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Restoration of inland brackish vegetation by large-scale transfer of coastal driftline material

Mineke Wolters, Saskia de Vries, Wim A. Ozinga & Jan P. Bakker

Keywords

brackish habitat; dispersal; driftline; grazing; saline habitat; salinity; sheep; target species; top soil removal; transfer rate

Nomenclature

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Abstract

Question: Does large-scale transfer of coastal driftline material enhance the establishment of inland brackish vegetation?

Location: The Klutenplas of 11 ha, a formerly reclaimed agricultural field, north coast of the Netherlands.

Methods: A large quantity of coastal driftline material of local origin was transferred to the restoration site in 2006 after top soil removal in 2005 leaving bare areas for control plots. *A priori* species composition of the driftline was analysed in a greenhouse germination study. Target species were assigned to saline and brackish ecological species groups and present and historic regional occurrences. Our procedure for selecting target species resulted in a list of 98 species characteristic of terrestrial salt and brackish ecological species groups. The establishment of plant species in the field was recorded annually from 2006 to 2009, with a final survey in 2012. A comparison between locations with and without driftline was made. The entire study site was grazed with sheep.

Results: Driftline material contained 39 species, including 26 target species. During the first 4 yr, the mean number of target species in the established vegetation of driftline plots was significantly higher than in control plots. When corrected for spontaneous occurrence by natural colonization in control plots, 44% of the target species in the established vegetation of driftline plots during the first 4 yr could be attributed to the transferred material. After 7 yr driftline and control plots converged to similar levels, probably as a result of dispersal by wind and animals.

Conclusions: Transfer of coastal driftline material enhanced the rate of establishment of inland brackish vegetation for at least the first 4 yr.

Introduction

The present clayey Dutch coastline is characterized by a sharp transition between coastal and inland habitats due to large-scale land reclamation and embankment of coastal marshes with extensive seawalls (Wolff 1992; Bakker et al. 2002). As a result, natural salinity gradients with their characteristic plant and animal species have largely disappeared (Lötze et al. 2005). After embankment, the hinterland showed strong subsidence as a result of artificial drainage with subsequent oxidation of the peat layer beneath the clay (Vos & Knol 2015). Subsequently, the vegetation became affected by saline groundwater. Although fragments of brackish vegetation often remained along ditches and in depressions of the reclaimed land

(Beefink 1975) these have recently been dominated by *Phragmites australis* after abandonment, agricultural optimization schemes and coastal defence works, with subsequent decreased seepage of saline water. The importance of salinity gradients for the preservation of biodiversity has been recognized and formalized into national and international legislation (Wolff 1993). This has led to the implementation of different restoration projects.

Restoration practices traditionally focused on creating suitable abiotic site conditions in the expectation that natural colonization of the target species would follow. As many restoration sites have a history of intensive agricultural exploitation, the established vegetation is generally devoid of target species. Also, the soil seed bank is likely to be either depleted or contain mainly long-term persistent

seeds of non-target species (Bakker & Berendse 1999). In such cases the target species have to come from local or distant source areas. Plant species are usually adapted to one or more dispersal strategies involving wind, water, animals or humans (Bakker et al. 1996). However, availability of dispersal agents, presence of dispersal barriers and distance to source areas are all factors affecting dispersal into a restoration site. With several studies suggesting dispersal constraints, different groups started to design methods to assist dispersal rates. A promising method is the large-scale transfer of plant material, frequently collected as fresh hay from local source areas, to restoration sites (Kiehl et al. 2010). Earlier results showed that target species establish at a faster rate and with higher numbers compared to natural colonization, especially when combined with top soil removal. While this was successful for calcareous grasslands (Kiehl & Wagner 2006; Kiehl & Pfadenhauer 2007), flood meadows (Hölzel & Otte 2003) and fens (Rasran et al. 2007), implementation of this strategy for inland brackish vegetation is not reported. Therefore alternative sources should be considered. One possibility is the collection of driftline material from coastal salt marshes seaward of inland brackish restoration sites. Driftline is frequently deposited at the foot of the seawall during autumn and winter storm surges. It usually contains a high number of seeds and vegetative parts of saline and brackish species of local origin (Persicke et al. 1999). Driftline material decays and causes die off of the sward because of light limitation, and thus negatively affects the seawall. Hence, driftline material is mostly continuously removed by the local authorities (Gerlach 1999; Gettner 2003). Transfer of driftline to restoration sites at the inland site of the seawall therefore seems to be practicable and financially attractive.

We hypothesize that restoration of inland brackish vegetation in a former arable field can be enhanced by addition of driftline material from an adjacent salt marsh. We hypothesize that the driftline material includes a considerable amount of target species. We take the number of established target species including their successional dynamics as criterion for restoration success, i.e. in the short term of 1–2 yr represented by pioneer target species, and in the longer term of 7 yr represented by target species of closed sward, or even tall forb species.

Methods

Study site

The 11-ha study area, De Klutenplas, is located on the northern coast of the Netherlands (53°25'N, 6°31'E). Seepage of saline groundwater from below the seawall occurs along the entire coastline of Groningen, and the saline groundwater is attracted upwards by the presence of

surface water in ditches and other water bodies. Klutenplas is part of the Linthorst Homanpolder, a former salt marsh that was reclaimed in 1943–1947 and which has been exploited as arable land ever since.

In autumn 2004, the upper 20 cm of nutrient-rich top soil was removed, resulting in a flat homogeneous site ranging from 110 to 120 cm above Dutch Ordnance Level NAP, and a series of parallel ditches, resembling the drainage network on the adjacent salt marsh, and some waterholes were dug. From one of the waterholes, brackish groundwater can be pumped through a series of interconnected ditches and the water level is periodically raised to ground surface level. Salinity is expressed as chloride concentration from 5 to 12 g·Cl⁻·L⁻¹, whereas that of the adjacent Wadden Sea amounts to 11.5 g·Cl⁻·L⁻¹ (Bosch 2004). In order to preclude complaints from neighbouring farmers, concentrations of thistles (*Cirsium arvense*, *C. vulgare*) are being cut by hand with a brush cutter annually in May before seed set. To maintain short vegetation, sheep grazing with 1 animal·ha⁻¹ from August to March after the breeding season was applied. Grazing was done across the entire restoration site of 11 ha with the threat of transferring seeds between the two different treatments.

In Mar 2005, after removal of the top soil, the viable soil seed bank was recorded in the top 5 cm. Samples were grown in the greenhouse. Only a few species could be detected, namely, *Chenopodium album*, *Tripleurospermum maritimum*, *Lamium purpureum* (>100 viable-seeds·m⁻²), *Persicaria maculosa*, *Stellaria media*, *Poa annua*, *Sonchus asper* (20–100 seeds·m⁻²), *Taraxacum officinale*, *Trifolium repens* (<20 seeds·m⁻²; Bakker et al. 2007).

Target species selection

For the selection of target species we followed the Standard List of the Dutch flora, which has been published every 4–8 yr since 1971. The most recent version comprises all vascular plant species occurring in the Netherlands, with information about their prevalence, origin, dispersal and the ecological species groups to which they belong (Tamis et al. 2004). We used the classification in ecological species groups of Runhaar et al. (2004) in which plant species are classified into groups on the basis of physico-chemical site conditions such as moisture, salinity, nutrients and acidity (www.synbiosys.alterra.nl/ecotope n/downloads/ecotopensysteemNederland-Vlaanderen). Runhaar et al. (2004) also include similarities in vegetation structure resulting from successional stages by acknowledging a pioneer group (open vegetation with annual species), sward group (closed vegetation with low-statured perennial species) and tall forb group (closed vegetation with tall forbs). We followed that approach as we

anticipated succession from bare soil after top soil removal to closed vegetation within the study period. Management by sheep grazing was thought to prevent succession to a tall forb community. We selected all species occurring in terrestrial brackish or saline habitats. The resulting list was checked for species that were excluded when originating from outside Europe. Species distribution data were consulted to verify whether the selected species occurred in the regional species pool (i.e. the northern mainland coast of the Netherlands (Provinces of Friesland and Groningen) before or after 1990 (www.verspreidingsatlas.nl/planten/; FLORON 2014).

Our procedure of selecting target species resulted in a list representing the regional species pool of 98 species typical of terrestrial salt and brackish ecological species groups and recorded along the northern mainland coast of the Netherlands before and/or after 1990 (Appendix S1). These species were subdivided into 41 pioneer, 43 sward and 14 tall forb species.

Driftline collection and germination study

Driftline material was collected from the foot of the seawall seaward of the study area on 14 Feb 2006. This material had been deposited during previous storm surges and was assumed to contain seeds and vegetative parts of species present on the fronting salt marsh. From an apparently structurally uniform stretch of driftline material ten samples were collected, at least 10 m apart, by cutting the material with a sharp knife along the inside edge of a 20 cm × 20 cm frame. The collected material was spread out in a thin layer on sterilized sand and transferred to the greenhouse (ambient temperature 15 °C night and 21 °C or above during the day). Ten control trays containing sterile sand only were interspersed to check for contamination with seeds from the surroundings. No contamination was found. Sprouting vegetative parts and seedlings were identified and removed as soon as possible or transferred to separate pots in case flowering was needed for identification. The procedure was repeated until no new seedlings emerged for at least 2 weeks. Recording periods of 2 mo were sufficient for all trays (Appendix S2).

Field transfer of driftline material

Large-scale transfer of driftline material took place on 13 and 14 Mar 2006 when the soil was slightly frozen, and the heavy machinery could drive into the wet study site. The material was collected by agricultural machinery from the foot of the nearby seawall. It was taken from the sward of the seawall without destroying the subsoil. This procedure prevented inclusion of seeds from the soil seed bank

Fig. 1. Schematic representation of the study area with transferred driftline material in shaded areas. D1–D6 are driftline locations, C1–C6 are control locations.

of the seawall. Portions of about 10 m³ were put into a manure spreader. Approximately 200-m³ material was spread using the manure spreader over approximately two-thirds of the study area in a layer of 5 cm, while the remaining part was left bare to allow comparison (Fig. 1). This procedure allowed us to resolve natural colonization and establishment from driftline material (Lepš et al. 2007).

Vegetation dynamics

Vegetation surveys were carried out annually in June/July from 2006 until 2009, with a final survey in 2012. In that year management has changed to facilitate breeding coastal birds by introducing large amounts of shells. Six locations with driftline material and six locations without (i.e. control) were selected. In each location the presence of a species was recorded in ten randomly distributed plots of 1 m × 1 m. The plots were randomly chosen in the homogeneous location every year, with the possibility

of including small spatial variations in environmental conditions.

Transfer rate

Established species can emerge from the transferred driftline material. They can also emerge from the soil seed bank, dispersal by wind or by animals, which play a role in both driftline and control plots. These factors cannot easily be separated. Hence, they are not separated in the Results section. We are aware of this threat. Fencing each individual driftline and control site to avoid sheep grazing was practically difficult. The experimental set-up may be considered pseudo-replication from a statistical point of view, i.e. limiting the statistical interference. Establishment from the soil seed bank or dispersal by wind is, however, a complex natural process and the landscape-scale of our manipulation restricts the feasibility of more complex experimental designs (see comments of Davies & Gray 2015 on the issue of pseudo-replication in ecological monitoring). Our paper addresses a very practical question: does large-scale transfer of driftline material enhance the establishment of target species. To provide some quantification of transfer rate, i.e. the measure for success of restoration by transfer of driftline material, this can be related to the number of naturally colonizing target species in control plots.

Data analyses

The effect of the addition of driftline material on the establishment of brackish and saline species in the field was tested with a one-tailed *t*-test for each of the surveyed years, using $P < 0.05$ for significant effects. A mean frequency of occurrence of species per treatment (i.e. the mean of six locations consisting of ten plots each) was used.

To test the significance and effect size of the addition of driftline material on the overall species composition we used ordination techniques, thereby quantifying the response of multiple species simultaneously. This was done using a CCA in which only the first two ordinations axis were constrained (by time and by the interaction effect of time $\times$ treatment), while the subsequent ordination axes were unconstrained (i.e. a hybrid ordination). The statistical significance of the effects of time and time $\times$ treatment on species composition were tested for deviation from randomness with Monte-Carlo permutation tests with 1000 permutations and with each block containing a single time series (Ter Braak & Šmilauer 2012). *P*-values were adjusted for multiple testing (Holm correction). The multivariate analyses were executed using Canoco 5 (Ter Braak & Šmilauer 2012).

Results

Driftline germination study

A total of 39 species emerged from the driftline material in the greenhouse (Appendix S2), including 26 target species; hence 67% of all species in driftline were target species (Appendix S1). Target species recorded with high frequency ($\geq 90\%$) are the pioneer species *Atriplex littoralis*, *A. portulacoides*, *A. prostrata*, *Salicornia* spp., *Suaeda maritima* and *Sedum acre*, closed sward species *Agrostis stolonifera* (v), *Limonium vulgare*, *Lolium perenne* (v), *Plantago maritima*, *Puccinellia maritima* (v) and *Artemisia maritima*, tall forb species *Aster tripolium* and *Elytrigia atherica*. *E. atherica* was by far the most abundant, with 800 seedlings on average in 20 cm $\times$ 20 cm (range: 588–1068 per sample). It was found in all ten samples. *Poa annua* (v), *P. trivialis* (v) and *Rumex obtusifolius* are non-target species. Species with a 'v' established from vegetative sprouts.

Vegetation dynamics

From 2006 to 2012 a total of 103 species were recorded in the vegetation, including 51 target species (Table 1). The total number of target species ranged from 30 to 41 of 48 to 62 total species during the survey (57%) for the different restoration years in the driftline plots and from 18 to 29 of 41 to 55 total species (47%) in the control plots. In the first year, 60 species (33 target species) occurred in driftline plots, whereas 41 species (18 target species) occurred in control plots. In the year 7, 48 species (30 target species) were found in driftline plots, and 54 species (32 target species) in control plots (Appendix S1). The mean number of target species was significantly higher ($P < 0.001$) in locations with driftline compared to control locations in the first 4 yr (Appendix S3, Fig. 2). In the seventh growing season the number of target species had decreased and no significant difference between treatments was found ($P = 0.208$). Pioneer and sward target species that established in the vegetation were mainly of wet and moist

Table 1. Species established in the vegetation in driftline or control plots in the period 2006–2012, and their occurrence in driftline germination study, and naturally established from soil seed bank or dispersed by wind or animals.

	Total	Target Species	Non-Target Species
Only in Driftline Material	34	23	11
Only in Seed Bank	5	1	4
In Driftline and Seed Bank	4	2	2
Not in Driftline or Seed Bank	60	25	35
Total	103	51	52
Only in Driftline, not Established	1	1	0

Fig. 2. Mean number of target species $\pm$ SD ($n = 6$) in driftline and control locations over a 7-yr study period (years 5 and 6 were not recorded). *significant difference at $P < 0.001$, n.s. no significant difference.

saline ecological species groups (i.e. salt marshes), and well represented in locations with addition of driftline material (Appendix S1). Tall forb species of wet saline and moist brackish ecological species groups were well represented, but irrespective of the addition of driftline.

In our study, two groups of species differing in their temporal development can be recognized. The first group includes species with decreasing frequency of occurrence in driftline plots especially after the first year of restoration (*Atriplex prostrata*, *Suaeda maritima*, *Artemisia maritima*, *Aster tripolium*, *Atriplex portulacoides*, *Spergularia media*, *Limonium vulgare*). These species are nearly all typical of saline moist or wet ecological species groups. The initially frequently occurring pioneer arable weed species, as a legacy of the former arable field exploitation, decreased after 7 yr in both driftline and control locations. The second group includes species with increasing or stable high frequency of occurrence in driftline plots during the first 4 yr of restoration. This group is characterized by the prevalence of several grass, sedge and rush species (*Puccinellia maritima*, *Festuca rubra*, *Lolium perenne*, *Agrostis stolonifera*, *Elytrigia atherica*, *Carex extensa*, *Juncus gerardii*) interspersed with perennial saline and brackish species (*Glaux maritima*, *Potentilla anserina*, *Triglochin maritima*) and some species indicative of moist nutrient-rich soil (*C. arvensis*, *Sonchus arvensis*, *Rumex crispus*, *Trifolium repens*). With the exception of *Festuca*, the above grass species also had a high prevalence in driftline samples.

Vegetation change can also be regarded from the perspective of dynamics of target and non-target species. Pioneer (*Atriplex portulacoides*, *A. prostrata*, *A. littoralis*, *Salicornia* spp., *Suaeda maritima*) and sward (*Limonium vulgare*, *Plantago maritima*, *Puccinellia maritima*, *Spergularia media*, *Artemisia maritima*) target species representing saline

ecological groups established specifically in locations with addition of driftline material during the first years of survey, whereas some later more or less disappeared (Fig. 3, details in Appendix S1). However, *Salicornia* spp., *Suaeda maritima*, *Atriplex prostrata* and *Puccinellia maritima* performed well in control plots in later years. Sward target species *Agrostis stolonifera*, *Festuca rubra*, *Lolium perenne* and *Potentilla anserina* and the tall forb species *Elytrigia atherica*, *C. arvensis* reached higher frequency in driftline than control locations, although it took some years.

Non-target species recorded are 25 pioneer species, 21 sward species and six tall forb species predominantly of moist, moderate or very nutrient-rich ecological species groups. *Polygonum aviculare*, *Linaria vulgaris* and *Rumex obtusifolius* established especially in locations with addition of driftline material and *Poa annua* was also recorded in the soil seed bank during the first years of survey, whereas they later more or less disappeared or decreased (Fig. 3, details in Appendix S1). A group of pioneer species, not present in driftline material, established and later decreased both in driftline material and control locations, such as *Epilobium parviflorum*, *E. tetragonum*, *Alopecurus myosuroides*, *Capsella bursa-pastoris*, *Veronica persica*, *Senecio vulgaris*, *Tussilago farfara*, *Lamium amplexicaule* and *Stellaria media* from the soil seed bank. Sward species, however, not present in driftline material gradually established both in driftline material and control locations, such as *Elytrigia repens*, *Geranium dissectum*, *Holcus lanatus*, *Dactylis glomerata*, *Medicago lupulina* and *Bromus hordeaceus*. The thistles *Sonchus arvensis*, *C. arvensis* and *C. vulgare* that were not present in driftline material, established immediately and were maintained in both driftline and control locations.

The results of the CCA (Table 2) show that the species composition changed significantly over time. In addition to this successional trend there is, however, also a significant treatment effect (i.e. an effect of the addition of driftline material) as expressed by the interaction effect of time $\times$ treatment. This is true for both its simple (marginal) effect and for its condition effect, i.e. the partial effect after accounting for the effect of year ($P_{\text{adj.}} < 0.001$; see Table 2).

Transfer rate

All 39 species, except *Sagina maritima*, encountered in the driftline germination study were also recorded in the established vegetation of driftline or control plots at some point during the 7-yr study period. The majority, namely 23 (67%), represented target species (Table 1, see Appendix S1 for details). In contrast, 60 established species were neither found in the driftline germination study, nor in the soil seed bank. Twenty-five target species represented 40%. Highest similarity between greenhouse samples and driftline locations occurred in the first year, when

Fig. 3. Temporal changes in mean number of target species per 10 plots of 1 m² in driftline locations. Species occurring in <10% of the locations (i.e. 6 × 10 plots) are not shown.

31 of the 38 species in driftline were recorded in the established vegetation, resulting in a transfer rate of 82%. Regarding target species only, the transfer rate increased to 92%, i.e. 25 target species in greenhouse samples and 23

target species in the established vegetation of driftline locations (Table 1, Appendix S1). In contrast, 19 species, of which were 12 target species, established in the control plots in the first year, resulting in a similarity of 50% for all

Table 2. Overview of the simple (marginal) effects and the partial (conditional) effects of the explanatory variables in the CCA based on Monte-Carlo permutation tests.

Variable	Simple (marginal) Effects:				Conditional Effects:			
	Explains %	pseudo-F	P	P (adj)	Explains %	pseudo-F	P	P (adj)
Year	14.1	9.3	0.001	0.005	14.1	9.3	0.001	0.005
Treatm.Drift × Year	10.6	6.7	0.001	0.005	4.9	3.4	0.001	0.005
Treatm.Control × Year	6.2	3.7	0.001	0.005	4.9	3.4	–	–

species and 48% for target species. Hence, the transfer rate of 92% of target species from driftline material could be corrected by 48% for naturally established target species, resulting in a corrected rate of 44%.

Discussion

Driftline material could be applied as a source for restoration of inland brackish vegetation, as it included target species. Transfer of driftline material was beneficial for the initial stages of the restoration of inland brackish vegetation. Transfer rate, corrected for naturally established species, amounted to 44%. Initially, target saline pioneer species established more in driftline than in control plots. Later, brackish sward species out-competed the initial set of species, with a subsequent decrease of target species in driftline plots. In the meantime, however, the number of target species in the control plots had increased, probably dispersed from the driftline-treated locations, which could be attributed to dispersal by grazing sheep in the entire study site and waterfowl, water and wind. After 7 yr, at the end of the study period, the number of target species in driftline plots had converged to the same level as in control plots.

Driftline germination study

In the present study, 26 target species emerged from the driftline material in the greenhouse. This is low considering the 98 potential target species, but in the range of other driftline studies within 120 km of our study site (Gerlach 1999; Persicke et al. 1999; Bakker et al. 2001, 2007; Wolters & Bakker 2002; Appendix S1). The composition of the driftline material in the above studies was largely determined by the locally established vegetation. Sampling time made a difference, with autumn driftline containing more propagules and more species than driftline sampled in spring (Bakker et al. 2001, 2007). Multiple harvest periods when different species with mature seeds are present increased transfer rate from 64% to 75% in an inland meadow (Scotton 2016).

Rare species such as *Crambe maritima*, *Atriplex glabriuscula*, *Glaucium flavum*, *Crithmum maritimum*, *Beta vulgaris*,

Lathyrus japonicus, *Eryngium maritimum*, *Ononis repens*, *Bupleurum tenuissimum*, *Carex extensa*, *Salsola kali*, *Honckenya peploides* and *Hordeum marinum* have been noted growing in driftline zones along the north Frisian coast of the Netherlands (Sollman & Kooiman 2004). Limited samples may also explain the absence of the target species *Bellis perennis*, *Juncus gerardii*, *Rumex crispus* and *Spergularia media* from driftline material, even though they occurred with higher prevalence in driftline plots compared to control plots. These species did occur in other driftline studies (see Appendix S1).

Six non-target species occurred with high abundance in driftline material: *Persicaria maculosa*, *Poa annua*, *P. pratensis*, *P. trivialis*, *Polygonum aviculare* and *Rumex obtusifolius*. These species had a similar or higher prevalence in the established vegetation of control plots, suggesting natural colonization also played a role.

Vegetation dynamics

During the 7-yr study period 103 different species established in the vegetation, of which 34 were also present in driftline material. Thus a large percentage of mainly non-target species established spontaneously through natural colonization. Nine species were also present in the upper 5 cm of the soil seed bank 1 yr prior to driftline transfer, but after top soil removal (Table 1, Appendix S1; Bakker et al. 2007). These were mostly arable weed species, but also the target species *Sonchus asper*, *T. maritimum* and *Trifolium repens*. To prevent the establishment of weedy species, sowing with low-diversity grassland mixtures has been applied in some restoration sites. Although this may be beneficial in the short term, it may hamper colonization by rare species and/or weak competitors (Török et al. 2011). In fact, a pilot study of driftline transfer to a nearby inland brackish restoration site demonstrated a negative relationship between the percentage cover of the present vegetation and the establishment of target species (Bakker et al. 2007). This accords with results from Van de Meutter et al. (2016) in the same ecosystem type.

The establishment of 21 target species could not be accounted for from the transferred material or the soil seed bank. Their establishment was mainly irregular, with low

frequencies except for *C. arvense*, *Epilobium hirsutum*, *Plantago major*, *Sonchus arvensis*, *Spergularia marina* and *Trifolium fragiferum*. The first four are not restricted to brackish or saline ecological species groups and may easily have been transported from nearby source areas by wind, animals or humans. Five other target species (*Bellis perennis*, *Juncus gerardii*, *Rumex crispus*, *Sonchus asper*, *Spergularia media*) were also absent from the driftline samples but occurred with higher frequency in driftline plots compared to control plots. These species either benefitted from the transferred material for entrapment of their dispersed propagules, or they had been present in the transferred material but were missing from the greenhouse samples.

The rapid spread of grasses in the driftline locations might be attributed to a low soil salinity and high nutrient availability as a result of decomposing driftline material. These grasses could rapidly expand, forming an increasingly dense sward and preventing establishment of less competitive saline species (Roozen & Westhoff 1985). Especially *Elytrigia atherica* is known for its rapid expansion in salt marshes that are not grazed by livestock (Andresen et al. 1990). *Festuca*, *Lolium*, *Agrostis* and *Elytrigia repens* were also abundant on the highest surface elevation of a mainland salt marsh restoration site on the nearby Dutch Frisian coast (Esselink et al. 2015). But in contrast to the inland site studied here, annual and perennial halophytes remained abundant over a 10-yr study period, implying a beneficial influence of saline tidal inundation. It seems that the low stocking density of 1 sheep-ha⁻¹ in the study site is not enough to prevent closing of the sward, and this species of livestock may be too light to create gaps through trampling. Nevertheless, flowering stalks of *Aster tripolium* were severely grazed by sheep and reduced after the first growing season, in agreement with observations of Kiehl et al. (1996).

Transfer rate

Of all target species present in driftline material, 92% had established in the driftline plots in the first restoration year. This is higher than the transfer rates mentioned in other studies (i.e. 40–70% in fens by Rasran et al. (2007), 69–89% in calcareous grasslands by Kiehl & Wagner (2006), 53–72% in flood meadows by Hölzel & Otte (2003) and 64–75% in meadows by Scotton (2016)). Unfortunately, the above studies did not correct for target species establishing naturally in control plots. This issue was also addressed in long-term studies on introduction of species by hay or sowing including controls that faced experimental problems due to natural colonization (Lepš et al. 2007). In our study, 48% of the target species were also present in the established vegetation of control plots with natural colonization, resulting in a corrected transfer rate of 44%.

Implications for management

A prerequisite for successful restoration of inland brackish communities is the creation of appropriate hydrological conditions such as salinity (>4 g·Cl⁻·L⁻¹), mean spring groundwater level (from -25 cm to surface level) and duration of inundation (<10 d·yr⁻¹; Van de Meutter et al. 2016). However, this study shows that transfer of driftline material from a salt marsh towards an inland site into which brackish groundwater is pumped or brackish seepage water is facilitated proved to be successful. To maximize its success, the material should preferably be collected in autumn from areas with highly diverse salt marsh vegetation including saline lower marsh and brackish higher marsh. Material collected in spring may contain fewer propagules, and seeds of some species may have germinated. Wintering birds forage on seeds in driftline material (Dierschke 2002). Application of driftline material includes large availability with zero impact on existing populations and low collection costs (Balestri et al. 2011). Driftline material will be removed anyway in the framework of protection of the seawall. Alternatively, old still existing inland sites with brackish seepage water could also be used as a source of target species.

Short vegetation may prevent competition from tall forbs and facilitate establishment of target species in the restoration site. Management by hay-making is an option to prevent spread of thistles that are not eaten by livestock. Creating patches of bare soil is important. Hence, grazing is a better option, preferably with cattle that can prevent spread of tall species (Van de Meutter et al. 2016). Top soil removal plays an important role in restoration of target species, which can double this number from about 15 to about 35, as found in the Netherlands (Bosch 2004).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Percentage frequency of occurrence of species in the established vegetation of driftline and control locations, in driftline material and in the soil seed bank.

Appendix S2. Number of germinated seeds from driftline samples during a 2-mo greenhouse period.

Appendix S3. Results of one-tailed *t*-test for comparison of number of target species with driftline compared to control locations (Fig. 2).