NOTE

Precipitation during El Niño correlates with increasing spread of *Phragmites australis* in New England, USA, coastal marshes

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ABSTRACT: The grass *Phragmites australis* has historically been restricted to the relatively benign upper border of coastal marshes, but over the past century, and particularly in recent decades, it has been spreading aggressively in New England throughout brackish and salt marshes with high soil salinities that are physiologically stressful to the plant. Here I tested the hypothesis that variations in climatic conditions, particularly increased precipitation during the 1997-98 El Niño event, buffer harsh abiotic conditions and enhance the performance of this nuisance species. I monitored the growth and reproductive output of *P. australis* in the year before, during, and after the 1997-98 El Niño in coastal brackish marshes of southern New England, USA. During the El Niño year, *P. australis* produced on average 30% more shoots, which were 25% taller, and yielded an order of magnitude more inflorescences than in the other 2 years. Soil porewater salinities were negatively related to precipitation during the 3 years of the study, and the growing season during the El Niño year was one of the wettest of the past century. Consequently, increased precipitation during El Niño may facilitate the spread of less salt-tolerant nuisance and invasive species throughout brackish and salt marshes.

KEY WORDS: Coastal marshes · El Niño · Global climate change · Invasive species · La Niña · *Phragmites australis* · Salinity · Temperature

Climatic changes associated with the El Niño Southern Oscillation have biological consequences for a diversity of taxa in both marine and terrestrial habitats (Glynn 1990, Dayton et al. 1999, Holmgren et al. 2001). In stressful terrestrial environments such as deserts, seed production, recruitment, and growth of plants have all been linked to variations in rainfall due to El Niño (Holmgren et al. 2001). The impacts of El Niño on species in estuarine habitats such as coastal marshes have rarely been investigated, yet plants in these environments, which are characterised by thermal stress and high soil salinity, may be particularly susceptible to climatic extremes.

Over the past century, and particularly in recent decades, the grass *Phragmites australis* (Cav.) Trin ex Steud (often called 'common reed' and hereafter termed *Phragmites*) has been aggressively invading coastal marshes of North America, often displacing other marsh plants and forming extensive monospecific stands (Marks et al. 1994, Tiner 1997, Chambers et al. 1999, Meyerson et al. 2000). There is concern that the continued expansion of *Phragmites* will dramatically alter the structure and function of coastal marsh ecosystems. Historically, *P. australis* has been a minor component of the assemblage of plants along the relatively benign upper border of freshwater and brackish marshes (Niering et al. 1977, Clark 1986, Orson et al. 1987), whereas now it is expanding into more physiologically stressful sectors, including more seaward areas of brackish marshes and along the upper border of salt marshes. One explanation for the recent expansion is that hydrological changes resulting from urban and agricultural development have reduced stressful salinity conditions of the soil, creating an environment suitable for *Phragmites* (Niering & Warren 1980, Roman et al. 1984, Hellings & Gallagher 1992, Chambers et al. 1998, Burdick et al. 2001), although evidence suggests the recent introduction of a non-native genotype morphologically similar to the native *Phragmites*, but with tolerance to a wider range of environmental conditions (Saltonstall 2002). Whether native or introduced, episodic climatic events such as increased precipitation during El Niño are expected to enhance the growth of *Phragmites* by reducing salinity stress (Zedler 1983, Allison 1992, 1996).

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Here I report the results of field surveys where I measured the performance of *Phragmites* in 2 brackish marshes in southern New England, USA, at the end of 3 growing seasons before, during, and after the 1997-98 El Niño event, which was one of the 2 strongest El Niño events of the past century (Wolter & Timlin 1998). I tested the hypothesis that the vegetative growth and reproductive output of *Phragmites* is greater in the El Niño year than in the other 2 years, and that these differences are linked to variations in air temperature and precipitation. Results showed that the El Niño year had one of the wettest growing seasons of the past century and a corresponding dramatic increase in the performance of *Phragmites*. Determining how climatic conditions affect invasive species will help to predict their patterns of spread and interactions with native species.

Methods. I monitored the performance of *Phragmites* from April 1997 to September 1999 at 2 coastal brackish marshes, one along the Runnins River (41° 47' N, 71° 20' W) in East Providence, Rhode Island, and the other about 4 km away along the Palmer River (41° 47' N, 71° 16' W) in Rehoboth, Massachusetts. These marshes

are located in developed suburban environments, and are comprised of typical plant assemblages of brackish and salt marshes in southern New England (e.g. Niering & Warren 1980, Tiner 1987). The marshes experience semi-diurnal tides with a maximum range of about 2.4 m, and water salinities vary from 0 to 30 (unpubl. data). *Phragmites* is a clonal grass with annual shoots and perennial rhizomes that spreads primarily by vegetative growth to form monospecific stands along the upper border of brackish and salt marshes (Haslam 1972, Niering & Warren 1980, Meyerson et al. 2000). Rhizomes grow primarily during autumn (September to November), and associated buds that give rise to new shoots may develop at almost any time of the year (Haslam 1969a). In southern New England, shoots emerge and grow mainly in spring and early summer (April to June), reach a maximal height and develop inflorescences and seeds at the end of the growing season in late summer or early autumn (August or September), and then senesce (Tiner 1997, Meyerson 2000). While *Phragmites* is considered a nuisance species in regions of North America (Marks et al. 1994, Tiner 1997, Chambers et al. 1999), it is valued in
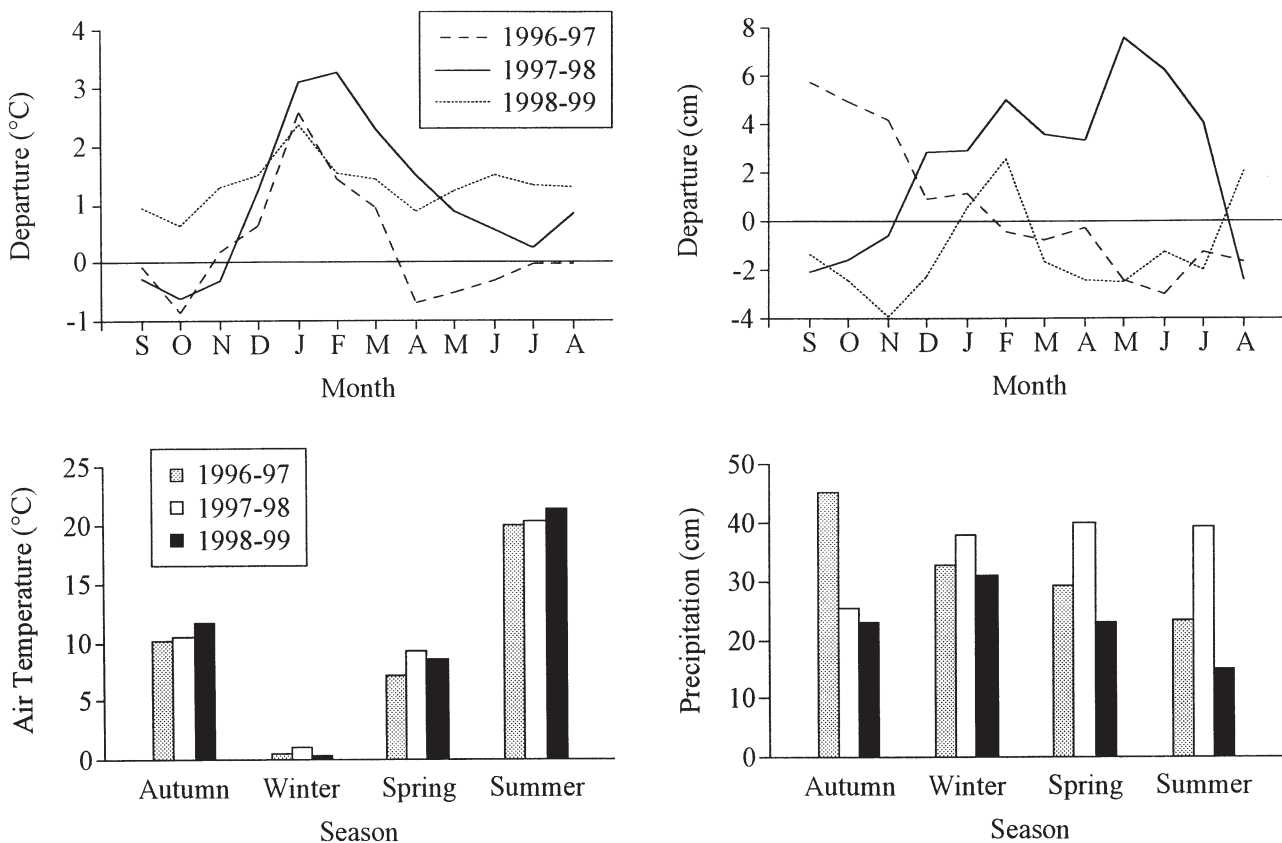

Fig. 1. Temperature and precipitation averages for Rhode Island and Massachusetts in the 1996-97 neutral year, the 1997-98 El Niño year, and the 1998-99 La Niña year. Top: departures from long-term averages for the past 105 years in the monthly means of air temperature (left) and precipitation (right). Bottom: mean air temperatures (left) and total precipitation (right) from autumn (September to November) of one year to the winter (December to February), spring (March to May), and summer (June to August) of the next

Europe where there is concern over its recent die-back (van der Putten 1997; but see Güsewell & Klötzli 1998 for concern over the expansion of *Phragmites* in the fen meadows of Switzlerland).

   At the end of the growing seasons of 1997, 1998 and 1999, I quantified the vegetative growth and reproductive output of *Phragmites* in 3 quadrats randomly located along each of 2 stands at the upper border of each marsh. This yielded a hierarchical sampling design, with 2 stands nested within each of 2 marshes. Quadrats (3 m^2 at Runnins, 1.5 m^2 at Palmer) were located along the edges of the stands where *Phragmites* is spreading seaward into the marsh dominated by a mixture of the rush *Juncus gerardi* and the grasses *Spartina patens* and *Distichlis spicata* (Tiner 1987). In each quadrat, I counted the number of shoots that emerged during the growing season and the number with inflorescences, and measured the heights of 20 randomly selected shoots. At roughly monthly intervals during the growing season in all 3 years, I measured soil porewater salinity at the marsh surface (0 to 5 cm depth) at several sites along the upper border of each marsh using a handheld refractometer. I obtained climatic data from the Northeast Regional Climate Center, National Oceanic and Atmospheric Administration (http://met-www.cit.cornell.edu). Raw data are presented as well as departures (averaged for Rhode Island and Massachusetts) in the monthly means of air temperature and precipitation from long-term averages for the past 105 yr. To highlight seasonal trends, I smoothed the data with a 3 month running mean comprising the month presented and the previous and following months.

   Results. Extreme air temperatures and precipitation characterized the 1997-98 El Niño year from winter until early summer (Fig. 1). The winter and spring seasons during El Niño were among the 10 hottest and wettest of the past 105 yr. Climatic conditions in 1998-99, which was a La Niña year, were also severe, with above-average air temperatures and below-average precipitation (Fig. 1). In contrast to the El Niño year, the spring and summer growing seasons experienced drought, and the summer during La Niña was the third-hottest and eighth-driest of the past 105 yr. Climate during 1996-97, which was a neutral year, was less extreme, but still exhibited a wet autumn, a mild winter similar to the El Niño and La Niña years, and a dry spring and summer, as in the La Niña year (Fig. 1). Simple linear regression showed that square-root-transformed estimates of soil porewater salinity (range = 1 to 39; median = 17; mean ± SD = 18 ± 10; n = 41) in one month were negatively related to total precipitation (r^2 = 0.68, p < 0.001, n = 41) and positively related to average air temperatures (r^2 = 0.22, p < 0.01, n = 41) in the previous month.
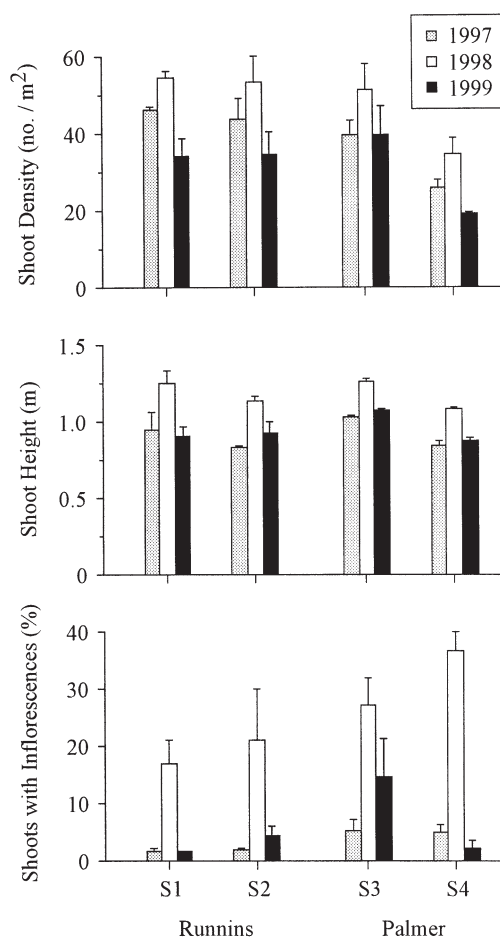

Fig. 2. *Phragmites australis*. Density, height, and percentage of shoots with inflorescences (means ± SE) at the end of the growing season for each of 2 stands of *Phragmites* in each of 2 marshes in 1997 (1996-97 neutral year), 1998 (1997-98 El Niño year), and 1999 (1998-99 La Niña year)

   Stands of *Phragmites* produced about 25% more shoots in 1998 than in 1997, and this density was reduced by about 35% in 1999 (Fig. 2, Table 1). Shoots in 1998 were on average about 25% taller than those in 1997 or 1999. Similar to the absolute density of inflorescences (no. m^{-2}) produced in each year (1997: 1.3 ± 0.29; 1998: 11.5 ± 1.11; 1999: 1.8 ± 0.71; n = 12, mean ± SE), the percentage of shoots with inflorescences in 1998 was on average 5 and 7 times greater than those produced in 1999 and 1997, respectively. Differences in the performance of *P. australis* among years were consistent despite variation in the densities and heights of shoots among stands and in the percentage of shoots producing inflorescences between marshes (Fig. 1, Table 1).

   Discussion. The performance of *Phragmites* was linked to climatic variations associated with the El Niño Southern Oscillation. Precipitation, and associated freshwater run-off, appears to be an important

Table 1. *Phragmites australis*. ANOVA of shoot density (natural logarithms), height, and percentage with inflorescences at the end of the growing season for each of 2 stands of in each of 2 marshes in 1997 (1996-97 neutral year), 1998 (1997-98 El Niño year), and 1999 (1998-99 La Niña year). Year is a fixed factor, marsh is a random factor, and stand is a random factor nested within a marsh. Outcomes of Student-Newman-Keuls multiple comparisons tests (SNK; p < 0.05) for the effect of year are given in the last row. ns = not significant; * = p < 0.05; *** = p < 0.001

Source	df	Density MS	Density F	Height MS	Height F	Inflorescences MS	Inflorescences F
Year: Y	2	0.605	42.4*	2525.0	51.25*	1744.9	23.64*
Marsh: M	1	0.645	1.13 ns	57.3	0.06 ns	474.7	30.73*
Stand (M): S(M)	2	0.570	13.25***	881.5	10.70***	15.4	0.35 ns
Y × M	2	0.014	0.61 ns	49.3	1.10 ns	73.8	0.80 ns
Y × S(M)	4	0.023	0.55 ns	44.8	0.54 ns	92.5	2.10 ns
Residual	24	0.043		82.4		44.1	
SNK for year		98 > 97 > 99		98 > 99 = 97		98 > 99 = 97	

climatic parameter influencing the spread of *Phragmites* because production (i.e. density and height of shoots) and reproductive output were greater during the extremely wet El Niño year than during the other 2 years, which were characterized by dry conditions, particularly the La Niña year when there was drought. The strong negative relationship between precipitation and soil salinity suggests that the increased performance of *Phragmites* during the wet El Niño year might have been due to freshwater input ameliorating stressful salinity conditions, which have been observed to reduce the growth of *Phragmites* (Hellings & Gallagher 1992, Lissner & Schierup 1997, Chambers et al. 1998, Burdick et al. 2001). Other correlated factors that might also affect the growth of *Phragmites*, such as increased sedimentation due to freshwater run-off, cannot be ruled out (Allison 1996). The spring and summer growing season, rather than autumn when rhizome extension and bud formation occurs, appears to be the critical period when climatic conditions affect the performance of *Phragmites* (Zemlin et al. 2000). A warm and wet winter may also promote the emergence and growth of *P. australis*, but all 3 winters were extremely mild, so this is difficult to ascertain. In contrast, air temperatures were positively related to soil salinity and, therefore, the high air temperatures during the growing season of the El Niño and La Niña years might have reduced the performance of *Phragmites* by increasing evaporation and, consequently, soil salinity. In more freshwater habitats, high air temperatures have been shown to increase the growth of *Phragmites* (Haslam 1969b, Zemlin et al. 2000). The influence of air temperature on *Phragmites* may, therefore, be positive when accompanied by heavy precipitation, as in the El Niño year, and negative during drought conditions, as in the La Niña year.

Climate change, particularly increased precipitation due to El Niño, is unlikely to be the cause of the recent expansion of *Phragmites* throughout North American marshes. The widespread invasion of *Phragmites* may be due to a new, introduced genotype, which is likely to be prevalent in southern New England (Saltonstall 2002). Nevertheless, results here indicate that, whatever the cause, increased precipitation during El Niño may further accelerate the regional spread of *Phragmites*. Although this study was only done over 3 years surrounding a single El Niño event, the strong differences in climatic conditions among years (particularly the levels of precipitation between the El Niño year and the other 2 years) and the corresponding dramatic changes in the performance of *Phragmites* present strong evidence for a link between El Niño, precipitation, and the spread of *Phragmites*. Indeed, the performance of *Phragmites* was consistent across stands separated by tens to hundreds of metres and marshes separated by kilometres, suggesting a regional effect of climate. Climatic variations appear to contribute to the regional expansion of this nuisance species by increasing the probability that wind-dispersed seeds will colonise neighbouring marshes and that vegetatively expanding shoots will displace existing marsh plants. Therefore, climate may alter the intensity of ecological interactions between native and invasive species (Bertness & Ewanchuk 2002). With the increase in the frequency, strength, and duration of El Niño events in recent, and perhaps coming, decades (Trenberth & Hoar 1996, Fedorov & Philander 2000), a shift in the species composition of coastal marshes from diverse assemblages to monospecific stands of *P. australis* may arrive sooner than anticipated (Chambers et al. 1999, Windham & Lathrop 1999, Keller 2000, Meyerson et al. 2000).

Precipitation and freshwater pulses, such as those during El Niño, have a regional influence on the demography of plants in terrestrial habitats (Holmgren et al. 2001) and can influence the assemblage structure of plants in salt marshes (Zedler 1983, Allison 1992, 1996). Brackish and salt marshes may be particularly susceptible to invasion by less salt-tolerant nuisance and invasive species during El Niño or other episodic climate events (Zedler 1983, Allison 1992, 1996, Dukes & Mooney 1999). At these times, managers of coastal marshes should be particularly vigilant in their efforts to detect colonisation by such species. Determining how changes in the demography of invasive species and their ecological interactions with other members of

the species assemblage are affected by these climatic episodes may not only help in the management and control of problem species, but may also provide a window of insight into the future consequences of global climate change.

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