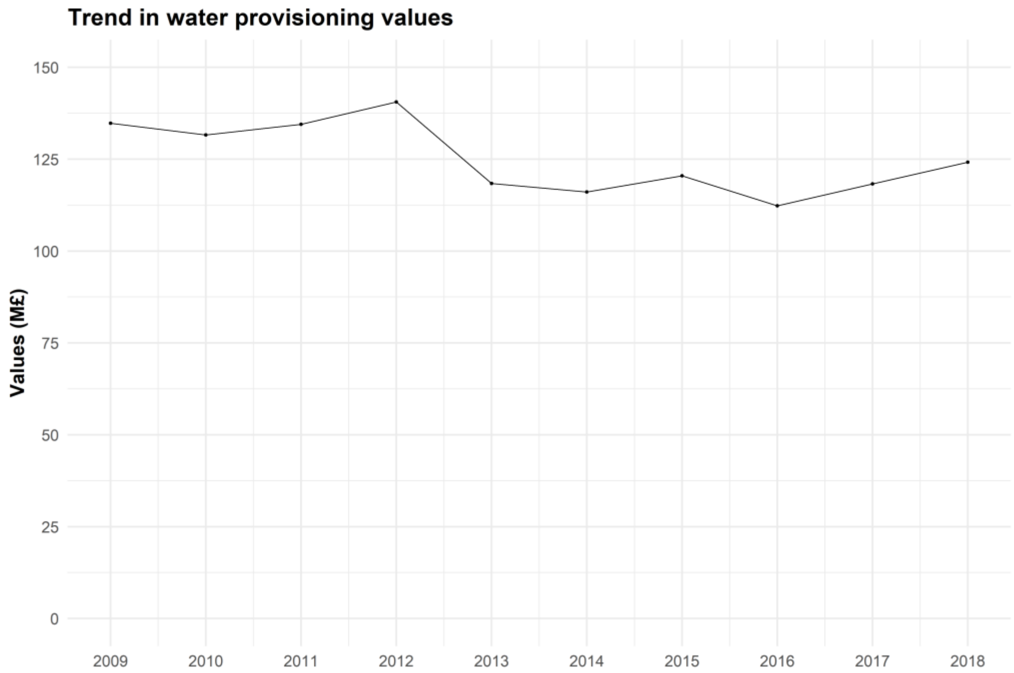

Figure 1c: Water provisioning values (million £) over the years 2009-2018.

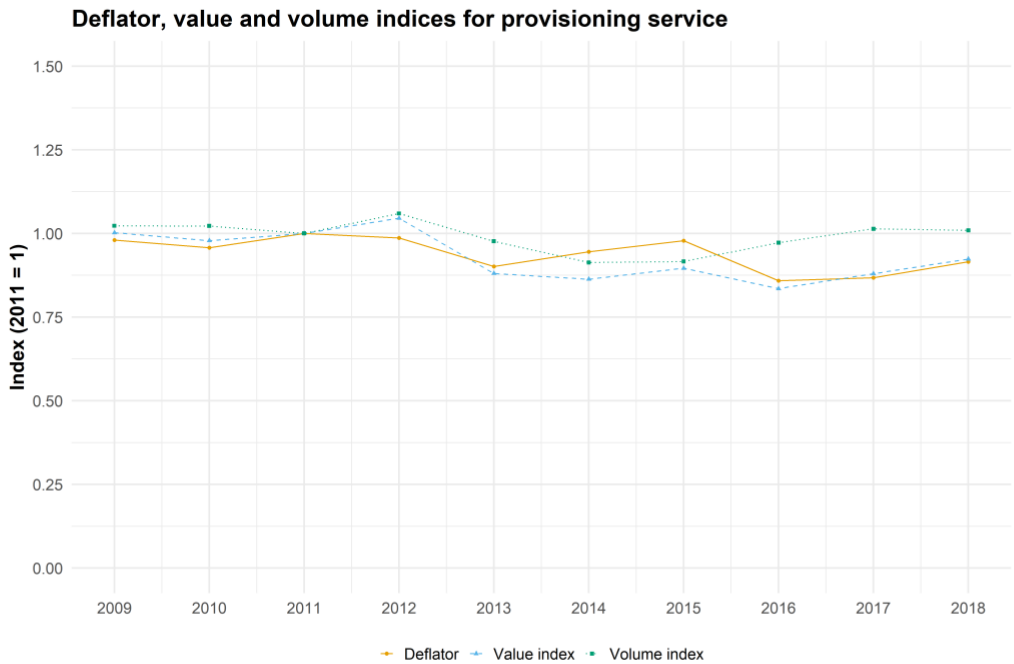

Figure 1d: Water provisioning indices over the years 2009-2018.

4.2. Recreation and tourism service

Table 2 reports prices, the corresponding deflator, current-price values, value index, quantities, the 2011-price volume series, and the volume index for the recreation and tourism service provided by freshwater, wetlands, and floodplains over the period 2011–2023, with 2011 as the base year. Figures 2a–2c show the evolution of prices, visits and values, while Figure 2d presents the associated indices.

The results reveal substantial variability in both prices (which vary by for than a factor of 10) and quantities (which vary by nearly a factor of 3) over time, particularly around 2020, when recreation visits increase and unit prices decline. As a result, we see a significant drop in the deflator, while the volume index rises substantially. These contrary movements in price and volume largely cancel each other out in the value index, which returns close to its 2011 figure by the end of the period (Figure 2d). However, the increase in the number of visits dominated, so that the volume of the service grew substantially in 2020.

This pattern may partly reflect a change in measurement, as the survey methodology shifted from MENE to PaNS between 2019 and 2020, affecting comparability across years (ONS, 2025b). As MENE and PaNS are not directly comparable due to changes in survey design and mode, some of the increase in visits observed from 2020 onwards is likely attributable to the survey change rather than actual behavioural change. The shift from MENE to PaNS between 2019 and 2020 means that estimates before and after that point are not directly comparable. Therefore, 2020 should be treated as a break in the series, and the pre- and post-2020 periods should be interpreted separately. Nevertheless, the empirical illustration covers the full period, as the primary aim is to demonstrate the methodological framework rather than to draw substantive conclusions about trends in recreation values.

The other possible driver is the COVID-19 pandemic, when restrictions may have increased the frequency of local outdoor activities such as walking, thereby raising the number of visits. At the same time, unit prices declined, as these are derived from travel-related expenditures, which were significantly reduced during this period (e.g., switching travel mode from driving to walking and shorter travel distances).

Table 2: Freshwater, wetlands, and floodplains recreation and tourism service unit price, deflator, value (million £), value index, quantity (number of visits, million), volumes (million £,2011 prices) and volume index (2011-2023).

Year	Price (£)	Deflator	Value (M£)	Value index	Quantity (number of visits)	Volume (M£, 2011 prices)	Volume index
2011	2.94	1.000	472.458	1.000	160.7	472.46	1.000
2012	2.50	0.850	373.500	0.791	149.4	439.24	0.930
2013	2.36	0.803	404.268	0.856	171.3	503.62	1.066
2014	2.30	0.782	394.910	0.836	171.7	504.80	1.068
2015	2.34	0.796	474.318	1.004	202.7	595.94	1.261
2016	3.59	1.221	632.199	1.338	176.1	517.73	1.096
2017	1.68	0.571	325.080	0.688	193.5	568.89	1.204
2018	3.62	1.231	537.932	1.139	148.6	436.88	0.925
2019	2.66	0.905	479.864	1.016	180.4	530.38	1.123
2020	0.35	0.119	171.605	0.363	490.3	1441.48	3.051
2021	0.82	0.279	355.634	0.753	433.7	1275.08	2.699
2022	1.00	0.340	430.300	0.911	430.3	1265.08	2.678
2023	1.07	0.364	503.649	1.066	470.7	1383.86	2.929

Note: Minor discrepancies may occur due to rounding, as calculations are based on unrounded values while reported figures are rounded for readability.

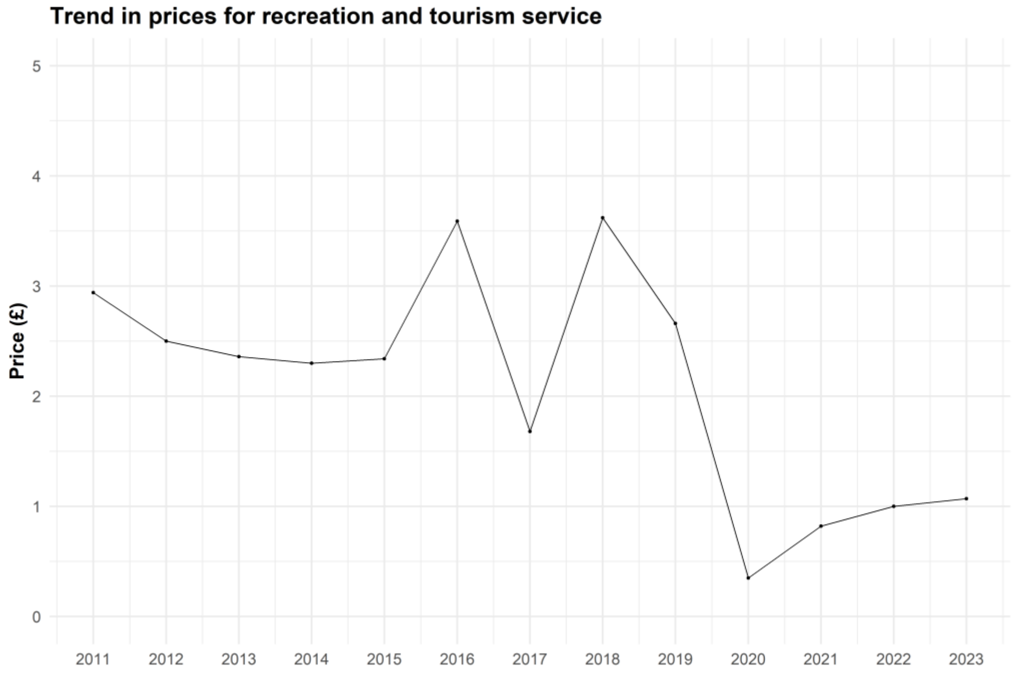

Figure 2a: The trend of recreation and tourism service prices over the years 2011-2023.

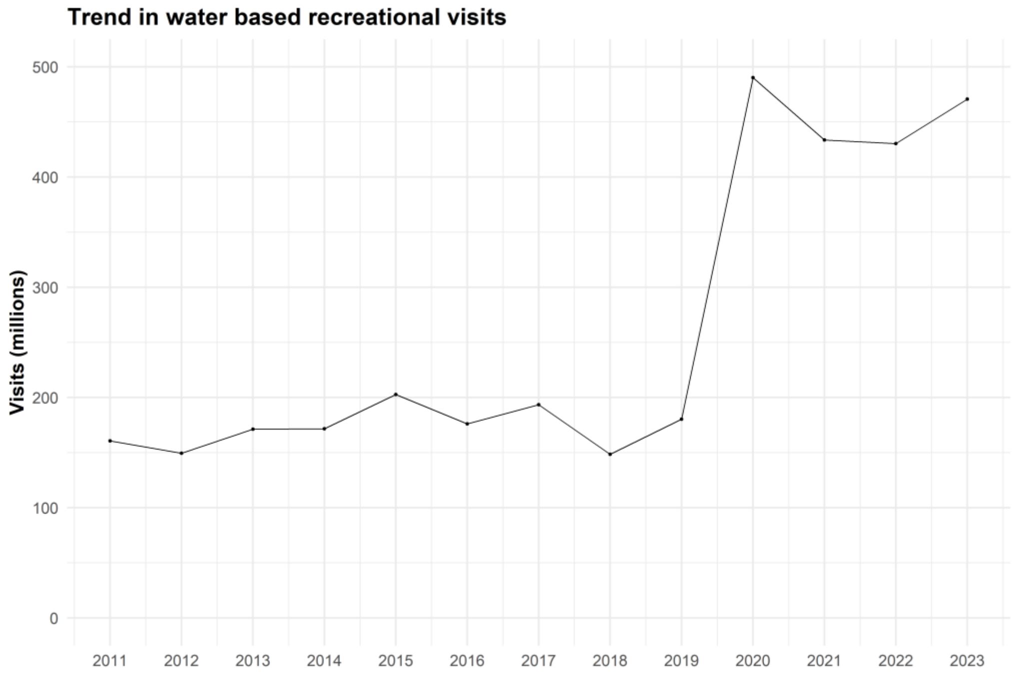

Figure 2b: Water-based recreation visits (million) over the years 2011-2023.

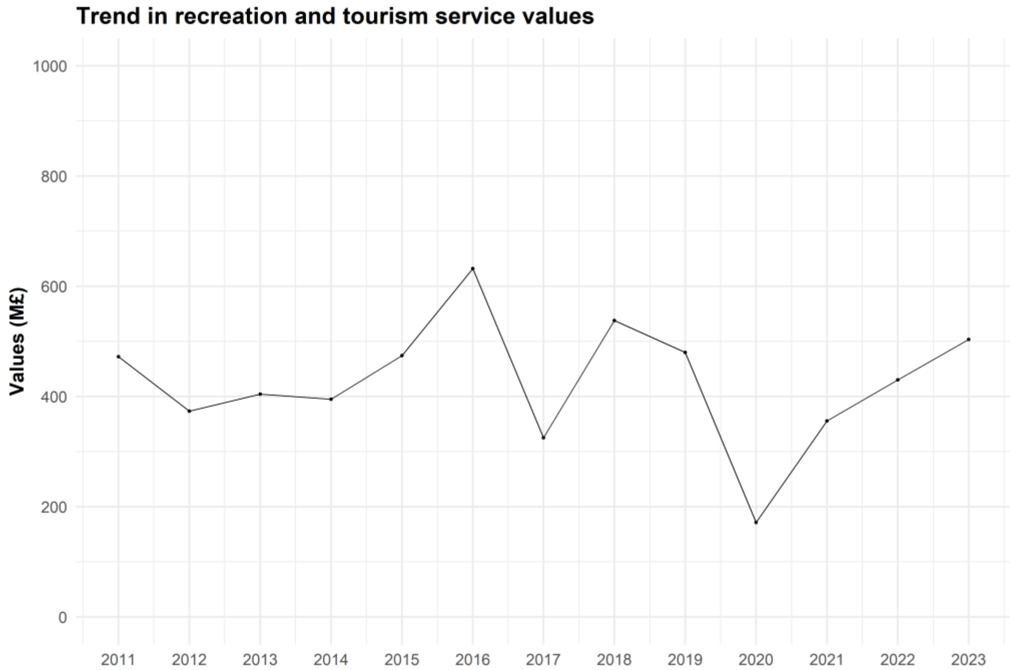

Figure 2c: Water-based recreation and tourism values (million £) over the years 2011-2023.

Figure 2d: Water-based recreation deflator, value and volume indices over the years 2011-2023.

4.3. Aggregated deflator

Table 4 shows the total value of the two selected ES, i.e., water provisioning and water recreation and tourism, along with the aggregated deflator, the volume series computed accordingly $\left(\frac{V_{2011}}{D_{2011}}, \frac{V_{2012}}{D_{2012}}, \dots \frac{V_{2018}}{D_{2018}}\right)$, and the value and the volume indices. Finally, figure 3a shows the aggregated deflator, value and volume indexes over the period 2011-2018.

The three indices show considerable variability, largely reflecting the variability of the recreation and tourism service. The deflator and value index move broadly together for most of the period, with the most notable divergences in 2015 and 2017. The volume index diverges from the value index in several years, most evidently in 2017, when the real volume of aggregate service provision increased relative to the base year despite the decline in nominal values.

Table 4: Aggregate value, deflator, volume series, and value and volume indices for the selected ES over the years 2011-2018.

Year	Value tot (M£)	Deflator	Volume (M£, 2011 prices)	Value index	Volume index
2011	606.950	1.000	606.950	1.000	1.000
2012	514.100	0.884	581.758	0.847	0.958
2013	522.668	0.823	634.943	0.861	1.046
2014	511.010	0.814	627.612	0.842	1.034
2015	594.818	0.827	719.145	0.980	1.185
2016	744.499	1.148	648.503	1.227	1.068
2017	443.380	0.629	705.247	0.731	1.162
2018	662.132	1.156	572.614	1.091	0.943

Note: Minor discrepancies may occur due to rounding, as calculations are based on unrounded values while reported figures are rounded for readability.

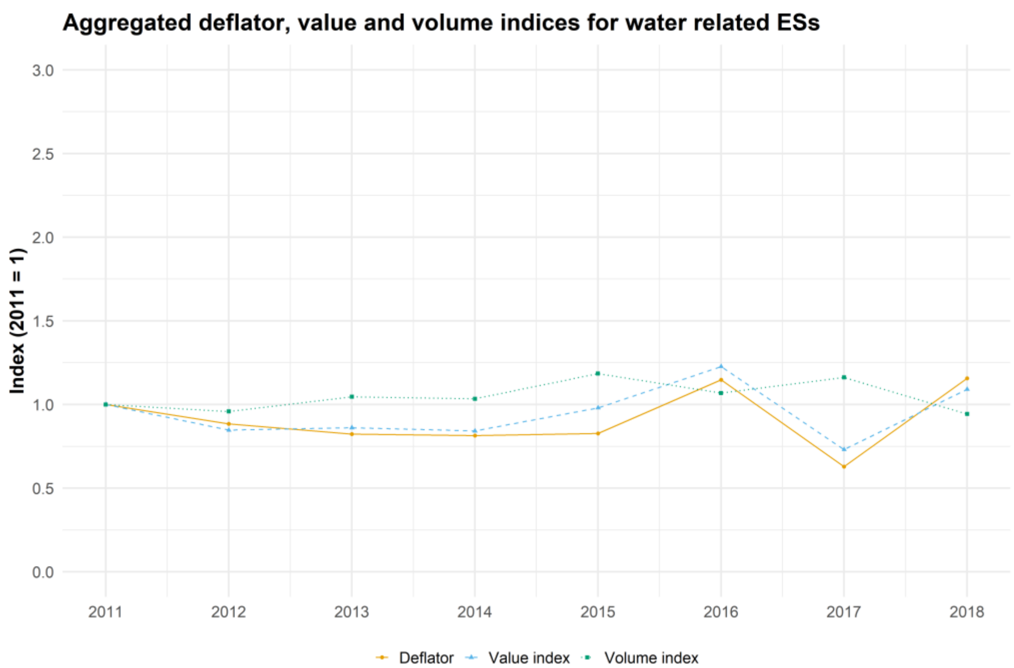

Figure 3a: Aggregated deflator, value and volume indices over the years 2011-2018.

5. Discussion and concluding remarks

From a national accounting perspective, service-specific price deflators are important as they allow us to separate price changes from changes in the quantity of individual ecosystem services. At the same time, a combined deflator is needed to assess overall trends across services and to ensure consistency with standard economic indicators such as GDP. In this context, the present paper contributes by providing both a theoretical foundation and an empirical illustration of how such deflators can be constructed for natural capital assets. The discussion that follows reflects on the main methodological considerations arising from this exercise and outlines directions for further research.

First, the empirical illustration highlights a fundamental constraint: the construction of meaningful deflators requires sufficiently long and consistent time series of both prices and quantities, and the data currently remain insufficient for this purpose. Regarding the two examples of ESs considered in the empirical illustration, provisioning estimates rely on observed quantities only up to 2018, while recreation estimates are affected by potential incomparability arising from changes in survey methodology (ONS, 2025b).

Second, when dealing with environmental assets, particularly water, both their extent (quantity) and condition (quality) underpin the provision of ecosystem services (La Notte et al., 2022). In the case of water, extent refers to the total area covered by freshwater related ecosystems, such as rivers, lakes and wetlands, within the accounting area. In addition to the area covered by freshwaters, it can also be useful to calculate the water volumes (in m^3) contained within it. Condition captures the quality of these ecosystems (United Nations et al., 2024). In principle, changes in prices - observed or imputed - which are solely due to changes in quality should not be reflected in a change in the deflator. Otherwise, we would not be comparing like with like. However, further development of valuation methods should aim to account for how changes in ecosystem condition affect the prices and values of ESs (La Notte et al., 2022; Pisani et al. 2024).

A third consideration concerns the supply-side and the institutional context assumptions that underpin the treatment of exchange prices and values and are not explicitly accounted for in the construction of the deflators presented in this paper. National accounting frameworks typically rely on institutional arrangements in which transactions between buyers and sellers are observable. In the context of the SEEA EA, however, this distinction becomes less clear. While buyers are those who benefit from the service, identifying the seller is more challenging, as services are generated by ecosystem assets such as a forest or a river (Atkinson and Obst, 2017). Previous scholars have given some consideration to the supply of ESs. For example, Scheufele and Pascoe (2023), when valuing recreation-related ecosystem services (recreational fishing trips), assume that the supply curve follows the cost incurred by a hypothetical management of the underlying ecosystem asset. The authors report the results under different scenarios, where costs are (i) fixed, (ii) partially variable, and (iii) entirely variable, i.e., depending on the number of visits. Moreover, following Caparrós et al. (2017), they assume that the supplier operates in a monopolistic market.

These assumptions may have direct implications for the construction of deflators for ecosystem services whose prices are derived by making assumptions about the supply curve. In the empirical illustration, we use abstraction prices for water provisioning and travel expenditures for the recreation and tourism service, both of which reflect actual transactions between two economic units. When no monetary transaction occurs, for example in the case of water purification, where society enjoys the benefit for free, and valuation relies on approaches such as the replacement cost method, consideration of the institutional context becomes necessary.

A related consideration arises in respect of the consistency of natural capital valuations with the SNA production boundary. Estimates of GDP (within the production boundary) contain both observable market transactions and some non-market transactions. Similarly, in assessing ecosystem services provided by a natural asset, it is important to distinguish between services already captured within the SNA production boundary, such as water provisioning and recreation and tourism services in the present application, and those that fall outside it, such as water purification. Careful attention to this distinction is necessary to avoid double-counting, prior to the derivation of any deflator or volume measure.

Related to this point, although the empirical illustration presented in this paper relies on observed exchange values derived from actual transactions, such transactions may not be available for all ecosystem services. In these cases, the SEEA EA recognises the possibility of estimating exchange values based on marginal willingness to pay (WTP), which may be derived using well-established non-market valuation techniques and can provide alternative, and potentially higher, valuations of ecosystem services, particularly where observed prices are absent or equal to zero. This may be the case for some ecosystem services and has also been discussed in the context of free digital products (Schreyer, 2025). However, careful attention is required to ensure consistency with the accounting boundary of the SNA. Similarly, measures incorporating consumer surplus extend beyond the exchange value concept used in national accounting (Coyle and Wdowin, 2025).

Finally, a common international practice, followed for example by the ONS, is to deflate natural capital estimates expressed in monetary terms into volume estimates using the GDP deflator. This has clear drawbacks. There is no reason why the inflation experienced by GDP and its various components should have any relationship to price changes in completely separate natural assets outside the SNA boundary. By contrast, the procedure set out in this paper provides a way of deflating natural capital assets and services based on the specific price movements experienced by those assets, as referenced by the estimated changes in valuation over time. At the same time, by aggregating the estimated deflators for individual assets and services by use of a Paasche index, the resulting aggregate deflator for natural capital articulates directly and consistently with the GDP deflator. This would appear to represent a significant advantage over the current procedures.

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