SHINGLE BIODIVERSITY & HABITAT DISTURBANCE

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Introduction

Beach structure

Coastal vegetated shingle is recognised as an internationally important habitat (http1), with two shingle habitats listed in Annex I of the EU Habitats Directive (CD92/43/EEC), annual vegetation of driftlines and perennial vegetation of stony banks (http2). Although rare in Europe, shingle is a major beach constituent of approximately 900 km of the English and Welsh coastlines (Randall, 1977a), southeast England possessing a high proportion of this resource. Shingle beaches form on wave dominated shorelines where material larger than sand occurs, with particles over 2 mm considered as constituting shingle (after King, 1959). Coastal shingle structures have been divided into 5 categories (Hepburn, 1952; Pye, 2001):

- **Fringing beaches**
    - Accreting
    - Stable
    - Eroding
- **Spits**
- **Bar or Barriers**
- **Cuspate Forelands/ Apposition beach**
- **Offshore Barrier Islands**

Most shingle occurs as a **fringing beach**, which is a continually mobile ribbon of material moving with the dominant wave and current direction (littoral drift) and may bear sparse ephemeral vegetation (after Randall, 1977a). These shingle structures are commonly found along the Channel coast of England and France (Randall, 1977a) often along cliff toes. The fringing beach may be divided into accreting, where the shingle is being deposited by wave action and the beach is building up, stable, where the rate of accretion equals the rate of erosion, or eroding, where the beach profile has become very steep due to removal of beach material by wave action. Eroding beaches are a major problem in this region due to reduced littoral drift hampered by the placement of groynes downdrift. **Spits**, coastal ridges that terminate in open water, and **bars/ barriers**, that often extend from one headland to another (Packham & Willis, 1997), are also highly mobile substrates, regularly washed by spray and storm waves (Randall, 1977a). However more substantial shingle vegetation may be found on these shingle structures. Where larger quantities of shingle have built up as **cuspate forelands**, formed by deposition of shingle driven landward by storm waves, and **offshore barrier islands**, the structure is more stable (Randall, 1977b) and supports more terrestrial vegetation. Nevertheless, the seaward ridges of these formations are also subject to the same environmental conditions as the fringing beaches.

Vegetated Shingle Habitat

The vegetated shingle community requires specific conditions in order to exist; the supply of available water, presence of a fine matrix in the coarse shingle that will retain moisture and a threshold level of disturbance of the shingle by constructive and destructive wave movement (Scott, 1963; Fuller, 1987; Davy, Willis & Beerling, 2001). However absence of the habitat may also be due to human influence on the shingle environment, the habitat is subject to many environmental pressures; mechanical beach management, trampling and climate change.

The southeast coast of England is a highly managed coastline and in some areas, e.g. Seaford and Pevensey, there are shingle maintenance programmes including import of marine dredged material, annual reprofiling and recycling on a large scale to maintain sea defences. The direct disturbance of the shingle environment coupled with the access of large vehicles to carry out the maintenance seems to indicate that the fragile shingle community in these areas has little chance of becoming successfully established.

On urban shingle seafronts there is also a distinct lack of vegetation, e.g. Brighton & Hove, likely due to trampling by the high number of visitors to these coasts. However a lack of vegetation may also be due to a beach being too mobile and inundated by the tide too regularly to support any permanent vegetation, as mentioned above where the entire beach is an intertidal area with high water often reaching the seawall. Vegetated shingle habitats in developed areas are also under attack from invasive garden species where private property backs directly onto shingle beaches.

Over time, with potential impacts of climate change, including sea-level rise and increased storminess with the potential for storm surges (Bray, Hook & Carter, 1997), pressures on the shingle habitat are set to increase. In a phenomenon known as ‘coastal squeeze’ (English Nature, 1992), rising sea-levels will reduce the space available for the shingle vegetation where the habitat is backed by seawalls or cliffs. In unrestricted areas the vegetation may be able to migrate landwards, providing there is adequate shingle cover and the rate at which sea level rises does not exceed the possible rate of migration of pioneer shingle community species. Increased storminess may in some regions disturb the shingle beyond the threshold of shingle organisms' ability to adapt.

Pioneer Species – Shingle Flora

With the current pressures on the shingle community coupled with those linked to potential climate change the continued existence of this rare habitat will depend on the ability of shingle species to cope with the changing environmental conditions (http 3). Although the above threats may endanger all parts of the vegetated shingle community, research for this D.Phil. focuses on the area of vegetated shingle that occupies the ‘pioneer’ zone, primarily perennial vegetation of stony banks (Annex I habitats, EU Habitats Directive, http 4) and associated organisms.

The pioneer zone in the vegetated shingle habitat is the area subject to most change whether artificial (beach recharge or recycling, trampling) or natural (tidal waves, wind driven storm surges). Pioneer plants are those species that first colonise bare shingle and may cope with most disturbance however it is difficult to define where exactly on a shingle beach this pioneer zone will extend to inland. Scott (1963) describes shingle shore vegetation as consisting of:

- **No vegetation** – where shingle is disturbed too often to support plant life
- **Summer annuals** – where beach is stable from spring to autumn, species consisting mainly of *Atriplex spp*. associated with the driftline left by winter tides
- **Short-lived perennials** – where beach is stable for 3-4 years, species present depending on the matrix
- **Long-lived perennials** – beach is rarely subject to disturbance but still subject to occasional inundation or heavy sea-spray
- **Heath** – beach free from heavy spray (terrestrial)

Annual vegetation of driftlines is defined as being found ‘on deposits of shingle lying at or above mean high-water spring tides’ (http 5) represented by Scott’s (1963) ‘summer annuals’. Project work on the vegetated shingle habitat encompasses the region where the beach is still subject to some maritime influence or disturbance. The vegetation continuum that is being studied includes (seaward to landward): the summer annual driftline vegetation, the region landward where pioneer species (short-lived perennials) predominate and the ‘intermediate’ area described by Scott (1963) as being colonised by ‘long –lived perennials’ where the percentage of bare shingle cover still exceeds the percentage of immature grassland.

Although the number of plant species growing amongst driftline debris at a particular site is highly variable from year to year, the plant species that are primarily associated with the driftline in southeast England are the annual *Atriplex spp.* mainly *Atriplex glabriuscula* (Babington’s Orache). Other perennial pioneers colonising bare shingle that may occur on the foreshore near, but always landward of, *Atriplex spp*. include *Beta maritima* (syn. *Beta vulgaris ssp. maritima*)(Sea Beet), *Crambe maritima* (Sea Kale), *Glaucium flavum* (Yellow-horned Poppy), *Honckenya peploides* (Sea Sandwort), *Eryngium maritimum* (Sea Holly), *Cakile maritima* (Sea Rocket), *Rumex crispus* (Curled Dock) and *Lathyrus japonicus* (Sea Pea) (pers. obs.). The intermediate zone that extends further landward again may include the pioneer species *C. maritima*, *G. flavum, R. crispus* and *L. japonicus* but also consists of the intermediate species *Solanum dulcamara* (Bittersweet), *Tripleurospermum maritimum* (Sea Mayweed), *Raphanus maritimus* (syn. *Raphanus raphanistrum ssp. maritimus)*(Sea Radish), *Echium vulgare* (Viper’s Bugloss), *Linaria vulgaris* (Common Toadflax), *Geranium robertianum* (Herb Robert), *Anagallis arvensis* (Scarlet pimpernel), *Sedum acre* (Biting Stonecrop), *Senecio jacobea* (Ragwort), *Senecio viscosus* (Sticky groundsel), *Galium aparine* (Cleavers) and the invasives *Arrhenatherum elatius* (False-oat Grass) and *Centranthus ruber* (Red Valerian), though this list is far from exhaustive.

Although literature listing shingle species (Scott, 1963; Hubbard, 1970; Randall, 1989; Ferry, 2001) exists there is no definitive reference book for shingle species biology. Despite having a relatively limited number of species, the shingle habitat is a complicated one to study the quantitative ecology of, since the vegetation cover is sparse and the shingle particles may be very varied in size and arrangement. The vegetation may therefore change depending on the substrate particle size and fine fraction type (i.e. whether it is organic matter, sand or driftline seaweed). The NVC maritime plant classifications (Rodwell *Ed*., 2000) describe shingle plant communities in terms of other coastal habitats (sand dune - SD, salt marsh – SM & maritime cliff - MC), lacking any classifications that correspond only to the vegetated shingle communities. Following the NVC maritime plant classifications the only assemblage recognised and characterised from coastal shingle takes the sand dune code SD1 representing the *Rumex crispus – Glaucium flavum* community. However, in 1993, Sneddon & Randall carried out a survey of coastal vegetated shingle structures in the UK suggesting modifications of current NVC classification in order to establish classifications specific to the shingle community. Shingle vegetation was identified and separated into seven major divisions (see Figure 1) and then further subdivided into shingle plant communities each taking the code prefix SH. However the survey focussed only on the flora of stable shingle beaches and therefore did not include the flora of strandlines (after Sneddon & Randall, 1993).

Figure 1 Major divisions of the shingle vegetation classification

1. Scrub communities
2. Heath communities
3. Grassland communities
4a. Mature grassland communities
4b. Less mature grassland communities
5. Secondary pioneer communities
6. Pioneer communities

This study focuses on the following maritime species: *C. maritima, G. flavum, R. crispus var. littoreus, T. maritimum, L. japonicus* and *A. glabriuscula.*
Table 1 is a much condensed form of the information contained in Appendix A. Details are almost exclusively from *Botanical Flora of the British Isles* (British Ecological Society), but please refer to Appendix A for quoted references.

Table 1 Overview of major shingle plant species life histories

Distribution	Morphology	Biology
***Crambe maritima* L.** European temperate distribution, mostly restricted to sea-level. Usually within reach of salt spray but out of reach of normal spring tides. Suggested preference for drained conditions.	Long-lived fleshy deciduous perennial with a brittle fleshy root system that may extend horizontally up to 200cm. Leaves have crisped edges and a waxy water repellent lamina and grow out from a central bud in a rosette formation.	Only underground parts survive winter, new leaves appear mid-April. Takes 5 years to flower and are insect pollinated. The large corky seeds produced are then dispersed by wind and sea. Vegetative reproduction may also occur where stem or root parts broken off may root elsewhere on a beach.
***Glaucium flavum* Crantz.** Naturally occurring on the coasts of warm temperate Europe and the middle East as far as Syria. Occurs inland in central Europe and extends up rivers in Spain, Portugal and France. Apparently confined to well drained conditions.	Short-lived glaucous perennial herb with an often spirally twisted taproot that may penetrate to 40 cm deep. Leaves are arranged in a rosette shape and are covered with a dense mat of hairs and a waxy covering for water proofing.	The plant does not reproduce vegetatively but produces large numbers of small seeds. Plants flower from their second year onwards, each inflorescence lasting one day only. After pollination the fruit ripens as a long thin pod.
***Rumex crispus* var. *littoreus* Hardy** *R. crispus* is one of the most widely spread plants in the world and is a serious agricultural weed. The distribution of *R. crispus* var. *littoreus* is coastal and found primarily on shingle beaches in more disturbed areas.	Perennial herb that has fleshy leaves and a thick fleshy underground stem on top of a largely unbranched vertical tap root. The branched inflorescences are often dense and all three segments that surround the seed possess large tubercles (as opposed to one tubercle only on other varieties of *R. crispus*). The plant may reach 160 cm in height.	It survives winter by perennation of underground parts or as a rosette, with regrowth occurring in February/March. Plants may produce flowers in their first year and are wind pollinated and the fruits wind dispersed.
***Lathyrus japonicus* Willd.** Circumpolar coastal distribution although no records of the species on the coast of Arctic Siberia. An isolated localised species in the UK, formerly also found in France (extinct 1940s). Found on well drained soils.	Prostrate grey-green perennial herb with stems that may reach 100 cm. The root may descend unbranched to more than 100 cm, with the functional roots in the lower zone. Roots are shorter and more branched in sandier substrates.	Plants flower from their third year onwards and are pollinated by long tongued bumble bees. Seeds will float and dispersal will occur where plants are growing near to the spring high water mark. Vegetative reproduction takes place via lateral shoots that form on the rhizostomatous part of stems in late summer, lying dormant until the next growing season.
***Atriplex glabriuscula* Edmonst.** An ephemeral inhabitant of strandline communities. It is a salt tolerant species that will grow in regions of the beach that are flooded at extreme high water. It may also occur on heavily trampled foreshores.	Annual fleshy, usually prostrate herb with stems 10 – 60 cm radiating from single central stem.	Seeds form in triangular shaped bracts by August and are ripe and falling (still within the bract) from the parent plant into the shingle interstices by October (pers obs.). There is no innate dormancy besides the bracts, which inhibit the germination of mature seed in the autumn. In Scotland, germination of *A. glabriuscula* was recorded 4 weeks after the spring equinoctial tides (end April).

Pioneer Species – Shingle Fauna

There is still relatively little known about the organisms associated with shingle vegetation and even less published work on organisms living within the shingle matrix. However, Shardlow (2001) comprehensively reviews invertebrate species associated with shingle and unpublished reports by Cadbury & Shardlow (1997) describe invertebrates found at RSPB reserves, in particular Snettisham, using subterranean pitfall traps. JNCC has also produced some literature concerned with shingle invertebrates. Invertebrates are not only found at the shingle surface or only associated with surface vegetation but also occur in the shingle matrix itself (e.g. *Megalesia yatesi*, a scuttle fly known only from shingle beaches in East Sussex). Spiders can build webs in the shingle interstices, e.g. *Trichoncus affinis* (money spider) and hunt between the sediment grains e.g. *Sitticus inexpectus* (jumping spider) (Shardlow, 2001). Where there is sand in the shingle matrix, species with burrowing larvae can exist, e.g. *Actebia praecox* (Portland Moth) and *Tipula midcornis* (Cranefly), and where the shingle is close to a water source ground beetles such as *Dyschirus angustatus* and *Bembidion bipuncutatum* occur (Shardlow, 2001).

Study Rationale

To gain an enhanced understanding of the ecological dynamics of disturbed coastal shingle communities.

This research investigates the coping mechanisms that allow organisms to live in this constantly changing coastal environment, where physical disturbance is commonplace. To date, research on vegetation in the shingle habitat has concentrated on habitat ecology (for example: Scott, 1963; Fuller, 1987; Davy, Willis, & Beerling, 2001; Packham & Spiers, 2001) and potential for restoration of the vegetation where it has been cleared for development (Walmsley and Davy, 1997a; Walmsley and Davy, 1997b; Walmsley and Davy, 1997c), with no published literature on the direct effects of human disturbance on the habitat. Physical threshold disturbance levels for shingle vegetation establishment may already be quantified: the greater the mobility of the shingle due to wave action the less likely true terrestrial vegetation will colonise.

Climatic Disturbance

It is predicted that climate change will have a significant influence on the erosion dynamics, and therefore shape, of coastal regions. Shingle beach plants will need to adapt to environmental change if the habitat is to survive and continue to exist.

With projected increases in sea-level and storminess (IPCC, 2001) plants may experience burial due to a landward movement of beach material. In the coastal environment no published material seems to exist regarding plant burial experiments in the shingle habitat. Most literature is associated with the sand dune habitat (for example: Cheplick & Demetri, 1999; Gagné & Houle, 2002; Franks & Peterson, 2003) as this is more often where significant plant burial takes place due to the transient nature of sand particles. However the shingle habitat is also dynamic and pebble displacement occurs on a tidal basis. It has been discussed above that most shingle foreshores are devoid of any vegetation due to the high frequency of shingle disturbance, however the summer annuals and plants closely associated with the driftline often withstand submergence during spring tides occurring with stormy on-shore winds. With regard to climatic influence on the shingle habitat in the future the whole habitat may be affected by greater shingle mobility on a more regular basis. A burial experiment on four different species found on the shingle beach aims to show the potential of young plants of these species to cope with such disturbance. The species that are most resistant to burial will be those most likely to be able to adapt to the changing beach topography.

The coastal shingle habitat is as hostile as any sandy coastal environment, with equally poor water holding capabilities that lead to rapid percolation of precipitation water (Salisbury, 1952, as cited by Gagné & Houle, 2002). Where the shingle lacks any fine fraction the water loss through the shingle interstices may be even greater than that in sandy coastal habitats. However some shingle plant species are known to have morphological adaptations that reduce water loss (e.g. the waxy waterproof leaves of *C. maritima* and the hairy leaves of *G. flavum*) or have adapted maritime forms (e.g. the fleshy maritime form of *Tripleurospermum maritimum*). In addition to the existing physiological stresses of a well drained habitat, predicted decreases in rainfall during summer months (IPCC, 2001), the primary growing period of plants, will mean that only those plants that are able to grow and develop with least water input are most likely to survive the additional water stress.

The following experimental studies are designed to gauge the effect of burial and different watering regimes on young plants (hereafter to referred to as plantlings). Plantlings are studied because they are likely to be most sensitive to environmental change as their root systems are less developed than adult plants and are therefore less likely to be able to buffer plants through stressful periods.

All the species used (*Crambe maritima*, *Glaucium flavum*, *Rumex crispus*, *Solanum dulcamara*, *Atriplex glabriuscula* and *Centranthus ruber*) are those whose wild seed may easily be collected from local beaches and are important components of the vegetated shingle habitat in East Sussex. See Appendix B for seed preparation.

Experimental Preparation

Seeds in the above list were germinated in a mix of coarse sand and compost (John Innes Loam-based ‘Seedling’) in seed trays. For the purpose of these initial investigations the germination procedure is not trying to mimic germination in the wild, as the natural substrate on which these species grow may be extremely varied. However the experimental conditions tried to mirror the environmental conditions. The aim of the experiment was to see how plantlings of approximately the same age tolerate changes in their immediate environment to mirror effects that will be experienced in the natural environment as climatic change occurs.

For these experiments plantlings were transplanted to individual 20 cm clear plastic tubes with a 6:1:1 mix of gravel (Silvaperl Washed & Graded Coarse Grit), sand (potting sand) and compost (John Innes Loam-based 'Plantling’). Tubes were employed instead of pots so that downward root growth would not be restricted. Each effect (burial and different watering regime) was investigated separately with all tubes arranged by treatment but moved round the greenhouse on a rotational basis to ensure that any environmental variables would not bias results. The greenhouse conditions were 12 h light : 12 h dark, thermo-period 10/20 ºC. The invasive *C. ruber* is often found encroaching on many pioneer areas of shingle beaches to the apparent exclusion of other species (pers. comm. – Yates, 2003). This species was included in the watering experiment to find out its tolerance to different watering regimes, which may help to explain its vigour in the shingle habitat (there were not enough successful germinations to use this species in the burial experiment).

Methods

Burial

Seedling age at time of burial is approximately the same, so that plants will be at the same stage of development. Burial was standardised and calculated as percentage of plant height covered (plant covered to tallest leaf = 100 % burial depth). Burial depths were chosen to investigate the difference between partial burial (0 – 75 %) where there are still parts of the plant that may photosynthesise and full burial (100, 200 & 1000 %) where light availability will be minimal (100, 200 %) to absent (1000 %). The hypothesis states that plants with part of the plant structure still receiving light will be able to recover from burial whereas those entirely buried are less likely to survive. The likely reason for this is that the former may continue photosynthesising while the latter cannot and will have to rely on any energy stores whilst growing through the shingle interstices. Before burial measurements of the initial stem length - from the soil surface to the tip of the tallest leaf (after Cheplick & Demetri, 1999) and number and length of leaves on each plant were taken for each plant.

Ten plantlings of *Crambe maritima*, *Rumex crispus*, *Solanum dulcamara* and *Glaucium flavum* were subjected to the following treatments:

Treatment no.	Burial depth (% plant height)
1	0 (unburied)
2	25
3	50
4	75
5	100 (full plant height)
6	200
7	1000

Time and greenhouse space constraints precluded examining burial using different sizes of shingle; here one size of 'shingle' was used on all species for the described burial depths. Plants were covered with coarse washed gravel (Silvaperl Washed & Graded Coarse Grit), θ c.5 mm. This shingle size falls into smallest sizes of shingle (shingle size ranges from 2 mm to 200 mm). The local shingle foreshore habitat often consists of shingle ranging from 5 mm to 40 mm (pers. obs.) and in this region of the beach the fine fraction frequently consists of small shingle 'gravel' rather than sand/humus as further landward.

For treatments 5 – 7, throughout the experiment, appearance of plants through the shingle covering was documented. The experiment continued for 69 days (9/02/04 – 19/04/04) after which shingle applied to bury the plants was removed and the final stem length and number and length of leaves on each plant was measured. The plants were then removed and sorted into above and below ground parts, and plant material dried at 65 °C for 72 hours (after Franks & Peterson, 2003). Total biomass and root/shoot ratios were plotted against treatment to look for any patterns in species response to the treatments. The data did not produce a sufficient homogeneity of variance to employ a one-way ANOVA statistical analysis as had been planned.

Different Watering Regimes

Ten plantlings of *Crambe maritima*, *Rumex crispus*, *Solanum dulcamara* and *Centranthus ruber* were subjected to the following conditions:

Treatment no.	Volume of water applied (ml)	Watering regime (every x days)
1	50	0 (watered every day)
2	50	1 (watered every other day)
3	50	3 (watered every 3rd day)
4	50	5 (watered every 5th day)
5	50	10 (watered every 10th day)
6	50	Watering on day 1, thereafter no watering

The experiment continued for 59 days (12/01/04 – 12/03/04) after which plant survival was noted and final stem length and number of leaves and their lengths recorded. Plants were then removed and sorted into above and below ground parts and plant material dried at 65 °C for 72 hours (after Franks & Peterson, 2003). Total biomass and root/shoot ratios were plotted against treatment to look for any patterns in species response to the treatments. The data did not produce a sufficient homogeneity of variance to employ a one-way ANOVA statistical analysis as had been planned.

Results

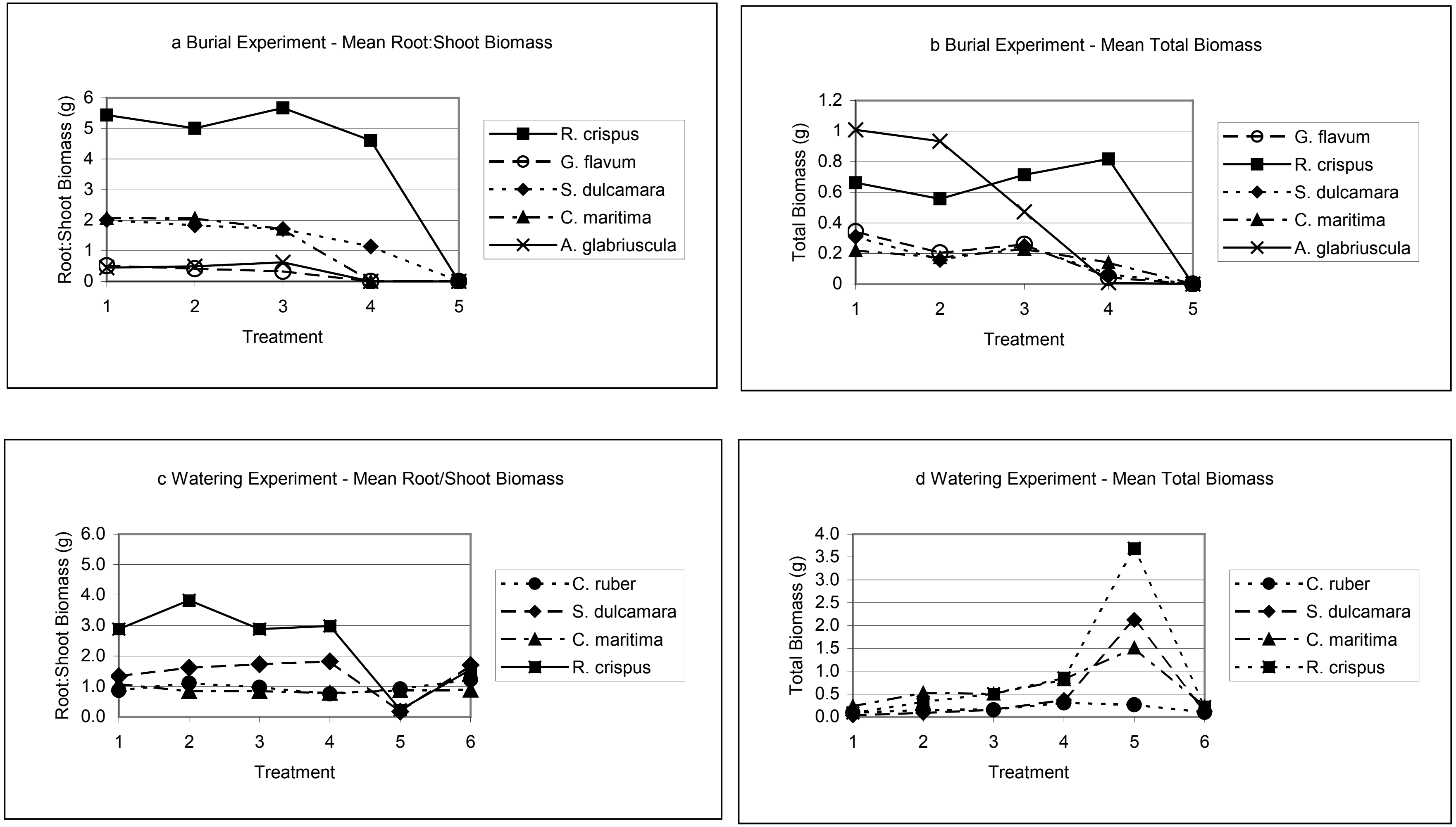

Figure 2 (a) mean root:shoot biomass and (b) mean total biomass for each species and treatment in burial experiment (some species yielded no viable results for treatment 5). (c) mean root:shoot biomass and (d) mean total biomass for each species and treatment in watering experiment. Note different scales on total biomass graphs between experiments.

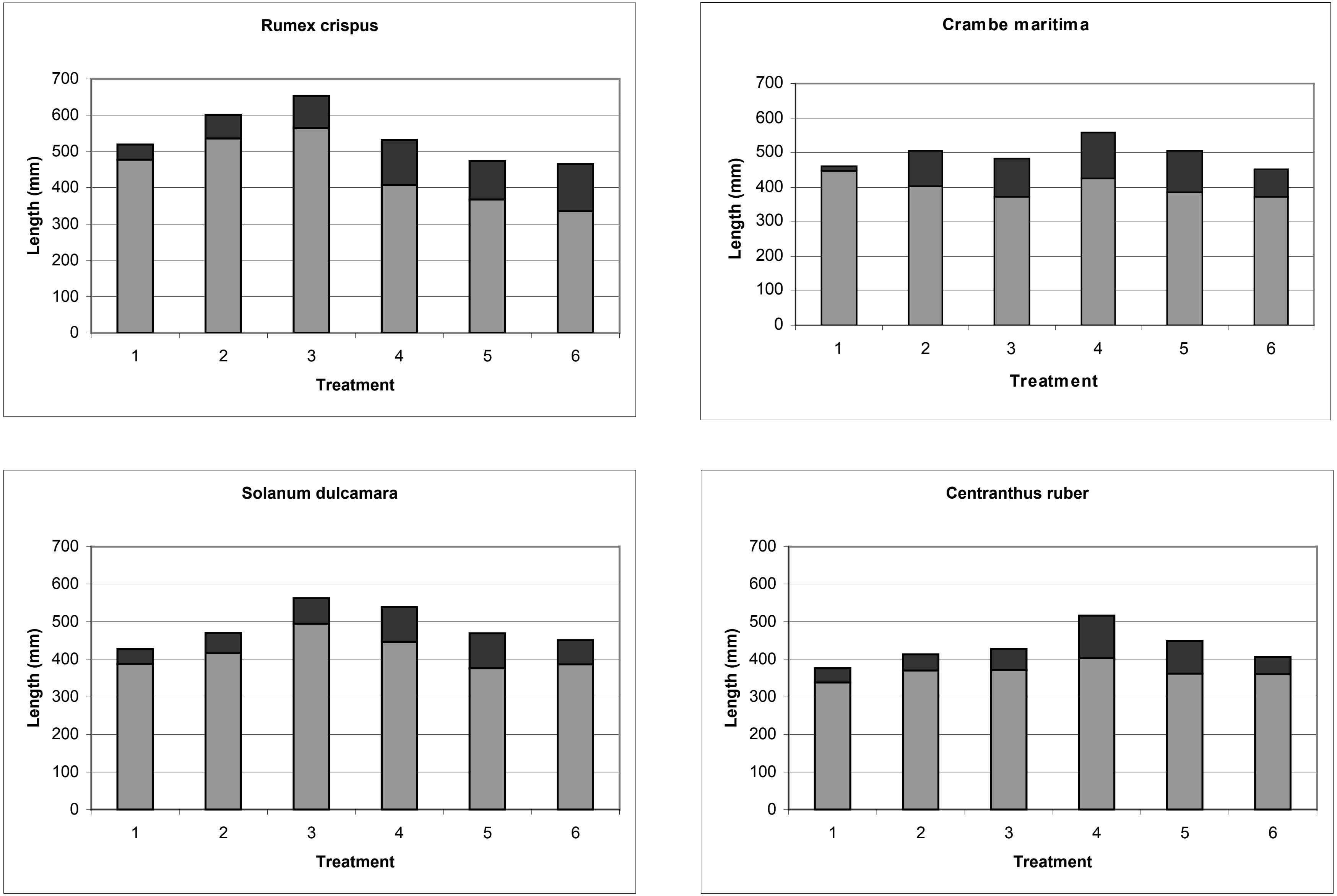

Figure 3 Mean stem (black bar) and root (grey bar) length per treatment for each species after completion of watering experiment.

R. crispus showed the greatest root/shoot ratio for both experiments, showing greater investment in root biomass overall. For the burial experiment the hypothesis states that plants with part of the plant structure still receiving light will be able to recover from burial whereas those entirely buried are less likely to survive. For 1000% burial, only three plantlings of *S. dulcamara* survived, no other species survived. *G. flavum* and *C. maritima* showed overall lowest biomass and therefore lowest growth for all burial treatments, *A. glabriuscula* particularly showed poor ability to cope with deeper burial (fig 2 b treatments 3-5). For the watering experiment, root/shoot ratio (fig 2 c) was lowest for treatment 5 (watering every 10th day) however with regard to total biomass (fig 2 d) all plants also produced greatest biomass during this treatment. This indicates that above ground growth proliferated during this treatment. In addition mean total biomass (fig 2 d) for the invasive species, *C. ruber*, included in the experiment, was lowest for all the species. This could have benefits for a future reduction of the invasion of this plant species in the shingle habitat. Figure 3 shows a general trend of longest root growth in treatments 2, 3 & 4.

Discussion

The results revealed that the species regarded as likely to best cope with the environmental disturbance were not those species that were typical ‘shingle adapted plants’ i.e. *G. flavum* and *C. maritima*. *S. dulcamara*, an opportunistic species that may be found in many ecologically contrasted habitats, was the only species able to penetrate 1000% shingle burial. The poor ability of *A. glabriuscula* to cope with deeper burial was then surprising as it is a species associated with the driftline - the most mobile part of the beach with which terrestrial vegetation is associated. Therefore increased frequency of burial of young plants associated with the shingle habitat appears to be a threat to vegetated shingle species diversity.

R. crispus (var *littoreus*) showed overall greatest capability to cope with both burial and infrequent watering, The coastal subspecies is known to be tolerant of dry surface conditions (Cavers & Harper, 1964) but the watering experiment revealed that plantlings of the species also do well with relatively infrequent watering of the substrate. In the watering experiment greatest overall biomass occurred with relatively infrequent watering. Projected decreases in rainfall may therefore not be of great disturbance to shingle plants as there appears to be preadaptation of these species to drier climate conditions. However rainier conditions may also cause the fine fraction, important to small plants due to its water-holding capacity and nutrients (sand and compost respectively in this experiment) in the shingle to be washed away creating a sub-optimal soil conditions for plant growth. However shingle adapted plants show rapid root growth with 8 week old plants having root systems 6+ times longer than above ground plant material.

Current Disturbance

Climatic change is a projected increase in disturbance to the habitat. However current disturbances have already been quantified as coastal management, development and recreational pressure. The latter is extremely important as the dense population of south eastern England corresponds to high visitor numbers and therefore high recreational pressure to popular coastal areas. In order to explore effects of vegetation trampling by humans, a site with vegetated shingle and high visitor pressure needed to be located so that an exclusion study could be carried out. However this also needed to be an area with least likelihood of vandalism to the study site, an unfortunate result of working in areas of high human frequentation. The vegetated shingle beach in Seven Sisters Country Park was therefore selected as a suitable site for study.

In situ study

The Seven Sisters chalk cliffs in East Sussex particularly attract thousands of visitors every week during the summer months. One of the most popular ways to access this area of the coast is through Seven Sisters Country Park, which receives up to 13,000 visitors per week during busy summer months (pers. com. – James, C.). The shingle beach in the park is therefore heavily visited by tourists and school parties. The beach is divided into two parts (West and East) either side of the artificially guided Cuckmere river mouth. Cuckmere Haven East shingle beach possesses associated shingle flora, most notably *Crambe maritima* and *Glaucium flavum*.

Method

Many different methodologies have been employed in previous vegetation trampling studies carried out in several different habitats. Some have been invasive (Burden & Randerson, 1972; Kutiel, Eden & Zhevelev, 2000) consisting of purposely damaging the vegetation at different intensities and quantifying the effect, methods for which have been published by Cole & Bayfield (1993). Some have monitored natural trampling of the habitat but employed invasive techniques to sample the vegetation (Liddle & Grieg-Smith, 1975). However, due to the rarity of the vegetated shingle habitat and its status on Annex 1 of the EU Habitats Directive a non-invasive study needed to be created where change between a protected and adjacent identical non-protected area could be monitored rather than experimentally trampling the vegetation. Vegetation cover in relation to distance from a point of high trampling near a habitat access point such as car parks (McDonnell, 1981), or areas of defined high trampling intensity such as paths through vegetation (Andersen, 1995) are common methodologies. Although the shingle beach at Cuckmere Haven East only has two major access points there are no clearly defined pathways that visitors follow as the vegetation is sufficiently sparse for visitors to choose their own path through the vegetation. The highest point along the width of the beach, an artificially elevated shingle berm, does however seem to have the closest resemblance to a pathway. Although taller plants do exist here, vegetation cover is especially sparse and characterised by small areas of grass turf including plants less sensitive to trampling such as *Plantago spp*. (Liddle, 1975; Burden & Randerson, 1972).

An experiment was set out in August 2004 to investigate whether fencing off an area of beach would promote vegetation restoration. Permission for fencing part of the Cuckmere Haven East beach off was granted with the proviso that minimum obstruction to public access would occur, that a bird nesting area occurring in the western part of the beach be included but left undisturbed by experimental activity and that any fencing used gave minimum visual impact. The central region of the beach was therefore chosen as the study site (fig 1) and was fenced off using stakes and sisal rope. It was therefore not possible to study all vegetation landward from the driftline as this would obstruct public access along the beach. Although the site was some distance away from beach access points, a portion of the more heavily trampled top beach was included in the fenced off area.

The trapezium shaped roped off area was laid out so that it would guide people entering the beach from the western entrance towards the top beach area favoured by most visitors. The fenced off region was divided into the following areas:

- top beach
- back slope
- back flat

The western adjacent unfenced area was divided in the same way. Six randomly selected 1m2 quadrats were located in each area in both fenced off and unfenced regions (n tot = 36). In each quadrat the number of species occurring, percentage cover and frequency, and maximum height were recorded. In addition to these, six further quadrats, in both the fenced off and unfenced regions (n tot =12) containing a high number of *G.flavum* plantlings were also selected to look at young plant survival in the protected and unprotected area. A high resolution digital photo was taken of each quadrat and the four points of the quadrat marked using GPS. The fenced off area was also marked using GPS.

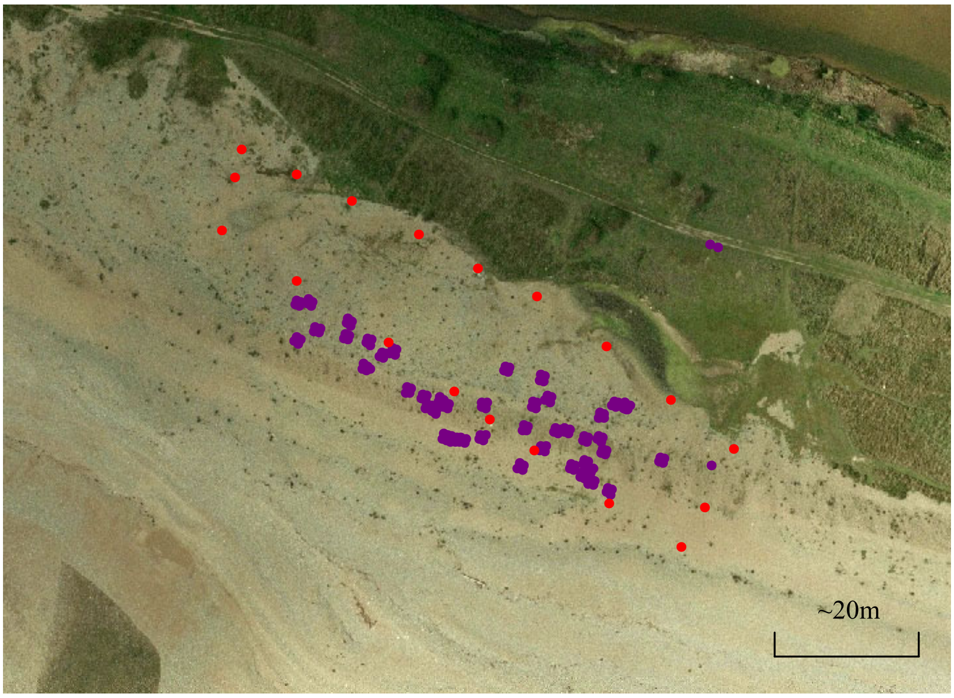

Figure 1 Aerial photo of Cuckmere Haven East with GPS points. Red circles show location of fence posts, purple circles denote quadrat location. Vegetation may be seen as green mottled areas on shingle beach substrate.

Each photo was geo-referenced using marked GPS points and inserted into an aerial photo of the beach area to clearly show its exact location on the beach. For each quadrat the area of every *C. maritima* and *G. flavum* plant was calculated by making each plant a polygon using ArcView software.

The diversity and abundance data combined with the polygon data for August 2004 will be compared to identical measurements for each quadrat in August 2005. These data will then be used to identify any change in vegetation diversity and abundance in the fenced off area. The species present and their frequency within each quadrat will be studied to see if particular species do better in protected areas.

Ex situ study

A lab based trampling study will be carried out on shingle beach plant species in order to explain and quantify potential change in vegetation cover seen in the field.

Further Studies

Pilot study of the effect of humans on the invertebrate fauna in the vegetated shingle habitat.

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http1 - www.biodiversitysussex.org/vegetatedshingle.htm#CurrentStatus
http2 - http://www.jncc.gov.uk/Publications/JNCC312/UK_habitat_list.asp
http3 - http://www.ukbap.org.uk/asp/UKPlans.asp?UKListID=29#1
http4 - http://europa.eu.int/comm/environment/nature/hab-an1en.htm
http5 - http://www.jncc.gov.uk/ProtectedSites/SACselection/habitat.asp?FeatureIntCode=H1210

Appendix A

Major Shingle Plant Species Life Histories

Crambe maritima L.

Unless quoted otherwise all details on this species are taken from the *Botanical Flora of the British Isles* paper on *Crambe maritima* (Scott & Randall, 1976).

Distribution

C. maritima is a long-lived fleshy deciduous perennial crucifer (Rose, 1981), however the literature does not define exactly how long a plant may live for. It is restricted to temperate climates with mean annual temperature limits of 5 – 15 °C and c. 500 – 2000 mm of annual precipitation. It is a maritime plant, primarily confined to sea level although occasionally found on cliffs. In the UK it is locally common on the west and south coasts of England, however its geographical range expands north as far as the Clyde on the west coast and as far as Fife on the east coast, where it is less common. In 1976, by comparing county flora records from earlier in the century and field work data from 1973-74, Scott & Randall had already established that almost all localities had experienced a decline in *C. maritima* populations. Elsewhere, the species also occurs along the Atlantic coasts of Europe (from northern Spain to southern Norway) and the Baltic coasts.

Habitat

On the shore, plants are usually within reach of salt spray in winter but out of reach of normal spring tides, however inundation by extreme storm tides may occur. Plants may be found on a range of substrata, from gravel or shingle with buried drift seaweed, shingle with clay, shingle with sand and sometimes on beaches with 75 % sand. In Scandinavia, *C. maritima* is noted as growing best on shingle and sand banks (Eklund, 1931 as cited by Scott & Randall, 1976). Abundant growth on the side of embankments at the Dungeness ranges (Kent) and on the Dungeness-Camber road seems to indicate a preference for drained conditions, since plants are less plentiful at the foot of the embankments. Plants may also be found in grassland at the edge of shingle beaches, as on the Isle of Arran, but are likely to be relicts of open shingle vegetation predating the grassland (Scott, 1960).

Life History (Morphology & Biology)

The plant is a rosette hemicryptophyte, with only the underground parts surviving the winter. Most plants are in leaf by mid-April which, when developing from the bud, are often a crimson colour gradually changing to green-blue. The leaves have crisped edges and their glaucous waxy nature acts as a water-repellent layer. Flowering peaks mid-May to June and fruits are ripe around early September – fruit is ripe approximately 2 to 3 months after flowering (Scott, 1960). Plants take at least 5 years to flower and produce seed for sexual reproduction. Restriction to the maritime area, and more frequently the beach area, is likely to be due to some dispersal by sea of the buoyant fruits. The seeds have a corky coat that allows them to remain afloat for up to 26 days (Scott, 1963). Wind dispersal also takes place (pers. obs.; Eklund, 1927 as cited by Scott & Randall, 1976) where dry inflorescences (with dried fruit) detach from the main plant and tumble along the beach with wind gusts. Vegetative reproduction may also occur where stem or root parts, broken off by eroding tides, root elsewhere on the beach. Stems may also be buried to a depth of 50 cm (and probably more) thus often what is seen on the beach is an older corky stem and not a thick taproot. *C. maritima* plants have a brittle fleshy root system that is wide and deep, and whose lateral roots may extend horizontally as far as 200 cm in sand. There is dense packing of starch grains in nearly all parenchyma cells of the cortex and stele in both roots and stems. According to Scott (1963) *C. maritima* is capable of withstanding at least occasional burial - since no decrease in the starch reserve is noted during the spring, it is likely that this supply is kept so that if the plant experiences any burial it may still grow upwards whilst not photosynthesising. As the plant matures, the stem at ground level may also divide, with short stiff branches radiating out a few centimetres above ground appearing as a ring of shoots around the parent plant. Leaves begin to die down in late autumn, with change in leaf form and colour taking place in reverse and by November all above ground vegetation has withered back often leaving a dry, protective layer above the dormant ground level buds.

Biotic effects

Greatest losses of this species are attributed to trampling by humans and to some degree by coastal development. *Chloris chloris chloris* L. (Greenfinches) feed on the fruits and plants are sometimes infested with caterpillars of *Pieris brassicae* L. (Large White Butterfly). Bacterial black-rot of the stems is associated with poor soil conditions, especially water logging but does not seem to affect the plants growth.

Glaucium flavum Crantz.

Unless quoted otherwise all details on this species are taken from the *Botanical Flora of the British Isles* paper on *Glaucium flavum* (Scott, 1963).

Distribution

Glaucium flavum is a short-lived glaucous perennial herb that, for most of its range, is found in regions with warm temperate climates, apparently lacking any preference for a specific rainfall regime. However it generally occurs where the mean annual temperature limits are 17 – 21 °C with c. 500 – 1500 mm of annual precipitation. It is found in Britain south of the Forth-Clyde line and is a species that may be extremely locally abundant. However, it is most commonly found in the south of England. Elsewhere it may be found along all shores of the Mediterranean extending to the Black Sea and likely further east, on the western shores of Europe as far north as Jutland, south Sweden and Norway and it extends up rivers in Spain, Portugal and France. It occurs inland in central Europe near Bremen, Leipzig and Erfurt in Switzerland at the lake of Neuchatel, in the Vienna Basin and rarely in Bohemia. The species may also be found in Palestine, Jordan, Syria and Lebanon. It has become naturalised in New Zealand on Cook Strait and on the eastern coast and also in North America in Maryland and Massachusetts coasts and inland near Los Angeles. In Britain *G. flavum* is generally restricted to sea-level however, in the 1970s *G. flavum* was found growing in an inland chalk pit (now a landfill site) at Asham, East Sussex (pers. comm. – Williams, 2003). In Lebanon it may be found at 2000m above sea-level.

Habitat

In Britain *G. flavum* is commonly found on shingle beaches (Rose, 1981) as an important species in the pioneer community as a coloniser of bare shingle (and of bare ground in general). It tends to be found with herbaceous plants rather than woody plants and is associated with a large number of other species. Except for the highest spring tides, *G. flavum* usually occurs out of reach of high tide. The species is apparently confined to well-drained habitats such as shingle, gravel, sand and cliffs and is out of reach of the water table in most habitats. There also seems to be a preference for recently disturbed ground and basic soils. Slight frost has little effect on the adult plant and the species, although its overall performance is affected, is also tolerant to drought as it is able withstand long periods without rain.

Life History (Morphology & Biology)

The species is described as a semi-rosette hemicryptophyte[1] and may live for 2 to 5 years, each year the number of leaf rosettes increasing. In autumn each

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[1] According to Raunkiaer's biological spectrum of life forms a hemicryptophyte is a plant with perennating buds are at the soil surface (Packham & Willis, 1997)

rosette at the crown of the root dies after flowering to be replaced by usually two or three new rosettes developing from buds at the base of the flower stalk with which the plant overwinters. New leaves appear by mid to late March. The leaves are covered with a dense mat of long, stiff, multi-cellular hairs and the leaf lamina has a waxy covering rendering the leaves almost unwettable. In dry shingle the plants tend to stay in small rosettes, flower less freely and have denser hair covering the leaves. The taproot is often spirally twisted, penetrates to 30 – 40 cm in old plants, and, due to secondary thickening, possesses a thick layer of dead fibrous tissues. The plant does not reproduce vegetatively, however it does have some competitive ability through the large number of viable seeds it produces. The plant produces flowers from its second year onwards with the flowering stalk usually appearing in May and flowering taking place from mid May. However flowering in a colony may continue until (at the latest) the beginning of October. The flowers last for one day and are probably insect pollinated (although self pollination also leads to seed production) since visiting insects are frequently seen. The fruit then ripens, taking approximately two months to do so. The fruit is a long thin pod and a plant may bear 1 to 218 pods depending on its age and condition this is, however, an average of 17 pods per plant. Each pod may contain an average of approximately 280 seeds (n = 4 to 442). Seed dispersal occurs primarily by the dehiscing of the pods during autumn and early winter and shaking of the pods in the wind. Seeds may also be dispersed by sea although they do no float in calm water. In rougher water they do not float for any length of time but are still capable of being transported by wave action for short distances (germination is not affected by shaking seeds in seawater for 9 hours). Seeds are very small (c. 1 mm) and germinate on fine material from April onwards (Scott, 1960). *G. flavum* will tolerate burial under a few centimetres of drift-line debris and established plants will survive moderate trampling.

Biotic Effects

The weevil *Ceuthorhynchus verrucatus* Gyll. eats the seeds of *G. flavum* and fungi parasites are found on the plant, including *Entyloma glaucii* and *Pleospora herbarum* (abundant on dry seed pods).

Rumex crispus var. littoreus Hardy

All details on this species are taken from the *Botanical Flora of the British Isles* paper on *Rumex obtusifolius & Rumex crispus* (Cavers & Harper, 1964), unless quoted otherwise.

Distribution

R. crispus var*. littoreus* is the maritime form of *R. crispus*. *R. crispus* is a perennial herb with erect flowering stems that may reach 160 cm. It is a very variable species and the many forms and varieties that have been described are very confused. The species is found in all areas of Britain but is rarer in the North. It is a native species common on waste ground, grassland and shingle beaches. In Britain it may be found from sea-level to 1500 m. The species is one of the most widely spread plants in the world and is a serious agricultural weed. It occurs in Europe up to a latitude of 69 ° N, and is present in the Faroes and Iceland but not in Greenland. It is also found in the Middle East and cultivated areas of Asia, Japan, Australia and New Zealand. It occurs in many regions of Africa and is naturalised in North America to 65 ° N and in South America in temperate regions.

Habitat

The maritime form is found primarily on shingle beaches occupying the more disturbed and open parts of the beach that are sometimes covered by the spring high water level. Young seedlings may survive seawater immersion. *R. crispus* in general is found on all soils, with the exception of those that are acidic. On the shingle beach *R. crispus* var. *littoreus* is an important species of tidal drift vegetation. Frost apparently has no effect on the species and the maritime form is particularly tolerant of very dry surface conditions.

Life History (Morphology & Biology)

R. crispus var*. littoreus* (a hemicryptophyte – see footnote 1) has leaves that are fleshy and the panicles (branched elongated inflorescences) are often dense. All three perianth segments that encapsulate the seed possess large tubercles. This contrasts to other varieties of *R. crispus* that possess only one tubercle. Seeds of *R. crispus* var. *littoreus* are buoyant due to these tubercles, and are capable of floating for over up to 15 months in salt water. The seeds show no innate dormancy (Walmsley, 1995) which is not typical of the species in general however it is suggested that the maritime form shows significantly less dormancy than the inland species (Walmsley & Davy, 1997; Cavers & Harper, 1966). The plant has a thick fleshy underground stem of approximately 3-4 cm length with a width of 5 cm or more on top of the largely unbranched vertical tap root. The plant survives the winter as a rosette or by perennation of the below ground parts. Regrowth from the rosette stage begins in February/March with the first warm weather and inflorescences first appear in April/early May. Plants may produce flowers in their first year but in more unfavourable habitats may not flower until their second or subsequent years. The flowers are wind pollinated and maritime plants often have high self-fertility. One seed is generated per fruit and 20 to 50 may cover a panicle. On a whole plant 100 to 40,000 seeds have been documented. Until the tap root system is established the slow growing seedlings of *R. crispus* are poor competitors amongst more vigorous species. The cotyledons drop from the plant after approximately 2 to 3 weeks and the typical crisped edge of the leaves only becomes apparent in the sixth leaf.

Biotic Effects

The species is harmful if ingested. Many animal feeders and parasites have been documented including members of the Thysanoptera, Hemiptera, Homoptera, Lepidoptera, Coleoptera, Hymenoptera and Diptera insect families. *Pyrrhula pyrrhula* (Bull Finch) feeds on the fruits and *Phasianus colchicus* (Pheasant) eats the leaves at various times of the year. Viral, bacterial and fungal species also affect *R. crispus*.

Lathyrus japonicus Willd.

Unless quoted otherwise all details on this species are taken from the *Botanical Flora of the British Isles* article on *Lathyrus japonicus*, written by Brightmore & White (1963).

Distribution

L. japonicus is a prostrate, grey-green leguminous perennial herb with stems that may reach 100 cm long (after Rose, 1981). It has a circumpolar distribution (Hulten, 1950, as cited by Brightmore & White, 1963) and within this range many varietal forms exist. *L. japonicus* is a native plant and primary coloniser of shingle beaches in the U.K. It is now found in isolated localities from Dorset to Norfolk with remote populations in Angus and Shetland. In the U.K. its altitudinal range is usually between 3 and 4.5 m and it seems to lack any climatic limitation. However temperature determines its northern limit, which corresponds the –26.7 °C January isotherm. Elsewhere its distribution includes the coasts of Denmark, Norway, the shores of the Baltic, Gulfs of Finland and Bothnia and Lakes Ladoga and Oneda. There are no records of it growing on the coast of Arctic Siberia however it does appear in Eastern Siberia through Kamchatka to Japan where it is a common plant of coastal sand dunes. In North America it is found from northern California to Alaska (Cooper, 1936, as cited by Brightmore & White, 1963) then reappears extending southwards from Newfoundland to Long Island the lower St. Lawrence and the Great Lakes. It also occurs in Greenland (Polunin, 1959 as cited by Brightmore & White, 1963) and Iceland. Formerly *L. japonicus* was also found on the Cayeux Spit, Picardy, France, it is likely to have become locally extinct in the mid-1940s (Géhu, 1960).

Habitat

This species is found on well drained soils, usually on stable shingle beaches and normally occurs as isolated plants or small patches. According to Hepburn (1952) it also generally prefers ‘fairly mobile’ shingle. However closed stands of 20-25 m may occur and some patches may remain virtually pure for a number of years. Where the shingle lacks a substantial fine matrix the plants and the leaves are smaller and fewer flowers are produced. In dune conditions *L. japonicus* is susceptible to invasion by *Agropyron junceiforme* and *Ammophila arenaria* causing it to develop a scrambling habit. The plant and its seedlings are frost resistant however early summer drought causes death of seedlings and young plants. Small plants are killed by a covering of more than 15 cm but older plants are able to survive by producing axillary shoots on the stems which quickly grow almost vertically through up to 40 cm of blown sand.

Life History (Morphology & Biology)

The species is defined as a rhizostomatous geophyte[2] with the rootstock often descending unbranched more than 100 cm with the functional roots in the lower zone. The roots will be shorter and more branched in substrates with a greater sand content. Reproduction may be vegetative and/or sexual. Mid to late summer axillary buds or short lateral shoots with hooked tips form on the rhizostomatous part of the stems up to 10 cm below the substrate surface, remaining dormant until the following growing season. By the end of February bud elongation has begun which by early April have become fleshy cream coloured stems that start to show above ground. Maximum growth of these buds occurs during May and June. The main flowering period in Britain taking place from late May to late July, however, flowering may occur as early as mid-April. This species flowers from its third year onwards. Flowers are pollinated by *Bombus agrorum* Fab., *B. hortorum* L. and *B. lapidaries* L. (long-tongued bumble bees) and fruits ripen 3 to 4 weeks later. Seed dispersal will occur by sea where species are found near the storm crest of the beach – the seeds are light and float well and will retain their buoyancy and viability for up to 5 years. Green unripened seeds will germinate after 7-14 days and chipped hard (ripened) seeds will germinate within 8 days during summertime and 55 days in the autumn. Seedlings are able to survive severe frost (-8 ° C). Where violent storms had eroded and broken subterranean parts of the plant at Shingle Street, Suffolk, new plants were seen to have regenerated from short lengths of rhizome. Late summer/early autumn the above ground vegetation dies back with leaflets falling but the stem (now dry) is visible, attached to the plant , until well into the following year.

Biotic Effects

At Rye Harbour, East Sussex *Columba palumbus palumbus* L. (Wood pigeons) and *C. aenas* L. (Stock doves) have been seen to feed on *L. japonicus* seeds. The snail *Cernuella* (C.) *virgata* sometimes eats the leaves and in Britain the plant is the food source of *Epischnia boisduvaliella* (Pyralid moth). At Rye harbour *L. japonicus* seeds were collected in August 2003 dried and refrigerated. Two months later, on chipping the seed coats, live weevils (*Bruchus loti*) emerged, leaving an almost empty seed shell.

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[2] Rhizostomatous geophyte = a plant with perennating buds buried beneath the soil (Packham & Willis, 1997)

Atriplex glabriuscula Edmonst.

There is a paucity of published literature on this species, most details are taken from Ignaciuk & Lee (1980) unless stated otherwise.

Distribution

A. glabriuscula is an annual, fleshy, usually prostrate herb (Rose, 1981) and an ephemeral inhabitant of strandline communities. It may occur even on heavily trampled foreshores such as Shoreham beach, however in 2003 it was absent from Cuckmere Haven East beach, also a heavily trampled environment (pers. obs.).

Habitat

It is more salt tolerant than other shingle species and consequently may grow in areas flooded by extreme high tides (Packham and Willis, 1997). In East Sussex, it is primarily found at the spring high water level on the shingle foreshore.

Life History (Morphology & Biology)

During field visits to Rye Harbour, East Sussex, (pers. obs.) seedlings had appeared on the storm ridge by late May (pers. obs). Plants grow in a prostrate manner across the shingle surface from a central main stem. Seeds have begun to form in triangular shaped bracts by August and are ripe and falling (still within the bract) from the parent plant into the shingle interstices by October (pers obs.). Although there is no innate dormancy, the seeds are shed enclosed within the bracts, which inhibit the germination of mature seed in the autumn (Beadle, 1952). Weakened by abrasion and decay during the winter the bracts are likely to be ineffective in enforcing any dormancy the following spring. Along the strandline of the Solway Firth, Cumbria/Dumfries & Galloway, germination of *A. glabriuscula* was observed 4 weeks after the spring equinoctial tides (end April), although the main germination period was May. Under laboratory conditions, greatest germination occurs when plants are under alternating temperatures (10/30 ºC thermo-period).

Biotic Effects

No animals were observed feeding on the seeds, but this does not preclude this possibility. Parasites/disease have not been investigated.

Appendix B

Seed treatment

If seeds are stored in paper bags and dried at room temperature for 5 – 13 weeks then transferred to paper envelopes and stored over silica gel in air-tight plastic containers and kept in a cold room at 2 ± 2 °C in darkness (Wells, Bell and Frost's method, 1981, as cited by Walmsley & Davy, 1997) then seed viability may be maintained for up to seven years (Walmsley & Davy, 1997). Seeds of *Crambe maritima*, *Glaucium flavum*, *Lathyrus japonicus*, *Rumex crispus* were collected during August 2003 and *Solanum dulcamara*, *Atriplex glabriuscula*, *Centranthus ruber* and *Arrhenatherum elatius* in October 2003. Due to time constraints seeds were dried in air for a minimum of two weeks (seeds collected in October) and a maximum of eight weeks on non-absorbent paper. This drying time was considered sufficient since it is unlikely that seed viability needs to be maintained over several years, most seeds being used in these preliminary experiments. The reason for the longer desiccation time is to ensure that all physiological activity (which cannot function without water) ceases in order to lengthen seed life (Woods - pers. comm., 2003). All seeds were then stored at 4 °C in labelled paper sachets in an airtight container containing 500ml of desiccant (silica gel crystals).

All species collected were subject to a pilot study to establish seed viability of the wild seed and time taken to germinate in the greenhouse. All were sown in seed trays containing a 5000 ml 1:1 mix of coarse sand and John Innes Loam-based seedling compost (mix suggested by WSVSP[1], 2003, for successful shingle plant germination and growth). Trays were placed in a greenhouse on 10/10/03 and time taken to germination recorded. Minimum and maximum temperatures were recorded approximately every other day and there was no extra lighting or heating until 31/10/03 when a 12h light/12h dark regime was initiated and an air heater installed to prevent any freezing temperatures in the greenhouse. The substrate surface was sprayed with water approximately every other day and seed trays were initially covered with clear perspex to keep the substrate moist (but removed when seedlings began germinating).

However, before any germination was possible some dormancy mechanisms needed to be released. Here follows treatments carried out on the species before sowing and figure 1 lists the time taken to germination for each species.

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[1] WSVSP – West Sussex Vegetated Shingle Project produced a Shingle Wildlife Garden Code of Conduct. The document gives guidance to the general public on how to successfully propagate shingle species in their own garden.

Crambe maritima

According to Walmsley (1995), in order for germination to take place under artificial conditions it is necessary to remove the pericarp (seed coat). However this was deemed unnecessary by Woods (pers. comm., 2003), since germination tests carried out at the Millennium Seed Bank laboratories on *C. maritima* with seed coat still intact were successful. Both methods were tested by sowing seeds with their seed coat intact (n = 25, 5 rows of 5 seeds) and without their seed coat (n = 25). However the WSVSP code of conduct (2003) also suggests 2 months of stratification and previous experiments with *C. maritima* by Hempenius (2003) revealed that no seeds germinated without being cold treated for at least one month. The sown seeds were therefore stratified for six weeks in a fridge at 4 °C, then moved to the greenhouse and successful germination occurred of seeds with and without seed coats approximately 1 week later.

Glaucium flavum

Stratification for *G. flavum* followed the method for *C. maritima* for similar reasons. However two trays of seeds (n= 56, 8 rows of 7 seeds) were sown both in the 1:1 mix of coarse sand and peat-free seedling compost but one tray was also covered with a 5 mm layer of coarse gravel (500 ml) to investigate whether this would prevent algae or mould forming on the substrate surface, a method suggested by Woods (pers. comm., 2003). Limited germination occurred 4 weeks after trays were moved to the greenhouse.

Rumex crispus

The seeds of *R. crispus* var. *littoreus* apparently show no innate dormancy (Walmsley, 1995). This is not typical of the species in general however it is suggested that this maritime form shows significantly less dormancy than the inland species (Walmsley & Davy, 1997; Cavers & Harper, 1966). Seeds from two locations (Rye Harbour and Cuckmere Haven) were sown in the same seed tray, (n = 25 from each beach) to investigate any distinct difference in viability and germination time between locations before using any seed for further experiments. Seeds germinated after 18 days in the greenhouse.

Solanum dulcamara

Ripe fruits (red berries) collected from plants in October 2003 were pulped in a fine sieve to remove all wet fruit material leaving behind all seeds (method for removing tomato seeds – RHS, 1999). Pegtel (1985) discovered, in separate germination experiments on populations from different habitats, that there was increased germination with alternating temperatures e.g. (20/30 ºC) and at constant temperatures in the dark. His stratification experiment also revealed that when seeds were cold-stratified they were capable of germinating at relatively low temperatures. A large number of seeds were sown (n = 56) to increase chances of obtaining some seedlings. Seeds were not cold stratified but put under a diurnal temperature regime of approx. 10/ 20 ºC (ambient temperatures in the greenhouse). Seeds germinated three and a half weeks after sowing.

Lathyrus japonicus

L. japonicus seeds require scarification if they are to germinate (Walmsley, 1995). Seeds were placed in H_2SO_4 (96%) according to Walmsley's method (1995) and stirred for 45 minutes to soften the testa (scarification). However Woods (pers. comm., 2003) stated that manual scarification (chipping) of the seed coat with a sharp blade is just as successful. Both techniques were employed (n = 25 for each method) and the germination success of each method noted. An interesting discovery on manual scarification of *L. japonicus* seeds revealed that 1 in approximately every 3 seeds was inhabited by a weevil (*Bruchus loti*), which emerged alive from the seed on chipping the coat. These seeds were discarded, as most of the seed had been consumed/broken down. In the acid scarification although there was no remaining evidence of the weevils it was clear to see which seeds had been broken down, these were also discarded. The latter method was deemed more time efficient in determining which seeds were viable. Seeds germinated 5 days after sowing.

Atriplex glabriuscula

Seeds and their attached bracts collected in October 2003 were initially dried together and then two weeks later half the seeds were removed from the bracts and dried separately. Seeds with and without their surrounding bract were sown (n= 25 of each) in the same seed tray. According to Ignaciuk & Lee (1980) this species has no innate dormancy besides the encapsulation of the seed by the bract. Germination is poor at constant temperatures but is significantly greater in warmer temperatures (Ignaciuk & Lee, 1980). However the optimal thermo-period for germination is 10/30 ºC (Ignaciuk & Lee, 1980), unfortunately these details were discovered weeks after the sowing event. This species took a significant amount of time to germinate poorly, only two plants after 36 days (but the correct germination conditions were not applied from the start – plants are now under a warmer temperature regime).

Centranthus ruber

A previous experiment by Hempenius (2003) revealed that *C. ruber*, when planted in the same medium as other shingle species and subjected to same light and watering regimes, germinates earlier and has a root system that is larger and grows faster than some other shingle species. The species shows no innate dormancy. Seeds were sown in the sand/compost mix (n = 56). Interestingly, *L. japonicus* germinated before *C. ruber*.

Species	Date sown	Date first germinated	Time taken to germinate (days)
Lathyrus japonicus	15/10/03	20/10/03	5
Centranthus ruber	14/10/03	28/10/03	14
Rumex crispus	10/10/03	28/10/03	18
Solanum dulcamara	10/10/03	05/11/03	26
Atriplex glabriuscula	14/10/03	19/11/03	36
Crambe maritima	10/10/03	01/12/03	52
Glaucium flavum	06/10/03	22/12/03	63

Figure 1 Time taken for each species to germinate (quickest to slowest listed top to bottom, respectively).