Natural Resources Forum

WILEY

ARTICLE OPEN ACCESS

300 Years of Degradation in Wales Estuaries and Coasts

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Received: 20 December 2024 | **Revised:** 5 February 2026 | **Accepted:** 22 April 2026

ABSTRACT

The world's oceans are in a severe state of degradation, yet our understanding of that degradation is often based on changes observed only in the past 20–50 years. This narrow view leads to marine conservation efforts that aim to preserve already degraded ecosystems, shaped by shifted ecological baselines. Historical ecology offers a broader perspective by examining past environments and biodiversity. In this study, we analyse historical records including maps, reports, and written accounts to explore the transformation of estuarine and coastal environments in Wales, a key centre of the Industrial Revolution. Our findings reveal widespread historical modification: 33 of the 42 Welsh estuaries studied show major alterations, including land reclamation, embankment construction, and channel rerouting. Some estuaries were completely erased, and islands no longer separate from the mainland. The resulting disruption of sediment dynamics, water quality, and habitat complexity has had long-term impacts on biodiversity and ecosystem services. We hypothesise these changes led to the widespread loss of critical habitats such as salt marshes, oyster beds and seagrass meadows, which support marine biodiversity and ecosystem health. Wales is only at the start of a habitat restoration journey, and the nation can learn from other regions of the world where restoration has successfully improved ecosystem function. But Wales faces a legacy of degradation with few, if any, 'low-impact' baselines remaining. We argue that current restoration efforts in Wales should not aim to return ecosystems to an imagined baseline or historical state. Instead, restoration should be reimagined with modern goals focusing on enhancing biodiversity, ecosystem resilience, and human well-being through the lens of a changing climate. Wales' estuarine environments, though heavily modified, present unique opportunities. By recognising the true extent of historical change, we can move beyond outdated notions of conservation and embrace degraded ecosystems as foundations for future recovery.

1 | Introduction

The global ocean is the planet's dominant ecosystem, shaping our weather and climate, underpinning the global economy, facilitating over 90% of world trade, and directly supporting the 40% of humanity that lives within 100 km of the coast. Yet this vast system is now widely degraded. Coastal and marine habitats such as seagrass meadows, mangrove forests, salt marshes, coral reefs and oyster reefs exist largely as remnants of their former extent and condition (Jackson et al. 2001; Waycott et al. 2009; Dunic et al. 2021; Eddy et al. 2021). Climate change is expected to accelerate their decline (Frieler et al. 2013; Cornwall et al. 2021; Dixon et al. 2022), leaving behind degraded ecosystems. Such degraded ecosystems are commonly referred to as 'Novel Ecosystems' that have been significantly altered by human activities, resulting in new combinations of species and ecological functions that differ from historical precedents (Hobbs et al. 2009).

Most ecosystems are undergoing change and are unlikely to revert to pre-industrial or pre-human states. With a growing understanding of these changes, and given its intrinsic link to both human and planetary health (Viana et al. 2024), there is increasing recognition of the need for bold action to restore ocean health and rebuild biodiversity (Duarte et al. 2020). Restoration of marine and coastal ecosystems is central to the UN Decade on Ecosystem Restoration, with growing global momentum (Saunders et al. 2020). These efforts also offer the potential to deliver genuine Nature-based Solutions (NbS) to some of the most pressing challenges facing humanity (Seddon et al. 2020). Beyond ecological necessity (Duarte et al. 2020), restoration is becoming a legal imperative, embedded within frameworks such as the Kunming-Montreal Treaty and the EU Nature Restoration Law (Fu et al. 2024).

To succeed at the scale required, restoration must be guided by evidence-based decisions that integrate ecological, environmental and socio-economic considerations. Restoration ecology traditionally draws on historical data and modelling to assess past distributions and validate site suitability. This often includes the use of historical ecology and Indigenous or local knowledge (Fremout et al. 2021), while recognising the need for landscape-scale integration across habitat types (Stefanes et al. 2016; Pittman et al. 2022). Restoration must also account for both proximate and distal factors, including climate change impacts such as sea-level rise, species shifts and increased storm activity (Timpane-Padgham et al. 2017).

Central to these processes is the notion of ecological baselines. Despite debate over their definition and utility (Campbell et al. 2009; Humphries and Winemiller 2009), baselines continue to underpin ecological management (Cardinale et al. 2011; Bouleau and Pont 2015). Where quantitative ecological survey data are lacking, historical ecology provides empirical data for reconstructing baselines. In marine systems, this has typically involved assessing species presence through archival records, often focusing on commercially valuable fisheries species (Pinnegar and Engelhard 2008; Zu Ermgassen et al. 2012). In contrast, habitats with limited direct economic value, such as seagrasses, remain underrepresented (Leonie and Chris 2008), as do the broader environmental drivers of degradation, such as coastal development and mining. Additionally, little is known about the social implications of coastal habitat decline.

While we increasingly understand how contemporary anthropogenic stressors affect marine ecosystems, for example, how deforestation increases sedimentation and reduces coral light availability (Bartley et al. 2014), we rarely consider historical analogues or their long-term community impacts. To scale up marine restoration effectively, we must also understand the legacy of long-term environmental change and loss, particularly to build the case for funding, permits, and social licence. Although restoration on land is increasingly linked to human health outcomes (Nabhan et al. 2020), this framing remains largely absent in the marine realm.

Seagrasses have recently gained prominence in marine conservation, but historically, their ecological role was overlooked due to ‘plant blindness’ and their limited economic value (Unsworth et al. 2022). Their sensitivity to environmental change makes them valuable sentinels of ecosystem health (Dennison et al. 1993). Seagrasses provide wide-ranging ecosystem services, from acting as green coastal infrastructure that mitigates pathogens in seafood (Dawkins et al. 2024) to stabilising shorelines through wave attenuation and sediment retention (Twomey et al. 2020).

Prior to the 20th century, scientific references to seagrasses were sparse, with two brief periods of attention: the 1930s, due to seagrass wasting disease (Green et al. 2021), and the late 1800s, when *Zostera marina* was investigated as an alternative fibre following a collapse in cotton prices. Despite cultural importance in some regions (Mtwana Nordlund et al. 2016), seagrasses were not widely documented, unlike oysters, for which sufficient historical data exist to map their pan-European extent (Thurstan et al. 2024). In the absence of similar data for seagrasses, we must instead analyse the historical processes, such as coastal development, that likely drove habitat change.

Wales, as one of the first industrialised nations, underwent profound transformation from the late 1700s to the mid-1800s, driven by extractive industries (coal, slate, copper and iron) under the influence of English landowners. This industrialisation more than doubled the population and left significant terrestrial ecological impacts (Clapp 1994; Garcés-Pastor et al. 2023) with limited insight into concurrent coastal ecosystem change. Yet we know that the associated development of ports and other infrastructure likely affected marine habitats such as seagrasses, which are vulnerable to sedimentation and physical disturbance (Erftemeijer and Lewis 2006; McMahon et al. 2011). Given the timing mismatch between seagrass documentation, industrialisation and the onset of marine biological recording, it is plausible that these habitats were among the earliest casualties of the Industrial Revolution in Wales.

The geology of Wales made it a hub of industrialisation and coastal development, degrading ecosystems. We hypothesise that the scale of non-fisheries-based ecological change before 1900 fundamentally redefined Welsh coastal ecology, with significant repercussions for local community well-being (Alfonso et al. 2017).

Today, Wales is once again at the forefront of industrial development, this time of the ‘Blue Acceleration’ (Jouffray et al. 2020) with major investments in offshore renewables, including Gwynt y Môr (the world's fifth-largest offshore wind farm) and ambitious projects like the Swansea and North Wales Tidal Lagoons. Welsh law mandates consideration of future generations' well-being, aligning with the growing acceptance of the ‘One Health’ approach (Zinsstag et al. 2011; Buttke et al. 2015), which links human, animal, and ecosystem health.

We suggest that the historical scale of degradation has distorted our understanding of contemporary baselines. What remains is not a resilient seascape from which to restore, but a blank ecological canvas. Embracing this reality allows us to reimagine the future of Welsh marine ecosystems, rooted in nature restoration and a holistic, One Health approach. Acknowledging the blank canvas can help drive strategic, evidence-based restoration and ensure that blue growth is aligned with social, ecological, and health outcomes.

This study utilises historical ecology to analyse the extent of degradation in Welsh estuaries and coasts over the past 300 years. By examining archival records and maps, the researchers aim to quantify major physical modifications, such as land reclamation, embankments, and channel rerouting, that have fundamentally altered these environments. The investigation seeks to highlight the loss of critical habitats like seagrass and oyster beds while challenging distorted ecological baselines. Ultimately, the study advocates for a 'One Health' restoration framework focused on future resilience and biodiversity rather than an unattainable historical status quo.

2 | Methods

Understanding the human dimensions of marine ecosystems in a historical context includes assessing how proximate human impacts have changed through time, as well as how ultimate, or underlying, social factors mediate human-environmental interactions in these systems. Historical ecology provides a means of assembling data that helps understand these human dimensions in marine ecosystems in a historical context where quantitative ecological or social data is not available. An integrated approach to historical ecology has been defined as a field that seeks to gain a 'practical understanding of past and current relationships among environmental and human systems, requiring a culturally specific temporal and spatial perspective applied at the regional scale' (Crumley 1994). Using such a framework, we examine the presence, type and extent of major estuarine and coastal modification along the coast of Wales over time.

Information was collated alongside data on past and current distributions of seagrass meadows. Information searches were conducted using the written word; no oral histories were included. This search focused exclusively on information available in online content and reports. While we recognise that this online and report-based approach is contrary to the guidelines outlined in recent seminal papers in Historical Ecology (Santana-Cordero et al. 2024; Navarro et al. 2025). We made a clear decision that this approach provided sufficient detail to examine the level of data necessary for this project. Examination of maps and the collation of key timelines of coastal development construction could all be done via online sources, particularly given the archives available online via the National Library of Wales. We were not attempting to describe the ecological distribution of species in detail, which would have required more extensive traditional archival searches, but instead we sought to document the construction-type events that would have affected whole ecosystems.

A list of Wales estuaries was created, initially using that of Davidson (1991), but making additions using maps and Google Earth to include areas of sheltered waters influenced by estuaries and to include many smaller estuaries not covered in that list. The list of estuaries (in Welsh and English) was searched in a range of databases, including government records, Ordnance Survey maps, nautical charts, naturalists' accounts, popular media, and scientific journals. In addition to the name of the estuary, the terms 'embankment', 'reclamation', 'reclaimed', 'impoundment', 'drained', 'draining', 'rerouting', 'channel', 'dock', 'pier', 'jetty', 'quarry', 'port', 'harbour' and 'barrage' were searched alongside those terms. Many references to various changes to these estuaries were initially picked up on popular history discussions or local society websites (e.g., historypoints.org). When these had limited, if any reference, additional information was sought to back these up (e.g., reference to an act of Parliament was then secondary searched on the UK Parliament website). We also searched newspaper archives (Welsh Newspapers Online, 1804–1919) and examined the online resource of Tithe maps held by the National Library of Wales.

Where possible, the date and the extent of a modification were determined. The date we use in the figures refers to the most recent major modification. However, we recognise that within many of the Ports, major modifications have happened periodically (e.g., Tiger Bay/Cardiff Bay). The assessment of the extent of change (hectares or distance) either used existing measurements of an estuary area or length (Davidson 1991) and knowledge of the modification in reports or the academic literature, or alternatively used Google Earth to create estimates of the area. In many locations (e.g., Harlech), it was not possible to estimate any area or find a date, only to know that a change happened at an approximate estuary-wide scale (e.g., old paintings).

In addition to coastal development type modification, we also sought information on the removal of oysters from the seabed at each locality, as this was a physical change to the environment that would have influenced many other environmental and biological factors present. Although not a physical impact, we also identified those estuaries impacted by historic metal mining. This inclusion is important as although we do not examine water quality, metal mining activity has been occurring in Welsh catchments since Roman times and has had continuous impacts rather than episodic events, and in many cases, the impacts of these mines still impact the associated estuarine environments.

Data on estuarine and coastal modification were examined relative to the known current and historic distribution of seagrass using data available in Kay (1998), from SeagrassSpotter.org and DataMapWales. All data on seagrass groups the two species of Zostera (*Nanozostera noltii* and *Z. marina*) as one due to numerous historic errors in identification. No reference is made in this study to the third species of seagrass (*Ruppia maritima*) due to incomplete contemporary as well as historic records.

3 | Results

There are multiple different lists of estuaries in Wales, including that of Davidson (1991), listing 26. Based on our analysis, we extend that list to include locations where estuaries previously existed ($n=2$) and estuaries within estuaries ($n=5$). Due to the enormity of the size of the Severn Estuary, we assessed the area up to Beachley Point as being the Severn (before the first Severn Bridge) and examined the numerous estuaries leading into the Severn separately (e.g., the Wye and Usk). The Milford Haven Waterway was treated as one estuary rather than multiple ones. We have chosen to include the Cymyran Strait, although this is not an estuary; it is influenced by an estuary, and in its current form, its shallow water environment creates conditions similar to the lagoons at the mouth of many estuaries.

Our analysis of 42 estuaries in Wales reveals clear evidence that 33 (79%) of these have been significantly modified by major engineering works (Figures 1 and 2) and are now degraded ecosystems with the potential to operate as 'Novel Ecosystems' (Hobbs et al. 2009). These modifications take the form of five different

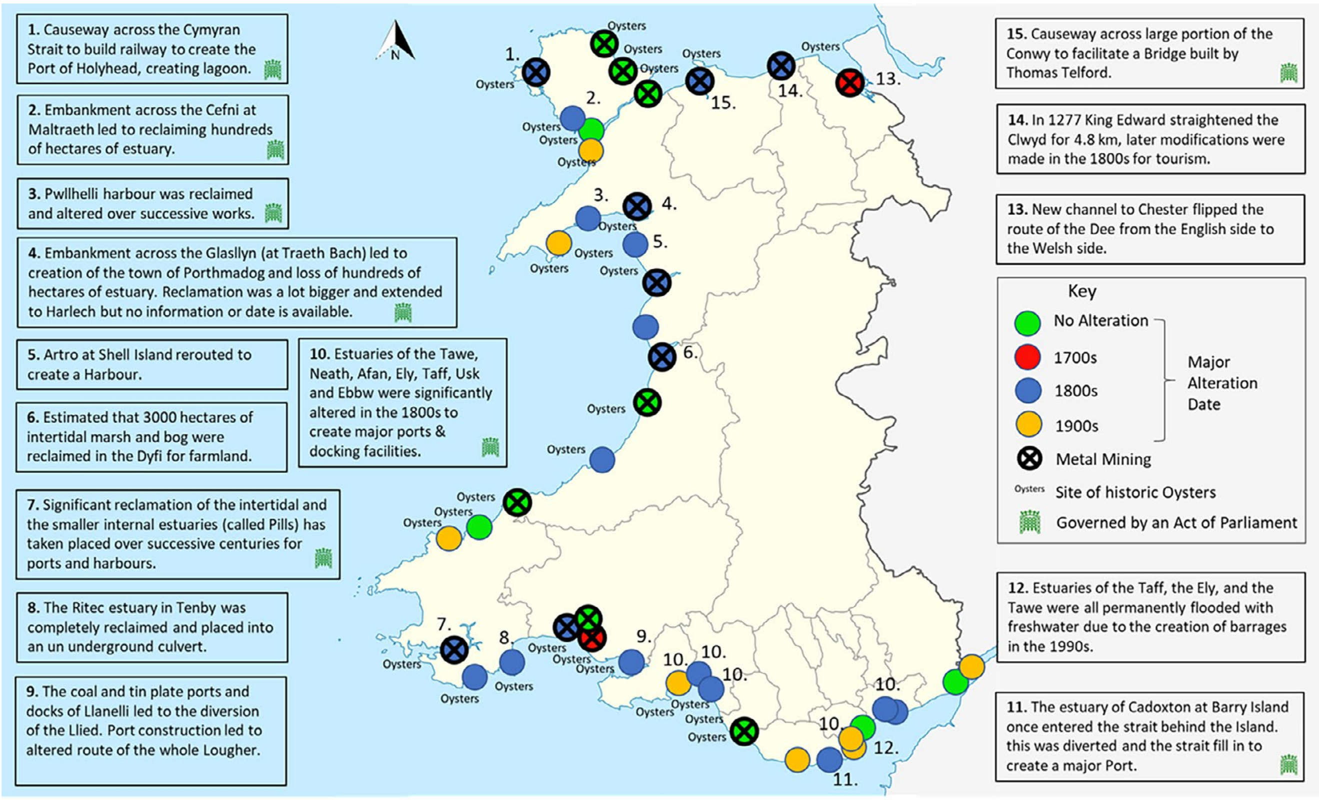

FIGURE 1 | Locations of the major alterations made to Wales estuaries and coasts and their timings. Additional narrative is added within the figure about the changes undertaken in the most significant and well-understood alterations. The locations of the metal mining activity within the associated catchments are marked on the map, but there is insufficient relative understanding of the extent of the impacts of these across locations, with only evidence of present and ongoing contamination in some.

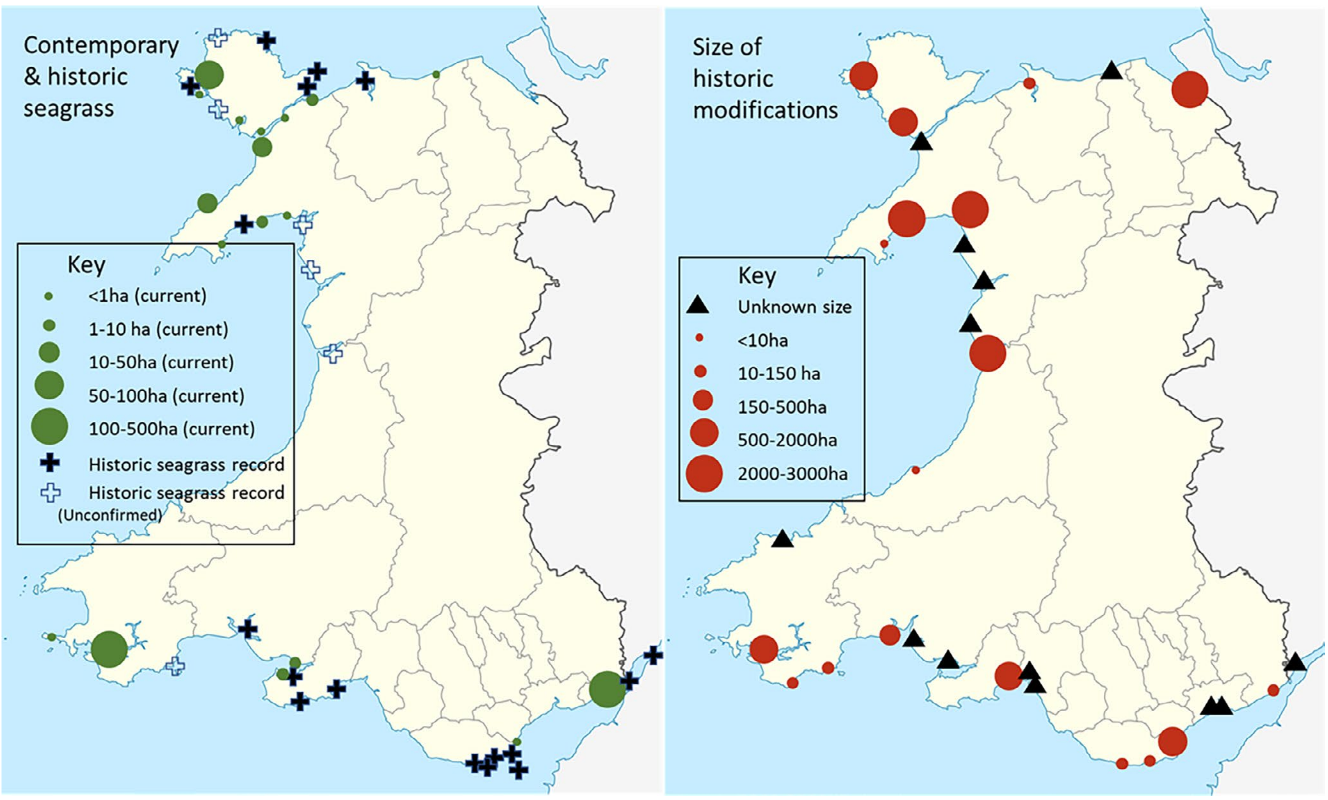

FIGURE 2 | Estimates of size of the estuarine and coastal modifications made around Wales alongside a map of the current and known historic distribution of seagrass (note this is not a complete historic distribution, just the locations where seagrass has been described as present, including some records that have limited detail and cannot be confirmed).

types of change: (1) the impoundment of an estuary into a lagoon, (2) an embankment (mostly leading to land reclamation), (3) channel rerouting, (4) port and dock development and (5) sea defence creation.

3.1 | Impoundments

Impoundment modifications have occurred in seven locations: Cardiff Bay, previously Tiger Bay (Taff and the Ely) (Figure 3), Swansea Bay (Tawe), the Cymyran Strait, the Bosherston, the Cadoxon (Barry Island) (Figure 4), the Severn (only at Oldbury) and Westfield Pill within Milford Haven Waterway below the Daugleddau. In addition, one estuary was completely hidden away in underground tunnels (the Ritec) in South Beach, Tenby. Within the Milford Haven Waterway, Castle Pill was partially impounded for a period in the past; some remains so. Additional smaller impoundments are found within the estuarine reaches of the various tributaries at Carew Millpond, Pembroke River just below the Castle, at Hubberston Pill and at Pickleridge lagoon.

FIGURE 3 | Change over time in Cardiff Bay showing the bay before the port construction and then before and after the barrage construction. The orange star reflects approximately the same position in each image. Credits: 2013 and 1947 from Google Earth, 1883 from the National Library of Wales and 1999 from Ben Salter.

FIGURE 4 | Change over time in Barry Island showing the channel separating the island from the mainland before the port construction in the 1800s and then in recent times (2022). Red star refers to the same location (Friars Point) in all three maps. Maps sourced from Google Earth and the National Library of Wales.

3.2 | Embankments

Embankments were also a very significant source of change to Welsh estuaries, with embankments being made across the Cefni (Malltraeth), the Glaslyn (Porthmadoc), the Conwy and the Cymyran Strait. These resulted in significant land reclamation. For example, the township of Porthmadoc was created alongside an estimated 500 ha of land through the development of the 'Cob' built by William Madocks in 1808–1811 (see Figure 5). Various available information (e.g., BBC History Archives) describes the concurrent rerouting of the river. However, no information on the wider impacts on the broader Traeth Bach estuary has been found. Across the other side of the wider estuary at Harlech, historic paintings and drawings picture the town being immediately adjacent to the sea, rather than as now surrounded by farmland and over a kilometre from the sea.

The embankment built across the Cefni in SW Anglesey had a probably bigger impact again, claiming what could be around 858 ha of land and transforming the town of Llangefni from being a town serviced by marine access to a land-locked market town surrounded by farming. The creation of the bridge over the river Conwy in 1826, led by Thomas Telford, was another example of a major embankment that closed off a portion of the estuary, leading to a narrow channelling of the estuary on the western side. Although not impounding the estuary, the change would have had a significant impact on the geomorphology of the estuary. Another major embankment was built on the Dyfi Estuary (Pye and Blott 2014) around 1830, resulting in the draining of approximately 3000 ha of salt marsh and bogs (CCW 2011). An additional embankment was constructed on the Froyd, but the date of this remains unclear (possibly during World War 2 and associated with the RAF base), and whether it resulted in drainage or modification is unknown. The Mawddach estuary had a series of embankments built upon the southern side to facilitate the construction of the main railway bridge across the estuary in the 1860s. It is not clear what the area of containment was, but it is clear that salt marsh areas were reclaimed, either before or as a result of those constructions. Given the estimates of the area of the Dyfi reclamation and the similar size and structure of that estuary, it is likely that a similar amount of area was reclaimed. Also, Cwm Ivy, at Whiteford in the Lougher Estuary (also referred to as the Burry Inlet), was reclaimed at least twice, hundreds of years ago (but the date of which is unclear) (Dale et al. 2021). Fortunately, this is the site of a managed realignment to inundate the area with seawater once more through breaching of the sea wall.

3.3 | Port and Dock Facilities

Land reclamation was also part of the establishment of a range of major dock facilities throughout Wales. Although it is not possible to quantify the exact footprint of the majority of these developments, the entire South Trevor Coast and many locations around the rest of Wales have suffered major dock developments, stripping the coastline of shallow water and intertidal environments and creating areas of deep and mostly permanently flooded water based around hard substrata. All along the South Wales coast, every single estuary between (but excluding) the Wye and the Tywi has had major port infrastructure built on it. The Usk, Ebbw (both Newport), Ely, Taff (both Cardiff), Cadoxton (Barry Island), Afan, Neath, Tawe, Lougher and Gwendraeth were all developed into major port facilities in the 1800s. The one exception was the Thaw, which was rerouted in the 1960s. This disruption to the coastline extends 148 km.

Moving further west, the Milford Haven Waterway has been utilised for major shipping for centuries due to its natural deep-water channel, and this has resulted in major port facilities being built on a range of tributaries across the whole waterway. A key facilitator of this is the 1790 Act of Parliament that granted permission to: 'make and provide Quays, Docks, Piers and other erections and establish a Market with proper Roads and Avenues' in Milford Haven. This ultimately led to the eventual impounding of Hubberston Pill and the narrowing of Castle Pill. Developments at Cosherston Pill and Pembroke Dock led to large amounts of land reclamation and associated port infrastructure development (including the impacts of shipbuilding, shipbreaking and other naval infrastructure). An embankment was also created at Landshipping. In more recent times, major oil and gas terminals, port upgrades and power stations have been built (with major abstraction and discharge structures), further putting pressure on the availability of shallow water and intertidal areas. An assessment of a small section of the Milford Haven Waterway (Pembroke River, Cosheston Pill, Huberston Pill and Pembroke Dock) using historic aircraft aerial footage revealed that since WW2, extensive areas of intertidal (601 ha) throughout the Waterway have been reclaimed and mostly turned into hard infrastructure (Howell 2002).

FIGURE 5 | Reclamation of the Glaslyn estuary involved the construction of a 1.4 km embankment known as the Cob. That led to the creation of extensive farmland and the development of Porthmadog as a town and port. Image credit: 1811 National Library of Wales, 2007 Peter Humphries and 2025 Google Earth.

Further north, there were major port infrastructure developments in Pwllheli Harbour with aligned channel modifications and land reclamation, and one of the UK's biggest ferry terminals has been developed in Holyhead Harbour, where extensive land reclamation, dredging and channel modification have occurred. The development of Pwllheli Harbour resulted in considerable land reclamation of marshland, possibly as much as 3000 ha, a figure referred to in various historical narratives but which cannot be verified.

3.4 | Sea Defence Walls

The whole of the Welsh coast is littered with numerous small sea defence (breakwater) structures that have been built to provide shelter for particular communities or harbours; however, most are less than 50–100 m long (e.g., Porthdinllaen in North Wales). Two locations at the mouth of estuaries (Fishguard and Holyhead) have had sea defence walls (breakwaters) built that are an order of magnitude bigger, at 1.6 and 2.4 km, respectively. These structures have both had profound implications for these areas as they have transformed sites once largely exposed to the prevailing conditions into sheltered environments; although unquantified, the impacts would have likely been to cause increased sedimentation, but to have also created sheltered conditions for different types of habitat (e.g., seagrass).

3.5 | Channel Rerouting

Seventeen of the 42 (40%) estuaries in Wales have suffered some level of channel rerouting. Although we cannot precisely determine the exact length of each rerouting, we estimate that 130 km of estuarine channel has been rerouted, mostly since 1700. In most cases, this has been the indirect impact of land claim or other developments; however, in some cases, this has been a planned exercise. As far back as 1277, King Edward I sited a castle next to the River Clwyd and had the channel diverted into a straight line and deepened to aid with navigation. In 1700, an act of parliament led to the removal of 1.5 million tons of earth to cut a new water course in the Dee Estuary. This alteration led to the shift of the main Dee Estuary (length of 36.8 km) from the English side to the Welsh side and resulted in a fundamental change in the sediment dynamics of the Dee (Marker 1967).

3.6 | Timelines

Although we cannot quantify the spatial impact of many of the developments, it was possible to estimate that, at a conservative minimum, 13,493 ha of direct physical alteration (complete loss of marine/estuarine habitat) of estuarine areas has occurred across Wales. The potential indirect impact of this (e.g., in terms of channel movement, sediment remobilisation and instability) may, in fact, be much bigger. By examining the timelines (see Figure 6) of these, we show that most of these impacts occurred (or at least first commenced) in the 1800s. In the space of 100 years, many Welsh estuaries were physically modified, and in particular areas (e.g., Tremadog Bay and the South Wales Coast), almost every estuary was modified. Major modifications did not stop during this period and continued up until 1999, when the most recent modification occurred with the completion of the 1.1 km Cardiff Bay barrage. In 1996, the second Severn estuary crossing was completed, which involved the construction of a series of major concrete footings across the estuary. Kay (1998) describes how this led to a substantial but unquantified loss of seagrass.

3.7 | Seagrass

Seagrass remains extensive at a range of sites around Wales, with large areas in Milford Haven Waterway, at Bedwin Sands (Near Magor) and in the Inland Sea (near Holyhead). However, our assessment of the historic descriptions of seagrass finds that 24 of the 45 areas known to have historically contained seagrass no longer have any present (Figure 2). In estuaries where an extensive modification has been undertaken (Dee, Conwy, Cenfi, Pwllheli, Glaslyn, Dovey, Mawddach, Tawe and Taff/Ely), there is very little, if any, seagrass. Although extensive modification has been undertaken in the Milford Haven Waterway, the relative area in proportion to its overall size is small compared to other estuaries.

3.8 | Ecosystem Consequences of Environmental Degradation

Definitive assertions as to the consequences of unquantified levels of habitat loss and major change are difficult (at best) and nearly impossible to provide. However, we know that large areas of intertidal habitat were lost to land claims in Wales during the 1800s and 1900s, and the condition of subtidal habitat would have also declined due to elevated sediments and turbidity. Areas where change has unequivocally happened would have previously included key sites for biodiversity, which were structurally complex and supported high fisheries productivity, all factors that contribute towards supporting a more amenable environment for wildlife and people. We know that the large-scale alteration of coastal ecosystems during this period (1800s) created new livelihoods, opportunities and training for people, in everything from industry (e.g., mining), to farming (e.g.,

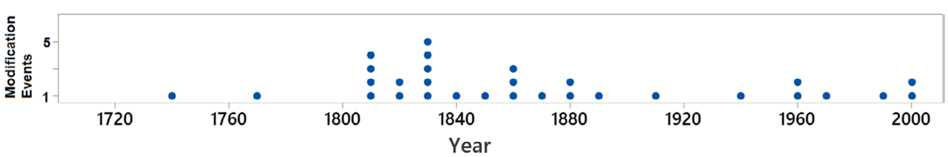

FIGURE 6 | The timeline of major estuarine and coastal modification events in Wales. Each unit (circle) equals one known major modification event.

creation of new lands) and tourism (e.g., train routes opening up tourism hubs); we also know that the associated environment would have been degraded as a result, but no evidence has been found which show that such impacts were apparent to the human populations present at the time.

In the present, although some locations examined clearly have benefited biologically from historic alteration (e.g., the Inland Sea in Anglesey), the locations of the historic major alterations lack habitat of high structural complexity and likely do not contain the same diversity, richness and productivity of seabed carpeted in biogenic habitats (Eriksson et al. 2006).

We hypothesise that these locations in the context of 'One Health' provide reduced ecosystem services, limiting opportunity for wildlife and potentially negatively impacting human health and well-being (Sweet et al. 2021; Unsworth, Comey, et al. 2026). Locations considered here, such as the Conwy estuary, Glasllyn and the Dyfi, are systems of high sediment instability, reduced productivity and limited provision of services that support healthy wildlife and human communities (Figure 8). This is in contrast to a growing number of examples globally of where habitat restoration has created a marine environment in support of human livelihoods, green infrastructure and abundant wildlife (Orth et al. 2020) (see Figure 8).

FIGURE 7 | Summary statistics of the major alterations of Wales estuaries and coasts.

4 | Discussion

Estuarine and coastal habitats, and their biodiversity, are vital to ecosystem health. They support wildlife, human well-being, coastal resilience, and livelihoods. Here, we provide a unique case study of how such productive and diverse ecosystems have been almost totally degraded over a period of 300 years. Along the Welsh coastline, nearly every estuary and coastal environment has been physically altered since the Industrial Revolution. These alterations, through land reclamation, port development, transport infrastructure, and changes to freshwater inputs, have led to the loss of at least 13.5 km^2 of intertidal and subtidal seabed. Though this represents less than 0.1% of Wales' ~15,000 km^2 of inshore waters, it includes some of the most biologically productive zones (Nixon et al. 1986), supporting numerous ecological functions (Fulford et al. 2020).

Beyond physical change, many estuaries have suffered persistent pollution, particularly from the remnants of historic heavy metal mining, as seen along the South Wales coast (Duquesne et al. 2006). Oyster dredging also caused extensive seabed degradation, driving near-total population collapse (Thurstan et al. 2024). The Irish Sea, meanwhile, has undergone globally significant levels of seabed trawling, leading to declines in benthic health (Pitcher et al. 2022) and the disappearance and population decline of many top predators (Roberts 2009; Moore et al. 2024).

Our analysis shows that most Welsh estuarine and coastal environments have been substantially modified (Figure 7). Through a combination of dredging, embankments, land reclamation, and barrage construction, Wales has lost the majority of its soft sediment biogenic habitats, including large areas of salt marsh and seagrass meadows. In their place, 'Novel Ecosystems' have likely emerged, resulting in new combinations of species and ecological functions (Hobbs et al. 2009).

4.1 | Consequences of Habitat Modification

Global research highlights the ecological impacts of coastal development (Kennish 2002; Huang et al. 2021), including altered sediment dynamics, shifts in bathymetry, and disruptions to tidal patterns (van Maren et al. 2016; Cheng et al. 2020). In Wales, most of this change occurred before modern environmental regulation and monitoring. An estimated 130 km of estuarine channels were re-engineered, embankments built and entire estuaries effectively erased. Many are now characterised by unstable, shifting sands strongly linked to historical alteration (Kennish 2002; Corrêa et al. 2019).

Oyster dredging caused industrial-scale seabed alteration (Hayden-Hughes et al. 2023; Thurstan et al. 2024). Oysters are adapted to soft substrates (Chinzei 2013) and act as ecosystem engineers, stabilising sediment, improving water clarity and forming reef structures that support biodiversity (Reise 2002). Their loss has degraded both habitat structure and function. Meanwhile, fish populations in the Irish Sea have collapsed, reducing predator biomass and ecosystem functionality (Moore et al. 2024) with probable cascading food web consequences (Baden et al. 2012).

Recent examples of alteration provide further insight. Flooding Cardiff's Tiger Bay disrupted bird communities (Burton et al. 2003) and turned an estuarine system into freshwater; the Severn Estuary lost expansive seagrass beds after bridge construction (Kay 1998); and Milford Haven's LNG terminal expansion nearly eliminated the last major maerl bed in Wales (Camplin 2007). Sediment mobilisation from dredging and hydrological modification continues to smother sensitive habitats

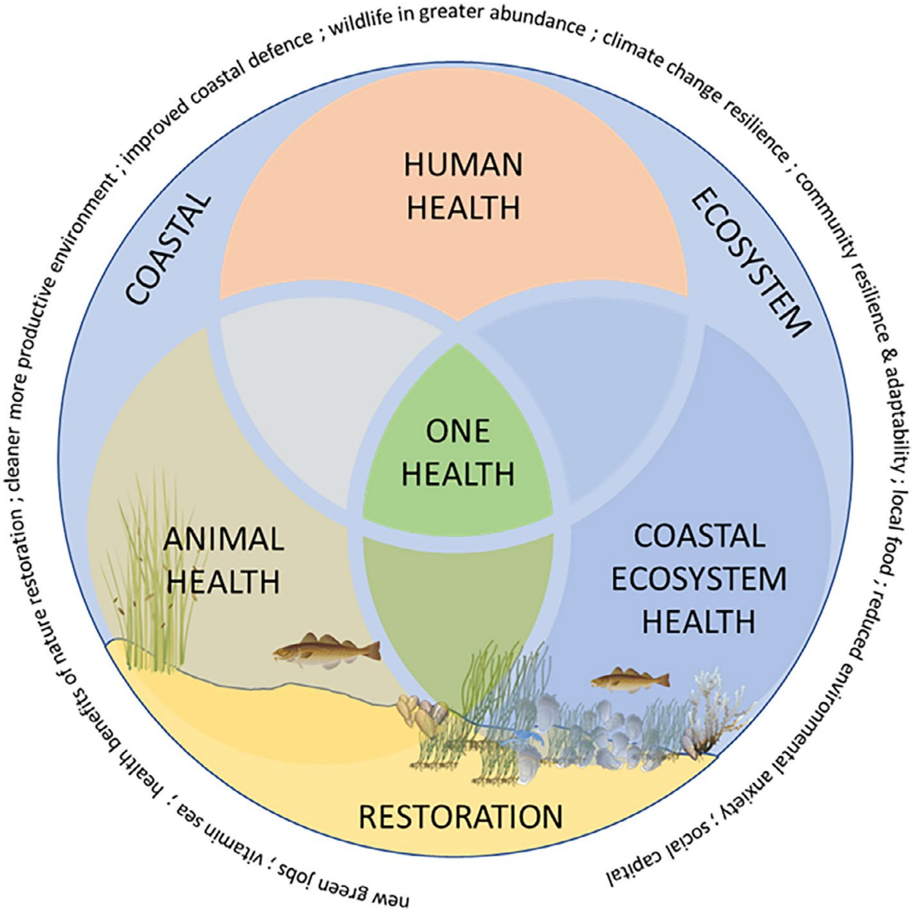

FIGURE 8 | Framework for how the restoration of the coastal and estuarine environment contributes towards achieving 'One Health'.

(Thrush and Dayton 2002), with habitats like seagrass particularly vulnerable to sedimentation and turbidity (Long et al. 1996; Erftemeijer and Lewis 2006).

4.2 | Seagrass Decline

Seagrass was historically under-recorded in Wales (Kay 1998), with little societal motivation to monitor it. As a result, our understanding of past distributions is limited. Recent modelling (Green et al. 2021) and new data show seagrass now persists in only 12 of the 45 historically documented locations, and just 7 of the 42 estuarine areas. Of those estuaries where major modification occurred, 24 no longer support seagrass at all. The remaining meadows are typically small and fragmented, with higher relative abundance only in the Milford Haven Waterway and Holyhead/Alaw region. These locations still align with suitable environmental conditions (Brown 2015; Bertelli et al. 2023), suggesting that habitat degradation, not unsuitable environment, is responsible for the decline.

While historical presence in some areas like Cardigan Bay cannot be confirmed, ecological knowledge suggests most Welsh estuaries likely once supported seagrass (Kay 1998). We argue that habitat degradation, including the loss of oysters and increased sedimentation, is a key driver of this absence (de Boer 2007). These systems are now locked in feedback loops that prevent seagrass recovery (Maxwell et al. 2017).

4.3 | Pollution From Historic Mining

Chemical pollution is another key driver of ecosystem degradation. Wales has over 1300 abandoned metal and coal mines. Many of the 10 estuaries with limited physical alteration are instead impacted by legacy mining. Though large-scale extraction ceased by the 1920s, pollution persists through mine discharges and spoil heap erosion (Hudson-Edwards et al. 2008).

Today, over 500 t of heavy metals enter Welsh rivers annually, impacting around 700 km of waterways and contributing to 6% of rivers failing to meet ecological standards (Mayes et al. 2009). These metals accumulate in coastal sediments and can directly inhibit seagrass photosynthesis and growth (Li et al. 2023; Zhang et al. 2023). This is in addition to the ongoing excess nitrogen from agriculture, industry and sewage that enters these systems (Jones and Unsworth 2016), making the waters eutrophic, weakening the productivity and resilience of associated biodiversity (Unsworth et al. 2015). Ongoing contamination may therefore be limiting both natural recovery and restoration potential.

4.4 | Impacts on Fisheries and Biodiversity

Much of Wales' coastal modification occurred rapidly during the 1800s to the early 1900s. While its full ecological impact remains uncertain, the scale of habitat loss likely contributed to regional declines in fisheries productivity (Moore et al. 2024). Seagrass meadows, salt marshes, and oysters are all important nursery habitats for many commercial species (Bertelli and Unsworth 2014; Unsworth et al. 2018; Lefcheck et al. 2019). Although overfishing played a major role in the fishery collapse, the simultaneous loss of supporting habitats complicates the narrative (Seitz et al. 2013). This habitat loss also diminished other ecosystem functions, reducing biodiversity, water filtration, and ecosystem resilience.

As foundational habitats have disappeared, ecosystems have become increasingly dominated by opportunistic or invasive species, such as the slipper limpet, which utilise the newfound space but provide a lower ecological value (Powell-Jennings and Callaway 2018). Lower biodiversity reduces ecosystem function and can increase problems like coastal erosion and degraded water quality.

4.5 | Novel Ecosystems and Opportunities

In Milford Haven, seagrass remains frequent (Bertelli et al. 2018), with current coverage possibly greater than previously recorded, potentially aided by localised sea temperature changes linked to power station outflows. However, the broader area now supports 'Novel Ecosystems', including many invasive species such as the Slipper Limpet (*Crepidula fornicata*) that carpets the seabed (Quinn et al. 2022). Elsewhere in Wales, estuarine modification has unintentionally created sheltered environments where new habitats can form. For example, the Holyhead embankment and Fishguard sea wall have created lagoonal environments suitable for seagrass and other marine life. Similarly, re-channelling of the Dee Estuary likely destroyed former habitats, but coincided with new salt marsh growth on the English side (Marker 1967). These cases illustrate that not all modifications lead to ecological loss; some changes can support biodiversity if well managed (Martins et al. 2016).

4.6 | Looking Forward

Today, Wales' estuarine and coastal ecosystems no longer deliver the ecosystem services needed to support productive marine life. Oyster reefs are gone, seagrass exists only in remnants, and other key habitats like maerl and horse mussel beds are near extinction. No part of Wales' marine ecosystems can be accurately described as pristine or natural. Yet, many conservation strategies still operate under this assumption. Most protected areas now conserve simplified, low-diversity, soft-sediment systems, products of centuries of degradation. These are not natural endpoints but symptoms of a shifted baseline.

We argue that these historically modified, degraded, and now commonly referred to as 'Novel Ecosystems' (Hobbs et al. 2009) should be viewed as restoration opportunities. Rather than maintaining degraded conditions, we should treat these seascapes as semi-blank canvases for ecosystem recovery. With targeted interventions, they could deliver NbS and support thriving coastal communities. Policy must acknowledge the altered state of Welsh estuaries and coasts, and focus not on preserving the status quo, but on actively improving it.

Nature recovery of Wales marine, coastal and estuarine environments is not simply a case of planting new habitat, or creating a network of marine protected areas to protect the status quo. What is required now are biodiversity enhancement plans for Welsh waters that start to deliver on the increasing legal obligations to restore biodiversity. Governments, based on working with communities and stakeholders, are reimagining a connected seascape (Preston et al. 2025) to deliver ecosystem services (Pouso et al. 2019) for people, planet and biodiversity. These need to be built on sound policy and governance (Evans et al. 2025), but importantly, they need to be developed based on holistic multidisciplinary science. Given the complexity of the historic impacts on Wales, this requires studies that seek to take a large-scale approach that aims to understand the sedimentary, morphological and hydrodynamic feedbacks preventing restoration and then the response of the environment to new habitats and processes brought about by restoration (George et al. 2012).

Biodiversity enhancement plans for Welsh waters must be developed in collaboration with communities and stakeholders (Unsworth, Cullen-Unsworth, et al. 2026) and grounded in a reimagining of a connected seascape that delivers ecosystem services for people, the planet, and biodiversity (Pouso et al. 2019; Preston et al. 2025). The Wellbeing of Future Generations Act in Wales provides a unique opportunity of taking a 'One Health' approach (Figure 8) to rebuild marine life for and with the people of Wales (Zinsstag et al. 2011). With increasingly rapid climate change, habitats need to be restored that are resilient to future conditions and support community needs. To succeed, these initiatives must be underpinned by robust policy and governance frameworks (Evans et al. 2025) and, crucially, be informed by multidisciplinary science. While this research doesn't examine the ongoing problems of degraded water quality in Wales (Jones et al. 2018; Dallison et al. 2022), creating a vision for the recovery of marine nature in Wales necessitates a joined-up catchment to coast partnership (Ledoux et al. 2005). Given the long and complex history of environmental impacts in Wales, restoration must begin with large-scale studies that examine how sedimentary, morphological, and hydrodynamic feedbacks may be hindering recovery. Only with this understanding can we predict how new habitats and processes introduced through restoration will interact with and shape the environment (George et al. 2012).

Author Contributions

All authors developed the project concept. R.K.F.U. conducted the data collection and analysis. All authors contributed to writing and editing the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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