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**Are agri-environment schemes successful in delivering conservation grazing management on saltmarsh?**

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Short title: Saltmarsh conservation grazing and agri-environment schemes

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## Abstract

1. Grasslands occur around the globe and, in temperate regions, their natural management by fire, drought and wild herbivores has largely been replaced by grazing with domestic livestock. Successful management for agriculture is not always suitable for conservation and can have a detrimental effect on biodiversity. Conservation grazing of saltmarshes, delivered through agri-environment schemes, may provide a solution to counteract biodiversity loss by providing farmers with financial incentives to graze these internationally important coastal wetlands more sensitively.
2. To assess whether conservation grazing is being achieved, and whether agri-environment schemes are effective in delivering this management, we conducted a national survey on English saltmarshes, scoring the management on each site as optimal, suboptimal or detrimental in terms of suitability for achieving conservation aims for five aspects of grazing: presence, stock type, intensity, timing and habitat impact.
3. Although most saltmarshes suitable for grazing in England were grazed, conservation grazing was not being achieved. Sites under agri-environment management for longer did score higher and approached optimal levels in terms of grazing intensity in one region, but sites with agri-environment agreements were no more likely to be grazed at optimal conservation levels than sites without them overall, indicating that agri-environment schemes, in their current form, are an ineffective delivery mechanism for conservation grazing on saltmarsh.
4. The low specificity of agri-environment prescription wording may contribute to this failure, with prescriptions either being vague or specifying suboptimal or detrimental management objectives, particularly for grazing intensity, timing and stock type. These objectives are often set too high or too low, during unsuitable periods, or using stock types inappropriate for achieving conservation aims.

5. *Synthesis and applications.* Our national survey indicates that agri-environment schemes are not currently delivering conservation grazing on English saltmarshes. Agri-environment schemes are the only mechanism through which such grazing can be implemented on a national scale, so improving their effectiveness is a priority. Policymakers, researchers and managers need to work together to ensure better translation of conservation guidelines into schemes, increasing the specificity of management prescriptions and improving understanding of the need for management measures. A more detailed and reliable system of auditing to ensure that management activities are taking place would be beneficial, or alternatively moving to a results-based scheme where payments are made on desirable outcomes rather than on evidence of management.

**Keywords:** countryside stewardship, higher level stewardship, livestock, site condition, agri-environment schemes, saltmarsh, wetlands, grazing

## Introduction

Maintaining and enhancing biodiversity through conservation action requires appropriate habitat management to ensure suitable conditions for the species or community of interest. Such management can encourage a return to a near-natural habitat state, encouraging restoration of ecosystem functioning and stability (Ausden 2007). Livestock grazing is an important tool used widely for conservation management across a wide range of grassland habitats, with livestock replacing the role of natural grazers where these have been lost (Ausden 2007). Grazing, both for conservation management and for food production, is a major driver of vegetation structure and therefore resource availability in natural systems

globally (Watkinson & Ormerod 2001) and can help to counteract the negative impacts of climate change (Clausen, Stjernholm & Clausen 2013).

The restricted nature of livestock grazing for conservation management (such as lower stocking rates or timing restrictions) reduces its profitability relative to high-intensity farming, so uptake incentives are often provided to land managers in the form of payments for management through Agri-Environment Schemes (AES; Batáry *et al.* 2015). These are a key mechanism by which conservation grazing can be delivered at national levels. Targeted AES have been successful in delivering conservation management to benefit many wetland systems (e.g. Schekkerman, Teunissen & Oosterveld 2008; Smart *et al.* 2014), but inadequate monitoring has made the overall assessment of AES effectiveness difficult (Kleijn & Sutherland 2003)

Saltmarshes, that cover ~5.5 million hectares of land surface globally (McOwen *et al.* 2017), are an example of a system traditionally managed by livestock grazing (cattle, sheep, horses; Dijkema 1990; Jones *et al.* 2011) for food production, and where AES are commonly used to encourage conservation management. Saltmarshes are highly productive ecosystems supporting rich communities of halophytic plants, invertebrates and birds through their provision of important resources and habitat conditions for bird breeding, wintering and migratory staging, as well as important fish nursery grounds, human recreational opportunities and ecosystem services in the form of tidal defence, water quality regulation and carbon storage (e.g. Boorman 2003; Barbier *et al.* 2011).

Over 50% of saltmarshes have been lost or degraded globally (UNEP 2006; Gedan, Silliman & Bertness 2009), with the rate of degradation now exacerbated by climate change and

associated sea level rise (Doody 2004; Hughes 2004; FitzGerald *et al.* 2008). In western Europe the biodiversity value of saltmarshes is declining despite protection under the EU Habitats and Water Framework Directives (Doody 2008; Garbutt *et al.* 2017; McOwen *et al.* 2017), with over 50% of the European coastal protected sites network now in 'unfavourable inadequate' or bad condition (European Environment Agency 2009). Agricultural intensification is a key factor in these biodiversity declines, with increases in grazing intensity or abandonment in recent decades resulting in declines in saltmarsh-breeding birds and plant and invertebrate community changes (Norris *et al.* 1998; Chatters 2004; Davidson *et al.* 2017).

Five aspects of grazing (termed 'conservation grazing') are particularly important for the conservation management of saltmarshes in western Europe: 1) whether sites should be grazed or not, 2) stock type, 3) grazing intensity, 4) timing of grazing and 5) the resulting habitat structure. Although recommendations for these five aspects vary between species or communities of interest (e.g. Davidson *et al.* 2017), the consensus from published and accessible grey literature (see Table S1 in Supporting Information) is that 'historically-grazed' sites should continue to be grazed using cattle (Adnitt *et al.* 2007), in a mosaic or rotation of 'low' to 'moderate' grazing intensity (Doody 2007; Mandema *et al.* 2015; van Klink *et al.* 2016; Lagendijk *et al.* 2017) from April–October if targeting plant communities, or from June–October if targeting breeding birds (winter grazing November–March prevents optimal sward regrowth and causes soil compaction, poaching and erosion, while grazing in spring causes considerable bird nest losses to trampling; e.g. Adnitt *et al.* 2007; Doody 2008; Sharps *et al.* 2017). The resulting habitat should then present a mosaic of sward heights where the majority of standing crop is still present to support breeding birds and habitat diversity (JNCC 2004; Malpas *et al.* 2013).

Despite these freely available conservation grazing recommendations (Adnitt *et al.* 2007; Doody 2008), many saltmarshes in western Europe are still grazed at suboptimal levels (Malpas *et al.* 2013). In England, 'input-based' AES systems (where payments are made based on the agreed management being undertaken; Hanley *et al.* 2012), have existed since 1991 and include saltmarsh management or grazing options where implementation relies on a list of management prescriptions. These schemes, and similar management on nature reserves, had little effect on grazing pressure on English saltmarsh and did not influence the associated decline in saltmarsh-breeding birds between 1996 and 2011, indicating they may not be delivering necessary habitat management or conservation outcomes (Malpas *et al.* 2013). There was therefore an urgent need to assess whether or not conservation grazing was being achieved on saltmarshes on a national scale, whether AES were effective in influencing this management and how they could be improved.

## Materials and methods

### *Study sites*

We surveyed 213 saltmarsh sites in three English regions in 2013 representing 50% (16,824 ha) of the vegetated saltmarsh in England (33,572 ha; Phelan, Shaw & Baylis 2011; Fig. 1).

The regions (East, Northwest, South) represent major divisions between saltmarsh types and grazing practices (Burd 1989) and were managed by different statutory agency (Natural England) regional teams. Of our 213 study sites, 114 (54%) received payments for saltmarsh management and/or conservation grazing options through AES under Higher Level Stewardship (HLS, in the Environmental Stewardship Scheme; Natural England 2013) or the Countryside Stewardship Scheme (CSS; DEFRA 2004; Fig. 1, Table 1, Table S2). These

AES sites encompassed 94% (10,573 ha) of the vegetated saltmarsh under AES management in the three regions.

Outlines of UK Rural Land Registry land-holding parcels with saltmarsh management options for each AES agreement were used as site boundaries for AES sites. Most agreements (n = 99, 87%) included one or more contiguous parcel(s) of saltmarsh habitat, all of which we defined as one site. For the few agreements (n = 7) that incorporated multiple non-contiguous parcels of saltmarsh, each parcel was considered a separate site because grazing management and management prescriptions may differ between geographically separate parcels, even within the same agreement (max no. separate parcels per agreement = 3; total no. AES agreements = 106). Non-AES site boundaries were hand-digitised with reference to Ordnance Survey 1:25,000 maps, online aerial imagery and seaward boundaries of predicted saltmarsh extent (Environment Agency 2015) in GIS (MapInfo Professional v.6 2000). The area (ha) of each site was calculated using ArcGIS (version 10.3.1 2014).

Some sites comprised multiple grazing management blocks (hereafter 'grazing areas') separated by fencing or natural barriers to livestock movement, or formed part of larger grazing areas extending beyond site boundaries with livestock free to graze across the whole area (sometimes encompassing both saltmarsh and adjacent non-saltmarsh habitat).

We therefore collected survey data at the grazing area scale to allow more-accurate assessment of conservation grazing per hectare of available grazing land associated with each site.

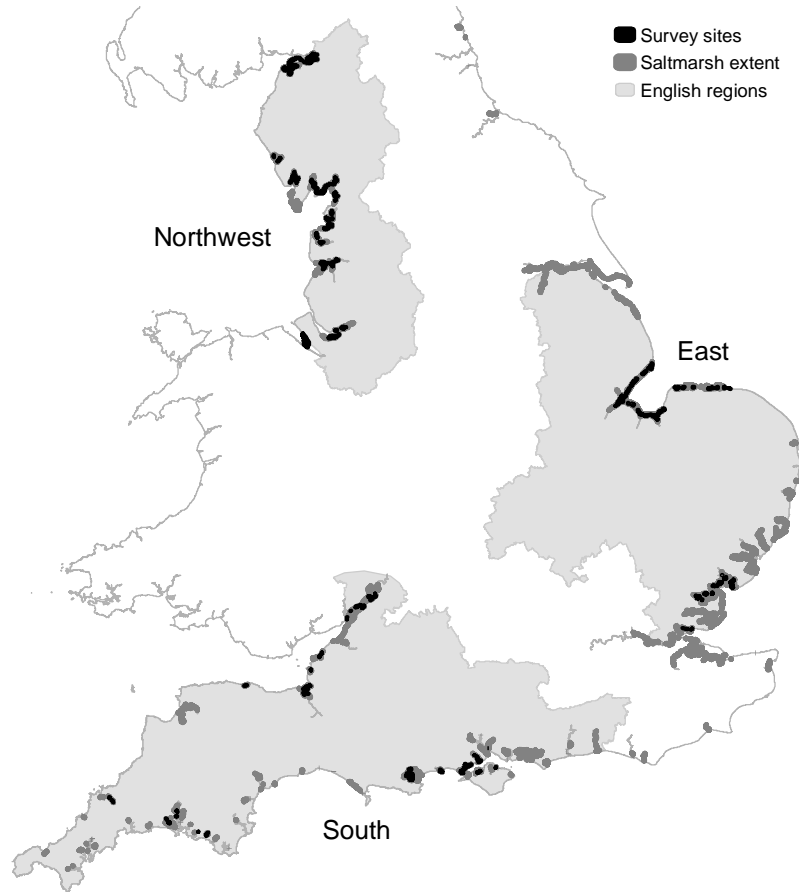


Figure 1. Locations of the 213 saltmarsh survey sites in relation to the distribution of saltmarsh within three English regions. For site types and spatial-pairings see Fig. S1.



Table 1. Agri-environment scheme (AES) management options and supplements relating to saltmarsh management and/or conservation grazing present on AES sites, the number of sites with each option and annual payments per ha. CSS: Countryside Stewardship Scheme, HLS: Higher Level Stewardship.

AES	Management option		Payment	# Sites
	Code	Option		
CSS	IT1	Managing intertidal habitats	£20	8
HLS	HP5	Maintenance of coastal saltmarsh	£30	82
	HP6	Restoration of coastal saltmarsh	£30	14
	HP8	Creation of inter-tidal and saline habitat on grassland	up to £500	2
	HP10	Supplement for extensive grazing on saltmarsh	£70	36
	HP11	Saltmarsh livestock exclusion supplement	£40	4
	HR1	Grazing supplement for cattle	up to £35	16

Is conservation grazing being achieved on English saltmarshes?

#### *Grazing surveys*

We visited each site up to four times during the core grazing period (April–October; mean no. survey visits to each site = 3.9, grazed sites = 122, 4 visits = 113, 3 visits = 6, 2 visits = 2, 1 visit = 1), with at least four weeks between visits, and recorded the number, type, age-class and distribution of livestock in each grazing area on each visit. We assumed that the absence of grazing animals in any survey visit meant the area was not being grazed at that time. There is a small chance that livestock could be temporarily removed during spring high tides but in most sites, livestock had access to alternative areas not affected by tides (e.g. sea walls or inland fields) so would still be present and observable within the grazing area.

Grazing intensities were expressed as Livestock Units (LUs) per hectare to allow direct comparison between stock types and sites. LUs were calculated from the number of adult livestock for each grazing area visit based on standard conversion coefficients (DEFRA 2010), where 1 LU is equivalent to 1 dairy cow, 9 lowland ewes and 0.8 horses respectively (Table S3). LUs/ha were calculated by summing the LUs recorded across all grazing areas per site visit, and dividing this total by the site area (ha).

We also assessed the longer-term impact of grazing on saltmarsh habitat in relation to the vegetation communities present (grazing alters the presence and diversity of saltmarsh plant communities, Hill 1988), and the sward height and heterogeneity by assigning each site or grazing area within sites a 'grazing index' value (Norris *et al.* 1998; Malpas *et al.* 2013). Here 0 = matted vegetation, no standing crop removed, low sward heterogeneity; 1 = majority of standing crop not removed, high sward heterogeneity; 2 = majority of standing crop removed, moderate sward heterogeneity; 3 = all standing crop removed, sward height < 10cm, low sward heterogeneity (JNCC 2004). Although crude, this index gives a reasonable reflection of the habitat structure and grazing pressure (Norris *et al.* 1997).

#### *Scoring 'conservation grazing'*

For each visit to each grazing area, we used survey data to derive scores for five aspects of saltmarsh conservation grazing according to whether they represented optimal, suboptimal or detrimental saltmarsh management practices in relation to their suitability for achieving conservation aims (Table 2). These conservation grazing scores, derived at the grazing area scale for each visit, were summarised at the site-level using methods in Table 2 to allow analysis at the site-visit level (each row in the resulting score dataset corresponding to an individual site-visit).

Table 2. Optimal, suboptimal and detrimental levels of five aspects of conservation grazing and the methods used to summarise across grazing areas to generate site-visit conservation grazing scores for each aspect, along with rationalisation and evidence sources.

Aspect	Scoring method	Conservation grazing level and scoring criteria		
		Optimal (score = 1)	Suboptimal (score = 1)	Detrimental (score = 0)
(1) Presence/Absence	Sites suitable for grazing = directly accessible from land, with infrastructure to contain livestock and drinking water. Grazed = grazing recorded in at least one grazing area per site-visit. Binomial visit-level score (0, 1)	Site SUITABLE and GRAZED or Site UNSUITABLE and UNGRAZED	Site SUITABLE and UNGRAZED or Site UNSUITABLE and GRAZED	Site SUITABLE and UNGRAZED or Site UNSUITABLE and GRAZED
<i>Rationalisation/Source: Historically-grazed sites should continue to be grazed at conservation levels (abandonment being detrimental to saltmarsh biodiversity) while historically-ungrazed sites should remain ungrazed (Adnitt et al. 2007). The true grazing history of a site in the UK is difficult to determine however, particularly if sites were abandoned outside of living or documented memory. For the purposes of this study we considered that sites classed as suitable for grazing during surveys (i.e. accessible to livestock and agricultural workers from the sea wall and surrounded by agricultural land) will most likely have been utilised for grazing historically (Chatters 2004).</i>				
(2) Stock type	Stock type categorised per grazing area per visit as: Cattle, Sheep, Horses, Mixed with Cattle, Mixed without Cattle, or None (Table S3). Score based on the combination of stock type categories present across all grazing areas per site-visit. Numeric visit-level score (0-2).	CATTLE GRAZING ONLY Stock type = Cattle in at least one grazing area; no other stock types recorded	SOME CATTLE GRAZING WITH OTHER STOCK TYPES PRESENT Stock type = Cattle or Mixed with Cattle in at least one grazing area, in the presence or absence of other stock types.	NO CATTLE GRAZING or NO STOCK PRESENT Stock type = Sheep, Horse, Mixed without Cattle or None in all grazing areas
<i>Rationalisation/Source: Cattle produce more structurally diverse vegetation than sheep or horses (e.g. Adnitt et al. 2007).</i>				
(3) Grazing intensity	LUs calculated for each grazing area then summed across grazing areas for each site visit. Score based on value of site-visit LUs/ha (summed site-visit LUs divided by site area). Numeric visit-level score (0-2).	LOW $0 < \text{LUs/ha} \leq 0.3$	LOW-MODERATE $0.3 < \text{LUs/ha} \leq 0.7$	HIGH or NONE $\text{LUs/ha} > 0.7$ or $\text{LUs/ha} = 0$
<i>Rationalisation/Source: Criteria based on mean maximum LUs/ha values classed as low, low-moderate or high by 26 sources where this information was quantified and accompanied by an assessment of suitability for conservation grazing (Table S1).</i>				
(4) Timing of grazing	Grazing areas scored for optimal grazing timing for breeding birds and/or vegetation based on the first and last visit grazing was recorded. The minimum score from any grazing area per site then extended across all visit to provide a site-visit level score (accounting for the most detrimental grazing period from any part of a site). Numeric visit-level score (0-2).	BIRDS = Optimal VEG = Optimal	BIRDS = Optimal, VEG = Suboptimal or BIRDS = Suboptimal, VEG = Optimal	BIRDS = Suboptimal VEG = Suboptimal
<i>Rationalisation/Source: BREEDING BIRDS: Optimal = grazing starts after the peak nesting period (end of May, i.e. after visit 1), Suboptimal = grazing starts visit 1 (April – May). Grazing in the peak nesting period causes considerable bird nest losses to trampling (Sharps et al. 2017). VEGETATION: Optimal = grazing April-October (grazing starts visit 1 or later, ends before visit 4), Suboptimal = grazing continues after October (grazing still recorded visit 4). Winter grazing after October prevents optimal sward regrowth and is likely to cause soil compaction, poaching and erosion (e.g. Adnitt et al. 2007; Doody 2008).</i>				
(5) Habitat impact	Gazing index value assessed for each grazing area per visit. Score based on maximum grazing pressure index from any grazing area per site-visit (accounting for the most detrimental grazing impact from any part of a	Grazing index = 1	Grazing index = 0 or Grazing index = 2	Grazing index = 3

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site). Numeric visit-level score (0-2).

*Rationalisation/Source: Grazing index indicates grazing impact on habitat where essentially 0 = no grazing, matted vegetation, no standing crop removed; 1 = light grazing, majority of standing crop not removed; 2 = moderate grazing, majority of standing crop removed; 3 = heavy grazing, all standing crop removed, sward height < 10cm (JNCC 2004). Breeding bird densities and habitat diversity highest where index = 1, intermediate where index = 0 or 2, lowest where index = 3 (Malpas et al. 2013).*

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### *Are sites achieving conservation grazing?*

To assess the extent to which the five aspects of conservation grazing are being achieved nationally, and whether this differs between regions with different traditional grazing practices, we ran a modelling analysis where the categorical effect of region was the only predictor. We ran generalised linear mixed models (GLMMs) in R (R Core Team 2017) with site-visit scores for each aspect of conservation grazing as separate response variables. We included the random effect of site in all models to control for repeated site-visits. Model structures and error distributions were as specified in Table 5. For aspect 1 we included all sites in analysis; the score for this aspect was on a binomial scale (Table 2), results indicating the probability that sites that were suitable for grazing had grazing present (i.e. optimal for grazing presence). The achievement of conservation grazing for aspects 2-5 was only relevant for grazed sites however (Table 2), so for these models we included grazed sites only (Table 5), and used a Conway-Maxwell Poisson error distribution to account for underdispersion (response variable mean > variance; Lynch, Thorson & Shelton 2014). To assess how well grazed sites are achieving overall, we also analysed the number of grazing aspects scored as optimal as an additional response variable (max score = 4). The level of support for regional differences was assessed by comparing regional models ( $M_{\text{region}}$ ) with national models ( $M_{\text{national}}$ ; Table 5) with Information-Theoretic methods based on AIC (Burnham & Anderson 2002).

Are AES a successful mechanism for delivering conservation grazing, and to what extent is AES agreement wording fit for purpose?

To compare conservation grazing management on sites experiencing similar environmental characteristics in the presence or absence of AES, we spatially-paired AES and non-AES sites. Paired sites were directly adjacent (where possible), or contiguous, in the same estuary or on the same immediate stretch of coastline if no adjacent sites existed (Fig. S1).

In some cases, multiple AES or non-AES sites were contiguous or on the same coastline stretch so these were included in one paired-group for analysis (Table S2). All paired-groups (n=76) contained at least one AES site and at least one non-AES site for direct comparison (total sites in paired-groups = 200; mean number of AES sites per group = 1.5, mean number of Non-AES sites = 1.1). One AES site and 12 non-AES sites could not be paired or grouped with others (no other sites in vicinity, or no AES sites on the whole coastline stretch respectively) so these were excluded from analysis.

#### *Assessing AES as a delivery mechanism*

To test whether scores for the five aspects of grazing (Table 2) differed between AES and Non-AES sites, and whether the type of AES, the inclusion of specific grazing supplements or the agreement age (Table 3) influenced this difference, we ran GLMMs with site-visit scores for each grazing aspect as separate response variables (model structures in Table 6). We also included the number of grazing aspects scored as optimal on grazed sites as an additional response variable to assess how well sites achieved optimal management overall. Models for each response variable contained each of four partially-nested AES effect variables (Table 3) with or without a regional interaction (plus constituent main effects) as

well as the null model. The effect of region was included to determine if the level of conservation grazing achieved by their AES sites relative to Non-AES sites varied among different statutory agency teams. For aspect 1, all sites within AES paired-groups were included (Table S2); for aspects 2-5 which are only relevant for grazed sites, we only included sites from paired-groups where at least one AES and one Non-AES site were grazed (i.e. comparing spatially-paired grazed AES and Non-AES sites; Table 6). To directly compare spatially-paired AES and non-AES sites within models, and to control for repeated site-visits, models incorporated the random effect of site nested within paired-group. Support for AES and regional effects was assessed using Information-Theoretic methods based on AIC.

Table 3. Agri-environment scheme (AES) effect variables used in the assessment of AES as a delivery mechanism for conservation grazing.

AES variable	Type: Levels (* reference category) or Range	Hypothesis
Site type	Categorical: Non-AES*, AES	AES sites expected to attain higher conservation grazing scores if AES are a successful delivery mechanism.
AES type	Categorical: Non-AES*, CSS, HLS	Different AES may differ in the specificity of conservation grazing prescribed and therefore the conservation grazing score attained. CSS = Countryside Stewardship; HLS = Higher Level Stewardship
Grazing options	Categorical: Non-AES*, AES-, AES+	AES with supplements paid specifically for conservation grazing management (HP10/HP11/HR1, Table 1) expected to attain a higher conservation grazing score. AES- = AES without HP10/HP11/HR1, AES+ = AES with HP10/HP11/HR1
Years in AES	Continuous: 0–10	Agreement age in 2013: older agreements have had more time to implement conservation grazing, or younger agreements may be based on more recent conservation grazing research recommendations, thereby affecting conservation grazing score. Years in AES = 0 ( <i>intercept</i> , average score for Non-AES sites), Years in AES = 1-10 ( <i>gradient</i> , score relative to agreement age for AES sites).

*Is AES agreement wording fit for purpose?*

We examined AES agreement documents for 104 of our 106 AES agreements (two not available) and extracted the wording for management prescriptions associated with saltmarsh management and grazing options (Table 1). Management prescriptions were scored in relation to whether they were specific or not combined with how optimal they were for conservation grazing (Table 4), following criteria in Table 2 and Table S4. Prescription scores were on the same scales and therefore directly comparable with conservation grazing scores defined above.

To assess whether prescription scores were reflected in the delivery of conservation grazing, we compared site-level conservation grazing scores (continuous response variable: mean score per site) with prescription scores for each of the five grazing aspects separately using linear mixed models (LMMs) containing the random effect of region. For grazing presence, prescription score was categorical (levels: 0,1), for all other aspects prescription score was continuous (range 0-2). Support for an effect of prescription score was assessed by comparing AIC between models with and without this variable (Table S5 for model structures and outcomes)

Table 4. Score definitions for the specificity and level of conservation grazing stipulated in agri-environment scheme management prescriptions for the five aspects of conservation grazing.

Aspect(s)	Prescription score and definition
(1) Grazing presence	0 = Not specific (aspect not specified in prescriptions) 1 = Specific & Optimal (aspect specified at optimal conservation levels) Binary score, range = 0-1
(2) Stock type	0 = Not specific (aspect not specified in prescriptions)
(3) Grazing intensity	1 = Specific & Suboptimal/Detrimental (aspect specified but not at optimal levels)
(4) Timing of grazing	2 = Specific & Optimal (aspect specified at optimal conservation levels)
(5) Habitat impact	Numeric score, range 0-2

## Results

Is conservation grazing being achieved on English saltmarshes?

At a national level there is a high probability that sites suitable for grazing are being grazed (grazing presence; Table 5, Fig. 2a). However, grazed sites scored < 1 on average for all other aspects of conservation grazing nationally and regionally (Table 5, Fig. 2b), achieving optimal levels for no more than one grazing aspect per site (Fig. 2c). Sites are therefore failing to achieve optimal and in many cases suboptimal levels of conservation grazing. Nationally, sites scored the worst in terms of grazing timing and impact on the habitat. Regional differences in scores were supported for stock type, grazing intensity, grazing timing and habitat impact, but the direction of the regional effect differed, with no region scoring higher than other regions overall, and all regions scoring <1 on average for all aspects (Table 5, Fig. 2b).



Table 5. Results from generalised linear mixed models (GLMMs) assessing the spatial variation in scores for the five aspects of conservation grazing, and the number of aspects scored as optimal on grazed sites, at national ( $M_{\text{national}}$ ) and regional ( $M_{\text{regional}}$ ) scales. Bold values indicate support for regional differences.

Response	$M_{\text{national}}$				$M_{\text{regional}}$				Regional differences	
	~ 1 + (1 Site)				~ Region + (1 Site)				$\Delta\text{AIC}$	ratio
	AIC	logLik(df)	w	$\sigma^2$	AIC	logLik(df)	w	$\sigma^2$		
(1) Grazing presence score (0,1) <sup>a</sup>	839.9	-418.0(3)	0.38	7.92	838.9	-415.5(5)	0.62	7.54	0.95	1.6
(2) Stock type score (0-2) <sup>b</sup>	1133.3	-563.7(3)	0.06	0.70	<b>1127.8</b>	<b>-559.9(5)</b>	<b>0.94</b>	<b>0.65</b>	<b>5.47</b>	<b>15.4</b>
(3) Grazing intensity score (0-2) <sup>b</sup>	1076.2	-535.1(3)	0.10	0.46	<b>1071.8</b>	<b>-530.9(5)</b>	<b>0.90</b>	<b>0.41</b>	<b>4.38</b>	<b>8.9</b>
(4) Grazing timing score (0-2) <sup>b</sup>	594.2	-294.0(3)	0.06	1.35	<b>588.7</b>	<b>-289.4(5)</b>	<b>0.94</b>	<b>1.21</b>	<b>5.46</b>	<b>15.3</b>
(5) Habitat impact score (0-2) <sup>b</sup>	608.3	-301.1(3)	0.00	2.18	<b>594.4</b>	<b>-292.2(5)</b>	<b>1.00</b>	<b>2.01</b>	<b>13.88</b>	<b>1034.3</b>
No. of aspects with optimal score <sup>b</sup>	965.6	-479.8(3)	0.41	0.16	964.9	-477.5(5)	0.59	0.15	0.70	1.4

<sup>a</sup> All sites, n=213, site-visits =822; binomial error distribution, logit link, Laplace likelihood, lme4 (Bates *et al.* 2015). <sup>b</sup> Grazed sites only, n=122, site-visits =475; Conway-Maxwell Poisson error distribution, log link, ML, glmmTMB (Magnusson *et al.* 2017). AIC: AIC value, logLik: log-likelihood, df: degrees of freedom, w: Akaike weight (the relative likelihood of each model ( $\exp[-0.5 * \Delta\text{AIC}]$ ) divided by the sum of these values across both models);  $\sigma^2$ : variance of the random effect term (1|Site),  $\Delta\text{AIC}$ : the difference in AIC between the model with the lowest (emboldened) and highest AIC for the two models, ratio: ratio of relative support for  $M_{\text{regional}}$  over  $M_{\text{national}}$  [evidence ratio =  $w(M_{\text{regional}}) / w(M_{\text{national}})$ ]. Support for regional differences assumed where  $\text{AIC}(M_{\text{regional}}) < \text{AIC}(M_{\text{national}})$  and  $\Delta\text{AIC} > 2$  (Burnham & Anderson 2002).

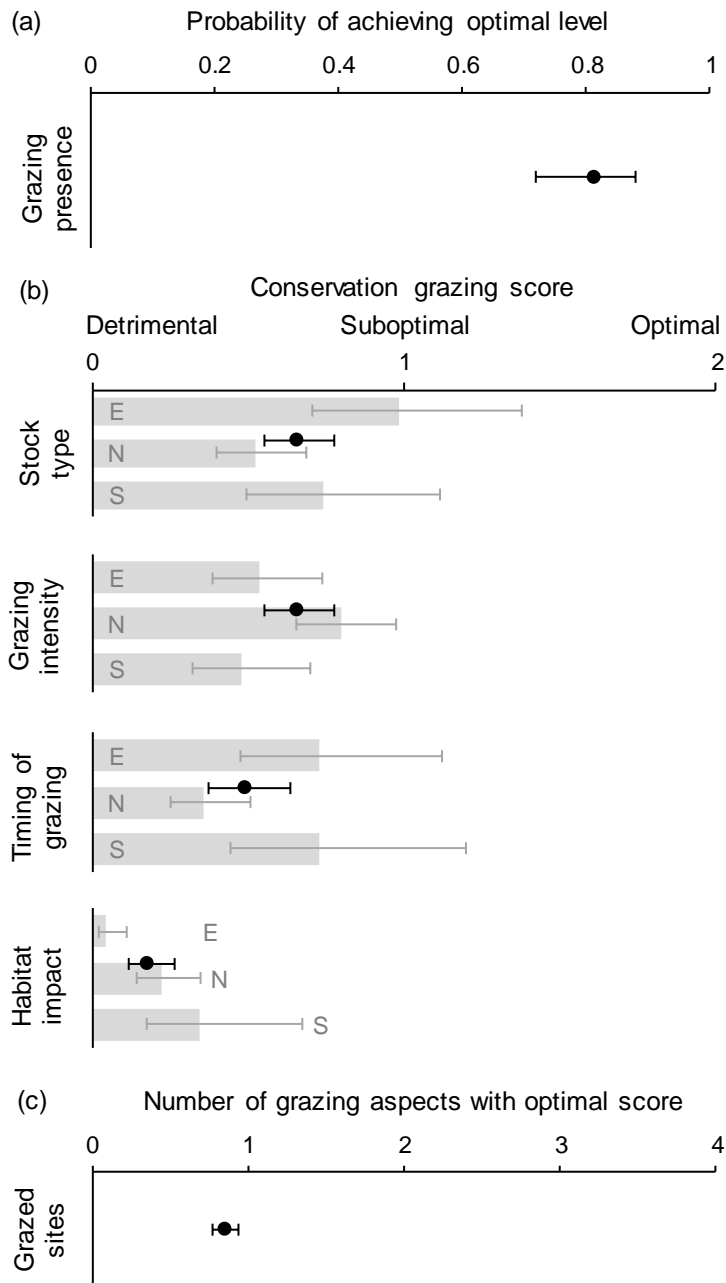


Figure 2. Assessments of conservation grazing on English saltmarshes. Shown are national (point) and regional (bar) mean values estimated by binomial (a) or Conway-Maxwell Poisson (b and c) GLMMs assessing the probability of achieving an optimal grazing presence score (grazing present on suitable sites) across all sites (a), and on grazed sites the scores for the other aspects of conservation grazing (b) and the number of these aspects achieving optimal scores (c). Regional averages are only shown where regional differences were supported by AIC comparisons (East = E, Northwest = N, South = S). Error bars are 95% confidence intervals.

Are AES a successful mechanism for delivering conservation grazing, and to what extent is AES agreement wording fit for purpose?

### *Assessing AES as a delivery mechanism*

At both the national and regional level, the probability that sites suitable for grazing are being grazed was not influenced by the presence of AES, irrespective of AES type, specific grazing options or agreement age (Table 6). The scores achieved for the other aspects of conservation grazing, and the number of aspects which were scored as optimal, also did not differ between grazed spatially-paired AES and non-AES sites with the exception of grazing intensity on sites in the East, where older AES sites scored substantially higher and approached optimal levels (Table 6, Fig. 3).

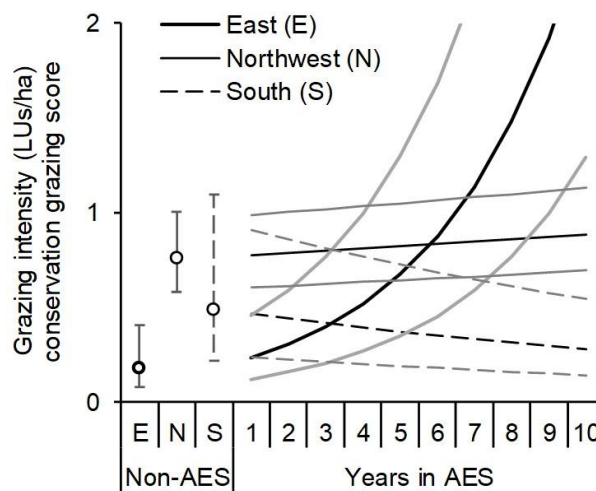


Figure 3. Effects of AES on grazing intensity conservation grazing score on English saltmarshes (Table 6). Points indicate the regional average score for sites without AES agreements (non-AES; years in AES = 0), lines ( $\pm 95\%$  CIs) indicate the regional predicted change in score on AES sites with increasing age of AES agreement (years in AES > 0). Error bars are 95% confidence intervals.

Table 6. Results from generalised linear mixed models (GLMMs) assessing the regional variation in scores for five aspects of conservation grazing, and the number of aspects scored as optimal on grazed sites (aspects 2-5 only), in relation to AES effects (~X = AES variables singly, ~X\*R = their interaction with Region plus constituent main effects and ~1 = the null model). For each response variable the AIC of the best model (lowest AIC, dark-grey shaded) is reported, with the difference in AIC between the focal model and the best model ( $\Delta$ AIC) reported for all other models (models with similar support to the best model ( $\Delta$ AIC < 2) are light-grey highlighted (Burnham & Anderson 2002)). For full model selection tables and top model coefficients see Table S6. Regional interactions could not be run in some cases because of over-parameterisation issues (insufficient variation in response variable for all category combinations; “—” models not run). The final column indicates whether an effect of AES on conservation grazing score was concluded (i.e. the best model included an AES variable and had substantially more support than the null model:  $\Delta$ AIC < 2), with the effect direction in parentheses (positive + in favour of AES sites).

AES variable (X)	Site type		AES type		Grazing options		Years in AES		AES effect upheld? (direction)	
	Non-AES	AES	Non-AES	CSS, HLS	Non-AES	AES+, AES-	Continuous: 0-10			
Categories/range										
Model specification	~1	~X	~X*R	~X	~X*R	~X	~X*R	~X	~X*R	
(1) Grazing presence (0,1) <sup>a</sup>	785.5	0.1	3.4	1.8	7.6	1.7	8.3	1.4	5.9	No
(2) Stock type score (0-2) <sup>b</sup>	1.1	768.6	—	2.0	—	1.4	—	0.8	—	No
(3) Grazing intensity score (0-2) <sup>b</sup>	4.5	5.8	1.1	7.8	—	7.3	4.9	5.6	764.0	Yes (+)
(4) Grazing timing score (0-2) <sup>b</sup>	435.5	1.8	1.9	3.8	—	3.7	6.1	1.5	2.1	No
(5) Habitat impact score (0-2) <sup>b</sup>	426.8	0.9	—	2.2	—	1.2	—	2.0	—	No
No. of aspects with optimal score <sup>b</sup>	670.5	2.0	1.4	3.9	—	3.9	5.8	1.9	2.5	No

<sup>a</sup> All spatially-paired AES/Non-AES sites: paired-groups = 76, sites = 200, site-visits = 772; binomial error distribution, logit link, Laplace likelihood estimation, lme4 (Bates *et al.* 2015), optimizer bobyqa (Powell 2009). <sup>b</sup> Grazed spatially-paired AES/Non-AES sites only: paired-groups = 33, grazed sites = 90, site-visits = 347; Conway-Maxwell Poisson error distribution, log link, Maximum likelihood estimation, glmmTMB (Magnusson *et al.* 2017).

*Is AES agreement wording fit for purpose?*

Management prescriptions within AES agreements scored very highly for the presence of grazing at a national and regional level (Fig. 4a). Conservation grazing scores actually achieved by AES sites for this aspect also largely matched their corresponding management prescription scores (conservation grazing score = 1 where prescription score = 1 in 80% of cases), although overall there was no difference in conservation grazing score for either prescription score level for this grazing aspect (Fig. 5a; Table S5).

For conservation grazing aspects relevant for grazed sites, AES agreements also achieved high prescription scores in relation to habitat impact both nationally and regionally, indicating that this aspect of conservation grazing is specified more often at optimal conservation levels within management prescriptions (Fig. 4b). Prescription scores were low for stock type, grazing intensity and grazing timing at both spatial scales however (Fig. 4b). This is reflected in the low total number of grazing aspects with specific and optimal prescription wording (Fig. 4c)

There was a shallow but increasing trend in conservation grazing score in relation to prescription score for stock type and grazing timing, but no or shallow-negative relationships for grazing intensity and habitat impact (Fig. 5, Table S5). No sites achieved optimal conservation grazing (i.e. conservation grazing score = 2) even when prescriptions specified optimal management however (prescription score = 2; Fig. 5).

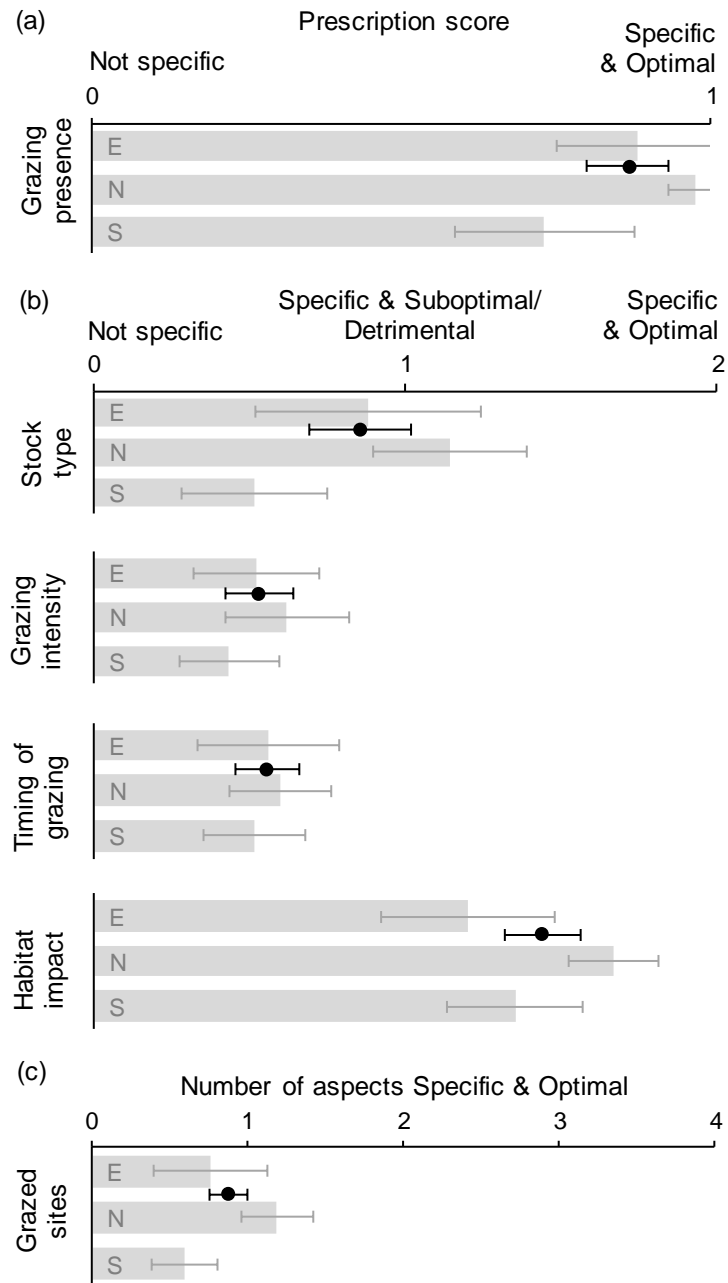


Figure 4. Summary of the agri-environment scheme management prescription scores.

Shown are the mean  $\pm$  95% confidence interval national (points) and regional (bars: East E, Northwest N, South S) prescription scores for five aspects of conservation grazing (a & b), and (c) the number of aspects where prescription wording was specific and optimal for the aspects relevant to grazed sites (those shown in b).

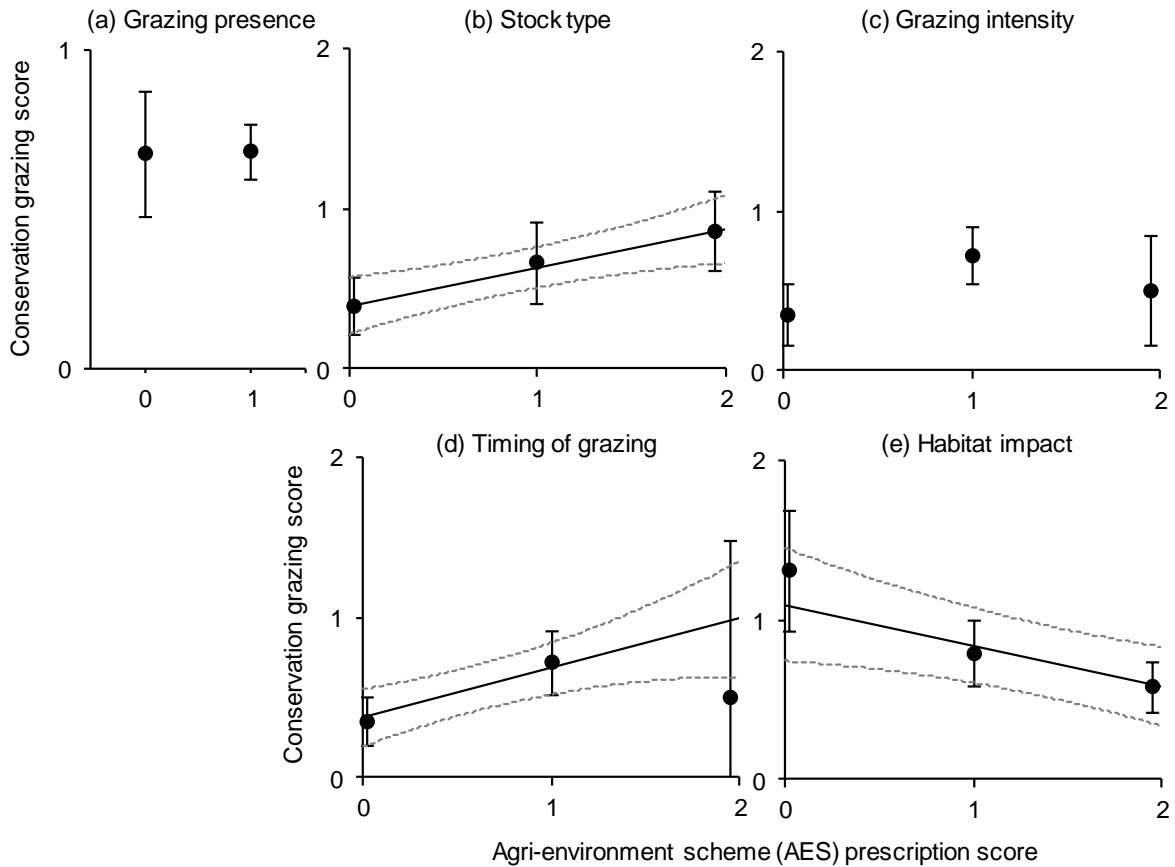


Figure 5. Conservation grazing scores on AES sites in relation to their prescription scores for five aspects of conservation grazing. All points are means  $\pm$ 95% confidence intervals predicted by LMMs (a) or from raw data at a given prescription score (b-e). For (b-e) lines show the predicted relationships between conservation grazing and prescription scores from LMM models for aspects where this relationship was supported by AIC comparisons (solid = predicted relationship, dotted = 95% CI; Table S5).

## Discussion

Our results indicate that although most saltmarsh sites in England that are capable of supporting grazing are grazed by livestock, conservation grazing is not being achieved.

Grazing is therefore not being conducted by cattle at 'low/moderate' grazing intensity from April or June to October, with variable sward heights and retained standing vegetation crops in the resulting habitat across English sites overall (Table 2; Adnitt *et al.* 2007; Doody 2008; Mandema *et al.* 2015; van Klink *et al.* 2016; Lagendijk *et al.* 2017; Sharps *et al.* 2017). At a national level, the timing of grazing and the impact of grazing on the habitat had the lowest scores, indicating that these two aspects of conservation grazing are where management is failing the most. There were regional differences in scores relating to stock type, grazing intensity, grazing timing and habitat impacts, but no region scored higher than others overall.

Additionally, we found that sites with AES agreements were no more likely to be grazed than sites without AES, and although AES did marginally influence grazing intensity, the presence of AES did not enable sites to achieve optimal conservation grazing requirements, indicating that AES in their current form are an ineffective conservation grazing delivery mechanism on saltmarsh.

In temperate regions around the world, grazing by domestic livestock is an important component of the management of a range of grassland habitats (Watkinson & Ormerod 2001). The end goal of grazing can vary from commercial agriculture to biodiversity conservation but, in natural or semi-natural habitats, grazing often has a dual purpose whereby biodiversity areas require sensitive grazing yet only commercial grazing animals are available for the task. In these situations, payments from agri-environment schemes aim to compensate farmers for loss of income through grazing more sensitively for biodiversity. Here we use a relatively novel approach to assess whether AES delivers grazing that is



likely to benefit biodiversity conservation, based on key aspects of conservation grazing reviewed from the literature. This approach is novel in its application to grazing management but was adapted from a similar approach used more widely to score habitat suitability for breeding lapwings *Vanellus vanellus* and to relate those scores to agri-environment management (Smart *et al.* 2013). We argue that this approach could be more widely adopted in the assessment of the success of any conservation action, not just AES, assuming the specific desired outcomes of management are clear and the success of conservation interventions at achieving those outcomes can be assessed.

The UK supports ~17% of the saltmarsh designated under Natura 2000 (Doody 2008) but 37% of saltmarsh priority sites are not achieving the target conservation value under the UK Biodiversity Action Plan (JNCC 2004). Livestock grazing is the main tool by which saltmarsh condition could be improved through direct management intervention, and what constitutes optimal conservation grazing is well-studied on European saltmarshes (we found 26 papers 1972-2017 recommending saltmarsh grazing levels: Table S1). However, our results and those from other parts of Europe where saltmarsh condition is declining, show that saltmarsh conservation grazing is not being achieved (Wolff *et al.* 2010; Exo *et al.* 2017; Haynes *et al.* 2017), so despite frequent exchanges between researchers (Garbutt *et al.* 2017) this knowledge is not adequately disseminated to policymakers and managers. The issue therefore is not a lack of evidence about how saltmarshes should be managed, but an issue of the translation of evidence into recommendations for hands-on management and in encouraging land managers to implement recommendations when these go against traditional farming practices and economic gain.

The main way in which research findings can be translated into actions while providing an incentive to land managers is through AES, so the overall failure of English AES in

influencing conservation grazing is concerning, particularly if AES sites are already biased towards those where habitat conditions and land-owner enthusiasm are more conducive to conservation (Kleijn & Sutherland 2003). We did find some evidence that AES sites improve over time in one region. This is perhaps because older agreements have longer for beneficial management changes to be implemented and take effect or were more prescriptive and provided with better guidance closer to their scheme's start. These findings, both the overall lack of beneficial effects on AES sites and minor positive effects of agreement age are supported by other studies from Europe (e.g. Kleijn *et al.* 2001; Smart *et al.* 2013).

The annual cost of saltmarsh and grazing management options in the agreements studied was £543,075 for 10,218 ha of saltmarsh, equating to over £5 million spent on saltmarsh management options over the course of 10 years. Livestock grazing is the only active saltmarsh management method available through English AES agreements, but grazing was no more likely on AES sites than non-AES sites, and only half (51%) of AES sites were recorded as grazed during our surveys. This implies that many AES sites were paid to maintain saltmarsh by essentially doing nothing, a seemingly uneconomical exercise when 96% of the sites we surveyed were already protected against damaging actions through UK-national and/or European designations (Sites of Special Scientific Interest, Special Protection Areas, Special Areas of Conservation, Ramsar sites; JNCC 2004). Even if all AES sites had been grazed, the current prescriptions for the grazing management of saltmarsh are clearly not cost effective if the agreements are not delivering the necessary conservation management for this habitat and the species it supports.

The low specificity of AES prescription wording provides one mechanism through which the failure of AES in influencing saltmarsh grazing management could be explained. Prescription wording scored highly for the presence of grazing on sites that have been traditionally grazed. However, the more major areas of failure were grazing intensity, timing and stock type, where management was either not specific or specified suboptimal conservation levels. Agreement-holders are required to follow these prescriptions strictly, so it is perhaps not surprising that the lack of specificity has resulted in a lack of optimal conservation grazing on the ground. In addition, the restricted nature of livestock grazing for conservation management (i.e. lower stocking rates, restrictions on timing and stock type) introduces practical and economic constraints that are likely to influence the management decisions of land managers. Practical constraints include the availability of grazing animals of the appropriate type, capacity to move animals or to restrict their access in space and time, the logistics and economics of operating smaller herds and ensuring that livestock have access to water and safe areas where they can escape from high tides. Economic constraints are also likely to be important and the restricted nature of conservation grazing will undoubtedly reduce income relative to unrestricted grazing. If AES payments are not sufficient to remove these economic constraints, then it is likely that grazing patterns will tend more towards commercial rather than conservation goals. The current grazing management on English saltmarshes is therefore likely to reflect land managers attempting to maximise income while operating within the constraints imposed by their AES prescriptions and the practicalities of grazing saltmarshes.

Conversely, if prescription wording could be improved then on-site grazing management is also likely to improve, as where prescriptions were more specific and optimal, sites implemented better conservation management in terms of stock type and timing of grazing. Being the simplest to define, these are perhaps the easiest aspects to translate into on-site management and subsequently enforce. Grazing intensity and habitat condition are aspects

which are more difficult to quantify and therefore enforce, which may explain the lack of translation into on-site grazing even when prescriptions specify optimal management.

Currently, the prescriptions in each agreement are selected by a statutory-agency regional adviser from a pre-defined set of mandatory and elective phrases. The phrases relating to grazing are all elective, lack detail and make no reference to or suggestions for recommended stock types, grazing intensity or timing (although advisers may add additional details if they wish). Agreement wording could therefore be greatly improved if grazing-related prescriptions were made mandatory for livestock-grazed sites, and provided specific guidance in terms of stock type, grazing intensity and timing. Improved translation of saltmarsh research findings into recommendations for actual management would be of direct benefit here, as would detailed consultations with researchers and land managers by policymakers when developing new schemes to ensure the incorporation of relevant and recent evidence for beneficial management (Barnett 2007).

Saltmarsh sites in this study were not achieving conservation grazing, and AES sites were grazed no differently than non-AES sites. However, AES are still the only mechanism through which conservation grazing can be implemented nationally on saltmarshes, and the large proportion of English saltmarsh already under AES presents a unique opportunity for comprehensive landscape-scale intervention if these AES could be improved to deliver the necessary outcomes (Smart *et al.* 2013). We propose that the five aspects of saltmarsh conservation grazing be incorporated into AES prescriptions in future to dramatically increase the specificity of AES agreements and their utility for conservation management (Appendix S1). Additionally, a more detailed and reliable system of auditing would be beneficial ([www.gov.uk](http://www.gov.uk); JNCC 2004), to ensure that management activities take place to the necessary standard prior to payments. Moving to a results-based scheme where payments

are made on desirable outcomes rather than on evidence of management may also improve the overall conservation value and economic efficiency of saltmarsh AES options

(Armsworth *et al.* 2012; Hanley *et al.* 2012; Hasund 2013; Keenleyside *et al.* 2014).

Policymakers, researchers and land managers need to work together to ensure that AES effectiveness is improved, particularly through better translation of conservation guidelines into AES, detailed consultations with land managers and researchers when designing new schemes, and the increased specificity of prescription wording with detailed rationales to improve mutual understanding of particular grazing management between agreement advisers and managers. In habitats where this process has already been undertaken (e.g. for lowland wet grassland in the UK), bespoke AES in combination with site protection are much more successful in delivering conservation outcomes (e.g. improved breeding habitat for wading birds, Smart *et al.* 2014). A similar tailoring process on saltmarsh is likely to benefit multiple species and processes within the saltmarsh ecosystem.

## Authors' contributions

Study conceived by LRM & JS; designed by LRM. Data acquired by AF, NG, CV & LRM.

Analyses conducted and paper written by LRM; JS provided revisions. All authors approved and are accountable for the final manuscript.

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## Data accessibility

Data available via the Dryad Digital Repository <https://doi:10.5061/dryad.p3g44gh> (Mason *et al.* 2019)

## Supporting information

**Figure S1.** Site location maps

**Table S1.** Conservation grazing rates

**Table S2.** Study site information

**Table S3.** Livestock Unit conversions

**Table S4.** Prescription scoring

**Table S5.** Prescription analysis results

**Table S6.** Model selection tables

**Appendix S1.** Recommendations for prescription wording

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