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Improving the definition of a coastal habitat: Putting the salt back into saltmarsh

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ABSTRACT

Definitions of saltmarsh vary, with approaches based on the European Union Water Framework Directive (WFD) and the Habitats Directive differing from major definitions in the literature, and from each other, giving rise to confusion and differing approaches to calculations of extent. Habitats Directive definitions also differ across Europe. This paper's main aim is to derive a detailed definition of the saltmarsh habitat that satisfies the ecological principles of saltmarsh as defined in the literature. This is then related to the Directives by examining each Directive in the context of phytosociology and UK and European Ellenberg Numbers for Salinity. A definition is offered that is precise in vegetational terms and complies with most literature definitions, notably in respect of the importance of halophytes. Although our method has been applied to the UK National Vegetation Classification, the technique can be extended to any vegetation type for which a salt tolerance index is available. Conflation of saltmarsh definition and conservation is reviewed and removed in a way that retains the ability to protect the habitat in its wider context. It is essential that all accounts of saltmarsh, and especially those that quantify extent, specify their terms of reference.

1. Introduction

A recent, comprehensive work on saltmarsh notes that "there is no universally accepted technical definition as to what comprises a saltmarsh" (Chatters, 2017). A proliferation of habitat classifications and two European Union Directives have led to considerable confusion as to how saltmarsh can be defined, posing problems for comparisons of attributes such as extent. Without defining his terms, Davidson (2018) calculated that the UK supported 34.7% of European saltmarsh, more than any other country, although the largest contiguous saltmarsh was the Wadden Sea (27.6%) extending across three countries. We review the definitions provided by both Directives for the UK and for the Habitats Directive on the Wadden Sea, thus covering 62.3% of European saltmarsh. There is no agreement on spelling, so that multiple online searches are required: there is a choice of saltmarsh, salt marsh or salt-marsh. The first is favoured here. Annex I of the Habitats Directive also uses the term 'salt meadow', and some UK sites are referred to as 'saltings'.

Most of the contemporary confusion appears to arise from different approaches by the Habitats Directive and the Water Framework Directive (WFD), with authors of reports associated with the Directives rarely mentioning that alternative definitions of the habitat are available. This lack of precision gives rise to particular confusion when the habitat is quantified, especially where area comparisons are involved. In theory this should not matter so long as saltmarsh is clearly defined but often the definition is vague or missing. The scale of the problem is illustrated by the significant difference between statistics for saltmarsh extent submitted on behalf of the UK Government: the UK Office of National Statistics (ONS, 2016) gave a UK saltmarsh area of 44,512 ha while the UK Joint Nature Conservation Committee (JNCC) reported an aggregate area of 36,132 ha for the four UK coastal Annex I saltmarshes under Article 17 reporting for the period 2013–2018 (JNCC, 2019), a discrepancy of 8380 ha. Recent figures for saltmarsh area in England are closer: 35,505 ha (Environment Agency, 2022) and 32,462 ha (Natural England and RSPB, 2019), a difference of 3043 ha.

When reporting in respect of both Directives, employing Biodiversity Net Gain metrics or (in time) the Greenhouse Gas Inventory, this confusion risks undermining conservation management, so it is essential to alert the audience for such documents to the existence of this ambiguity, and ideally to remove the ambiguity entirely. Habitat mapping and estimations of extent rely on the identification of fixed boundaries within an environmental continuum; for any such system to be effective,

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a pragmatic approach is required, in turn requiring a high level of knowledge of the habitat(s) involved, especially in respect of their definition.

2. Methods

Literature definitions of saltmarsh were examined and common and/or prominent themes identified, chief of which was that saltmarsh should comprise mainly halophytic (salt-tolerant) intertidal vegetation. Published accounts of saltmarsh by or for the UK conservation agencies were then used to identify vegetation types associated with differences between EU Directives using the UK National Vegetation Classification (Rodwell, 1995, 2000). These types were typically associated with more brackish situations or terrestrial transitions. Each vegetation type was then reviewed for halophytic affinity using UK and European Ellenberg Values for salinity (Hill et al., 2004; Tichý et al., 2023) for all species having a constancy of III or more (present in more than 40% of stands). This enabled the identification of halophytic UK vegetation types and from this their European equivalents, and the provision of a precise definition of saltmarsh in terms of vegetation types. The UK approach to the Habitats Directive was then compared to that of the Wadden Sea to evaluate consistency within that Directive.

Following convention, original species names used in the names of NVC vegetation types are retained throughout (Rodwell, 1995, 2000), but otherwise updated nomenclature is applied, following Stace (2019). Quoted text is retained as originally presented. NVC vegetation types cited here are referred to their European equivalents, based on the EuroVegChecklist (EVC) hierarchical system of Mucina et al. (2016), listing the EVC alliance code and name. This allows our focus on UK saltmarsh vegetation associated with confusion of definitions to be applied more widely, and our use of prominent halophytic vegetation to identify saltmarsh habitat can be employed for any vegetation type provided an index of salt tolerance is available, as is the case for all of Europe (Tichý et al., 2023). It is emphasised that this paper addresses coastal saltmarsh and does not attempt to cover inland saltmarshes.

3. Saltmarsh in the literature

Work associated with either of the Directives is excluded from this section. The *Oxford English Dictionary* (2023) defines salt marsh (sic) as “Marsh overflowed or flooded by the sea”. The classic sources in the ecological literature are largely helpful. Tansley (1953) describes saltmarsh as “essentially composed of halophytes”. Chapman (1960) defines saltmarshes as “areas of land bordering on the sea, more or less covered with vegetation, and subject to periodic inundation by the tide.” The salinity of the tide and how halophytic the vegetation might be are not included. Beeftink (1977) is more meticulous, stating “Salt-marsh can be defined as natural or semi-natural halophytic grassland and dwarf brushwood on the alluvial sediments bordering saline water bodies whose water level fluctuates either tidally or non-tidally. The salinity of the adjacent water bodies may vary from >38‰ [sic] to 5‰: if the salinity is below 5‰, however, salt-marsh is replaced by reed and rush marshes, willow coppice and tall herbage, etc. … salt-marshes find their upper limit where saline influences are so far reduced that halophytes are in the minority or are totally lacking”. Burd (1989) defined saltmarsh as “vegetation types described in the draft saltmarsh chapter of the National Vegetation Classification, and previously largely described by Adam (1981), as occurring within tidal limits, although excluding *Zostera* and *Ruppia*”. Adam (1981) defined saltmarsh as “an area in which the vegetation is predominantly phanerogamic (but excluding *Zostera* spp.) and which is subject to direct tidal influence”. Dijkema (1984) noted that saltmarsh vegetation “is characterised by its tolerance of the saline conditions and consists of halophytes”. Adam (1990) gave “areas, vegetated by herbs, grasses or low shrubs, bordering saline water bodies”. Allen (2000) defined saltmarsh as “areas of land covered chiefly by halophytic vegetation which are regularly flooded by the sea”. Rodwell (2000) noted that “Communities consisting predominantly or entirely of halophytes can sensibly be termed salt-marsh vegetation types but, towards the upper marsh limit and, in some areas (like the grazed marshes of the north and west of the UK) more extensively, communities consisting mainly or exclusively of glycophytes also occur in the salt-marsh habitat … Deciding whether a particular vegetation type is more closely related to a mainstream salt-marsh community or a predominantly inland community is sometimes very difficult”.

Four of the nine definitions cited above supply clarity in specifying “halophyte”, excluding tidal but non-saline water, or excluding non-halophytic vegetation such as reeds and rushes, i.e. confining saltmarsh to vegetation subject to *saline* influence. ‘Saline’ is defined by the Venice System (Anonymous, 1959) as a salinity above 30, with salinities below 30 regarded as ‘mixohaline’ (brackish). Two more, those of Burd (1989) and her source (an early draft of Rodwell, 2000), emphasise the role of halophytes but allow for the presence of glycophytes within the vegetation. The remaining three, Chapman (1960) and Adam (1981, 1990) allow for the inclusion of tidal non-saline vegetation but do not actually require it, and such areas tend to occur in the upper parts of estuaries and are not quite “bordering on the sea” or “bordering saline water bodies” as they describe. Furthermore, geomorphologists (e.g. Bird, 2003; Bartholdy, 2012) tend to define saltmarsh in terms of the vegetation, although of the two only Bird stresses the significance of halophytes.

4. Water Framework Directive saltmarsh

Saltmarsh reporting for the EU Water Framework Directive (WFD) is driven by a need to report on the status of transitional water bodies (estuaries) rather than the saltmarsh habitat *per se.* The Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG) (2014) used a combination of metrics addressing extent, zonation and diversity for its environmental reporting tool and required a “fully functioning saltmarsh” to “have all its major zones”. Five zones are defined in respect of England and Wales, and it is suggested that there might be fewer distinct zones in Scotland (Table 1): Scottish saltmarshes often lack a pioneer zone (Burd, 1989; Haynes, 2016), a situation that appears to be entirely natural in origin.

Clearly any metric for extent is dependent on the range of vegetation included, but also on the ability to represent this on maps, so that the gradual reduction in the density of *Salicornia* as the saltmarsh gives way down-shore to sediment flats, requires an arbitrary boundary. Phelan et al. (2011) recommend the mapping of only areas of “discrete” pioneer vegetation. Hambidge and Phelan (2014) expanded on the zonation concept, sub-dividing the zones and allocating NVC types to each. Only two Swamp types (S) were listed: S4 *Phragmites* was allocated to Zone 5 as would be expected, and S21 *Scirpus maritimus* (*Bolboschoenus maritimus*) was allocated to High Marsh Zone 4. Phelan et al. (2011) also included S19 *Eleocharis palustris* and S20 *Scirpus lacustris* ssp. *tabernaemontani* (*Schoenoplectus tabernaemontani*), yet defined saltmarsh as “any discrete marsh, or reed bed, subject to tidal inundation from *saline* waters” (italics inserted here).

Hill et al. (1999, 2004) gave Ellenberg values on a scale of 0–9 for a range of environmental attributes, including salt tolerance, slightly modified for the UK. These values represented affinity for salinity and make no direct reference to numerical values of salinity. On this scale, 0 represented intolerance of salinity and 9 represented tolerance of “extremely saline conditions”. Average European Ellenberg values (using the same scale) were provided by Tichý et al. (2023). These values were applied to the main species associated with the S (Swamp) NVC types included in WFD definitions of saltmarsh (Table 2).

Hill et al. (2004) associated a value for salt tolerance of 4 with “species of salt meadows and upper saltmarsh, mostly subjected to only very occasional tidal inundation (includes species of brackish conditions, i.e. of consistent but low salinity)”, and only species with a value of 4 or above were considered here as halophytic. Their list of species

Table 1
WFD-UKTAG saltmarsh zones (as given by WFD-UKTAG, 2014). *Elymus* replaces *Elytrigia* in the original.

1. Pioneer: Salicornia and pioneer species
2. Spartina dominant marsh
3. Mid-Low marsh mix (Atriplex, Puccinellia)
4. High marsh (Festuca rubra, Elymus dominant marsh, Bolboschoenus, Juncus dominant marsh)
5. Brackish water reedbeds (Phragmites).

Table 2
Ellenberg values for salinity for species of S (Swamp) NVC types included in WFD definitions of saltmarsh, with maximum constancy in any sub-community given in brackets where this is III (present in 41–60% of stands) or above. Source: Hill et al. (2004), with values (where given) from Tichý et al. (2023) in brackets. The S4 reedswamp is shown in more detail in Table 3. Species data from Rodwell (1995). EuroVegChecklist equivalents to NVC types taken from Mucina et al. (2016).

NVC (EVC equivalent)	Species	Ellenberg salinity
S4 Phragmites australis swamp and reed-beds (PHR-01 A Phragmition communis)	*Phragmites australis* (V)	2 (1.6)
S19 Eleocharis palustris swamp (PHR-06 A Eleocharito palustris – Sagittarion sagittifoliae)	*Eleocharis palustris* (V)	1 (0.7)
	Agrostis stolonifera (V)	1 (0.7)
	Littorella uniflora (IV)	0
	Equisetum fluviatile (III)	0 (0.1)
	Juncus bulbosus (III)	0 (0.2)
	Potentilla anserina (III)	2 (1.4)
	Lysimachia maritima (III)	4 (5.8)
	Triglochin maritima (III)	4 (6.7)
S20 Scirpus lacustris ssp. Tabernaemontani swamp (PHR-01 A Phragmition communis)	*Schoenoplectus tabernaemontani* (V)	3
	Agrostis stolonifera (V)	1 (0.7)
S21 Scirpus maritimus swamp (PHR-02 A Scirpion maritimi)	*Bolboschoenus maritimus* (V)	4 (3.7)
	Atriplex prostrata (V)	2 (2.1)
	Juncus gerardii (III)	3 (5.6)
	Potentilla anserina (V)	2 (1.4)

Table 3
UK Ellenberg values for salinity (from Hill et al., 2004) with European averages (where given) from Tichý et al. (2023) in brackets, for species in S4 reedswamp with a constancy of III (present in 41–60% of stands) or above as listed by Rodwell (1995). *Phragmites australis* itself has a maximum constancy of V (present in 81–99% of stands) and an Ellenberg value of 2 (Table 2). In S4a all species other than *Phragmites australis* have a constancy of I (present in only 1–20% of stands).

NVC	Species	Constancy	Ellenberg
S4b	*Galium palustre*	IV	0 (0.2)
	Mentha aquatica	III	0 (0.3)
S4c	*Menyanthes trifoliata*	IV	0 (0.0)
	Equisetum fluviatile	IV	0 (0.1)
	Carex rostrata	IV	0 (0.0)
	Nymphaea alba	III	0 (0.0)
	Potentilla palustris	III	0
S4di	*Atriplex prostrata*	V	2 (2.1)
S4dii	*Puccinellia maritima*	V	5 (7.3)
	Atriplex prostrata	III	2 (2.1)
	Tripolium pannonicum	III	5 (7.2)
S4diii	*Agrostis stolonifera*	V	1 (0.7)
	Atriplex prostrata	III	2 (2.1)
	Juncus gerardii	III	3 (5.6)

with a value of 4 includes *Triglochin maritima* and *Lysimachia maritima* which are regarded as saltmarsh species associated with SM13, SM15 and SM16 NVC types (Rodwell, 2000). An Ellenberg salinity value of 3 applies to "species most common in coastal sites … that are not obviously salt-affected".

In S19 *Eleocharis palustris* swamp, only the S19c *Agrostis stolonifera* sub-community contains species with an Ellenberg value for salinity of 4 or more (both 4, Table 2) but both of these, *Triglochin maritima* and *Lysimachia maritima*, have a constancy of only III (present in 41–60% of samples) and the species with maximum constancy in S19 (*Eleocharis palustris* and *Agrostis stolonifera*) have very low Ellenberg salinity values (1), so that S19 and even S19c cannot justifiably be regarded as halophytic vegetation. In transition from saltmarsh to sand dune, swamp (S) habitat develops in association with the freshwater dune aquifer, with complicated mosaics mingling wet upper saltmarsh (SM19, SM20), swamp (S19c) and wet grassland (MG11, MG13 and occasionally MG12), described by Rodwell (2000) as the influence of salinity being gradually joined by the influence of waterlogging. The only vegetation in Table 2 that appears to qualify as halophytic is S21 *Bolboschoenus maritimus* swamp, where the nominate species has an Ellenberg salinity value of 4. Although the *Juncus gerardii* of S21 has a lower constancy and an Ellenberg salinity value of only 3 in the UK, this rises to a more convincing 5.6 in a European context.

The statutory nature conservation body Scottish Natural Heritage (SNH, now NatureScot) and the Scottish Environment Protection Agency (SEPA), organisations reporting for the Habitats Directive and WFD respectively, specified that the contractor for their jointly commissioned Scottish Saltmarsh Survey should distinguish between fresh-water reedbeds S4 *Phragmites* and reedbeds influenced by saline input. Haynes (2016) reported that the task was problematic, as halophytes tended to disappear within 2 m of the edge of the reedbed and devised a method of distinguishing the two types on the basis of adjacent landward vegetation, but also noted that saline influence could extend into reedbeds via excavated channels. Full sea water usually has a salinity of around 34–35, and Chapman (1960) gives the maximum salinity "tolerated" by *Phragmites* as 27.5. Packer et al. (2017) reported that *Phragmites australis* becomes stressed at salinities greater than 12 and is killed by salinity exceeding 30, i.e. by saline water. *Phragmites australis* has a complex osmoregulatory mechanism which can also be influenced by microbial activity around its rhizomes (Borruso et al., 2014). Hill et al. (2004) give *Phragmites australis* a salinity Ellenberg value of 2, while Tichý et al. (2023) give it a value of 1.6. The highest value recorded by the latter across Europe was 3.0 in France and Italy.

Although *Phragmites* dominates the S4 reedswamp there are subtypes that merit more detailed consideration. Rodwell (1995) listed four sub-communities. Unusually, one of these (S4d) has variants, and one of these (S4dii) often contains two halophytes with UK Ellenberg values of 5: *Puccinellia maritima* and *Tripolium pannonicum*, with European values even higher (Table 3). There is thus a variant of S4 reedswamp that merits consideration as saltmarsh, although the variant is unlikely to survive prolonged exposure to full salinity sea water. S4dii contains one species with a European salinity value of 5.6 (*Juncus gerardii*, Table 3) but is absent from many stands. However, given that the nominate species of S4dii and SD4ii, *Phragmites australis*, has a constancy of V in all types of S4 reedswamp, and is not viable in 'saline' water (salinity above 30) it is difficult to justify the inclusion of any S4 vegetation within the definition of saltmarsh.

Phelan et al. (2011) attempted to distinguish their saltmarsh reedbeds from freshwater reedbeds by using Highest Astronomical Tide (HAT). HAT is not currently available as a national dataset in Scotland, but it should be noted that the vegetation map produced by Haynes (2016) showed the innermost identifiable halophytic vegetation in major inlets as occurring some 20 km downstream of Normal Tidal Limit (NTL) as identified on Ordnance Survey maps. Retention of reedbeds within a saltmarsh definition involves real difficulties in distinguishing saline from non-saline reedbed, either in the field or using remote sensing. Haynes (2016) reported stands of *Carex recta* and its hybrid *Carex recta* x *aquatilis* in brackish conditions at Bonar Bridge, at the head of the Dornoch Firth, and in the estuary of the River Wick, in the extreme NE of the Scottish mainland. *Carex salina* was found in mid-marsh creeks in the *Puccinellia* zone in three sites. These types tend to occur at the boundary of saline and brackish vegetation but are extremely rare, are difficult to map or classify in phytosociological terms at their Scottish locations (Haynes, 2016), and their extent is negligible in national (Scottish or UK) terms. Of the vegetation listed in Tables 2 and 3, only S21 yields persuasive evidence of saltmarsh status.

5. Habitats Directive saltmarsh

Although the UK has left the EU, the contents of the Habitats Directive have been largely retained via Statutory Instruments (Scottish Government, 2019; UK Government, 2019). The Habitats Directive Interpretation Manual (European Commission, 2013) lists 4 types of saltmarsh that occur in the UK (Table 4).

Thus UK saltmarsh as defined by the Habitats Directive covers only vegetation described as SM (saltmarsh) by the National Vegetation Classification (NVC) (Rodwell, 2000). SM1 and SM2 are seagrasses, and would be excluded by all saltmarsh definitions, but the omission of SM3, SM22-SM24, SM26, and SM28 is more puzzling. Applying the JNCC criteria rigidly would then raise the question of where these other SM vegetation types should sit in terms of Annex I habitat, as well as how S (swamp) types would be allocated. The former issue is addressed here and the latter in the Discussion. The JNCC's Common Standards Monitoring Guidance for saltmarsh (JNCC, 2004) used a definition that embraced all SM vegetation types from SM4 to SM28 but did not extend to any S communities.

Almost all the main species of the NVC types listed in Table 5 have Ellenberg values of 4 or more, apart from SM3, SM28, one out of four in SM23, and one out of three in SM24. SM3 *Eleocharis parvula* is very rare in the UK and has negligible extent. The NVC description for SM3 (Rodwell, 2000) is brief and suggests that this species occurs with a range of associates and in a range of positions on the saltmarsh, so it is difficult to categorise, but the larger of the two Scottish sites, at the head of the Cromarty Firth, is clearly brackish, and there is insufficient evidence to justify including SM3 within saltmarsh. Rodwell (2000) does not give floristic details for SM27 so it could not be included in Table 5, so is addressed in more detail below using additional information.

Observations of SM27 Ephemeral salt-marsh vegetation with *Sagina maritima* on the Dee Estuary, on the NE boundary between England and Wales (Dargie, 2001) and at the Morrich More, at the mouth of the Dornoch Firth in NE Scotland (Dargie, 2017) suggested that this vegetation is not confined to saltmarsh from which turf has been cut or other disturbed areas as Rodwell (2000) described but can occur in the driest upper saltmarsh zone where there is little or no organic strand deposition. At the Morrich More, SM27 occurs at the upper marsh edge in transition to sand dune, and as outliers on transitions to old linear embryo dunes with *Elymus junceiformis* (SD4) which were left surrounded by saltmarsh as the strandplain prograded seawards until the last two decades (Dargie, 2017). Because this situation in the uppermost zone is possibly transitional, the saltmarsh status of SM27 is reviewed in the same way as other transitional vegetation. Attributes of this vegetation are listed in Table 6.

In SM27 (Table 6), four of the seven constant species from the Dee

Table 4
NVC allocations for Habitats Directive saltmarsh Annex I types occurring in the UK (sources as in links). These also follow the EU Interpretation Manual (European Commission, 2013). 1410 Mediterranean salt meadow also occurs, but not in the UK.

Annex 1 Type	NVC (EVC equivalent, Mucina et al., 2016)	Link
1310 *Salicornia* and other annuals colonising mud and sand	SM7 Arthrocnemum perenne stands (SAL-01 A Salicornion fruticosae) SM8 Annual Salicornia community (THE-01 B Salicornion dolichostachyo-fragilis) SM9 Suaeda maritima community (THE-01 A Therosalicornion) SM27 Ephemeral salt-marsh vegetation with Sagina maritima (SAG-01 A Saginion maritimae)	https://sac.jncc.gov.uk/habitat/H1310/
1320 *Spartina* swards (*Spartinion maritimae*)	SM4 Spartina maritima community (SPA-01 A Spartinion glabrae) SM5 Spartina alterniflora community (SPA-01 A Spartinion glabrae) SM6 Spartina anglica community (SPA-01 A Spartinion glabrae)	https://sac.jncc.gov.uk/habitat/H1320/
1330 Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	SM10 Transitional low-marsh vegetation with Puccinellia maritima, annual Salicornia species and Suaeda maritima (THE-01 A Therosalicornion) SM11 Aster tripolium var. Discoideus community (JUN-03 A Festucion maritimae) SM12 Rayed Aster tripolium on salt-marshes (JUN-03 A Festucion maritimae) SM13 Puccinellia maritima community (JUN-03 A Festucion maritimae) SM14 Halimione portulacoides community (JUN-03 A Festucion maritimae) SM15 Juncus maritimus – Triglochin maritima community (JUN-01 A Juncion maritimi) SM16 Festuca rubra community (JUN-03C Armerion maritimae) SM17 Artemisia maritima community (JUN-03C Armerion maritimae) SM18 Juncus maritimus community (JUN-01 A Juncion maritimi) SM19 Blysmus rufus community (JUN-03C Armerion maritimae) SM20 Eleocharis uniglumis community (JUN-03C Armerion maritimae)	https://sac.jncc.gov.uk/habitat/H1330/
1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)	SM25 Suaeda vera drift-line community (SAL-01 A Salicornion fruticosae) SM21 Suaeda vera – Limonium binervosum community (SAL-01 A Salicornion fruticosae)	https://sac.jncc.gov.uk/habitat/H1420/

Table 5
UK Ellenberg values for salinity of main species (constancy III-V – present in at least 41% of stands) of SM NVC Communities omitted from JNCC saltmarsh definitions (source of values Hill et al., 2004, with European averages (where given) from Tichý et al. (2023) in brackets. Species listings and constancy values from Rodwell (2000). SM27 requires more detailed coverage and is shown in Table 6.

NVC (EVC equivalent, Mucina et al., 2016)	Species	Ellenberg salinity
SM3 Eleocharis parvula community (RUP-01 A Ruppion maritimae)	*Eleocharis parvula*	3 (4.0)
SM22 Halimione portulacoides - Frankenia laevis community (JUN-03C Armerion maritimae)	*Frankenia laevis* (V)	5 (5.7)
	Atriplex portulacoides (IV)	6 (7.3)
	Puccinellia maritima (IV)	5 (7.3)
	Armeria maritima (III)	3 (2.3)
	Spergularia media (III)	5 (6.6)
SM23 Spergularia marina – Puccinellia distans community (coastal only) (JUN-03 B Puccinellio maritimae – Spergularion salinae)	*Spergularia marina* (V)	5 (7.5)
	Puccinellia maritima (V)	5 (7.3)
	Salicornia agg. (III)	9 (8.5)
	Suaeda maritima (III)	7 (8.3)
SM24 Elymus pycnanthus community (JUN-02 A Agropyrion pungentis)	*Elymus athericus* (V)	4 (6)
	Atriplex portulacoides (III)	6 (7.3)
	Festuca rubra (III)	2 (0.7)
SM26 Inula crithmoides on salt-marshes (JUN-01 A Juncion maritimi)	*Inula crithmoides* (V)	5 (6.0)
	Atriplex portulacoides (V)	6 (7.3)
	Puccinellia maritima (V)	5 (7.3)
	Salicornia agg. (V)	9 (8.5)
	Limonium vulgare (V)	6 (7.3)
	Elymus athericus (IV)	4 (6.0)
	Plantago maritima (III)	3 (6.0)
	Armeria maritima (III)	3 (2.3)
	Suaeda maritima (III)	7 (8.3)
SM28 Elymus repens community (CAK-01C Agropyro-Rumicion)	*Elymus repens* (V)	2 (1.0)
	Festuca rubra (V)	2 (0.7)
	Agrostis stolonifera (IV)	1 (0.7)
	Atriplex prostrata (IV)	2 (2.1)
	Potentilla anserina (III)	2 (1.4)

Estuary have Ellenberg S values of 4 or more, while five have European S values of 3.8 or more. At the Scottish site, only two of the ten species listed have an Ellenberg S value (UK and Europe) of 4, with a third species having a European value of 5.4, so that saltmarsh status for SM27 cannot be allocated at the Morrich More. This is possibly explained by location within the tidal profile. At sites on the Dee Estuary where SM27 is associated with disturbed *saltmarsh* vegetation which it then displaces, it falls within the saltmarsh expanse and is subject to saltmarsh processes. At the Morrich More, the vegetation is within the transitional zone and contains fewer halophytes, conforming to the characteristics of other vegetation at this level in terms of Ellenberg salinity. We conclude that SM27 should be allocated to saltmarsh where it occurs within the expanse of halophytic vegetation, but where it occurs near the terrestrial margin, it should be allocated to transition marsh. SM27 is scarce and has restricted area, so this will usually be feasible.

Petersen et al. (2014) used a system based on Habitats Directive Annex I habitats to map habitats in the Wadden Sea. Their 1330 Atlantic saltmarsh was divided into 19 categories, including *Phragmites* swamp, *Bolboschoenus* swamp, brackish flooded grassland and ruderal vegetation, all of which are excluded from the UK definition of 1330. This classification was used in reporting saltmarsh extent by Esselink et al. (2017) who added ‘summer polders’ despite concluding that “Strictly speaking … most summer polders cannot be considered as salt marsh”. There are thus European-level saltmarsh definition conflicts within Annex I of the Habitats Directive, over and above any conflicts between this Directive and the WFD.

6. Other classifications and definitions

Phase 1 habitat survey involves only very basic and rapid habitat classification, and saltmarsh is barely described (JNCC, 2010). Because the classification is very broad, output from Phase 1 survey has limited application in saltmarsh survey. The UK Biodiversity Action Plan (BRIG, 2011) describes saltmarsh as having a lower limit indicated by the lowest pioneer plants and an upper limit 1 m above the level of the highest astronomical tide (HAT) so as to include transitions. HAT would extend to NTL, thus embracing much non-halophytic tidal marsh. UKHab Ltd (2023) includes saltmarsh within a ‘Primary’ (Level 2) category of “Marine inlets and transitional waters” which initially suggests an affinity with the Water Framework Directive, then opts for “Littoral sediment” as Level 3 and “Coastal Saltmarsh” as Level 4, which it refers to the UK Biodiversity Action Plan, with Level 5 specifying the Habitats Directive Annex I habitat, so that at detailed level the system most closely resembles the Habitats Directive approach.

IHS (Integrated Habitat System) (Somerset Environmental Records Centre, 2007) is a proprietary system developed by a local authority records centre, and is used mainly by local authorities. It aims to deliver maps of BAP habitats and Annex I habitats so is closest in approach to the Habitats Directive. Data obligations in respect of the EU Habitats Directive require the employment of EUNIS (European Nature Information System) (Davies et al., 2004), itself based on Annex I of the Habitats Directive and the earlier CORINE system (European Environment Agency, 1994). Accordingly, most of the conservation organisations have compiled detailed concordances for the NVC and EUNIS; the version used by NatureScot has been published (Strachan, 2017). Rodwell et al. (2002) linked EUNIS categories to European phytosociological alliances. Strachan (2017) allocated “saltmarsh” to Level 1 Category A (marine habitats) but divided swamps between category B (coastal habitats) and category C (fringing open waters). A spreadsheet giving correspondences between the categories in the various classifications (Phase 1, UKHab, NVC, EUNIS and HIS) has been produced by the UK Habitat Classification Working Group (2018). This concordance enables cross-compliance between classifications but it does not overcome the fundamental problem of multiple definitions for saltmarsh. The issue is not which of the many survey methods should be used but of a lack of agreed definition overall.

7. Discussion

7.1. Mapping

Ultimately all attempts at producing accurate figures for extent of coastal habitats are no more than a “best assessment” based on a snapshot in time. Firstly, coastal environments are dynamic, so all interpretations of extent must accommodate this. Secondly, there will always be [scale-dependent] areas of the selected habitat that are smaller than the mapping base, so that totals will under-record the incidence of the habitat. Thirdly, habitat survey is highly subjective and

Table 6
Floristic tables for SM27 Ephemeral salt-marsh vegetation with *Sagina maritima* (SAG-01 A *Saginetea maritimae* https://onlinelibrary.wiley.com/doi/pdf/10.1111/avsc.12257) from two UK locations. Sources for Ellenberg Values of salt tolerance as in Table 5.

	Dee Estuary (Dargie, 2001)		Morrich More 1988 & 2019 Quadrats 10Q		Morrich More Permanent quadrats 1992–2023 61Q		
Species	Constancy	Domin range	Constancy	Domin range	Constancy	Domin range	Ellenberg S
Sagina maritima	V	3–5	V	2–6	V	2–5	4 (3.8)
Agrostis stolonifera	IV	2–5	IV	3–6	V	2–8	1 (0.7)
Festuca rubra	IV	2–7	IV	5–9	V	4–8	2 (0.7)
Parapholis strigosa	IV	3–5					3 (2.3)
Plantago maritima	III	1–3	III	3–7	V	1–8	3 (6.0)
Puccinellia maritima	IV	2–4					5 (7.3)
Armeria maritima	II	3–5	IV	2–5	IV	1–7	3 (2.3)
Juncus gerardii			II	2–5	IV	2–5	3 (5.6)
Carex flacca					III	1–8	0 (0.6)
Elymus junceiformis	I	4	III	3–4			3 (5.4)
Lysimachia maritima	I	2	III	2–7	III	1–7	4 (5.8)
Plantago coronopus	III	4–6	III	2–4	III	1–6	2 (3.1)
Poa humilis			II	2–5	III	2–7	2
Trifolium repens			II	2–5	III	3–9	0 (0.7)

thus observer-dependent, with the additional complication of delivering many polygons with intermediate vegetation or containing two or more NVC types, some reflecting gradual transitions or nuanced local topographic variations: a map imposes a hard boundary on a blurred reality. Unless large, complex legends are employed, polygons containing multiple habitats can only be mapped by assigning hierarchies to the vegetation, introducing yet more observer bias. Fourthly, habitats occasionally occur in the 'wrong' place, e.g. relict vegetation. Highly localised circumstances create small areas of other habitats nested within the wider extent. Formulaic approaches to mapping habitat extent must thus be tempered with a large amount of pragmatism, ideally informed by field knowledge of the habitats involved and site history, if not experience of the site(s) involved, which is rarely achievable. That is not to suggest that such surveys do not have value: they are important tools in assessing the national status of any habitat, but consistent methodology, together with an understanding of habitat function, are required to enable repeat surveys to detect change and trends reliably, an understanding that is essential where Biodiversity Net Gain or habitat restoration are contemplated.

7.2. Importance of salinity

The words 'saline' and 'halophytic' are critical in saltmarsh definition, and the first syllable of 'saltmarsh' occasionally loses its relevance in how the term is applied. It could be argued that without saline influence and the presence of halophytes, saltmarsh is just marsh. It has to be conceded that the UK Ellenberg Values for salinity used here (Hill et al., 2004) were reached "on basis of subjective opinion", potentially opening to question our exclusion of at least some types of tidal non-saline vegetation. Smart and Scott (2004) recognised bias in Ellenberg values but concluded that individual values were unaffected by this, and that such bias as existed was more likely to be due to errors in environmental measurements. Jarvis et al. (2016) argued that the Ellenberg approach was essentially circular, but admitted its applicability at community level, which is what has been attempted here by listing values for all the main species in each community and using all of these to assess halophytic affinities of the vegetation, albeit with additional weighting to the most frequent species.

A slightly extended Habitats Directive definition, using all SM vegetation types from SM4 to SM26 is the easier Directive-based approach to use if the mapping base is the NVC, provided that S21 *Scirpus maritimus* (*Bolboschoenus maritimus*) is added. However, this leaves the problem of the allocation of S (Swamp) tidal marsh vegetation, especially S4 *Phragmites* beds. These are assumed to be included in Annex I habitat 1130 Estuaries https://sac.jncc.gov.uk/habitat/H1130/which defines the habitat as "the downstream part of a river valley, subject to the tide and extending from the limit of brackish water". However, this still allows for reedbeds to be overlooked: there is no mention of them in the JNCC citation for the Firth of Tay and Eden Estuary Special Area of Conservation in Scotland (included within the definition cited) despite the site supporting the largest reedbed in the UK.

7.3. Water Framework Directive

The WFD definition of saltmarsh has been widely adopted and is associated with some influential publications (e.g. Hudson et al., 2021; Pontee et al., 2021). The zonation element is regarded as important in the WFD approach, yet is absent from the Habitats Directive counterpart, at least as far as definition is concerned. There has been no zonation reporting from Scotland in respect of the WFD, mainly because of the difficulty of allocating zones from existing Scottish datasets. The WFD UK TAG inclusion of *Phragmites* beds within saltmarsh is problematic in mapping terms due to difficulties distinguishing freshwater reedbeds from brackish ones, but *Phragmites* swamp also falls outside generally accepted literature definitions of saltmarsh (Tansley, 1953; Beeftink, 1977; Dijkema, 1984; Allen, 2000), which require a saline as well as a tidal element.

There are halophytic elements within vegetation types that have been categorised here as tidal marsh, e.g. S19 *Eleocharis palustris* (Table 2). Phelan et al. (2011) include S19 in their definition of saltmarsh, but even although halophytes are present, the dominant vegetation types within these communities or sub-communities are not halophytic, strongly suggesting that the vegetation type (as opposed to some of its component species) cannot persist in truly saline conditions. The same argument could also apply to even the variants of S4d that include halophytes because the dominant species of the vegetation types – *Phragmites australis* – is unable to tolerate salinities >30. Although Rodwell (2006) raised the variants of the S4d to sub-community level, there remains a real difficulty in distinguishing the more saline S4 type from tidal marsh reedbeds via fieldwork or the use of remote sensing, although the reduced height (approx. 75 cm) of the *Phragmites* in the S4dii variant (Rodwell, 1995) suggests that this might be possible using LiDAR or aerial photogrammetry.

S4 *Phragmites* swamp is easily identified and mapped using remote sensing. The ability to use LiDAR to distinguish the brackish variant S4dii is untested, while overlay of a Highest Astronomical Tide line as a proxy for this is currently precluded at UK level as it has not yet been derived for the Scottish coastline and is in any case too inclusive of freshwater reedswamp and other non-halophytic tidal marsh in Scotland at least. Phelan et al. (2011) experienced difficulty separating fresh water reedbeds from those influenced by higher salinities. Furthermore, although survey methodology is moving increasingly towards Earth Observation (EO), classification of data will remain reliant on a robust and consistent habitat definition.

7.4. Habitats Directive

The Habitats Directive requires reporting in terms of Favourable Conservation Status, of which extent forms only part. Reporting on structure and function is also mandatory. Here the implementation of the Directive is influenced by its own highly compartmentalised approach, wherein reporting is on the basis of individual Annex I habitats, an approach that even extends to site safeguard, where developers and conservation authorities tend to concentrate almost exclusively on extent. Structure and function operate at a broader level, that of the ecosystem, which in the case of saltmarsh would be most of the estuary or embayment. This would include tidal (but non-saline) marsh and should also include the sediment flat that fronts the saltmarsh and any seagrass beds, as well as consideration of the role played by any coastal defences and nearshore morphology or habitats. Extent is naturally variable, involving exchanges of area between saltmarsh and sediment flat via the ‘alternative stable state’ (e.g. Silinski et al., 2016). A focus on extent can be additionally problematic, in that once a societal value has been assigned to extent, as in (for example) a Greenhouse Gas Inventory, any diminution of extent is likely to be perceived as a problem, no matter how natural that diminution might be, and any interventionist response aimed at countering loss of extent could result in new problems arising in respect of structure and function. Natural variability of extent thus justifies greater prioritisation of structure and function.

If pragmatism is introduced to quantitative reporting of habitat extent, then it is even more essential that informed pragmatism must be applied to the interpretation of data and information derived from such studies. This challenge can be reduced, but not eliminated, by standardising survey and reporting methodologies, but the pragmatic element of survey interpretation can only be standardised so far.

7.5. Resolving the conflicts

It is not unknown for organisations working to the Water Framework Directive and the Habitats Directive to employ different definitions (e.g. Newton et al., 2014) to the extent that mutually exclusive areas or extents might be involved (e.g. Angus, 2016) but at least with transitional waters and saline lagoons, different terminology is employed (transitional waters and estuaries v. Saline lagoons respectively). When agencies employ the same term but apply it differently, as with saltmarsh, confusion is inevitable, and this becomes particularly problematic in the context of quantitative studies. Even when original studies define their terms, subsequent citations often overlook the importance of the scope of the terms.

A definition of ‘true’ or ‘core’ saltmarsh habitat that accords adequate recognition to the first syllable of the habitat name might arguably extend only to SM4-SM26 plus S21 and some SM27. All other S vegetation within tidal but low salinity sections of estuaries would be termed tidal or transitional marsh rather than saltmarsh. Pethick (1992) noted the importance of the entire intertidal profile and cautioned against separating vegetated and unvegetated sediment flats, as did van Regteren et al. (2020). In functional terms the habitat would comprise core saltmarsh + tidal marsh + sediment flats + seagrass beds + nearshore morphology/habitats + other inland transitions + effect of any sheltering sediment ridge + hydrological context - effectively most of the estuary or embayment except for any dune or shingle systems at the estuary mouth that extend beyond a sheltering role.

Our definition requires an intertidal situation. This excludes inland saltmarshes but also coastal perched saltmarshes, beyond the altitudinal limits of tides and overwash as described by Cooper and Power (2003) and Haynes (2016). Perched saltmarshes occur in exposed situations, and any halophytic element of the vegetation is established by spray. Perched saltmarshes tend to be small and, although they support saltmarsh vegetation such as SM16 they are arguably not saltmarsh *habitat* because of the absence of important saltmarsh processes such as tidal inundation and sediment deposition. There is a parallel for this on machair, a coastal grassland confined globally to Scotland and Ireland where depressions in a generally flat vegetation surface support dune slack vegetation but are not structurally or functionally dune slacks (Dargie, 1998; Angus, 2001). Where appropriate, studies can add perched saltmarsh to their coverage of saltmarshes, provided that this is specified and, if extent is involved, quantified.

Transitions between saltmarsh and terrestrial vegetation can be very important in nature conservation (Rees et al., 2010). By definition, transitions are neither one thing nor the other, but something in between. Pragmatic approaches to habitat mapping can allocate transitions to one habitat or the other on the basis of relative abundance or importance, and they can be linked to one or other or both in any conservation management, via the need to accommodate structure and function, but including a transitional area within the *extent* of a habitat does not require its inclusion within the *definition* of the habitat. Any extent figures that involve habitat beyond the defined habitat should themselves be defined. It is essential, however, to ensure that reedswamp and other tidal marsh is adequately covered by the Habitats Directive and does not fall between designations. Just as tidal marsh is not saltmarsh but tidal marsh, brackish marsh is not saltmarsh but brackish marsh, which would feature mainly species with Ellenberg salinity values in the range 1–3.

Boundaries between saltmarsh and adjacent habitats are often nuanced, and are mapped using intermediate or ‘mosaic’ polygons, containing more than one vegetation sub-community or community. These transitional zones can be very important to ecosystem function, but pose obvious problems for mapping and calculation of extent. Where only saltmarsh is under consideration, it is possible to allocate the entire extent of all polygons containing any saltmarsh vegetation types to saltmarsh, provided that the process is transparent. Where more than one habitat is being mapped, the polygon can be allocated to the habitat better or best represented in the polygon but, if they are equally represented, a value judgement is the only option. Although it is possible to divide the polygon area between the vegetation types for calculation of extent, this is more of an arithmetic exercise than an ecological one, given that each vegetation type occurs throughout the polygon, albeit with reduced cover, and the entire polygon is subject to the processes that operate in all habitats present.

For mapping habitat extent, the upstream/inland limit of saltmarsh, where the habitat gives way to tidal marsh or transition marsh, would be defined as the upstream/inland margin of the polygon(s) containing any amount of the vegetation defined here as core saltmarsh. Except where they are extensive, pragmatism allows for polygons of vegetation not defined here as saltmarsh that are nested within core saltmarsh extent to be recorded as saltmarsh in extent terms if they are subject to saltmarsh processes, but not if they are isolated from these, e.g. by elevation.

The issue of parallel but different approaches to reporting saltmarsh in respect of European Directives is probably inevitable, but the confusion that has resulted is entirely avoidable, simply by specifying which definition and Directive has been used, and noting the existence of the other. As long as the definition is specified and consistency is maintained, there need be no confusion. Much of the confusion could be avoided simply by renaming the WFD habitat ‘estuarine marsh’, which is arguably more accurate and appropriate in any case, given that the estuary is the water body involved. UK Annex I definitions of saltmarsh are currently under review, and expanding these slightly as described here would enable academic research on saltmarsh to align with the Habitats Directive, with both of these in turn contributing to a wider WFD category of estuarine marsh.

The approach advocated here has the advantage of being simple and is largely compliant with the Habitats Directive, at least as currently applied in the UK. It can also be applied retrospectively to any saltmarsh vegetation geospatial dataset. Although arguments for definition expansion to assist conservation exist, these confuse habitat definition with habitat conservation. Annex I of the Habitats Directive compartmentalises the environment, but the wider Directive addresses functionality and context via the concept of Favourable Conservation Status (FCS). Expanding definitions beyond conventional limits in the name of conservation is unnecessary if FCS is employed. Ultimately saltmarsh is a component of the functional estuary, not a synonym for it.

Although the UK Habitats Directive approach is arguably more accurate than the Water Framework Directive approach, in that the former includes only halophytic vegetation while the latter and Wadden Sea Habitats Directive add non-halophytic Swamp vegetation (i.e. tidal marsh rather than saltmarsh), the WFD saltmarsh tool was designed to align with the classification and functionality of water bodies rather than the habitat *per se* (M Best, pers. comm.) and it is unrealistic to expect the WFD adherents to amend their definition. Although confusion can be easily avoided by specifying the terms of 'saltmarsh' in the introduction to all reports and publications where terms are open to more than one interpretation, it might be easier (as well as more accurate) to describe the habitat monitored for WFD as "estuarine marsh" rather than "saltmarsh". Ecologists who are not bound by either of the Directives have the freedom to employ a more realistic definition of the saltmarsh habitat … as long as they state clearly what that comprises.

7.6. Saltmarsh definition

Saltmarsh is defined here as *intertidal vegetation dominated by halophytic vascular plants (other than seagrasses). It tends to establish on fine substrates in sheltered situations but is not restricted to these. The surface is often interrupted by creeks (channels) and pans (pools) that are important to structure and function. Transitions to adjacent habitats tend to be gradual, complex, and dynamic. Saltmarsh is usually one component of a meta-ecosystem and operates at the structural and functional level of a wider estuary or inlet.* The issue of the functional context can also be addressed via habitat nomenclature. There is a precedent for this with machair: the Annex I machair habitat is referred to as "machair grassland" while its wider, functional context is referred to as the "machair system" (Curtis, 1991; Angus, 1994). A similar approach is advocated here, separating the halophytic "core saltmarsh" from the wider "saltmarsh ecosystem" thus.

7.7. Core saltmarsh

- 1310 SM7, SM8, SM9. SM27 (some), S21
- 1320 SM4, SM5, SM6
- 1330 SM10-SM20, SM22-24, SM26, S21
- 1420 SM25, SM21

7.8. Saltmarsh ecosystem

- Core saltmarsh SM4-SM26, some SM27, S21
- Sediment flats plus seagrasses SM1-SM2
- Nearshore morphology and/or vegetation
- Tidal marsh – SM3, upstream S (swamp, except S21), M (marsh) and inundation grasslands (e.g. MG11)
- Transition marsh SM28, some SM27, and landward S, M and MG (except S21)
- Dune and/or shingle ridges sheltering core saltmarsh
- Hydrological context
- Land use including coastal defences

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SA is employed part-time as Coastal Ecology Manager in NatureScot, which reports to the Habitats Directive (as amended). The paper has been written in an independent capacity, with minor facilitation by but no influence from NatureScot. Views within the paper are not necessarily the views of NatureScot.

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References

Adam, P., 1981. The vegetation of British saltmarshes. New Phytol. 88, 143–196.
Adam, P., 1990. Saltmarsh Ecology. Cambridge University Press, Cambridge.
Allen, J.R.L., 2000. Morphodynamics of holocene salt marshes: a review sketch from the atlantic and southern north sea coasts of Europe. Quat. Sci. Rev. 19, 1155–1231.
Angus, S., 1994. The conservation importance of the machair systems of the Scottish islands, with particular reference to the Outer Hebrides. In: Usher, M.B., Baxter, J. (Eds.), The Islands of Scotland: a Living Marine Heritage. HMSO, Edinburgh, pp. 95–120.
Angus, S., 2001. The Outer Hebrides: Moor and Machair. White Horse Press (Harris and Cambridge).
Angus, S., 2016. Monitoring and surveillance of a highly variable habitat: the challenge posed by Scottish saline lagoons. Regional Studies in Marine Science 8, 20–26.
Anonymous, 1959. Final resolution: the Venice System for the classification of marine waters according to salinity. Arch. Oceanogr. Limnol. 2 (Suppl. ment), 243–248, 2 (suppl).
Bartholdy, J., 2012. Salt marsh sedimentation. In: Davis, R.A., Dalrymple, R.W. (Eds.), Principles of Tidal Sedimentology. Springer, Dordrecht, pp. 151–186.
Beeftink, W.G., 1977. Salt-marshes. In: Barnes, R.S.K. (Ed.), 1977. The Coastline. Wiley, London, pp. 93–121.
Bird, E., 2003. Saltmarshes. In: May, V.J., Hansom, J.D. (Eds.), Coastal Geomorphology of Great Britain. Geological Conservation Review, vol. 28. NCC Peterborough, pp. 517–642, 2003.
Borruso, L., Bacci, G., Mengoni, A., De Philippis, R., Brusetti, L., 2014. Rhizosphere effect and salinity competing to shape microbial communities in *Phragmites australis* (Cav.) Trin. ex-Steud. FEMS (Fed. Eur. Microbiol. Soc.) Microbiol. Lett. 359, 193–200.
BRIG, 2011. UK biodiversity action plan: priority habitat descriptions. JNCC, Peterborough. https://hub.jncc.gov.uk/assets/2728792c-c8c6-4b8c-9ccd-a908cb0f1432.
Burd, F., 1989. The Saltmarsh Survey of Great Britain - an Inventory of British Saltmarshes. *Research And Survey In Nature Conservation* No. 17. Nature Conservancy Council, Peterborough.
Chapman, V.J., 1960. Salt Marshes and Salt Deserts of the World. Leonard Hill, London.
Chatters, C., 2017. Saltmarsh. Bloomsbury, London.
Cooper, J.A.G., Power, J., 2003. Perched salt marshes on a high energy coast: implications for sea level reconstructions. J. Coast Res. 19, 357–363.
Curtis, T.G.F., 1991. A site inventory of the sandy coasts of Ireland: their types and distribution. In: Quigley, M.B. (Ed.), 1991. A Guide to the Sand Dunes of Ireland. Compiled for the 3rd Congress of the European Union for Dune Conservation and Coastal Management. Galway, pp. 6–17.
Dargie, T.C.D., 1998. Sand dune vegetation survey of Scotland: western isles. Scottish Natural Heritage Research, Survey and Monitoring. Report No. 96.

Dargie, T., 2001. NVC Survey of the Saltmarsh and Other Habitats in the Dee & Clwyd Estuaries 2000. CCW Science Report No. 450. Countryside Council for Wales, Bangor.

Dargie, T., 2017. Morrich more coastal change analysis 1987 to 2015. Scottish Natural Heritage Commissioned Report No. 927. Battleby, Scottish Natural Heritage.

Davidson, N.C., 2018. European tidal saltmarshes. In: Finlayson, M., Everard, M., Irvine, K., McInnes, R.J., Middleton, B.A., van Dam, A.A., Davidson, N.C. (Eds.), The Wetland Book. Springer, pp. 959–972.

Davies, C.E., Moss, D., Hill, M.O., 2004. EUNIS Habitat Classification Revised 2004. European Topic Centre on Nature Protection and Biodiversity (Paris).

Dijkema, K.S. (Ed.), 1984. Salt Marshes in Europe. Strasbourg, France: Council of Europe, European Committee for the Conservation of Nature and Natural Resources, vol. 178p.

Environment Agency, 2022. The extent and zonation of saltmarsh in England: 2016-2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1097875/The_extent_and_zonation_of_saltmarsh_in_England_2016-2019_-_report.pdf.

Esselink, P., van Duin, W.E., Bunje, J., Cremer, J., Folmer, E.O., Frikke, J., Glahn, M., de Groot, A.V., Hecker, N., Hellwig, U., Jensen, K., Körber, P., Petersen, J., Stock, M., 2017. Salt marshes. In: Kloepper, S., et al. (Eds.), Wadden Sea Quality Status Report, Common Wadden Sea Secretariat. Wilhelmshaven, Germany. Last updated 21.12.2017. https://qsr.waddensea-worldheritage.org/reports/salt-marshes.

European Commission, 2013. Natura 2000 interpretation manual of European Union habitats. EUR28. European Commission, DG Environment. https://circabc.europa.eu/ui/group/3f466d71-92a7-49eb-9c63-6cb0fadf29dc/library/37d9e6d9-b7de-42ce-b789-622e9741b68f/details.

European Environment Agency, 1994. CORINE land cover. https://www.eea.europa.eu/publications/COR0-part1.

Hambidge, C., Phelan, N., 2014. Saltmarsh mapping standardisation for the water Framework directive. NMBAQC Scheme. https://www.nmbaqcs.org/media/5fjpq2qj/saltmarsh-mapping-standard_140814_final-1.pdf.

Haynes, T., 2016. Scottish saltmarsh survey - national report. Report to SNH and SEPA. *Scottish natural heritage commissioned report No. 786*. Scottish natural heritage, battleby. https://www.nature.scot/doc/naturescot-commissioned-report-786-scottish-saltmarsh-survey-national-report.

Hill, M.O., Mountford, J.O., Roy, D.B., Bunce, R.G.H., 1999. Ellenberg's indicator values for British plants. ECOFACT Volume 2. Technical Annex. Institute of Terrestrial Ecology. https://nora.nerc.ac.uk/id/eprint/6411/.

Hill, M.O., Preston, C.D., Roy, D., 2004. PLANTATT - attributes of British and Irish plants: status, size, life history, geography and habitats. Centre for Ecology & Hydrology, Abbotts Ripton. PLANTATT - Attributes of British and Irish Plants - Spreadsheet | Biological Records Centre (brc.ac.uk).

Hudson, R., Kenworthy, J., Best, M. (Eds.), 2021. *Saltmarsh Restoration Handbook:* UK and Ireland. Environment Agency, Bristol, UK.

Jarvis, S.G., Rowe, E.C., Henrys, P.A., Smart, S.M., Jones, L., Garbutt, A., 2016. Empirical realised niche models for British coastal plant species. J. Coast Conserv. 20, 107–116.

Joint Nature Conservation Committee, 2004. Common Standards Monitoring guidance for saltmarsh habitats. Version August 2004. https://hub.jncc.gov.uk/assets/7607ac0b-f3d9-4660-9dda-0e538334ed86.

Joint Nature Conservation Committee, 2010. Handbook for Phase 1 habitat survey – a technique for environmental audit. JNCC, Peterborough. https://data.jncc.gov.uk/data/9578d07b-e018-4c66-9c1b-47110f14df2a/Handbook-Phase1-HabitatSurvey-Revised-2016.pdf.

Joint Nature Conservation Committee, 2019. Fourth report by the United Kingdom under Article 17 on the implementation of the Directive from January 2013 to December 2018. Conservation status for the habitats H1310, H1320, H1330, H1420. https://jncc.gov.uk/our-work/article-17-habitats-directive-report-2019-habitats/#marine-coastal-and-halophytic-habitats.

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J.-P., Raus, T., Čarni, A., Šumberová, K., Willner, W., Dengler, J., García, G.R., Chytrý, M., Hájek, M., Pietro, R.D., Iakushenko, D., Pallas, J., Daniëls, F.J.A., Bergmeier, E., Guerra, A.S., Ermakov, N., Valachovič, M., Schaminée, J.H.J., Lysenko, T., Didukh, Y.P., Pignatti, S., Rodwell, J.S., Capelo, J., Weber, H.E., Solomeshch, A., Dimopoulos, P., Aguiar, C., Hennekens, S.M., Tichý, L., 2016. Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Appl. Veg. Sci. 19 (Suppl. 1), 3–264.

Natural England and RSPB, 2019. Climate Change Adaptation Manual - Evidence to Support Nature Conservation in a Changing Climate, second ed. Natural England, York, UK http://publications.naturalengland.org.uk/publication/5679197848862720.

Newton, A., Icely, J., Cristina, S., Brito, A., Cardoso, A.C., Colijn, F., Riva, S.D., Gertz, F., Hansen, J.W., Holmer, M., Ivanova, K., Leppäkoski, E., Canu, D.M., Mocenni, C., Mudge, S., Murray, N., Pejrup, M., Razinkovas, A., Reizopoulou, S., Pérez-Ruzafa, A., Schernewski, G., Schubert, H., Carr, L., Solidoro, C., Viaroli, P., Zaldívar, J.-M., 2014. An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters. Estuar. Coast Shelf Sci. 140, 95–122.

ONS, 2016. Scoping UK coastal margin ecosystem accounts. https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/scopingukcoastalmarginecosystemaccounts#s,coping-the-extent-account.

Oxford English dictionary. https://www-oed-com.nls.idm.oclc.org/view/Entry/170205, 2023.

Packer, J.G., Meyerson, L.A., Skálová, H., Pyšek, P., Kueffer, C., 2017. Biological flora of the British isles. Phragmites australis. Journal of Ecology 105, 1123–1162.

Petersen, J., Kers, B., Stock, M., 2014. TMAP-typology of coastal vegetation in the Wadden Sea area. Version 1.0.4. Wadden Sea Secretariat, Wilhelmshaven. https://www.waddensea-worldheritage.org/sites/default/files/2014_Ecosystem32_salt%20marsh%20typology.pdf.

Pethick, J.S., 1992. Saltmarsh geomorphology. In: Allen, J.R.L., Pye, K. (Eds.), Saltmarshes: Morphodynamics, Conservation and Engineering Significance. Cambridge University Press, Cambridge, pp. 41–62.

Phelan, N., Shaw, A., Baylis, A., 2011. The Extent of Saltmarsh in England and Wales: 2006–2009. Environment Agency, Bristol. https://assets.publishing.service.gov.uk/media/5a7c8d1ce5274a7b7e32132c/LIT_5799_a4e627.pdf.

Pontee, N., Pye, K., Tempest, J., Blott, S., 2021. What Is Coastal Squeeze? Project No. FRS17187. Environment Agency, London. https://assets.publishing.service.gov.uk/media/6038fafde90e07055c14049b/FRS17187_What_is_coastal_squeeze_-_report_1_.pdf.

Rees, S., Garbutt, A., Houston, J., 2010. Transitional habitats and coastal species in England: their conservation value and management. In: Dewulf, E., Van Nieuwenhuyse, H., Herrier, J.L. (Eds.), International Workshop on the Management of Dune Polder and Dune Marshland Transition Zones: Proceedings. Knokke-Heist (Belgium) 7 October 2010, pp. 125–156. Agentschap voor Natuur en Bos: Brussel. https://core.ac.uk/download/pdf/132492454.pdf.

Rodwell, J.S. (Ed.), 1995. British Plant Communities. Aquatic Communities, Swamps and Tall-Herb Fens, vol. 4. Cambridge University Press, Cambridge.

Rodwell, J.S. (Ed.), 2000. British Plant Communities. Maritime Communities and Vegetation of Open Habitats, ume 5. Cambridge University Press, Cambridge.

Rodwell, J.S., 2006. NVC Users' Handbook, JNCC. Peterborough. https://hub.jncc.gov.uk/assets/a407ebfc-2859-49cf-9710-1bde9c8e28c7.

Rodwell, J.S., Schamineé, J.H.J., Mucina, L., Pignatti, S., Dring, J., Moss, D., 2002. The Diversity of European Vegetation. An Overview of Phytosociological Alliances and Their Relationships to EUNIS Habitats. National Reference Centre for Agriculture, Nature and Fisheries (Wageningen).

Scottish Government, 2019. The conservation (natural habitats, &c.) (EU exit) (Scotland) (amendment) regulations 2019. https://www.legislation.gov.uk/ssi/2019/113/contents/made.

Silinski, A., van Belzen, J., Fransen, E., Bouma, T.J., Troch, P., Meire, P., Temmerman, S., 2016. Quantifying critical conditions for seaward expansion of tidal marshes: a transplantation experiment. Estuar. Coast Shelf Sci. 169, 227–237.

Smart, S.M., Scott, W.A., 2004. Bias in Ellenberg indicator values: problems with detection of the effect of vegetation type. J. Veg. Sci. 15, 843–846.

Somerset Environmental Records Centre, 2007. IHS definitions version 2-001. https://www.somerc.com/wp-content/uploads/2019/01/IHS-Definitions.pdf.

Stace, C.A., 2019. New Flora of the British Isles. Fourth Edition. C&M Floristics.

Strachan, I.M., 2017. Manual of terrestrial EUNIS habitats in Scotland. Scottish Natural Heritage Commissioned Report No. 766, Version 2. https://www.nature.scot/landscapes-and-habitats/habitat-map-scotland.

Tansley, A.G., 1953. The British Islands and Their Vegetation, vol. 2. Cambridge University Press, Cambridge.

Tichý, L., Axmanová, I., Dengler, J., Guarino, R., Jansen, F., Midolo, G., Nobis, M.P., Van Meerbeek, K., Aćić, S., Attorre, F., Bergmeier, E., Biurrun, I., Bonari, G., Bruelheide, H., Campos, J.A., Čarni, A., Chiarucci, A., Ćuk, M., Ćušterevska, R., Didukh, Y., Dítě, D., Dítě, Z., Dziuba, T., Fanelli, G., Fernández-Pascual, E., Garbolino, E., Gavilán, R.G., Gégout, J.-C., Graf, U., Güler, B., Hájek, M., Hennekens, S.M., Jandt, U., Jašková, A., Jiménez-Alfaro, B., Julve, P., Kambach, S., Karger, D.N., Karrer, G., Kavgacı, A., Knollová, I., Kuzemko, A., Küzmič, F., Landucci, F., Lengyel, A., Lenoir, J., Marcenò, C., Moeslund, J.E., Novák, P., Pérez-Haase, A., Peterka, T., Pielech, R., Pignatti, A., Rašomavičius, V., Rūsiņa, S., Saatkamp, A., Šilc, U., Škvorc, Ž., Theurillat, J.-P., Wohlgemuth, T., Chytrý, M., 2023. J. Veg. Sci.

UK Government, 2019. The conservation of habitats and species (amendment) (EU exit) regulations 2019. https://www.legislation.gov.uk/uksi/2019/579/contents/made.

UK Habitat Classification Working Group, 2018. The *UK habitat classification*. http://ecountability.co.uk/ukhabworkinggroup-ukhab.

UKHab Ltd, 2023. UK habitat classification version 2.0. https://www.ukhab.org.

van Regteren, M., Amptmeijer, D., de Groot, A.V., Baptist, M.J., Elschot, K., 2020. Where does the salt marsh start? Field-based evidence for the lack of a transitional area between a gradually sloping intertidal flat and salt marsh. Estuar. Coast Shelf Sci. 243, 106909.

Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG), 2014. UKTAG transitional and coastal water assessment method. Angiosperms. Saltmarsh Tool. WFD UK TAG. Stirling. http://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/TraC%20Saltmarsh%20Tool%20UKTAG%20Method%20Statement.PDF.