

Increasing status of non-native vascular plants in the Sefton Coast sand-dune system, north Merseyside, UK

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Abstract

Over 460 non-native (alien) taxa were recorded in a Sefton Coast sand-dune vascular plant inventory, their proportion in the flora increasing after 1999. Between 2005/06 and 2018, twice as many non-native as native plants were found. An analysis of occurrences of native and non-native taxa in six major habitat types found that a higher proportion of aliens was present in scrub/woodland and disturbed ground, while native plants had more occurrences in fixed dunes/dune grasslands, dune heath and wetlands. No differences between the two groups were detected for strandline/shingle and embryo/mobile dune habitats. Twenty-four non-native and 14 native taxa showed invasive characteristics in the duneland. The former included especially *Hippophae rhamnoides* and *Rosa rugosa*, both constituting major threats to sand-dune biodiversity. Particularly invasive native plants were *Arrhenatherum elatius*, *Betula* spp., *Salix cinerea*, and *Ulex europaea*. The main findings accord with studies elsewhere in Britain and Europe showing recent increases of neophytes in semi-natural habitats and that both non-native and native species can have invasive traits. The open habitats of coastal dunes seem to be particularly susceptible to plant invasions.

Key words: alien plants; garden escapes; invasive; Japanese rose; neophytes; sea buckthorn

Introduction

Non-native (alien) plants have attracted increasing interest in recent decades. Some species are highly invasive, contributing to globally significant environmental problems (Chytry *et al.*, 2008), while most are “common, conspicuous, pestiferous, beautiful, edible and otherwise useful or harmful” (Stace & Crawley, 2015). The latter authors remarked that alien plants add considerably to a rather limited British flora, contributing 2068 vascular taxa, or 59% of the total. About 1809 of these were considered neophytes or neonatives, of which 1138 (63%) were naturalised, 342 (19%) casuals and 329 (18%) survivors. Only 57 (5%) were deemed invasive. In addition, at least 2000 plants were beyond the scope of that study, having not been recorded since 1986 or only known as rare casuals. Preston *et al.* (2002) noted a marked increase in the distribution of neophytes in the British Isles from 1930 to 1999, though their analysis

probably underestimated the spread, as many species were not mapped in the 1962 Atlas and a “surprisingly large number” had become frequent in Britain.

Crawley *et al.* (1996) reported a clear declining trend of alien species-richness from Southern England (75% of the flora) northwards and westwards to northwest Scotland (13%). Nevertheless, Savidge *et al.* (1963) considered that the large number of non-native plants recorded in South Lancashire (v.c.59) in the previous 100 years was a “striking feature” of the flora. They cited 635 angiosperm introductions (45% of the flora) but also noted that only 22 (3%) had become common weeds, recorded from over 50 localities.

A more recent analysis of the non-native flora in Northwest England by Greenwood (1999) found a total of 685 taxa for v.c.59, of which 266 (39%) were naturalised and 419 (61%) casuals. He also pointed to an increasing proportion of non-native plants in the recorded flora, from 8% before 1830 to 44% between 1930 and 1979, a rate of addition of between one and two taxa per year. Greenwood suggested that this increase was almost entirely due to human activity, especially escapes from gardens, followed by medicinal and culinary herbs and plants grown in aquaria. Crop escapes were less important, a conclusion also supported by Crawley *et al.* (1996). Some habitats may be more susceptible to invasion by non-native plants. Thus, Crawley *et al.* (1996) claimed that British coastal dunes had high numbers of them, especially close to towns, while Stace & Crawley (2015) described sand-dunes as “a focus for alien plant establishment”. Similarly, Chytry *et al.* (2008) found that the greatest proportion of non-native plants in Catalonia, the Czech Republic and Great Britain occurred in man-made and coastal habitats. Carboni *et al.* (2010) noted that Italian dunes had a high susceptibility to alien plant invasion, especially near to human settlements containing propagule sources.

The largest sand-dune system in England (2100 ha) is situated on the Sefton Coast, north Merseyside, extending for about 20 km between the estuaries of the Mersey and Ribble. It supports an exceptionally rich vascular flora (Smith, 2009) which, by 2008, comprised 1143 vascular taxa of which 405 (35.4%) were introduced (Smith, 2010). The latter suggested that the number of neophytes becoming established in the dunes was increasing and, although most had a low impact, a small number of invasive aliens was causing actual or potential ecological problems. Edmondson (2010a) found that the main sources of non-native plants in this dune system were deliberate plantings of woody species in the past for commercial purposes and dune stabilisation works, dumping of garden waste and propagules washed onto the shore by tides.

An inventory of vascular plants for the Sefton Coast sand-dune system, initially compiled as a draft in 1999, completed in 2005 (Smith, 2006) and updated annually to 2019, provides an opportunity to examine trends in the numbers and proportion of non-native taxa, including invasive species, together with their preferred habitats, over a time-scale of 20 years.

Methods

The Sefton dune system was defined by the extent of blown sand deposits shown on the regional soil-map (Hall & Folland, 1967). This included most of several golf-courses

but not built-up areas and some intensively farmed land on the eastern fringes. The study covered all duneland statutorily and non-statutorily designated for its nature conservation interest (Sites of Special Scientific Interest, Special Areas of Conservation and Local Wildlife Sites).

Lists of vascular plants (species subspecies and hybrids), including non-native taxa, reliably identified in the dune system, were compiled from a variety of sources (Smith, 2015). Non-native or introduced native taxa included both archaeophytes and neophytes as defined in Preston *et al.* (2002). Neophytes and neonatives added since 2005/06 were defined as naturalised, casual or survivor taxa by reference to Stace & Crawley (2015). A Student's t-test was used to investigate differences between numbers of native and non-native plants found each year.

Occurrences of native and alien plants were ascribed to one or more of ten major habitats: strand-line/shingle, mobile (white) dune, fixed (grey) dune, dune scrub, dune woodland, dune heath, dune wetland, (seasonally flooded slacks, scrapes and ditches) and "disturbed ground", the latter including sites impacted by tipping of garden waste and land damaged or opened up by human trampling, vehicle use, development and agriculture. Chi-square tested the differences between occurrences of native and non-native taxa in the major habitat types.

Based on personal observations over a period of 50 years, it was possible to identify both native and non-native taxa showing invasive traits in the dune system. Stace & Crawley's (2015) definition of invasive species was used, namely those that attain a substantial proportion of the biomass of the invaded plant community. Nomenclature followed Stace (2019).

Results

By 2019, a total of 467 non-native vascular plants had been recorded on the Sefton dunes, 223 (48%) of them being considered naturalised, most of the remainder being casuals. Fig. 1 shows the relationship between number and time since 1999 for natives and non-natives. The trends for both are similar, showing an increase but with a gradual reduction in the rate of addition of new plants. Changes in the proportion of non-native taxa over time are shown in Fig. 2. There was an increase from about 26% aliens in 1999 to 38% in 2019, the rate of addition gradually levelling off.

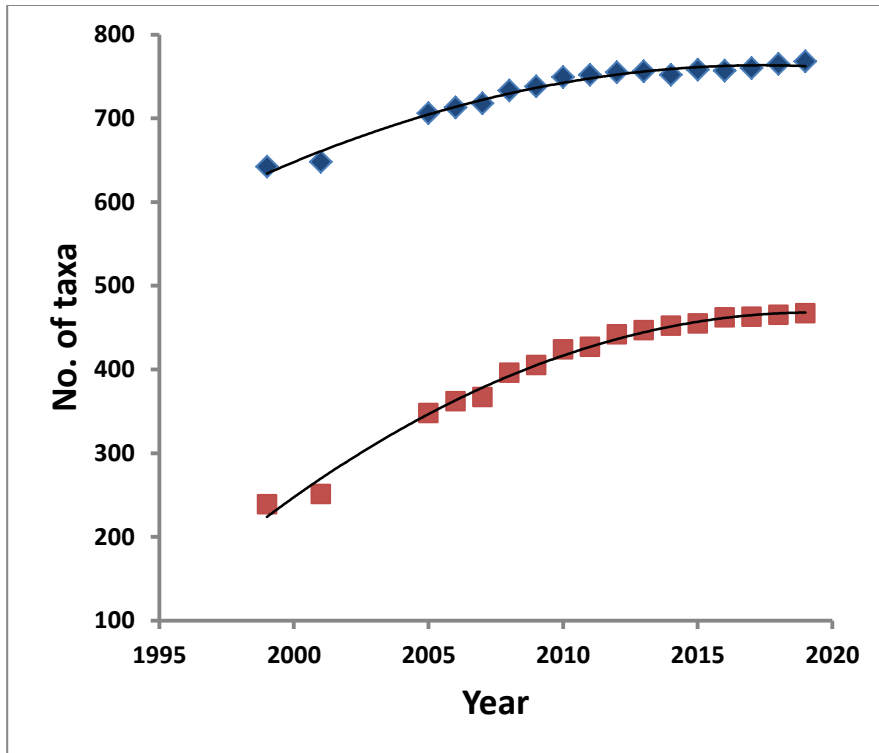


Figure 1. Number of native (blue) and non-native taxa (red) in the vascular plant inventory for the Sefton dune system, 1999-2019.

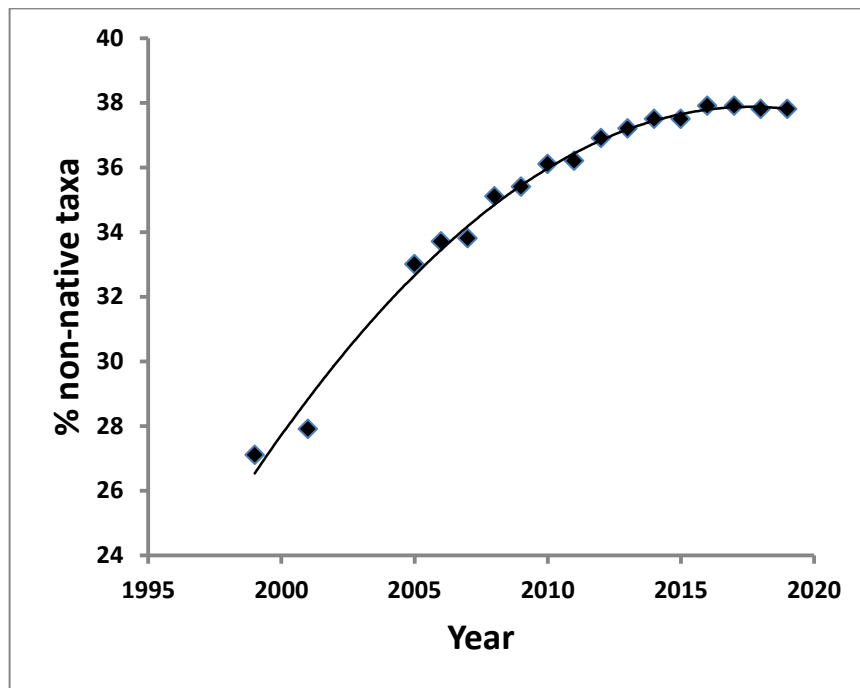


Figure 2. Changes in the proportion of non-native taxa over time in the vascular flora.

Table 1 shows the numbers of new native and non-native taxa found between 2005/06 and 2018. The annual number ranged from 0 to 6 for natives and 2 to 15 for non-natives, means of 3.2 and 6.3, respectively, being added per year. There is a significant difference between the means ($t = -2.58$; $p = 0.0079$). Only 10 (11.4%) of the non-natives were naturalised, as defined by Stace & Crawley (2015), a majority (47%) being casuals, while 17% were survivors. This leaves 21 taxa, 10 of which were listed as archaeophytes. The remaining 11 taxa were not tabulated by Stace & Crawley (2015), being amongst the 2000 rare casuals or survivors excluded from their work. The rate of addition of new alien plants declined during this period (Fig. 3).

Table 1. Numbers of new native and non-native vascular taxa added to the dune inventory each year from 2005/06 to 2019.

Year	Native	Non-native	Year	Native	Non-native
2005/06	6	14	2013	0	6
2007	6	7	2014	1	2
2008	5	9	2015	4	5
2009	4	7	2016	3	7
2010	3	5	2017	1	3
2011	3	3	2018	3	3
2012	3	15	2019	3	2
			Total	45	88
			Mean per annum	3.2	6.3

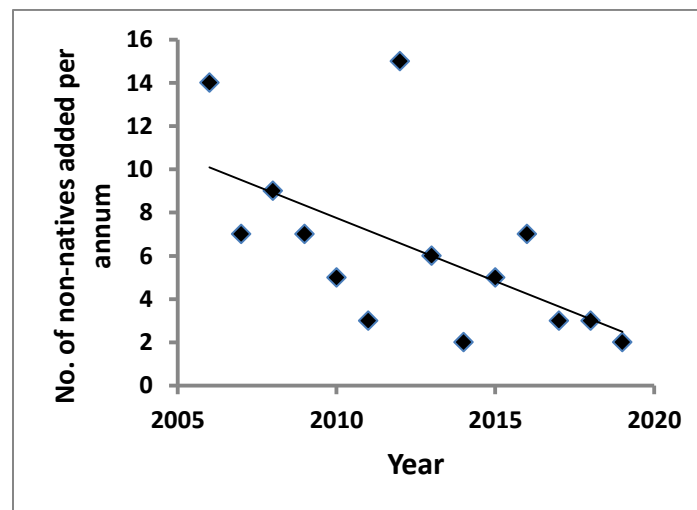


Figure 3. Numbers of non-native plants added per annum ($r = -0.599$, $p = 0.024$).

An analysis of occurrences of native and non-native taxa in the major habitats is shown in Table 2. Because the observed value for non-native occurrence in embryo

dunes was less than 5, this habitat was combined with strandline/shingle for Chi-square tests, the results being summarised as follows:

- There was no difference in the occurrences of native and non-native plants in strandline/shingle and in embryo/mobile dune habitats.
- Native plants had higher occurrences than non-natives in fixed dune and dune grassland habitats.
- A higher proportion of aliens than natives occurred in dune scrub and woodland.
- More natives than non-natives were associated with dune heath.
- Dune wetlands had a much lower proportion of non-native than native taxa.
- A much higher proportion of alien than native plants was associated with disturbed ground.

Table 2. Numbers and proportion of native and non-native (alien) vascular plants associated with major habitats in the Sefton Coast sand-dunes. Note that many taxa occur in more than one major habitat type.

Habitat	Native occurrences	%	Non-native occurrences	%	Total	χ^2	Prob.
Strandline/shingle	20	2.1	6	1	26	2.4	0.12
Embryo dunes	8	0.8	1	0.2	9		
Mobile (white) dunes	11	1.2	15	2.6	26	0.30	0.58
Fixed (grey) dunes	166	17.4	77	13.4	242	4.57	0.03
Dune grassland	120	12.6	18	3.1	138	38.7	≤0.001
Dune scrub	64	6.7	84	14.7	148	25.9	≤0.001
Woodland	71	7.3	64	11.2	134	5.8	0.016
Dune heath	45	4.7	7	1.2	52	13.3	0.0003
Dune wetland (slacks, scrapes and ditches)	277	28.9	35	6.1	310	124.4	≤0.001
Disturbed ground	174	18.2	267	46.5	440	138.9	≤0.001
Total	956		574		1525		

Table 3 lists the 24 non-native and 14 native plants judged to show invasive characteristics in the Sefton dunes. They represent 5% of the alien and 2% of the native flora, respectively. Nine of the invasive non-natives are woody plants, including *Pinus* spp. (pine) and *Populus* spp. (poplar), mostly introduced in the 19th century for commercial forestry or sand-fixing purposes. Pine plantations currently cover about 254 ha out of a total of 359 ha of designated woodland on the Sefton Coast (Anon, 2013). Seedlings and young trees of *Pinus* spp. were found colonising fixed dunes and dune heath (Fig. 4), while *Populus alba* (white poplar) and *P. xcanescens* (grey poplar) have produced extensive areas of secondary woodland since the 1970s, especially on fixed dunes at Birkdale Sandhills Local Nature Reserve (LNR) (Fig. 5). Other non-native tree-species, such as *Acer pseudoplatanus* (sycamore), *Alnus incana* (grey alder) and *Populus xjackii* (balm-of-Gilead) were also found to be important components of these

mixed secondary woodlands, presently occupying about 105 ha (5%) of the dune system (Anon, 2013).



Figure 4. *Pinus* invasion of dune heath at Freshfield.



Figure 5. Young secondary woodland of *Populus x canescens* with *Rubus fruticosus* (bramble) understory at Birkdale Sandhills LNR.

Table 3. Native and non-native vascular plants showing invasive traits in the Sefton Coast dune system (A = abundant; LA = locally abundant; VLA = very locally abundant; LD = locally dominant; O = occasional; R = rare).

<u>Native</u>		<u>Non-native or introduced native</u>	
Taxon	Frequency	Taxon	Frequency
<i>Alnus glutinosa</i>	LA	<i>Acer pseudoplatanus</i>	A
<i>Arrhenatherum elatius</i>	A	<i>Alnus incana</i>	O
<i>Betula pendula</i>	A	<i>Cerastium tomentosum</i>	LA
<i>Betula pubescens</i>	LA	<i>Clematis vitalba</i>	LA
<i>Calamagrostis epigejos</i>	VLA	<i>Crassula helmsii</i>	R
<i>Chamaenerion angustifolium</i>	A	<i>Euphorbia cyparissias</i>	LA
<i>Hedera hibernica</i>	LA	<i>Fallopia baldschuanica</i>	O
<i>Rubus fruticosus</i> agg.	A	<i>Hippophae rhamnoides</i>	A
<i>Phragmites australis</i>	LA	<i>Hyacinthoides ×massartiana</i>	LA
<i>Rubus tuberculatus</i>	A	<i>Impatiens glandulifera</i>	VLA
<i>Salix cinerea</i> ssp. <i>oleifolia</i>	A	<i>Lathyrus latifolius</i>	LA
<i>Salix repens</i>	A	<i>Myriophyllum aquaticum</i>	VLA
<i>Typha latifolia</i>	LA	<i>Pinus contorta</i>	LA
<i>Ulex europaeus</i>	LA	<i>Pinus nigra</i> ssp. <i>laricio</i>	LD
		<i>Populus ×canescens</i>	LA
		<i>Populus ×jackii</i>	A
		<i>Populus alba</i>	A
		<i>Reynoutria ×bohemica</i>	O
		<i>Reynoutria japonica</i>	O
		<i>Rosa rugosa</i>	LA
		<i>Sedum album</i>	LA
		<i>Solidago canadensis</i>	LA
		<i>Symphotrichum ×salignus</i>	LA
		<i>Symphotrichum novi-belgii</i>	LA
Total taxa 14		24	

Native on the east coast of Britain, *Hippophae rhamnoides* (sea buckthorn) (Fig. 6) was planted here in the 1890s by the former manorial estates to reduce sand-blow and as a means of excluding trespassers from private duneland (Walmesley-Cotham, 1935). The great reduction in rabbit (*Oryctolagus cuniculus*) numbers from the late 1950s onwards, due to disease, coincided with this shrub spreading through much of the dune system (Edmondson, 2010a; Smith, 2009). Atkinson & Houston (1993) quoted an “explosive spread” of *H. rhamnoides* in the slacks of Ainsdale Sand Dunes National Nature Reserve (NNR) in the period from 1960 to 1976. In three of the most invaded areas of duneland, total scrub area increased from 7.7 to 45.3 ha between 1945 and 1985, most of this being *H. rhamnoides* (Smith, 2009).



Figure 6. Dense, fruiting *Hippophae rhamnoides*, Birkdale Common.

With the exception of the aquarists' throw-out, *Crassula helmsii* (New Zealand pigmyweed), other invasive non-natives are garden-escapes. The most concerning of these is *Rosa rugosa* (Japanese rose) (Fig. 7), a 2014 survey recording 500 patches on the coast with a total area of nearly 6 ha (Smith & Deed, 2019). Boardman & Smith (2016) found that a sample of larger patches was growing in area at a rate of over 20% per annum, doubling in size every 4-5 years. The perennial herb, *Lathyrus latifolius* (broad-leaved everlasting-pea) is another potential problem species. First recorded at Waterloo, South Sefton, in about 1900 (Savidge *et al.*, 1963), it was not found during a 1988 UK National Vegetation Classification (NVC) survey of the dune system (Edmondson *et al.*, 1988/89) but was present in four out of 23 units surveyed for the second survey in 2004 (Gateley & Michell, 2004). Since then, *L. latifolius* has spread rapidly in mobile and semi-fixed dunes, with records in 20 out of 25 Sefton coastal tetrads in the *new flora of South Lancashire* database (D.P. Earl, personal communication). During the current study, extensive patches of *L. latifolius* were found (Fig. 8), especially at Ainsdale and Birkdale LNRs, one covering about 1 ha. Another garden-escape, *Symphotrichum* spp. (Michaelmas-daisy), was found to be widespread in the fixed dunes, a patch at Hightown dunes measuring 30 m in diameter.



Figure 7. *Rosa rugosa*, Birkdale frontal dunes.



Figure 8. *Lathyrus latifolius* spreading on the Ainsdale dunes.

Other invasive non-natives were more locally distributed, *Cerastium tomentosum* (snow-in-summer), *Fallopia baldschuanica* (Russian vine), *Reynoutria* spp. (knotweed), *Sedum album* (white stonecrop) and *Solidago canadensis* (Canadian goldenrod) forming

occasional dense, spreading patches, especially in fixed dunes and dune grassland or on the edges of scrub patches, while the extent of *Hyacinthoides ×massartiana* (hybrid bluebell) increased in areas of dune scrub and secondary broad-leaved woodland. *Clematis vitalba* (traveller's-joy) is regarded as non-native in South Lancashire (Fitzgerald, 2002; Savidge *et al.*, 1963). It was largely confined to about 10 ha of semi-fixed and fixed dune habitat north of Shore Road, Ainsdale, where it has been known since 1938 (Savidge *et al.*, 1963). In the last decade, it has increased markedly. *Euphorbia cyparissias* (cypress spurge) is mainly restricted to Hightown dunes where it has been naturalised for over 40 years (personal observations). Recently, it has begun to spread, being recorded as abundant in about 1 ha of dune grassland (Fig. 9).



Figure 9. Invasive *Euphorbia cyparissias* at Hightown dunes.

Of the 14 native taxa considered invasive, five are trees or shrubs. In recent decades, *Betula* spp. (birch) invaded fixed dunes, dune grasslands and dune heath, especially where pine plantations created shelter from prevailing winds (Fig. 10), as on Ainsdale NNR (Wheeler *et al.*, 1993). *Betula* and *Rubus* (bramble) spp. frequently colonised sites where *H. rhamnoides* or pine plantations had been cleared, presumably due to the presence of bare ground for seed germination and enhanced levels of soil nitrogen (Sturgess, 1993). Some wet slacks showed rapid succession to dominant stands of *Phragmites australis* (common reed) or *Typha latifolia* (bulrush), or the shrubs, *Salix repens* (creeping willow), *S. cinerea* (grey willow) and/or *Alnus glutinosa*

(alder), to the disadvantage of competitively inferior, nationally notable specialists such as *Juncus balticus* (Baltic rush) (Smith & Lockwood, 2016), *Carex viridula* (small-fruited yellow-sedge) (Smith, 2017) and *Blysmus compressus* (flat sedge) (Smith, 2019).

Although localised in the dunes, *Calamagrostis epigejos* (wood small-reed) formed a dense spreading patch in a small damp-slack near Ainsdale (Smith, 2009). *Ulex europaeus* (gorse) has spread rapidly on dune heath sites (Fig. 11). NVC studies of the dune system mapped 4.68 ha of W 23: *Ulex europaeus* – *Rubus fruticosus* scrub in 1988/89 and 9.02 ha in 2003/04, a 93% increase in 15 years (Gateley & Michell, 2004; Edmondson *et al.*, 1988/89).



Figure 10. *Betula* invading duneland in the shelter of pine plantation, Ainsdale NNR.

Discussion

The number and proportion of non-native vascular plants in the Sefton sand-dunes increased during a 20-year period, though the rate of addition of new taxa declined. By the end of the study, the 467 alien taxa recorded represented about 38% of the total flora. This is a substantial increase on previous numbers of non-native plants recorded for the dune system. Thus, Atkinson & Houston (1993) listed 47 garden-escapes during the 1988/89 NVC survey of the dunes, though they recognised that finding aliens was not a primary aim of the study. By the second NVC survey in 2004, the number of non-native vascular plants had increased substantially to 194 (Gateley & Michell, 2004),

though this was a much smaller total than the 348 recorded the following year for the current study. Between 2005/06 and 2018 an average of six new non-native plants was discovered each year in the dune system. This is a much higher rate than Greenwood's (1999) finding that between one and two alien vascular taxa per annum were added to the flora of South Lancashire over nearly 170 years. These data support the contention that sand-dunes are particularly susceptible to alien plant establishment, perhaps due to the presence of open habitats, high disturbance rates and reduced competition (Chytry *et al.*, 2008; Carboni *et al.*, 2010; Stace & Crawley, 2015).



Figure 11. *Ulex europaeus* colonising Sefton dune heath.

Atkinson & Houston (1993), Edmondson (2010a) and Smith (2009) highlighted the concentration of non-native plants on the interface between dunes and housing. A study of 8.3 km of dune-housing boundary in Sefton identified 145 alien taxa with, on average, a garden waste tip every 19 m and a plant introduction every 12 m (Edmondson & Smith, 2005) (Fig. 12).

Savidge *et al.* (1963) also reported garden refuse near houses as a frequent source of "troublesome" aliens. Smith (2009) found that the proportion of non-native plants on six intensively-studied Sefton dune sites ranged from 13% to 42%, depending on their proximity to residential development. He also pointed out that not only does garden-waste dumping lead to alien introductions, but it also enriches dune soils, thereby encouraging competitive, nutrient-demanding native species, such as *Urtica dioica* (common nettle). According to Crawley (1997), most naturalized alien plants usually occur within 10 m of buildings, gardens, walls, waste ground, roadsides or

railways, relatively few being seen more than 1 km from human disturbance. Similarly, Crawley *et al.* (1996) found that coastal dunes were rich in aliens where they occurred close to towns, as in Southern England and South Wales. The same could equally well apply to Sefton Borough, which is about 50% built-up, with several large settlements adjoining undeveloped duneland.



Figure 12. Garden waste tip, Falklands Way dunes, Ainsdale.

This study found no differences in strandline/shingle and embryo/mobile dune preferences for native and non-native taxa. This was unexpected as other studies (e.g. Carboni *et al.*, 2010; Valcheva *et al.*, 2019) detected relatively few alien taxa in early successional stages, suggesting that pioneer dune communities were composed mainly of specialized halophytes and psammophytes adapted to harsh conditions, while neophytes are more usually generalists lacking these adaptations. The small number of both plant groups associated with these habitats may account, in part, for the low occurrences of non-native species.

More native than alien plants were recorded in Sefton fixed dune, dune heath and, especially, dune grassland habitats. Fixed dune and dune heath soils are characterized by low nutrient status, free-drainage, poor water-holding capacity and, in the latter habitat, low pH (Maun, 2009; Millington *et al.*, 2010). Such characteristics may favour adapted native dune and heathland specialists rather than non-native generalists. While the open communities of the fixed dunes may permit colonisation by some hardy non-native plants, the closed swards of dune grassland provide more competitive conditions, perhaps accounting for the lower numbers of aliens recorded.

Dune scrub and woodland combined supported significantly more non-native than native taxa. This is due to widespread introductions of *Pinus* and *Populus* spp. for forestry and other purposes and the many shrubs that have escaped from gardens. Thus, 19 species and hybrids of *Cotoneaster* (cotoneaster) (Fig. 13), seven *Berberis* (barberry) and five *Spiraea* (bridewort) taxa are listed in the coast inventory.

The Sefton dunes are particularly well-endowed with freshwater wetlands, slacks covering at least 115 ha, representing 33% of the English resource of this habitat (Edmondson, 2010b). The dune wetlands were species-rich but had far more native than alien plants, perhaps due to edaphic conditions. Slack soils are ground-water gleys caused by prolonged seasonal flooding, waterlogging, low oxygen levels and often high sulphide concentrations (Davy *et al.*, 2006). Relatively few non-native plants seem to have evolved adaptations to thrive in such conditions.



Figure 13. Large bush of *Cotoneaster salicifolius* at Formby Point.

“Disturbed ground” was shown to support by far the greatest number and proportion of non-native plants. The accords with Crawley *et al.* (1996) who found that “waste ground” had the highest proportion of aliens in the British flora, while Weeda (2010) reported that most herbaceous neophytes in the Netherlands are characteristic of man-disturbed habitats. Stace & Crawley (2015) also noted a positive correlation between disturbance and alien plant abundance. They suggested that creation of bare soil would tend to reduce microsite limitations, such as competition from native plants and herbivory, which account for most aliens being relatively uncommon. Most Sefton dune soils are calcareous (Millington *et al.*, 2010), perhaps making these habitats more

likely to support non-natives, Stace & Crawley (2015) noting that there are few acid-loving aliens.

Only 25 non-native vascular plants (5.2% of aliens, 10.8% of naturalized aliens and 2% of the total flora) were considered invasive in the Sefton dune system. Williamson (1996) proposed a “rule of tens” in which 10% of invading species become established, while 10% of those may become pests. On this basis, the number of Sefton Coast aliens showing invasive traits is larger than might have been expected, though several of them remain relatively localised.

Schedule 9 of the Wildlife & Countryside Act 1981 (as amended) lists species for which it is an offence to “plant or otherwise cause to grow in the wild”. Twenty of them are present on the Sefton dunes (Table 4) but, currently, only seven are considered invasive. Five out of the six vascular plants in English Nature’s (2005) audit of non-native species having major adverse environmental effects in England are recorded for the study area (Table 5) but only two of them have invasive traits here. English Nature (2005) also listed 16 non-native plants that were “strongly increasing” (Table 6). Ten were found in the Sefton dunes; the wetland species *Crassula helmsii* and *Myriophyllum aquaticum* (parrot’s-feather) being the only invasive examples. The latter is restricted to one small pond, while the former has been controlled at most of its few sites by infilling, manual removal and/or use of selective herbicides.

Arguably, the most damaging of the introduced species are *Hippophae rhamnoides* and *Rosa rugosa*. These are classic examples of “high impact neophytes” capable of forming dense thickets that exclude most other plants by interspecific competition (Stace & Crawley, 2015). *H. rhamnoides* was recognised as a serious threat to duneland biodiversity as long ago as 1969, when the Nature Conservancy established a *Hippophae* Study Group (Ranwell, 1972). This shrub also adversely impacts coastal dunes in many parts of the Northwest European mainland (Isermann, 2008). In addition to shading out dune flora, *H. rhamnoides* fixes atmospheric nitrogen in root-nodules, thereby enriching the soil, making it less suitable for specialist dune plants, most of which are adapted to oligotrophic conditions (Richards & Burningham, 2011). Control measures in the Sefton dunes began on a small scale in the late 1960s, increasing in the 1980s and 1990s when heavy machinery was used to clear scrub from large areas (Atkinson & Houston, 1993). Latterly, funding cuts have meant that volunteers have increasingly been used to control *H. rhamnoides* (Fig. 14), co-ordinated through local conservation charities, land managers and the *Gems in the Dunes* project.

Rosa rugosa also represents a major threat to dune habitats, both in Britain and elsewhere in Western Europe (Bruun, 2005; Isermann, 2008; Smith & Deed, 2019; Weeda, 2010). This shrub forms impenetrable thickets, eliminating most other plants by shading, as well as hindering access (Isermann, 2008). Stefanowicz *et al.* (2019) showed that *R. rugosa* invasion of sand dunes increases soil organic carbon, total nitrogen and phosphate, while the organic matter layer under the shrub is thicker, with higher pH and calcium. Reduced microbial activity is possibly linked to production of secondary metabolites, high phenolic concentrations being found in senescing *R. rugosa* leaves. These findings show that *R. rugosa* alters the nutrient status of dune soils and may hinder recovery of habitats after removal of the plant. Despite known impacts

nationally and internationally and its inclusion in Schedule 9 of the Wildlife & Countryside Act, *R. rugosa* is still widely advertised, recommended on television gardening programmes and sold in garden centres. Weeda (2010) recommended that alien woody plants including *R. rugosa* should not be planted in or near to sand-dunes.

Table 4. Wildlife & Countryside Act Schedule 9 vascular taxa present on the Sefton Coast dunes (* considered invasive in the Sefton dune system).

Taxon	English name	Status on the Sefton Coast
<i>Azolla filiculoides</i>	water fern	Rare
<i>Cotoneaster bullatus</i>	hollyberry cotoneaster	Occasional
<i>Cotoneaster horizontalis</i>	wall cotoneaster	Rare
<i>Cotoneaster simonsii</i>	Himalayan cotoneaster	Occasional
<i>Crassula helmsii</i> *	New Zealand pigmy-weed	Rare
<i>Crocsmia ×crocsmiiflora</i>	montbretia	Occasional
<i>Elodea canadensis</i>	Canadian waterweed	Occasional
<i>Elodea nuttallii</i>	Nuttall's waterweed	Rare
<i>Heracleum mantegazzianum</i>	giant hogweed	Occasional
<i>Impatiens glandulifera</i> *	Himalayan balsam	Occasional
<i>Lagarosiphon major</i>	curly pondweed	Occasional
<i>Lamiastrum galeobdolon</i> ssp. <i>argentatum</i>	yellow archangel	Occasional
<i>Myriophyllum aquaticum</i> *	parrot's-feather	Rare
<i>Parthenocissus quinquefolia</i>	Virginia-creeper	Rare
<i>Reynoutria ×bohemica</i> *	Bohemian knotweed	Occasional
<i>Reynoutria japonica</i> *	Japanese knotweed	Occasional
<i>Reynoutria sachalinensis</i> *	giant knotweed	Rare
<i>Rhododendron ponticum</i>	rhododendron	Occasional
<i>Robinia pseudoacacia</i>	false-acacia	Rare
<i>Rosa rugosa</i> *	Japanese rose	Frequent

Table 5. Vascular taxa in English Nature's (2005) audit of non-native species in England having major adverse environmental effects (* = present in the Sefton dunes).

Taxon	English name	Status on Sefton dunes
<i>Acer pseudoplatanus</i> *	sycamore	Abundant; invasive
<i>Carpobrotus edulis</i>	hottentot-fig	Absent
<i>Heracleum mantegazzianum</i> *	giant hogweed	Occasional
<i>Quercus ilex</i> *	evergreen oak	Rare
<i>Reynoutria japonica</i> *	Japanese knotweed	Occasional; invasive
<i>Rhododendron ponticum</i> *	rhododendron	Occasional

Table 6. Strongly increasing non-native vascular plants in English Nature's (2005) audit of non-native species in England (* = present in the Sefton dunes).

Taxon	English name	Status in Sefton dunes
<i>Amsinckia micrantha</i> *	common fiddleneck	Rare
<i>Brassica napus</i> *	oil-seed rape	
<i>Buddleja davidii</i> *	butterfly-bush	Occasional
<i>Conyza sumatrensis</i> *	Guernsey fleabane	Occasional
<i>Cotoneaster integrifolius</i>	entire-leaved cotoneaster	
<i>Cotoneaster microphyllus</i> agg.	small-leaved cotoneaster	
<i>Crassula helmsii</i> *	New Zealand pigmyweed	Rare; invasive
<i>Hirschfeldia incana</i> *	hoary mustard	Occasional
<i>Hydrocotyle ranunculoides</i>	floating pennywort	
<i>Lamium galeobdolon</i> ssp. <i>argenteum</i> *	yellow archangel	Occasional
<i>Lemna minuta</i>	least duckweed	
<i>Leucanthemum ×superbum</i> *	shasta daisy	Occasional
<i>Linum usitatissimum</i> *	flax	Rare
<i>Myriophyllum aquaticum</i> *	parrot's-feather	Rare
<i>Polypodon viridis</i>	water-bent	
<i>Valerianella carinata</i>	keeled-fruited cornsalad	



Figure 14. Control of *Hippophae rhamnoides* by volunteers at Birkdale dunes.

Large-scale control of *R. rugosa* on the Sefton dunes began in 2017 with mechanical excavation and deep burial of bushes at Cabin Hill NNR and Altcar Training Camp (Fig. 15), supported by *Gems in the Dunes*, the Defence Infrastructure Organisation and Natural England. The *Dynamic Dunescapes* project proposes to extend this work to other parts of the dune system. Fortunately, the Sefton dunes are not threatened, as yet, by some woody invasives, such as *Prunus serotina* (rum cherry) and *Yucca* spp. (yucca), that have damaged the ecology of dune systems elsewhere in Europe. Weeda (2010) referred to the “huge and unforeseen problems” caused by *P. serotina* which was introduced to the Netherlands from North America. Only three bushes of this species have been found on the Sefton Coast and these show little sign of spreading. Similarly *Yucca* spp. are rare here, a small group of individuals having been removed during recent works to control *Rosa rugosa* on Altcar Training Camp dunes.



Figure 15. Mechanical removal of *Rosa rugosa* at Altcar Training Camp frontal dunes.

Another invasive non-native plant, *Cerastium tomentosum*, is problematic on duneland elsewhere in the UK, producing white carpets over hundreds of square metres in the North Norfolk dunes (Stace & Crawley, 2015). Houston (2011) reported the vigorous growth of *Clematis vitalba* at Gibraltar Point NNR and Saltfleetby-Theddlethorpe NNR in Lincolnshire, where it was described as invasive. Pearman *et al.* (2019) listed this species as one of ten most invasive “natives” in Cornwall, where it is becoming dominant in hedgerows and dune systems. Fitzgerald (2002) observed that *C.*

italba can form “virtual monocultures” on base-rich soils, while Pearman (2007) reported that *Euphorbia cyparissias* was increasing nationally on light soils. A literature search did not find any examples of *Lathyrus latifolius* as an invasive plant on sand-dunes, though Breeds (2004) mentioned that it was established in at least three places on Braunton Burrows, Devon.

Fourteen native plants were identified as being invasive in the Sefton dune system (Table 3), five being woody species. Scrub invasion by both non-native and native plants has been recognised as a major issue on the Sefton dunes for several decades (Smith, 2009). Wheeler *et al.* (1993) described rapid succession on fixed dunes towards dune scrub and woodland of limited nature conservation value, birch being widespread and increasing in abundance. They attributed this, in part, to a reduction in grazing pressure following a decline of the Rabbit population. Rodwell (2000) also highlighted birch invasion of dune grassland communities following the removal or demise of grazers.

Colonisation of dune slacks by bushy *Salix* spp. and *Betula pendula* (silver birch) was cited by Rodwell (2000) as a precursor to woodland. Smith & Kimpton (2008) described the effect of removing 1 ha of dense *Salix cinerea* from a slack at Cabin Hill NNR where most of the previously rich flora had been shaded out (Fig. 16). After clearance, the site was colonised by 139 vascular taxa over two years. However, the authors also highlighted the spread of mono-specific stands of *Phragmites australis* and *Phalaris arundinacea* (reed canary-grass) in the slack, with concerns for future biodiversity. Smith (2019) also reported the growth of larger *Salix* taxa as a potential threat to the Red List “Vulnerable” *Blysmus compressus*, recommending targeted scrub control in Sefton dune slacks supporting this species.



Figure 16. Dense *Salix cinerea* in a Cabin Hill NNR slack before clearance in 2005.

An increase from 11 ha in 1988/89 to nearly 160 ha in 2003/04 of mesotrophic grassland containing much *Arrhenatherum elatius* (false oat-grass) was reported on the Sefton Coast by Gateley & Michell (2004). During the same period, the NVC's SD9: *Ammophila arenaria*-*Arrhenatherum elatius* dune grassland community doubled in extent. This rank, tussocky, species-poor community extended seawards into previously open mobile-dune habitat. The development of coarse grassland on dunes has been widely reported elsewhere in Britain and Western Europe (Houston, 2008), being attributed not only to reduced grazing pressure but also to aerial deposition of nitrogen (Jones *et al.*, 2004) which exacerbates soil eutrophication.

The impact of invasive native species is widely acknowledged. Marrs *et al.* (2013) argued that a few aggressive native plants may have an equal or greater impact on some habitats than alien species, while Pearman (2004) contended that a small number of native plants was a greater threat to the UK's native flora than invasive non-natives. Pearman & Walker (2009) and Pearman *et al.* (2019) added to this debate, stressing that the great majority of naturalised alien plants are benign, most being restricted to highly modified environments near to urban centres. Analysis of tetrad distributions suggested that naturalised non-natives are "vanishingly rare" in closed semi-natural communities of high conservation value and that aggressive native species represent a much greater threat to our flora. However, Rand (2009) criticised Pearman & Walker's data analysis, pointing out that it did not address impacts on individual sites.

The current study demonstrates that a large sand-dune system is susceptible to invasion by both non-native and native plants, with introductions such as *Hippophae rhamnoides* and *Rosa rugosa* being especially problematic. However, native colonists including *Arrhenatherum elatius*, *Betula* spp., *Salix* spp. and *Ulex europaea*, can produce ecological impacts of a similar magnitude. A quantitative assessment of the distribution, population size and growth rate of invasive species on the Sefton dunes has only been carried out for *R. rugosa* (Boardman & Smith, 2016; Smith & Deed, 2019). Similar studies for taxa, such as *H. rhamnoides*, *L. latifolius*, *Betula* spp. and *Salix* spp. are urgently required so that strategies for their effective control can be formulated and enacted.

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