Spartina anglica eradication and inter-tidal recovery in Northern Ireland estuaries.

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Abstract In 1998 an experiment was initiated to study the effectiveness of eradication methods on two *S. anglica* swards. The effects of eradication treatments on live *S. anglica* stem density and other associated plant species were examined using the herbicides glyphosate and Dalapon, smothering with black plastic sheeting, and cutting. Glyphosate was relatively ineffective. Dalapon applied at a rate of 57 kg/ha and smothering were the most effective methods, reducing live *S. anglica* stem density by over 95% within one year. *S. anglica* re-establishment occurred over the two years following treatment applications indicating that eradication would require re-application of treatments. Cutting treatments in this study increased the abundance of *Puccinellia maritima* within one of the swards, suggesting that it may facilitate the establishment of other saltmarsh species. Legal constraints and limitations of resources makes eradication of *S. anglica* in most Northern Ireland estuaries unlikely. It may be possible to contain the current spread of *S. anglica* by removing seedlings, clumps and tussocks, whilst attempting to convert sward areas into mixed saltmarsh.

Keywords Control; mudflats; *Puccinellia*; saltmarsh.

INTRODUCTION

Spartina anglica C. E. Hubbard originated at Hythe, Southampton Water, England, in the nineteenth century (Gray *et al*. 1991). *Spartina anglica* was the result of chromosome doubling by *Spartina x townsendii* H. and J. Groves, the sterile hybrid between the native European *Spartina maritima* (Curtis) Fernald and the introduced North American *Spartina alterniflora* Loisel (Gray *et al.* 1991). *S. anglica* has a relatively narrow ecological amplitude. Gray et al. (1995) state that "broadly speaking *Spartina anglica* is distributed between Mean High Water Neap tides (MHWN), and Mean High Water Spring tides (MHWS)" in south and west Britain. This comprises a range of low-high elevation estuarine habitat.

As *Spartina* spp. grow they can accrete large volumes of tidal sediment leading to substantial increases in marsh elevation. This property made *Spartina anglica* a valuable species for coastal protection and reclamation schemes in the early twentieth century (Ranwell 1967). *S. anglica* was planted in Northern Ireland estuaries during the 1920-1950s (Bleakley 1979) and is currently expanding its range.

S. anglica spread occurs in two phases, initial invasion and establishment of seedlings or plant fragments on open mudflats, and then expansion of tussocks by radial clonal growth. Spreading tussocks fuse to form clumps that can expand into extensive meadows. Seed production of *S. anglica* is variable both temporally and spatially (Gray *et al.* 1991). It is thought that *S. anglica* does not form a seedbank in estuarine substrates.

Several Northern Ireland estuaries are of international importance for wildfowl and waders, such as an over-wintering population of pale-bellied brent geese (*Branta bernicla hrota*). Both estuaries in this study, Strangford Lough and Lough Foyle, have been designated as 'Ramsar' sites. The introduction and spread of *S. anglica* into wildfowl and wader feeding areas is seen as a threat to bird populations. *Zostera* spp. beds, which are an important food source for wildfowl in Northern Ireland, may decline in abundance due to *S. anglica* invasion (Oliver 1925; Madden *et al.* 1993). Waders are also likely to be affected by *S. anglica* invasion as dense stands physically prevent their access to invertebrate prey species inhabiting the sediments of *S. anglica* swards.

Since the late 1960s attempts have been made to control and eradicate *S. anglica* in Northern Ireland. Dalapon (2,2 dichloropropionic acid) application has been the main method used, but digging was also attempted. Digging was, however, only successful on plants smaller than 50 cm in diameter (Furphy 1970). Early trials in Britain suggested that Dalapon was one of the most effective herbicides for eradicating *S. anglica*, achieving over 90% kill (Ranwell and Downing 1960; Taylor and Burrows 1968). Dalapon is, however, no longer manufactured and the Environment and Heritage Service in Northern Ireland, which is responsible for management of Northern Ireland estuaries, requires a replacement herbicide for *S. anglica* eradication. Several other herbicides have been tried in *Spartina* spp. eradication experiments in other countries. Of these, fluazifop-P-butyl, haloxyfop, and imazapyr have achieved over 90% *Spartina* spp. kill (Pritchard 1996; Shaw and Gosling 1996). Glyphosate, however, is to date, the only other herbicide licensed for use in estuarine environments in Northern Ireland. Licensing of other herbicides is likely to be a costly and slow process. The greatest successes using glyphosate, achieving over 75% kill, have been obtained using glyphosate along with an added surfactant (Garnett *et al.* 1992; Kilbride *et al*. 1995; Crockett 1997, Major and Grue 1997; Norman and Patten 1997). Surfactants are currently banned from use in Northern Ireland inter-tidal areas. Previous work suggests that applications of glyphosate on its own produces poor *S. anglica* kill rates (Garnett et al. 1992).

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The Environmental and Heritage Service also wanted to investigate the potential of non-herbicidal methods for *S. anglica* eradication due to environmental and health concerns about herbicide use, and due to a ban of herbicide use in shellfish designated areas (see Discussion). Smothering and burying are the only non-herbicide techniques that have reduced *Spartina* spp. stem density by over 90%. Initial attempts at burying using a rotoburying machine at Lindisfarne (England) resulted in over 95% *S. anglica* kill (Davey *et al*. 1996). Rotoburying machine use is unsuitable in Northern Ireland estuaries due to soft sediments. Smothering is therefore a more suitable option. Covering plants with black plastic sheeting prevents photosynthesis, and probably leads to increases in the temperature of sediments, thus leading to plant death. American and Australian studies using black plastic to smother *Spartina* spp. have reported kill rates of up to 99-100% (Aberle 1990; Lane 1996).

This study assesses the effectiveness of Dalapon and glyphosate for eradicating *S. anglica* in two swards. Cutting prior to herbicide application was also examined to determine if it increased *S. anglica* kill rates. These methods were compared with the non-herbicidal eradication method, smothering with black plastic sheeting. In addition the previously-unexamined effects of eradication treatments on other plant species within *S. anglica* swards were investigated.

METHODS

Study area

Two sites were selected for the *S. anglica* eradication trials. These sites were the only areas available for this study due to a herbicide ban in other locations. One of the sites was a 1.4 ha *S. anglica* sward at Lough Foyle (Fig. 1, 2; Grid ref. 55º 03'N, 7º 02.6'E) and the other a 0.15 ha *S. anglica* sward at Strangford Lough (Fig. 1, 3; Grid ref. 54º 31.8'N, 5º 40.6'E). Relatively uniform areas of *S. anglica* were selected for placement of experimental plots to avoid gullies.

Lough Foyle is a 200 km^2 marine inlet at the northern coast of Northern Ireland, with a tidal range of 1–2 m. *Spartina* spp. were introduced into the sheltered bay containing the trial plots in the 1930s. The plots within the *S. anglica* sward receive no tidal inundation at MHWN tides. During MHWS tides inundation levels range between 20-32 cm. *S. anglica* within the study plots had a mean stem density of 232 stems per square metre, and a mean stem height of 33.2 cm in July 1998. During this trial *S. anglica* was ob-

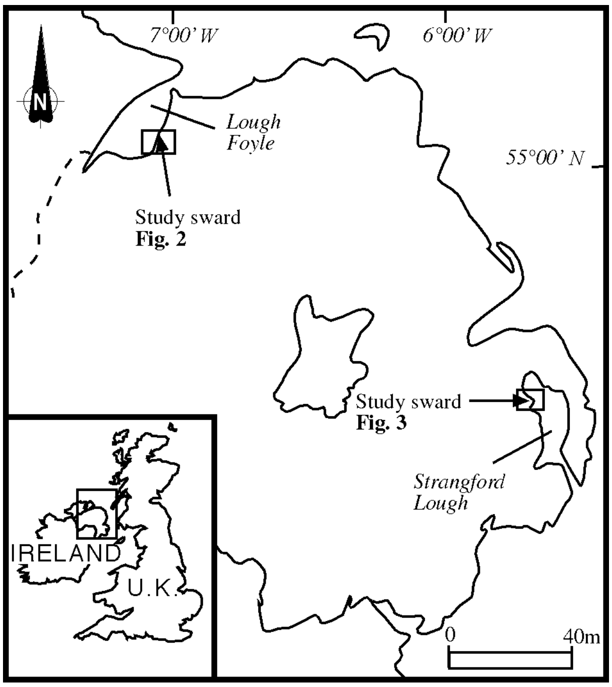

Fig. 1 Location of study areas in Northern Ireland.

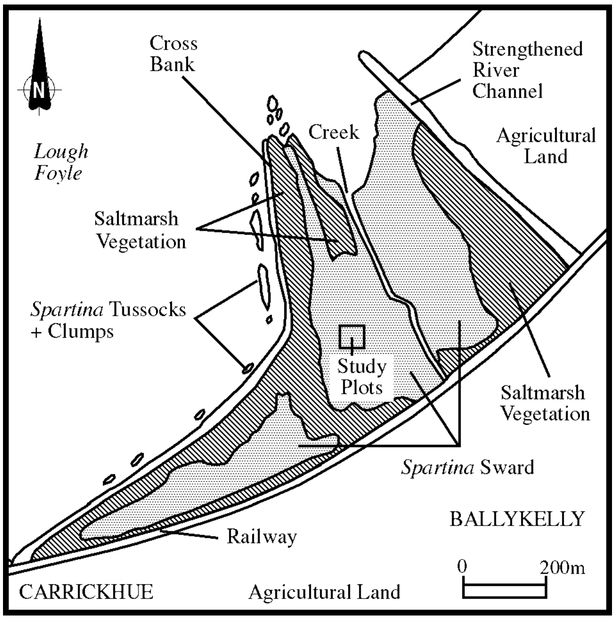

Fig. 2 *Spartina anglica* study sward, Lough Foyle.

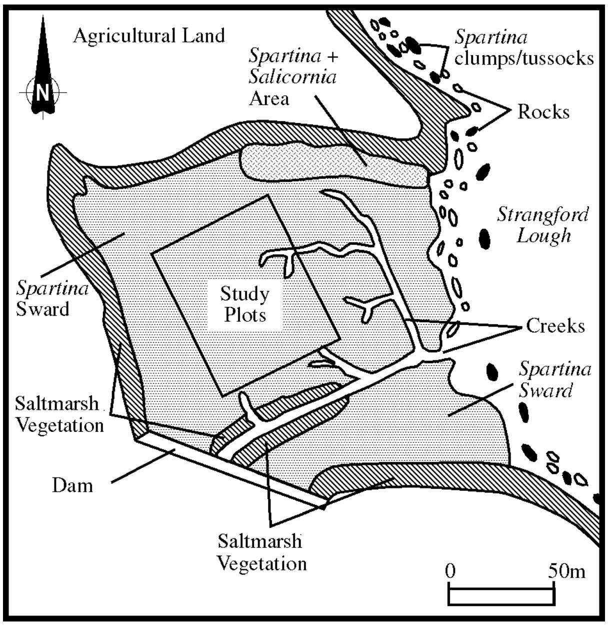

Fig. 3 *Spartina anglica* study sward, Strangford Lough.

served to begin growth in April and began flowering in June-July. The study area contained *Puccinellia maritima* (median Domin value 3-4), *Aster tripolium* and *Plantago maritima* (individuals of both, median Domin value <1) prior to the study. The vegetation community within the sward is similar to those found in mid-elevation *S. anglica* swards in other U.K. and Netherlands estuaries (cf. Brereton 1971; Adam 1981; Roozen and Westhoff 1985; Scholten and Rozema 1990; Gray 1992). Several saltmarsh strips dominated by *Puccinellia maritima* (Domin scale 6), *Agropyron pungens, Aster tripolium, Plantago maritima*, *Festuca rubra* (all Domin scale 5), and *Triglochin maritima* (Domin scale 4), with individuals of several other saltmarsh species including *Chenopodium rubrum,* were close to the sward (Fig 2).

Strangford Lough is a 150 km^2 marine inlet on the south-eastern side of Northern Ireland, with a tidal range of 2-3.5 m. *Spartina* spp. were introduced into Strangford Lough in the 1930s and 1940s. The *S. anglica* sward in this study was first recorded in 1969 and is confined to a sheltered bay. The plots in the sward receive no tidal inundation at Mean High Water Neap tides. During Mean High Water Spring tides inundation levels range between 51-67 cm. *S. anglica* within the study plots had a mean stem density of 336 stems per square metre, and a mean stem height of 23.7 cm in July 1998. During the study *S. anglica* was noted to begin growth in April and began flowering in June-July. *Puccinellia maritima* individuals were recorded (Domin value 1) in the experimental plots prior to the study. *P. maritima* and *Aster tripolium* occurred in raised micro-hummocks adjacent to the experimental plots, and *Salicornia* spp. were observed in other adjacent sward areas. The vegetation communities within the sward are similar to those found in low-elevation *S. anglica* swards in other U.K. and Netherlands estuaries (cf. Brereton 1971; Adam 1981; Roozen and Westhoff 1985; Scholten and Rozema 1990; Gray 1992). Several saltmarsh strips dominated by *Puccinellia maritima* (Domin scale 6), *Aster tripolium*, and *Plantago maritima* (both Domin scale 4), with a lower abundance of several other saltmarsh species, were close the sward (Fig. 3). An area dominated by *Spartina anglica* and *Salicornia* spp. (both Domin scale 8), was close to the study plots (Fig. 3).

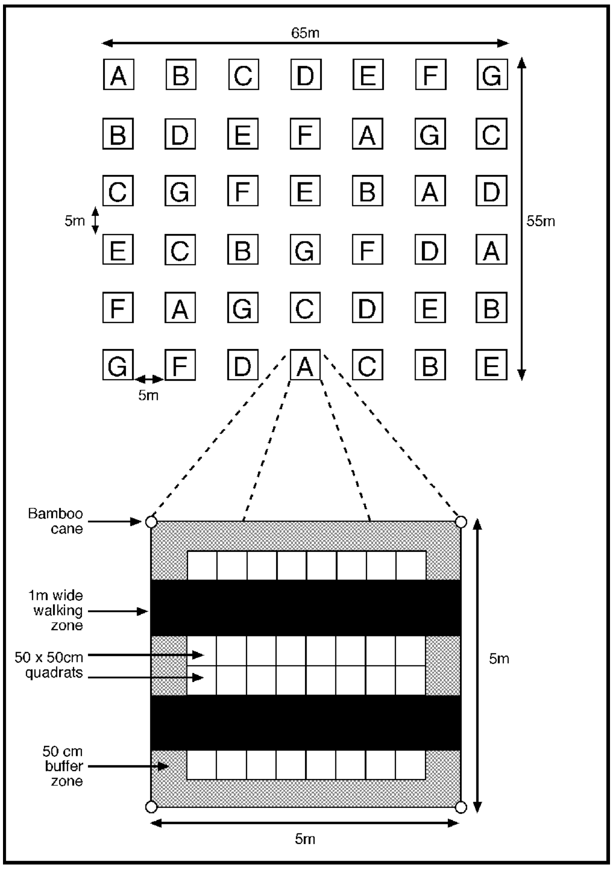

Fig. 4 Example of random block layout and experimental plot design. Treatments: A = Dalapon; B = Sward cut and glyphosate; C = Experimental Control; D = Glyphosate; E = Sward cut and smother; F = Sward cut; G = Sward cut and Dalapon.

Experimental layout

Six replicate plots were used, with seven different treatments. Plots of 5 m x 5 m were laid out in a random block formation angled approximately parallel to the shoreline, with a separating distance between plots of 5 m (Fig. 4). Within each plot, two 1m walking strips were retained for access when applying treatments and monitoring. A buffer zone of 50 cm was established around the inner edge of the plot. This area was not used for recording. The remaining areas were divided into thirty-two 0.5 m x 0.5 m quadrats for experimental recording.

The seven treatments applied were :

- Experimental Control (no treatment)
- Dalapon applied at a rate of 57 kg/ha
- Glyphosate without added surfactant applied at a rate of 5.0 *l*/ha
- Sward cut to 10 cm
- Sward cut to 10 cm and Dalapon applied after six weeks growth
- Sward cut to 10 cm and glyphosate applied after six weeks growth
- Sward cut to 10 cm and covered with black plastic sheeting for six months

Treatment application

The Dalapon application rate was suggested by Ranwell and Downing (1960) and Taylor and Burrows (1968). The form of Dalapon available for use was Farmon Dowpon, a wettable powder containing 85% of the sodium salt of Dalapon. The glyphosate application rate used is recommended by Monsanto to control grasses in the aquatic environment, and has previously been used by Garnett *et al.* (1992). The form of glyphosate used was Roundup Biactive, an aqueous concentrate containing 360 g/*l* glyphosate acid present as 480 g/*l* of the isopropylamine salt of glyphosate. Herbicides were applied using a Cooper Pegler CP15 knapsack sprayer. The sprayer was operated at a pressure of 1 bar (15 psi) and was fitted with a red floodjet/deflector nozzle that had a 2.0 m spray width from a nozzle height of 50 cm above the target. Herbicides were applied at least six hours before tidal inundation during neap tides, on cloudy, rainless days with wind speeds of less than 10 km/hr. Spraying was carried out in August 1998, before *S. anglica* seedheads had developed.

Mowing was accomplished with a hand-held brush cutter during July 1998. Cutting was done to within 10 cm of the substrate. Cut material was raked to one side and subsequently removed by tides. Follow-up herbicide applications were carried out six weeks later in August.

Industrial strength black plastic sheeting was cut into appropriately sized strips and laid out onto the plots during July 1998. Galvanised wire mesh was laid on top of the sheeting, extending beyond the edge of the plastic. Galvanised steel wire pegs were staked through the plastic and wire mesh to hold both layers in place. The plastic sheeting was removed in January 1999.

Records and analysis

The first data collection was carried out during July 1998, prior to the application of treatments. Recording was repeated in July 1999 and July 2000.

Every plot contained thirty-two 50 cm x 50 cm quadrats. Five randomly-drawn quadrats per plot were used to record live *S. anglica* stem density and Domin values of other plant species. Different quadrats were selected for each years recording. The number of live *S. anglica* stems in each quadrat were counted. The mean of the five stem density counts per plot was used to represent stem density of the plot, thus avoiding sacrificial pseudoreplication. The same five quadrats were used in each plot to estimate percentage cover of all plant species present excluding *S. anglica*. The mean percentage cover value from the five quadrats was calculated and converted into a Domin value for each species per plot.

For each year's results, Kruskal-Wallis tests were used to analyse differences between live *S. anglica* stem densities, and the abundance of saltmarsh plants, in the seven treatment groups (Sokal and Rohlf 1998). All statistical analysis was carried out using the statistical computer package SPSS Version 9.

RESULTS

Live *S. anglica* stem density

There was no significant difference between the mean live *S. anglica* stem density of the seven treatment groups prior to treatment application at both sites in July 1998. Significant differences (P, <0.001) amongst the live *S. anglica* stem densities of the treatment groups at each site were observed in July 1999 and July 2000 (Table 1).

The Dalapon, Cut + Dalapon, and Cut + Smothered treatments caused over 95% reductions in live *S. anglica* stem density at the Lough Foyle site between July 1998 and July 1999 (Table 1). The Cut, and Cut + Glyphosate treatments resulted in increases in stem density whilst the Experimental Control and Glyphosate treatments experienced reductions in stem density. By July 2000 the Cut + Smother treatments achieved over 90% reductions of live *S. anglica* stem density compared with pre-treatment levels. The live stem density levels within the Cut + Dalapon, and Dalapon treatments had increased between July 1999 and July 2000 resulting in approximately 60% reductions compared to pre-treatment levels. Stem densities also increased in the Experimental Control and Glyphosate treatments between July 1999 and July 2000. During the same time period the Cut + Glyphosate, and Cut treatments experienced reductions in live stem densities.

Table 1 Percentage changes in live *S. anglica* stem density between July 1998 (pre-treatment) and July 1999, and from July 1998 to July 2000 at Lough Foyle and Strangford Lough.

	Lough Foyle		Strangford Lough	
Treatment	1998 - 1999	1998 - 2000	1998 - 1999	1998 - 2000
Cut	+ 50.3	+ 1.7	- 2.0	+ 2.0
Cut + Dalapon	- 96.8	- 58.1	- 99.6	- 98.0
Cut + Glyphosate	+ 58.8	+ 10.6	- 25.4	- 11.3
Cut + Smother	- 98.9	- 90.3	- 99.9	- 99.9
Dalapon	- 96.3	- 57.5	- 95.8	- 92.3
Glyphosate	- 14.8	+ 69.1	- 52.2	- 30.0
Experimental Control	- 15.3	+ 45.3	- 52.6	- 50.1
Significant difference between groups	< 0.001***	< 0.001***	< 0.001***	< 0.001***

Significance level: *P<0.05, **P<0.01, ***P<0.001

The Dalapon, Cut + Dalapon, and Cut + Smother treatments caused over 95% reductions in live *S. anglica* stem density at the Strangford Lough site between July 1998 and July 1999 (Table 1). During the same time period the Experimental Control and Glyphosate treatments experienced approximately 50% reductions of live stem density, the Cut + Glyphosate treatment reductions of 25%, and the Cut treatment a reduction of 2%. By July 2000 the Cut + Smother, and Cut + Dalapon still had live *S. anglica* stem density reductions of over 95% compared to pre-treatment levels, whilst the Dalapon treatment had reductions of over 90%. The Experimental Control had similar live stem densities as July 1999 levels. The Glyphosate, Cut, and Cut + Glyphosate treatments all experienced an increase in live stem density between July 1999 and July 2000.

Abundance of other plant species

In the Lough Foyle sward individuals of *Aster tripolium*, *Plantago maritima*, and *Puccinellia maritima* were recorded in plots during July 1998, July 1999, and July 2000. An individual of *Chenopodium rubrum* was recorded in July 2000. There were no significant differences in the abundance of *A. tripolium*, *Plantago maritima*, and *C. rubrum* between treatment groups in any year. There were no significant differences in *Puccinellia maritima* abundance between the seven different treatment groups in July 1998 prior to treatment application (Table 2). In July 1999 (one year after treatment application), there was a significant difference between the treatments. Since July 1998 the largest reductions in median *P. maritima* abundance occurred in the Dalapon, Glyphosate, and the Cut + Smother treatments. In the Experimental Control plots, and the Cut + Dalapon plots, smaller reductions in median *P. maritima* abundance were noted. The only treatments in which median *P. maritima* abundance increased were the Cut + Glyphosate, and Cut treatments. In July 2000 (two years after treatment application), there was no significant

Table 2 Median *Puccinellia maritima* Domin scale abundance in Lough Foyle plots in July 1998, July 1999 and July 2000.

Treatment	*Puccinellia maritima* abundance		
	1998	1999	2000
Cut	3.5	5.5	4.5
Cut + Dalapon	1	0.5	1.5
Cut + Glyphosate	3	6	6.5
Cut + Smother	4.5	1	4
Dalapon	3	0	3
Glyphosate	5	2	3.5
Experimental Control	1.5	1	1
Significant difference between groups	0.340	0.013*	0.247

Significance level: *P<0.05, **P<0.01, ***P<0.001

difference in *P. maritima* abundance between the treatment groups. Most of the treatment groups experienced an increase in *P. maritima* abundance between July 1999 and July 2000, except the Experimental Control which remained similar to July 1999 levels and the Cut treatment which showed a decline in *P. maritima* abundance.

In the Strangford Lough sward *Puccinellia maritima* was recorded in only one experimental plot in July 1998, July 1999, and July 2000. There were no significant differences between *P. maritima* abundance between treatment groups in any year. No other species apart from *S. anglica* and *P. maritima* were recorded in the Strangford Lough plots during July 1998 or July 1999. In July 2000 low abundance values (maximum 1%-4% cover) of *Salicornia* spp. were recorded in the Dalapon, Cut + Dalapon, and Cut + Smother plots. There were no significant differences between *Salicornia* spp. abundance and treatment groups.

DISCUSSION

S. anglica eradication techniques

Herbicides are the most frequently used *Spartina* spp. control method due to their practical ease of use and cost-effectiveness. This study shows that when used in suitable conditions, Dalapon applied at a rate of 57 kg/ha will cause over 95% reduction in live *S. anglica* stem density within the first year. Glyphosate was as ineffective with similar live *S. anglica* stem densities as the Experimental Control plots after one year. Cutting had no additive effect when applied before Dalapon application in this experiment. Preliminary results of an experiment in Washington, U.S.A, using a single cut of *S. alterniflora*, followed by glyphosate application gave a similar outcome (Major and Grue 1997). The single Cut treatments produced the highest live stem density values at each site in this study. A single cut will therefore not assist with *S. anglica* eradication. At Lough Foyle, live *S. anglica* stem density in Cut plots was lower than the Experimental Control after two years. This may indicate that rhizome energy reserves were extensively used-up in the year following the cut. It has been suggested that multiple cutting may reduce *S. anglica* vigour and reduce above ground biomass (Scott *et al*. 1990), but it is also possible that certain cutting regimes would cause increases in stem density (Hubbard 1970). Smothering caused over 95% reductions in live *S. anglica* stem density within the first year of application.

The experimental treatments failed to achieve 100% kill of *S. anglica*. Eradication would require repeat applications of eradication treatments, possibly on many occasions. In this study *S. anglica* re-establishment was more rapid in the mid-elevation Lough Foyle sward compared to the low-elevation Strangford Lough sward. Ranwell and Downing (1960) reported the complete recovery of *S. anglica* within sprayed areas two years after Dalapon application, whilst Taylor and Burrows (1968) reported 88%-98% reductions in *S. anglica* stem density two years after Dalapon application. This suggests that site specific factors will influence *S. anglica* re-establishment rates after treatment applications. The rapid recovery of *S. anglica* in some sites suggests that treatment re-application should occur in the year following initial application of treatments. Site-specific factors are also probably responsible for the unexplained difference in live *S. anglica* stem density in the Experimental Control plots between study sites.

Effects of *S. anglica* eradication treatments on other saltmarsh species

Any plant species in the *S. anglica* dominated sward that is within the range of plants affected by an applied herbicide, is likely to be killed. Reductions in abundance of *Salicornia* sp., *Suaeda* sp., and *Puccinellia* sp. have been noted when glyphosate is applied to *S. anglica* swards (Garnett *et al.* 1992). In the present study both Dalapon and glyphosate caused reductions in *Puccinellia maritima* abundance at Lough Foyle. Smothering should kill all vegetation due to the exclusion of light. *P. maritima*, and *Salicornia* spp. have been killed by algal mats and tidal litter due to the effect of smothering (Jefferies *et al.* 1981; Langlois *et al.* 2001). *P. maritima* abundance declined in smothered plots at Lough Foyle between July 1998 and July 1999. During the second year of the study *P. maritima* was noted to increase in abundance at Lough Foyle in the Dalapon and Smothered plots. This indicates that substrate and environmental conditions remaining after *S. anglica* removal are suitable for colonisation by other species.

Cutting or grazing of *S. anglica* swards may promote the growth of other species such as *P. maritima* (Beeftink 1985; Scholten and Rozema 1990; Scott *et al.* 1990). *P. maritima* abundance increased at Lough Foyle in the Cut + Glyphosate, and Cut plots over the first year of this experiment. The reduction of *S. anglica* height caused by cutting allows increased light penetration within the canopy, thus improving the growth of other light dependent species (Scholten and Rozema 1990). There was no further increase in *P. maritima* abundance in the Cut, and Cut + Glyphosate plots during the second year of this investigation. This suggests that the opportunity for *P. maritima* spread was short-lived. *S. anglica* growth during the growing season would have increased the height of the *S. anglica* canopy, reducing light penetration and thus hampering further spread of the lower-lying *P. maritima*.

In this study colonisation of other species was at a low level, suggesting that seed input into treated areas from surrounding saltmarsh vegetation is low. Other studies suggest that saltmarsh species, such as *Salicornia* spp., form no long-term seedbank in substrates and that the majority of seeds of many saltmarsh species fall within centimetres of the parent plant (Jefferies *et al.* 1981; Gray and Scott 1977; Ellison 1987; Hartman 1988). The species that colonise will be dependent upon local environmental conditions in relation to the regeneration niche of the individual species (Beeftink 1985) and the abundance of adult plants of each species in surrounding areas (Rand 2000). In this study the elevation of the two swards influenced the colonising species. The low-elevation Strangford Lough was suitable for *Salicornia* spp. colonisation, whilst the mid-elevation sward at Lough Foyle was suitable for colonisation by *Aster tripolium*, *Plantago maritima*, and *Puccinellia maritima*. The persistence of any colonising species will be affected by its competitive ability against other saltmarsh species, especially in areas were *S. anglica* re-establishment after control is rapid. *Puccinellia maritima*, for example, will outcompete *S. anglica* in northern latitudes (in the northern hemisphere) in upper marsh elevations with sandy nutrient-rich sediments (Scholten and Rozema 1990; Huckle *et al.* 2000).

Considerations for *S. anglica* management in Northern Ireland estuaries

The 95% reduction in live stem density caused by Dalapon applications or smothering treatments in this study suggests that eradication of *S. anglica* is feasible if treatment applications are repeated. We advise that treatment re-application begins in the year following initial applications as *S. anglica* recovery can be rapid. Treatments may have to be repeated on several occasions to achieve successful eradication. Smothering has proven to be effective, but the practicalities, cost-effectiveness and environmental impacts of using large-scale smothering are untested. Herbicides are the most cost-effective and practical eradication methods, but glyphosate is not a suitable replacement for Dalapon. Attempts should therefore be made to find a suitable herbicide replacement for use in Northern Ireland estuaries, possibly by obtaining off-label permits. This process would take a number of years as toxicity studies, risk assessments, and cost/benefit analyses are required before the herbicide is permitted for use in Northern Ireland estuaries. Research from other countries suggests that the herbicides fluazifop-P-butyl, haloxyfop, and imazapyr are worthy of further investigation (Pritchard 1996; Shaw and Gosling 1996).

Several issues are likely to constrain the effectiveness of eradication attempts in Northern Ireland, such as limitations of economic resources, the abundance of *S. anglica* within estuarine systems, public objections, and legal restraints (cf. Kriwoken and Hedge 2000). In Northern Ireland there is currently a ban on the use of herbicides in shellfish designated areas; the result of a legal dispute that occurred after an experiment to eradicate *S. anglica* in 1980 (Kirby 1994). A local oyster farmer settled out of court after claiming that the removal of *S. anglica* resulted in the liberation of silt, which subsequently smothered and killed his oysters. In these areas only minimal herbicide application is permitted. It is therefore unlikely that *S. anglica* will be eradicated from Northern Ireland estuaries in the near future. An alternative management strategy of eradication from selected estuaries/areas and containment is needed.

Areas with no legal restraints against herbicide use, and areas with high environmental value such as wildlife reserves or heavily-used recreation areas could be targeted for eradication using herbicide. We suggest that an initial phase of eradication could focus on preventing *S. anglica* establishment into new areas, eradication of tussocks and clumps, and preventing expansion of sward areas (see Moody and Mack 1988). Once achieved, annual monitoring and removal of *S. anglica* seedlings is required to keep these areas free from *S. anglica* re-establishment. The possible long-term cost of this proposal should be considered in any future management scheme.

The next phase of eradication could focus on low-elevation *S. anglica* swards. These swards will be more prone to erosion after *S. anglica* removal than mid-high-elevation swards. Eradicated areas may erode to former mudflat levels within three years (McGrorty and Goss-Custard 1987), or be colonised with low-marsh vascular species such as *Salicornia* species. This is likely to result in mud flat that is suitable for use as feeding grounds for wildfowl and waders (McGrorty & Goss-Custard 1987). Continuous monitoring and removal of *S. anglica* seedlings would be required in these areas if *S. anglica* plants remain within the estuarine system. The next phase of eradication could focus on mid-high elevation swards. High-level marsh may require a period of up to 20 years to erode to low-elevation mudflat after *S. anglica* eradication (McGrorty and Goss-Custard 1987). During this time the area would be open to colonisation by other saltmarsh species and develop into saltmarsh, rather than mudflat.

In areas where *S. anglica* eradication is not feasible containment strategies are suggested. Initial attention could focus on preventing further spread of *S. anglica*, especially into sites of environmental importance. Herbicides can be used in any area where they are permitted. Smothering may be suitable for killing small-scale *S. anglica* infestations in areas where herbicide use is banned, but will probably be unsuitable for large sward areas. It may also be possible to use control techniques, such as cutting, to encourage colonisation by, and growth of, other saltmarsh species within *S. anglica* swards, in order to promote the development of a mixed saltmarsh community. *Salicornia* spp. are the most likely colonisers of low-elevation sites. If *S. anglica* regrows it will outcompete *Salicornia* spp. (Beeftink 1985; Ellison 1987), and this could result in the area returning to mono-dominant *S. anglica* sward.

The lack of seed arriving into the controlled areas is likely to be a major factor in hampering the conversion of *S. anglica* swards into mixed saltmarsh communities (Hartman 1988; Rand 2000). There have been no studies that examine attempts to increase the abundance of native saltmarsh species within *S. anglica* swards. It may, however, be possible to overcome the lack of seed input into the area by using species transplants or seed additions. This alternative management method requires further investigation to evaluate its potential success.

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