

CONTRIBUTED PAPER

Using a residency index to estimate the economic value of coastal habitat provisioning services for commercially important fish species

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Abstract

Coastal habitats worldwide face various threats, including sea level rise and land conversion. Coastal habitat loss has important economic consequences, as many of these habitats provide valuable ecosystem services including flood protection, carbon sequestration, and nursery areas for commercially fished species. Quantifying the economic value of these ecosystem services helps target policies for coastal habitat restoration. Here, we demonstrate how to quantify the contribution made by coastal habitats to the revenue (e.g., ex-vessel values) of commercially fished species by estimating a residency index. This residency index weights the relative importance of a habitat along a species' lifecycle by explicitly incorporating the target species' life histories and the estimated proportion of time the species spends in that habitat at different life stages. We demonstrate how this method can be used to estimate the value of saltmarsh to UK commercial fisheries landings. This analysis suggests that UK saltmarsh contributes annually between 15% and 17.5% of total UK commercial landings for European seabass (*Dicentrarchus labrax*), European plaice (*Pleuronectes platessa*), and Common sole (*Solea solea*). Our findings support an economic argument for saltmarsh protection and restoration. Furthermore, our approach provides a general framework that integrates demographic methods and economic analyses to assess the value of saltmarsh and other coastal habitats for fisheries worldwide.

KEYWORDS

ecosystem services, fisheries, residency index, saltmarsh, United Kingdom

1 | INTRODUCTION

Globally, coastal-habitat extent is in severe decline (Balke, Stock, Jensen, Bouma, & Kleyer, 2015; Barbier et al., 2011; Waycott et al., 2009). This decline is caused by a variety of human-related activities including climate change, runoff,

and coastal development (Balke et al., 2015; Waycott et al., 2009). Destruction of coastal habitats can reduce the ecosystem service flows these habitats provide, leading to large economic losses (Luisetti et al., 2011). In response, governments worldwide have allocated resources to protect and restore coastal ecosystem extent (Bayraktarov

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et al., 2015). The economic value of services that coastal ecosystems provide has become a growing consideration when designating protected area status to coastal habitats, or when allocating resources for protection and restoration of coastal ecosystems (Bateman & Wheeler, 2018). For example, the United States government, through the “Principles, Requirements and Guidelines for Federal Investments in Water Resources” (2013), explicitly requires that ecosystem services are included in planning processes. Additionally, in 2019 the UK government expanded the criteria for selecting and designating Sites of Special Scientific Interest (SSSI) to consider ecosystem service provision (Rees, Angus, Creer, Lewis, & Mills, 2019). While ecosystem service valuation is becoming more widely utilized globally as a tool to support ecosystem protection and restoration, there is a growing need to develop and improve the techniques that underpin this work.

Coastal habitats provide key ecosystem services. These include flood defense (King & Lestert, 1995), recreation (Luisetti et al., 2011), carbon sequestration (Luisetti et al., 2014), and habitat for commercially important fish species (Green, Smith, Grey, & Underwood, 2012). One of the most highly valued contributions of coastal habitats to people is the provision of habitat for commercial fish species (Woodward & Wui, 2001). This ecosystem service is classified as a “material contribution” following the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2017), and is one of the most difficult ecosystem service values to quantify (Barbier et al., 2011). The difficulty arises because fish use coastal habitats differently depending on a range of factors including species, life stage, time of year, and tidal range (Scott, 2000). This means that fisheries value is often excluded from valuations of coastal habitats. For example, in a 2016 UK government report scoping the use of coastal margin ecosystem accounts in the UK, fisheries values are not estimated due to the lack of research and guidance on valuation methodologies (Office for National Statistics, 2016). Growing emphasis on ecosystem service valuation as a way to guide decision-making regarding protection and restoration of coastal habitats means that it is essential for research to improve and build upon existing methods. With this aim, this study extends an existing species-specific approach to quantify the commercial fisheries value provided by coastal habitats by developing a generalizable framework and offering solutions to overcome data deficiencies.

Because different species of fish use coastal habitats at different life stages (e.g., juvenile, adult) and for different purposes (e.g., feeding, reproduction), a species-specific approach to quantifying fisheries value is necessary. Scott (2000) developed a species-specific approach for quantifying the fisheries value of seagrass, using a

residency index. This method uses seagrass residency time as a proxy for habitat dependency and adds weighting based on life stage mortality rates (Jackson, Rees, Wilding, & Attrill, 2015; McArthur & Boland, 2006; Scott, 2000). The resulting residency index value describes a species' dependence on seagrass where 0 indicates no dependence, and 1 represents total dependency. This index is then applied to the species' fisheries revenue in order to apportion value to seagrass. Since this study was published, there have been several further studies that have used this method to estimate seagrass fisheries value. For example, Jackson et al. (2015) used this approach to estimate the commercial and recreational fisheries value of seagrass in the Mediterranean. However, this approach has not yet been adapted or generalized for other coastal habitats.

In this study, we operationalize a generalizable framework that draws on residency index methods to estimate the commercial fisheries value of any coastal habitat. Within this framework, we recommend how to overcome data deficiencies and present alternative parameterization approaches, specific to time and budget constraints. We describe our framework using UK saltmarsh as a case study. The purpose of this work is to generalize a prioritization tool that could be used by government agencies when allocating resources for habitat restoration. The proposed framework can be used to evaluate the fisheries benefits provided by coastal habitats around the world.

2 | METHODOLOGICAL FRAMEWORK

We present a generalizable framework to prioritize coastal habitat restoration—many of which are important

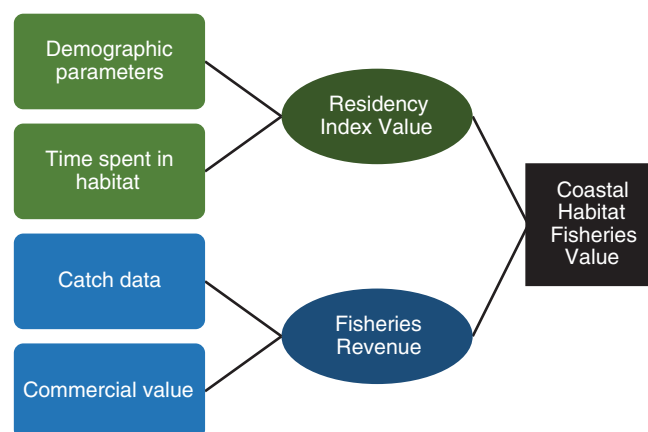


FIGURE 1 Generalisable framework showing the data required (left, four rectangles), the analyses they support (middle, two ovals), and the final output (right, black square)

fish resources and whose extent and condition are declining rapidly. We describe the key data (rectangles, Figure 1) and methods (ovals, Figure 1) used in this framework in Figure 1. Briefly, the two main analyses (ovals, Figure 1) are: (a) calculating a species-specific residency index value, and (b) estimating species-specific fisheries revenue. The first analysis, calculating the residency index value, requires both demographic data as well as estimates of proportion of time the species spends in the habitat of interest. We describe alternative methods for estimating proportion of time spent in coastal habitats, including tracking studies, expert elicitation, and meta-analysis. The second analysis, calculating fisheries revenue, requires both catch data and value per ton (or similar). These two analyses are then combined to estimate the habitat fisheries value (black square, Figure 1). When applying our methodology, the analyst should ensure that the commercial fish species they wish to assess meet(s) the following criteria: (a) species is known to spend time in the habitat of study, (b) species is of commercial importance, and (c) fisheries/landings data exists for the species. In the material to follow, we describe this process in further detail.

2.1 | Calculating residency index

The residency index (RI) represents fish dependency on the habitat in question, and is calculated using the following formula, developed by Scott (2000):

$$RI_{hi} = 1 - \exp\left\{-\left[\exp(-m_i(t_{ji}-t_{ai}))x_i + y_i\right]\right\} \quad (1)$$

Equation (1) quantifies RI for species i , in habitat h , where m is the natural (base-line) mortality rate; t_{ji} is the time (years) spent as a juvenile (j) and t_{ai} as an adult (a) along the lifecycle of the species; x_i is proportion of time spent in habitat h as a juvenile; and y_i is proportion of time spent in habitat h as an adult (Jackson et al., 2015; Scott, 2000). It is important to note that Equation (1) takes into account variable habitat use by juvenile and adult life stages (Scott, 2000). This distinction is necessary for the RI of a given species because some fish species use coastal habitats primarily as a nursery habitat but can spend the rest/part of their lifecycles in other habitats, for example European seabass (*D. labrax*) in saltmarsh (Colclough, Fonseca, Astley, Thomas, & Watts, 2005). Moreover, the mortality rate m of fish often depends on their life stage (Caswell, 2001). Thus, the quantification of the RI weights time spent in habitat h as juvenile and adult life stages based on potential differences in relative mortality rates. In practice, this

means that a life stage with a relatively high mortality rate is weighted higher in the final index. Mortality rates tend to be greater for juveniles than adults (Bailey & Duffy-Anderson, 2001), suggesting the importance of surviving as a juvenile to reach maturity. Therefore, the residency index adds greater weight to time spent in habitat h during juvenile life stages.

2.1.1 | Determining life history parameters

There are several potential sources for the life history parameters used in the Residency Index formula described above. The ideal source of these data is structured population models, where individuals in a population of interest, preferably within the study region, are classified into stages in a discrete-time model (e.g., life tables (Preston, Heuveline, & Guillet, 2000), matrix population models (Caswell, 2001) or integral projection models (Ellner, Childs, & Rees, 2016)). Here we showcase the application with matrix population models but note that these methods are equally applicable to life tables and integral projection models. Briefly, a matrix population model incorporates the vital rates (i.e., survival, development, and reproduction) that shape the dynamics of a population of interest while explicitly incorporating the contributions of individuals to the population along its lifecycle (Caswell, 2001). A matrix model includes the aforementioned vital rates for each of the stages in the lifecycle (e.g., juveniles and adult, as necessary for Equation (1)). However, building a matrix population model (MPM) for a species takes years of time and resource investment, and therefore relatively few fish species have existing matrix models (Vélez-Espino, Fox, & McLaughlin, 2006; Salguero Gomez et al., 2015).

An alternative source of demographic data is from stock assessment reports produced by government bodies such as NOAA Fisheries in the United States, or international bodies including the International Council for the Exploration of the Sea (ICES). While these reports may not provide all data necessary for calculating a residency index, they will often include natural mortality and age at maturity.

A third and final source of data are matrix population models from a closely related species. Overcoming data deficiencies in this way is a common practice in comparative demographic studies of animal species (Heinsohn et al., 2004; Koenig, 2008; Vélez-Espino et al., 2006), because demographic rates tend to be well-preserved across different lineages of the Animal kingdom

(Blomberg & Garland, 2002; Healy, Ezard, Jones, Salguero-gómez, & Buckley, 2019; Capdevila et al., 2020; James).

2.1.2 | Estimating proportion of time spent in habitat

The last piece of data necessary to complete the residency index calculation is an estimate of how much time a species spends in the habitat of interest at different life stages. There are several existing methods for determining these values. The method chosen will depend on available resources, funding, and timing. While we focus on three principle methods here, we recognize that more may exist.

Arguably, the most accurate way to estimate the proportion of time fish spend in a habitat would be through tagging individual fish and tracking their movements over the course of a year, to account for seasonal variations. Tagging studies are becoming increasingly popular for investigating fish movements, for example in Doyle, Haberlin, Clohessy, Bennison, and Jessopp (2017), and may already exist in the literature for the species in question. Ideally, the tagging study would take place in the region of study, include fish of varying ages, and capture a large sample size. Tagging studies, however, can be labor-intensive, costly, and for this purpose require over a year to complete, all of which limit their accessibility.

If a tagging study is unavailable, an alternative method for estimating the proportion of time a species spends in a habitat is through expert elicitation. Expert opinion is a useful tool for estimating uncertain values (Hanea, McBride, Burgman, & Wintle, 2016; Hemming, Burgman, Hanea, McBride, & Wintle, 2018; Speirs-Bridge et al., 2010). Past studies have developed useful guidance to ensure the effective use of expert elicitation to reduce bias and overconfidence (Hanea et al., 2016). For example, Hemming et al. (2018) outlines the IDEA protocol, which consists of the following steps: “investigating” the question, “discussing” as a group, “estimating” final values individually, and “aggregating” the estimations (Hemming et al., 2018). When developing a questionnaire for experts, it is important to structure the questions by season because many fish species follow migration patterns depending on the time of year (Colclough et al., 2005). It is also important to elicit minimum, maximum, and best guess value, as well as level of confidence, as outlined by Speirs-Bridge et al. (2010).

The third available method we present here is a meta-analysis. Due to the lack of habitat-specific demographic

information in the literature (Vasconcelos, Eggleston, Le, & Tulp, 2014), this approach will necessarily assume that, at a particular life stage, a species spends equal amounts of time in every habitat it is found to use at that stage. For example, if a fish can be found in four different habitats as a juvenile, one of which is habitat h , we assume that it spends 25% of its time in habitat h . This assumption simplifies species' habitat use, and therefore introduces the possibility of under- or over-estimating the importance of habitat h compared to other habitats. If a species is found to spend time in habitat h in a given life stage, the overall proportion of time spent in habitat h as a juvenile and an adult is calculated using the following formulas, adapted from Jackson et al. (2015)

$$x_{hi} = \frac{1}{H_{ji}} \quad (2)$$

and

$$y_{hi} = \frac{1}{H_{ai}} \quad (3)$$

where x_{hi} is proportion of time spent in habitat h as a juvenile, H_{ji} is total number of habitats used as a juvenile, y_{hi} is proportion of time spent in habitat h as an adult, and H_{ai} is total number of habitats used as an adult.

2.2 | Fisheries revenue

The availability of commercial fisheries data varies by country, and often by region. Government and international bodies will often have accessible catch and landings data, and is often an analyst's best option. We make the following recommendations for fisheries data: (a) Use spatially explicit catch data. This location-specific information allows the analyst to only include the catch areas adjacent to the study habitat to be included, under the assumption that species that have spent time in these habitats are most likely to be caught in these areas. (b) Find the average catch amount in each catch area over the past 5–10 years. Often, ecosystem service assessments are used to capture value over several years. Therefore, it is best to incorporate catch levels over several years to reflect the variation in catch levels of certain stocks or populations. (c) Use the value per ton estimate from the most recent year included in the study. This helps ensure that management recommendations reflect the most current market conditions. Multiplying average catch by average value per ton then gives an estimated fisheries revenue value for each species.

2.3 | Coastal habitat fisheries value

The final step in our framework is multiplying the residency index value for each species by their respective commercial fisheries revenue value. The values for individual species can then be aggregated to quantify the total commercial value provided by a habitat for the species of interest (Jackson et al., 2015). This is shown in the following Equation (4):

$$FV = \sum_i FV_i \times RI_{hi} \quad (4)$$

where FV is the total fisheries value, FV_i is the fisheries value for species i , and RI_{hi} is the residency index value for species i in habitat h .

3 | CASE STUDY

We illustrate our framework in a case study taken from the United Kingdom (UK), assessing the commercial fisheries value provided by saltmarsh. Saltmarsh is a nursery habitat for many commercially important fish species, including European seabass (*Dicentrarchus labrax*) in the UK (Colclough et al., 2005) and sea mullet (*Mugil cephalus*) in Australia (Taylor, Gaston, & Raoult, 2018). Global saltmarsh extent has experienced a drastic decrease, with 50% of the world's saltmarshes lost or rapidly declining (Barbier et al., 2011). The UK has 44,512 ha of saltmarsh (Office for National Statistics, 2016), and supports a fleet of 5,270 fishing vessels (Marine Management Organisation, 2019). The total value of fish landings brought in from the UK fleet to ports in the UK and abroad in 2015 was £776.3 million (Marine Management Organisation, 2016). This value corresponded to approximately 14.1% of the total landings value of the European fleet in 2015, which was £5.5 billion (STECF, 2017).

We selected species to assess in our case study by searching the literature and consulting experts to identify fish that spend time in UK saltmarsh. We then assessed whether UK landings data were available for the identified species, to determine which of these fish were commercially relevant. We chose to focus on three fish species: European seabass (*Dicentrarchus labrax*), European plaice (*Pleuronectus platessa*), and Common sole (*Solea solea*). These three species are well-studied, ensuring good data availability. We note that there are other commercially important species of fish that also spend time in saltmarsh, but it was beyond the scope of this study to access and compile data for these additional species. For our chosen species, time and budgetary

requirements prevented us from conducting a tagging study to estimate proportion of time spent in saltmarsh. Instead, we used the two other available methods (expert elicitation and meta-analysis) and compared the results using a sensitivity analysis. For details about the data used for the case study, see Figure 2. The parameters used to calculate the residency index values are shown in Table 1, along with their sources.

3.1 | Sensitivity analysis

We assess the utility of our approach through a sensitivity analysis. This step allows us to test the responsiveness of the final commercial fisheries value of saltmarsh to the different parameters used in the model, and therefore determine which parameters are most influential on the final results. To conduct this analysis, we calculated a species-specific sensitivity index for incremental changes in the following four parameters (a) natural mortality, (b) time spent as a juvenile, (c) time spent as an adult, and (d) the proportion of time a species spends in saltmarsh. We used the following equation from Yeo (1991):

$$SI_i = \frac{\frac{CFV_n - CFV_b}{CFV_b}}{\frac{P_{in} - P_{ib}}{P_{ib}}} \quad (5)$$

where SI_i is the sensitivity index for parameter P , P_{ib} is the original parameter value, P_{in} is the increased parameter value, CFV_b is the original commercial fisheries value calculated with P_{ib} and CFV_n is the new commercial fisheries value calculated with P_{in} .

We conducted all analyses using R Version 3.5.1 (R Core Team, 2018).

4 | RESULTS

Based on our analysis, between £2.9 ± 0.16 million (from expert elicitation) and £3.4 ± 0.13 million (from meta-analysis) of the total annual fisheries value for *Dicentrarchus labrax*, *Pleuronectus platessa*, and *Solea solea* can be attributed to saltmarsh (Figure 3). This makes up 15% to 17.5% of the total landings values for these species in 2015, which was £19.4 million (Marine Management Organisation, 2017). We compare our results with 2015 landings because we used MMO fisheries data from this year to calculate the value per ton for each species, as it was the year with the most recent species-specific, spatially-explicit value-per-ton estimates. Based on our expert elicitation and meta-analysis results,

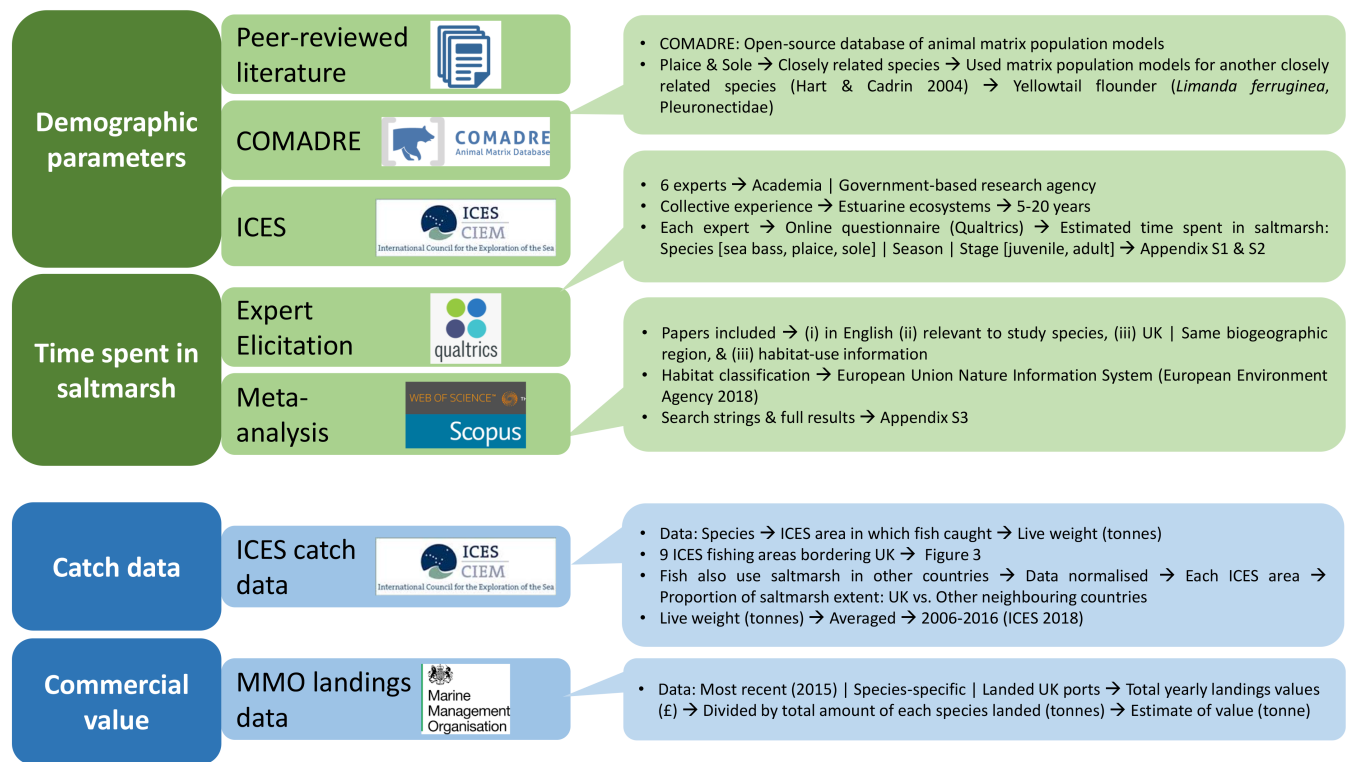


FIGURE 2 Description of the data sources for calculating residency index values and fisheries revenue for 3 study species (*Dicentrarchus labrax*, *Pleuronectes platessa*, *Solea solea*) included in a UK saltmarsh case study. Any details about the data sources or how data was obtained are described in the boxes on the right

TABLE 1 Life history parameters and their respective sources used for calculating Saltmarsh Residency Index values for the 3 study species, including age at maturity, time (in years) spent as a juvenile (t_j), time (year) spent as an adult (t_a), natural mortality (m)

Species name	Scientific name	Age at maturity (years)	Age at maturity reference	t_j	t_j reference	t_a	t_a reference	m	m reference
European seabass	<i>Dicentrarchus labrax</i>	6	Pawson, Kupschus, & Pickett, 2007	6	Pawson et al., 2007	14	Pawson et al., 2007	0.24	ICES, 2018
European plaice	<i>Pleuronectes platessa</i>	3	ICES, 2017	3	ICES, 2017	5.52	COMADRE ^a	0.1	ICES, 2017
Common sole	<i>Solea solea</i>	3	ICES, 2019	3	ICES, 2019	5.52	COMADRE ^a	0.1	ICES, 2019

^aFor Both *P. Platessa* and *S. Solea*, a closely related COMADRE proxy species was used: *Limanda ferruginea*, which is a member of the same family as both study species (Pleuronectidae).

we estimate that these three species spend between 13% and 44% of their juvenile life stages in saltmarsh (Table 2).

The provisioning services provided by UK saltmarsh to UK commercial fisheries were highest for *D. labrax* with an estimated value attributable to saltmarsh of £1.6 million–£1.7 million (Figure 4). This large contribution can be attributed to the high estimates of proportion of time spent in saltmarsh from both meta-analysis and expert elicitation, which results in high residency index values. The species with the lowest economic

contribution was *P. platessa*, with an estimated value of £0.5 million–£0.8 million attributable to saltmarsh. This low contribution can be explained by two factors: (a) *P. platessa* had the lowest landings value of all three species and (b) *P. platessa* had relatively low saltmarsh residency index estimates (expert elicitation: 0.15, meta-analysis: 0.28, Table 2).

An alternative way to assess the importance of saltmarsh to these three fish species is to focus on their respective saltmarsh residency index values. We calculated index values for each species using estimates of

FIGURE 3 UK commercial fisheries value of saltmarsh as calculated with proportion of time estimates from the meta-analysis (Saltmarsh value from lit review) and with proportion of time estimates from the expert study (Saltmarsh value from expert study) for the three focus species with recorded UK landings: *Dicentrarchus labrax*, *Pleuronectes platessa*, and *Solea solea*. Totalled estimates across all 3 species of saltmarsh value meta-analysis and expert study are also displayed

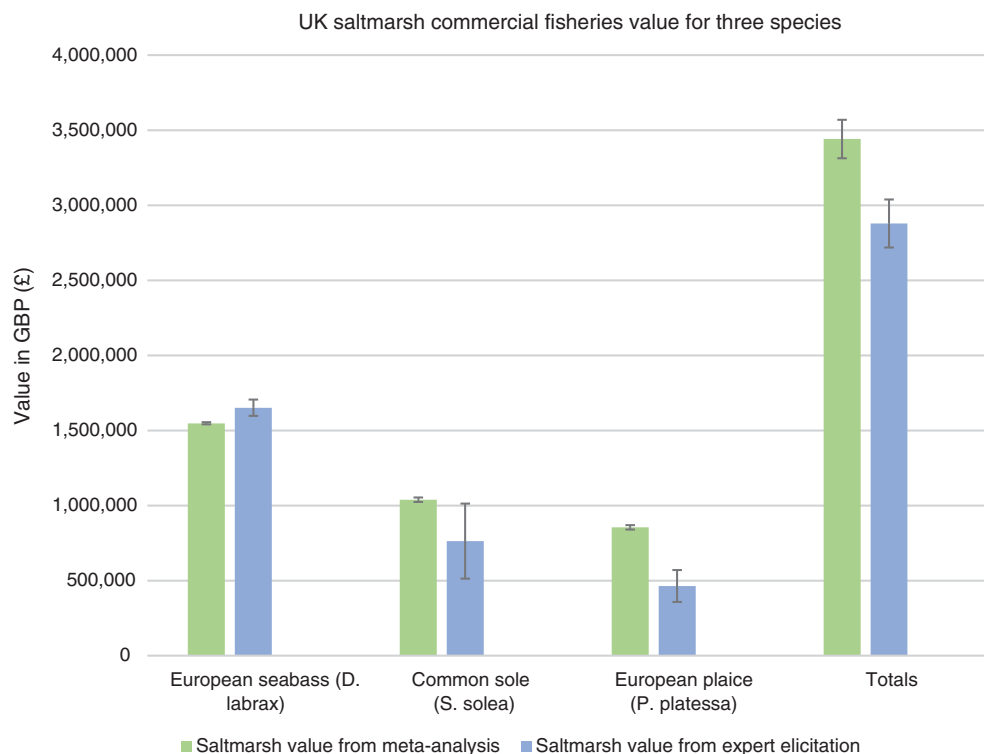


FIGURE 4 Map of the nine ICES areas that border the UK, in which fish that have spent time in UK saltmarsh are most likely to be caught. We used 2006–2016 catch data from these areas to obtain average catch per year for our target species: *Dicentrarchus labrax*, *Pleuronectes platessa*, *Solea solea*. Yearly catch in any area that borders additional countries was divided by the number of bordering countries to account for overestimation

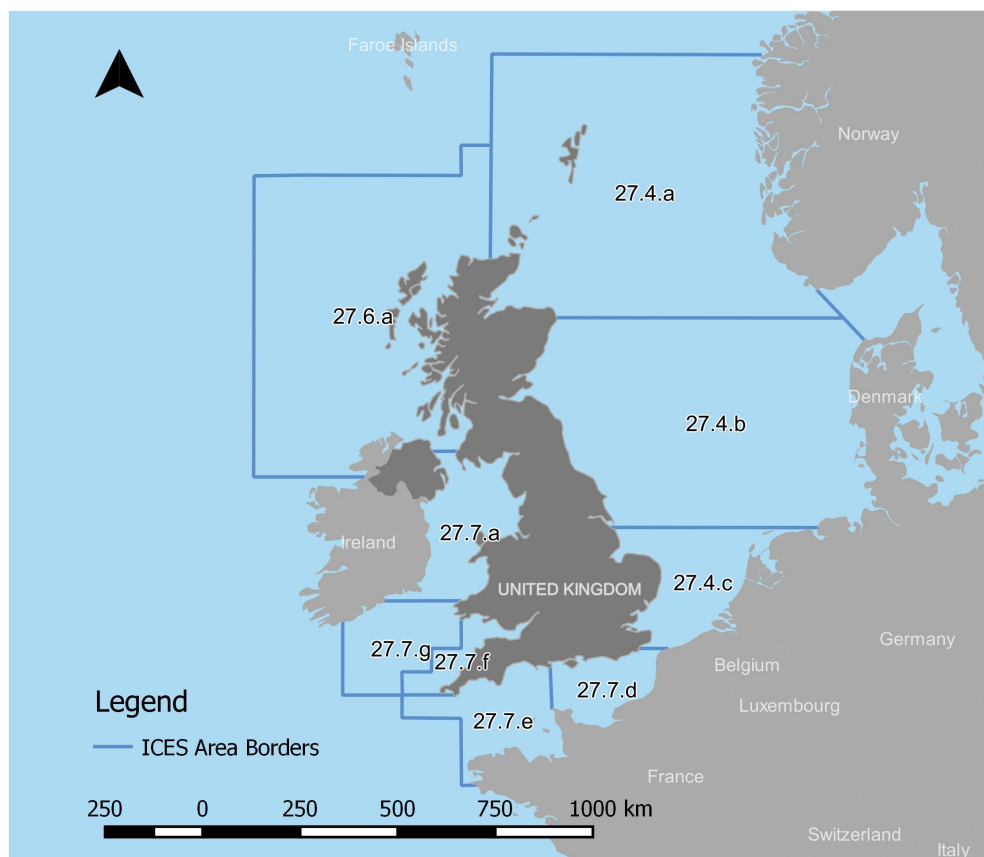


TABLE 2 Results from the meta-analysis and expert elicitation processes, showing estimated proportion of time juveniles spend in saltmarsh (x), estimated proportion of time adults spend in saltmarsh (y), SRI (Saltmarsh Residency Index) calculated through both processes, and the resulting commercial values

Common name	Scientific name	x meta-analysis	y meta-analysis	SRI meta-analysis	Saltmarsh value meta-analysis (£)	x expert elicitation	y expert elicitation	SRI expert elicitation	Saltmarsh value expert elicitation (£)	Total landings value (£)
European seabass	<i>Dicentrarchus labrax</i>	0.281	0.220	0.873 ± 0.004	1,547,862	0.444	0.175	0.931 ± 0.030	1,651,537	1,773,460
Common sole	<i>Solea solea</i>	0.186	0.000	0.212 ± 0.003	1,038,666	0.129	0.013	0.156 ± 0.051	762,956.5	4,896,928
European plaice	<i>Pleuronectes platessa</i>	0.262	0	0.284 ± 0.005	854,635.5	0.121	0.017	0.154 ± 0.035	464,075.2	3,005,897

proportion of time spent in saltmarsh derived from two alternative methods: a meta-analysis and expert elicitation. *D. labrax* was estimated to spend the most time in saltmarsh in both the meta-analysis and the expert elicitation process and resulted in the highest SRI value (meta-analysis: 0.87, expert elicitation: 0.93) (Table 2). For both *P. platessa* and *S. solea*, the meta-analysis resulted in a higher calculated index value than the expert elicitation. However, this was not true of *D. labrax*, for which the expert elicitation resulted in a higher index value. While the results presented here use the “best guess” expert elicitation values, we also calculated saltmarsh residency index values for each species for two alternate scenarios: (a) using the minimum expert elicitation estimates and (b) using the maximum expert elicitation estimates. To see the results of these alternate scenarios, see Appendix S4, Supporting Information.

The sensitivity analysis results show that a 50% increase in both proportion of time spent in saltmarsh as a juvenile and proportion of time spent in saltmarsh as an adult result in sensitivity index value of 0.787 (Table 3), making this the most sensitive parameter in the model. Sensitivity index values are bounded between 0 and 1, with 0 representing no sensitivity and 1 meaning maximum sensitivity. A sensitivity index value of 0.787 signifies that estimates of the fisheries value of saltmarsh are highly sensitive to proportion of time estimates. The other parameter with a relatively high sensitivity index value is time spent as an adult (0.620, Table 3). Mortality and time spent as a juvenile both scored with low sensitivity, demonstrating that large changes in these values do not have a significant impact on the final result.

5 | DISCUSSION

In this research, we have developed a generalizable framework for using residency index methods to estimate commercial fisheries value of a coastal habitat. Using UK saltmarsh as a case study, we exemplify a species-specific approach to estimate the value of saltmarsh for commercial fisheries. Our approach demonstrates how demographic and economic modeling can be combined to estimate saltmarsh commercial fisheries value.

Within our case study, we found that the commercial value of UK saltmarsh to the target species, European seabass (*Dicentrarchus labrax*), European plaice (*Pleuronectes platessa*), and common sole (*Solea solea*), when landed in the UK, ranges between £2.9 ± 0.16 million and £3.4 ± 0.13 million per year. Therefore, using this methodology it is estimated that at least 15%–17.5% of the total yearly commercial UK-landings value of these

species (£19.4 million, Marine Management Organisation, 2017) can be attributed to saltmarsh. It is important to note that these results present a conservative estimate for this provisioning service. Firstly, this analysis only includes three of the commercially important fish that spend time in UK saltmarsh. Additionally, the actual value is likely to be higher when considering the disproportionate influence saltmarsh may have on species' population growth, evidenced by its role in protecting fish from predators and allowing access to safe, plentiful feeding grounds (Colclough et al., 2005; Luisetti et al., 2014; McIvor & Odum, 1988).

The calculated saltmarsh residency index (SRI) values (Table 1) demonstrate the relationship between dependency (SRI value) and the estimated proportion of time a fish spends in saltmarsh. Instead of assuming saltmarsh carries the same level of importance for a species throughout its lifecycle, this method differentiates habitat importance according to life stage, and weights the relative importance of that life stage using stage duration and mortality rates. For example, a species with a high natural mortality rate that spends limited time in saltmarsh as a juvenile may have a higher Saltmarsh Residency Index value than a species that may spend more time in saltmarsh as a juvenile, but has a lower natural mortality rate. Prioritizing habitats based on life stage sensitivity is supported by previous studies (Jackson et al., 2015; Levin & Stunz, 2005; Scott, 2000), and rests on the theory that small changes to a habitat that is used during a sensitive life stage can disproportionately limit population growth (Levin & Stunz, 2005). For example, Sundblad, Bergstro, Sandstrom, and Eklov (2014) show that limiting nursery habitat could prohibit species' population growth. By contrast, a linear approach to calculating the fisheries value of saltmarsh, such as that used by Turner, Burgess, Hadley, Coombes, and Jackson (2007) and Luisetti et al. (2011), does not account for life stage variation and therefore may inaccurately estimate the economic value of this provisioning service.

The relationship between fisheries decline and saltmarsh loss has not been studied extensively. However,

the availability and connectivity of coastal foraging grounds and pelagic spawning sites has been shown to contribute to the success of demersal fish populations (Martinho et al., 2007). The UK Biodiversity Action Plan estimated that 100 ha of UK saltmarsh are lost every year (Maddock, 2011). Based on our results, there are significant opportunity costs associated with continued saltmarsh decline. Similarly, studies have shown that some fish populations show strong site fidelity to coastal feeding grounds (Doyle et al., 2017; Green et al., 2012). The results of these studies indicate that destruction of saltmarsh could lead to habitat fragmentation and insufficient nursery and feeding grounds (Doyle et al., 2017; Green et al., 2012). In this case, our results show that ecological implications could translate into economic implications. The Northern European *D. labrax* stock has experienced declining recruitment, and ICES have implemented trawling and catch size restrictions to save the stock (López, de Pontual, Bertignac, & Mahévas, 2015). Maintaining existing saltmarsh areas or undertaking managed realignment to increase saltmarsh extent may help with these measures.

The methods presented in this paper provide a flexible framework to calculate a conservative estimate of coastal habitat contributions to fisheries revenue for three species. Residency index methodology hinges on the assumption that the amount of time a species spends in a habitat is linked to its dependency on that habitat. This assumption builds on the habitat matching theory, which asserts that individuals do not randomly disperse across a landscape; rather, they seek environmental conditions that best suit their survival (Jacob, Bestion, Legrand, Clobert, & Cote, 2015). Under this theory, the habitats in which the individuals of a species are found give them some survival advantage based on their individual characteristics (Jacob et al., 2015). Survival needs change at different life stages and therefore habitat use also changes, which is reflected in the residency index methodology. This improves upon studies that estimate value under the assumption that there is no change in habitat use across a fish's lifecycle. For example, Aburto-Oropeza et al. (2008) estimates the value of mangroves to fisheries using a linear scaling approach, without considering the species that use mangroves primarily as a nursery habitat. Linear methods are likely to inaccurately represent a species' habitat dependency or the true economic value of a habitat to fisheries, because habitats contribute disproportionately to a species' survival at different life stages (Levin & Stunz, 2005).

While this method provides a baseline approach for apportioning fisheries value to coastal habitats, it should be used with some caution. Our understanding of fish habitat use, and therefore dependency, is still in its

TABLE 3 Results of the sensitivity analysis for the four parameters used in calculating saltmarsh residency index values. These index values reflect the sensitivity of the final commercial value to a 50% increase in the parameter value.

Parameter	Sensitivity index value
Proportion of time in saltmarsh	0.787
Mortality	0.258
Time spent as a juvenile	0.266
Time spent as an adult	0.620

infancy. This means the assumption that residency in a habitat represents dependency could under- or over- estimate the true value. However, our understanding of these relationships continues to improve with new research, especially with growing use of technology such as acoustic tagging studies. A suggestion for improving residency index methodology would be to incorporate additional parameters that may also represent species' dependence on a habitat. For example, instantaneous feeding ratio compares the fullness of a fish's stomach before entering a habitat with the same fish's stomach contents upon leaving the habitat, and could be an additional metric to consider when calculating habitat dependency (Laffaille, Brosse, Feunteun, Baisez, & Lefeuvre, 1998). A final promising area for future research would be to consider the relationship between habitat condition and habitat suitability for commercially and recreationally important fish species. Clear relationships between habitat condition and the provision of ecosystem services are currently missing, so we were unable to include habitat condition in this analysis ([Eds.] Burkhard & Maes, 2017).

When assessing the utility of this methodology, it is important to note that the accuracy of the model relies on the parameter values used in the analysis, as well as the regional scale of the study. The model will be most accurate when parameter values describe the behaviors and demographics of species from the area of interest. As the sensitivity analysis on the case study results showed, the model is highly sensitive to estimates of proportion of time a species spends in a habitat. This can be attributed to the foundational assumption of the model: that residency is a proxy for dependency. The model is also sensitive to time spent as an adult, which is in response to the weight the model adds to a relatively short juvenile stage when compared to the adult stage. These parameter values are not always readily available in the literature and estimates that are available may be outdated or from other regions. While technologies are improving to help us better understand fish behaviors and population dynamics, we must recognize the knowledge gaps that currently accompany this methodology.

As sea levels continue to rise (Wolters, Bakker, Bertness, Jefferies, & Möller, 2005) and claim coastal habitats that offer valuable ecological and economic benefits to the UK (Barbier et al., 2011), policy makers must prioritize action for conservation (Jones et al., 2011). With guidance for habitat protection and restoration moving to incorporate the value of ecosystem services, our study could directly inform decisions around coastal habitat conservation or restoration. The current work has outlined a flexible approach for calculating the material contributions that coastal habitats provide to fisheries. As ecosystem services are used more and more as a prioritization and decision-making tool, it is

important to continue improving and refining the methods used to calculate provisioning service value, including habitat contribution to fisheries.

6 | CONCLUSION

To efficiently allocate government resources for coastal habitat protection or restoration, it is essential that both the ecological benefits, as well as the economic benefits of these projects, are realistically estimated. We present a flexible framework for a region-specific, species-specific method to improve the estimation of coastal habitat value for fisheries, and demonstrate its use with UK saltmarsh as a case study. Regional-specific guidance for estimating the economic benefits of coastal habitats, as presented in our analysis, can help guide decision makers to efficiently allocate resources to maximize ecological and economic outcomes.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed to the design of the research and final survey instrument. Hannah McCormick led the demographic analysis with support from Rob S. Gómez and Katrina Davis. Hannah McCormick led the literature review process with support from Katrina Davis and Morena Mills. Hannah McCormick led the expert elicitation with support from Morena Mills and Katrina Davis. Hannah McCormick wrote the manuscript, with contributions and revisions from all authors.

DATA AVAILABILITY STATEMENT

All data is accessible in the supplementary information.

ETHICS STATEMENT

Imperial College London provided ethics approval for this research.

TARGET AUDIENCE

The target audience is researchers aiming to further the field of ecosystem service valuation, and those working in conjunction with policy makers and government agencies to support habitat restoration.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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