



Investigation into the habitat requirements of the Sea Aster mining bee in both man-made and natural habitats: Implications for conservation management actions to improve habitat opportunities with a view to enabling the reconnection of isolated populations.

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2013

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1.0 Executive summary

Climate change and biodiversity loss are interlinked. Climate change, and the associated sea level rise, is negatively impacting on our coastlines and causing a reduction in salt marsh habitats across the UK. The Sea Aster mining bee *Colletes halophilus*, a rare and endangered bee is a UKBAP priority species, Essex Red Data Book species; it is also nationally scarce (notable A) and is listed in section 41 of the Natural Environment and Rural Communities Act 2006. It is associated with salt marsh habitats, and other coastal areas, making it particularly vulnerable within these fragile and threatened habitats. In addition, high development pressure is currently assailing many parts of the United Kingdom, with the Thames Estuary area highlighted as being a major regeneration area in Europe. Due to this pressure that will be altering landscapes and habitats across the UK, it will be important to understand species responses to the new man-made habitats that are being created. Understanding the habitat requirements of a species will be fundamental to understanding their responses to changes to their environments so that conservation techniques can be tailored to help them.

This investigation has confirmed that *C. halophilus* will exploit both natural and man-made habitats as long as two key resources are present, forage and suitable nesting sites. Suitable nesting sites include areas that experience high incidences of solar radiation, like raised south-facing banks. The preferred soil type would consist of soils with a high sand content with sparse vegetation cover and with structural diversity in the form of pits and mounds. It is suggested that management in areas with large stands of Sea Aster could increase opportunities for *C. halophilus*, such as the removal of vegetation from south-facing sea wall banks. It may also be beneficial for new developments along the coastal areas where *C. halophilus* is distributed, to include invertebrate nesting areas in areas close to Sea Aster in the hope that this species and other invertebrates can utilise these areas and spread out their distribution. In addition, it was also noted that future options may become available that will be beneficial to this species, such as the progression of Michaelmas daisies into new areas, which may provide additional foraging opportunities for this late emerging bee. To this end, advice and recommendations have been included in the form of a 'Management Guidance Sheet', which can be found in a separate file.

2.0 Aims and objectives

The aim of this report is to investigate the specific habitat requirements of the Sea Aster mining bee, *Colletes halophilus*.

The main objectives of this report are to:

1. **Determine the ecology of the Sea Aster mining bee (*C. halophilus*) by collating existing knowledge, and from direct observations during the summer of 2013.**
2. **Identify the key habitat attributes and parameters influencing presence and abundance.**
3. **Assessment of the current locations where the bee is present and potential nesting areas where it is absent; consider possible reasons for its presence and absence with a view to inform management.**
4. **Examine the effectiveness of man-made habitats in comparison with naturally created areas of habitat.**
5. **Contribute to a 'management guidance sheet' for this species.**

3.0 Introduction

Biodiversity is experiencing major losses throughout the world due to various factors, including agricultural intensification, development and climate change (Harris and Johnson, 2004; Woodcock and Pywell, 2010; Zurbuchen *et al.*, 2010; Loss *et al.*, 2011). Climate change is particularly detrimental to many species and has particularly impacted on our coast lines, including increased erosion and inundation due to sea level rise (Luisetti *et al.*, 2011). Salt marsh habitats are particularly vulnerable to the effects of climate change and sea-level rise, and associated 'coastal squeeze' (JNCC, 2010; Friess *et al.*, 2012; Buglife, 2013), which is reducing salt marshes across the UK (Luisetti *et al.*, 2011; Evans and Potts, 2013).

The Sea Aster mining bee (*Colletes halophilus*), is a UKBAP priority species, Essex Red Data Book species (NBN, 2013), which is also nationally scarce (notable A) (Falk, 1991) and is listed in section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 (IUCN, 2013). It is an extremely rare and endangered bee associated with the margins of salt marshes and, occasionally, other coastal habitats (Falk, 1991; Kuhlmann *et al.*, 2007; Hymettus, 2009). Rarity is considered one of the most important indicators for nature conservation, with 'the rarer the species the greater the value' often cited (Eyre and Rushton, 1989), highlighting the importance of this rare native bee. In addition, bees are considered to be keystone species (McIntyre and Hostetler, 2001; Williams *et al.*, 2010), meaning their loss can have a larger impact than their abundance would suggest (McIntyre and Hostetler, 2001), potentially affecting all trophic levels and many more species than just bees (McIntyre and Hostetler, 2001).

Native bees are also thought to be an integral part of ecosystem functioning and provide services such as pollination, which could act as insurance against the large scale loss of pollinators that is currently being experienced (Greer, 1999; Winfree *et al.*, 2007), further emphasizing the importance of native bees like *Colletes halophilus*. Bees in particular, are currently experiencing dramatic declines in numbers due to a variety of factors including changes to their habitat and total loss of habitat (McIntyre and Hostetler, 2001). Therefore it is important that we understand more about their needs and requirements in order that we can tailor management to help conserve them.

Colletes halophilus has a very restricted UK distribution on the east and south coasts of England (BWARS, 2012a), with particularly important populations found on the margins of salt marshes of the East Anglian Coast and the Thames Estuary area (Falk, 1991; BWARS 2012a). However, intense development pressure in the Thames Gateway has, and may continue, to result in further losses to salt marsh habitat (Buglife, 2009). This could impact negatively on this rare species (*ibid.*) through the loss of nesting sites and forage resources, two of the main limiting factors for solitary bees (Cane, 2001; Gathmann and Tschardt, 2002; Potts *et al.*, 2005).

Habitat loss is affecting many different invertebrates, which has led to mitigation measures in the form of habitat creation and management for invertebrates using techniques such as beetle banks (Dicks *et al.*, 2012; Gedge *et al.*, 2012), scrapes (RSPB, 2010) and bee banks (Woods, 2011), which have often been very successful in providing nesting sites that can help increase invertebrate numbers (Bowler *et al.*, 2009; Dicks *et al.*, 2010). In addition, other man-made features, such as rock piles, sand pits, ditch edges, road embankments and sea walls have also been reported to provide nesting opportunities for some species (Westrich, 1996; Bowler *et al.*, 2009; Lee, 2011; Heneberg *et al.*, 2012; Evans and Potts, 2013; Personal Communication: Tim Strudwick, 6th August 2013). These artificial structures could be particularly important in providing options that could mitigate for the negative effects of development and climate change, threats currently assailing this and many other species.

Novel management to provide additional nesting opportunities for *Colletes halophilus* has been undertaken at Coalhouse Fort, a stronghold of this rare bee, located at East Tilbury (Kuhlmann *et al.*, 2007; Thurrock Council, 2010; Buglife, 2011). This experimental management, and its outcomes, may help to provide further evidence for management that may be able to enhance populations for this and other invertebrate species. Therefore,

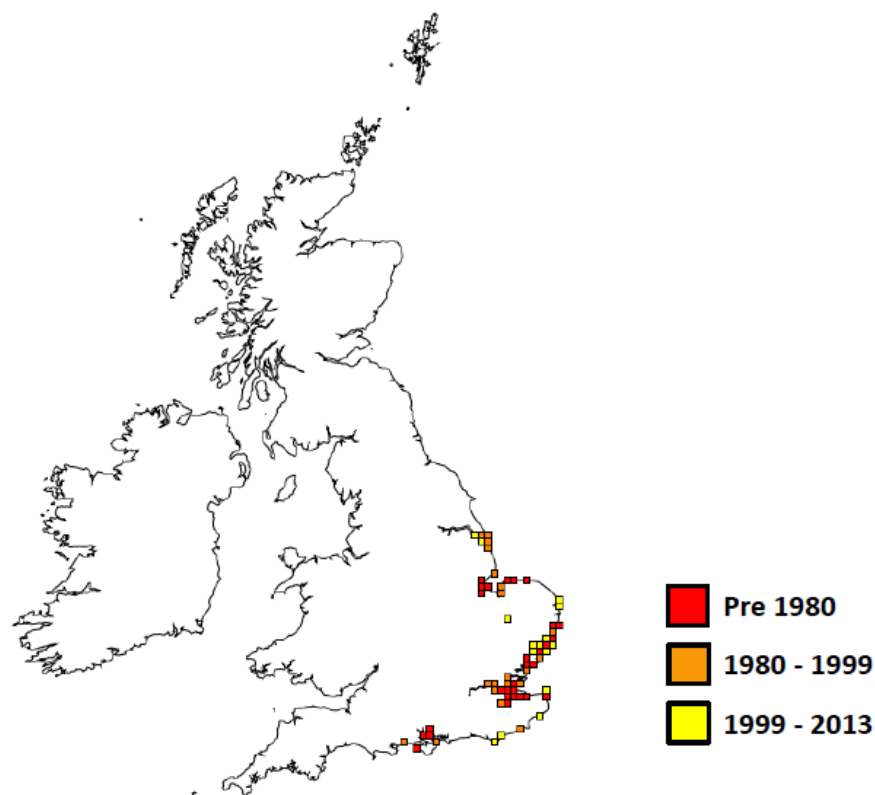
in order to inform conservation management for this rare bee, further knowledge regarding its preferences and specific habitat requirements, especially in both natural and man-made habitats, such as Coalhouse Fort, will be the focus of this report. Understanding those features which enable the successful colonisation of this bee will be fundamental in providing help and advice that could help mitigate for the serious threats of both development and climate change.

4.0 Sea Aster mining bee *Colletes halophilus* ecology

The Sea Aster mining bee *Colletes halophilus* is a short tongued solitary mining bee (Rooijackers and Sommeijer, 2009). It is an attractive bee approximately 11 – 14mm in length (Evans and Potts, 2012) with reddish brown hair on its thorax with a black abdomen with clearly defined pale whitish to yellow bands (males are smaller and paler) (Evans and Potts, 2013; Personal Observation 26th August 2013).

4.1 Known distribution

C. halophilus has a restricted UK distribution (Figure 1) on the south and east coasts of the United Kingdom (NBN, 2013) and can also be found globally at sites on the Atlantic coast of France and southern North Sea (Evans and Potts, 2013). It's relatively limited distribution may be due to the combined effects of its oligolectic nature and its preferences for salt marsh habitats, both limited resources which can increase its vulnerability (Harris and Johnson, 2004). The warmer climate of the south-east may also prove particularly important for this late emerging bee, and may restrict its migration further north or west.



Copyright NBN Gateway 2013.

Figure 1 The known distribution of *Colletes halophilus* within the United Kingdom. Source: NBN Gateway.

4.2 Life cycle

C. halophilus nest in large aggregations (Rooijackers and Sommeijer, 2009; Evans and Potts, 2013), and is considered a 'communal nester', which indicates that they prefer to nest in aggregations but seem to be strictly solitary, with each female reproducing individually, with no evidence of collaboration (Personal Communication: Steven Falk, 13th December 2013). They are active late in the summer, from the end of August until the end of October and sometimes, although rarely, the end of November (Belisle, 2011; BWARS, 2012a). Males emerge first and stay close to the emergence area to await the subsequent emergence of the female bees; once a female emerges, all males in the vicinity will swarm towards her in an attempt to mate (Evans and Potts, 2013; Personal Observation 26th August 2013). At the beginning of the emergence period when large numbers of males are present, a female may emerge alone to be mobbed by quite a few males to form what is known as a mating ball (Evans and Potts, 2013; Personal Observation, 26th August 2013) (Plates 1 and 2).



Plate 1 Males of *Colletes halophilus* 'mobbing' newly emerged female which has formed a mating ball. Copyright: Kara Alicia Hardy.



Plate 2 Newly emerged female *C. halophilus* being mobbed by waiting males to form a mating ball. Copyright: Kara Alicia Hardy.

Once the female has copulated, she will then excavate a short and sometimes curved nest burrows, at the end of which will be dug a cluster of 5 – 6 cells. She will line the cell wall with a waterproof polymer, made with glandular excretions, that also acts as an anti-fungal barrier to protect her brood (Klemm, 1996; Belisle, 2011) where she will lay her eggs and provision them with a pollen and nectar mix (Evans and Potts, 2013) (Plate 3).



Plate 3 Female *Colletes halophilus* returning from a foraging trip. Copyright: Kara Alicia Hardy.

C. halophilus are oligolectic, which means they only forage on a limited number of plant species for pollen, i.e. Asteraceae (Kuhlmann *et al.*, 2007; Davies *et al.*, 2012). However, they have been known to forage on plants

from other families, such as Perennial Wall Rocket *Diplotaxis tenuifolia* of the Brassicaceae family (Personal Observation, 26th September 2013), but females will mainly provision their brood cells with pollen from plants of the family Asteraceae (Evans and Potts, 2013). Bees, both male and female, will also need pollen themselves in order to fuel their flight (Westrich, 1996; Evans and Potts, 2013) therefore it is important that flowering plants are located in relatively close proximity to the nesting site. Sea Aster (*Aster tripolium*) is of particular importance, as large stands of this plant flowers from August, synchronously with the flight period of this bee, and is the preferred pollen source for females provisioning their eggs (Kuhlmann *et al.*, 2007; Evans and Potts, 2013). The laying of eggs at this late period of the year means that the young will overwinter in their cells to emerge the following year to continue the cycle, resulting in only one generation of bees produced each year (Belisle, 2011; Evans and Potts, 2013). Only one known species parasitizes on *C. halophilus*, which is a cleptoparasitic cuckoo bee, *Epeolus variegatus*, whose late emergence coincides with the emergence time of *C. halophilus* (BWARS 2012b).

4.3 Habitat

C. halophilus are mainly associated with salt marsh habitats, where they spend time foraging predominantly on flowers of the maritime halophyte Sea Aster, *Aster tripolium*, and also from members of the Asteraceae family (Falk, 1991; Evans and Potts, 2013). Males of this species focus primarily on mating opportunities, whilst female individuals concentrate on nest building and provisioning, therefore they require not only available pollen resources, but also suitable nesting habitat, two quite different types of habitat (Williams and Kremen, 2007).

Nest burrows are often excavated in soils with a high sand content and with very little vegetation cover (Kuhlmann *et al.*, 2007; Hymettus, 2009) and frequently found on south facing slopes (Falk, 1991; Hymettus, 2011; Essex Field Club, 2013) where insolation is higher for this thermophilic (warmth loving) species (Goulson, 2003; Woods, 2011) (Plate 4).



Plate 4 Nesting aggregation site: newly dug burrows at Colne Point Nature Reserve. Copyright: Kara Alicia Hardy.

Their typical nesting habitat, thought to be located in the transition zone between intertidal salt marsh and dry land has largely been lost through the large-scale provisioning of sea walls along our coastlines, thereby

reducing opportunities for this species (Knowles, 2011). However, brownfield habitats in coastal areas can support an abundance of both Asteraceae and disturbed, bare ground areas (Robins *et al.*, 2013), and therefore can also provide both foraging and nesting opportunities so essential for this species (*ibid.*). Brownfields are a UK BAP priority habitat, defined as 'open mosaic habitats on previously developed land' and may be particularly important in enabling the persistence of many other species within these highly industrialised coastal areas, such as the Thames Gateway area (Robins *et al.*, 2013).

C. halophilus have been observed exploiting other man-made structures, such as sea walls, sand piles and other artificial habitats (Knowles, 2011). This has prompted this investigation into finding those habitat variables most important for successful colonisation in order that conservation management can be tailored, where possible, to create and manage features that could increase numbers of this rare bee.

5.0 Methodology

This study was conducted during the summer of 2013, from the end of August until mid-October 2013, the main activity period of the Sea Aster mining bee, *Colletes halophilus* (Kuhlmann *et al.*, 2007). Investigations were limited to the East Anglian coast, Thames Estuary area and several sites along the Kent coastline. This investigation also included a one off visit to Selsey with Mike Edwards of BWARS (Bees, Wasps and Ants Recording Society) to observe the work to be undertaken to mitigate for invertebrates (including *C. halophilus*) at a managed realignment project in Medmerry.

Peter Harvey, Essex county recorder for hymenoptera, supplied details of known nesting aggregations of *C. halophilus*, which were visited in order to identify the key habitat attributes and parameters that may influence the presence and abundance of *C. halophilus*. Further sites on the Essex coastline, including known historical locations taken from the Essex Field Club website (www.essexfieldclub.org.uk), were visited in order to attempt to locate additional nesting aggregations of *C. Halophilus*. Timothy Strudwick (RSPB), Norfolk county recorder for hymenoptera, also supplied details of nesting aggregation locations on the coast of Norfolk, one of which was visited in order to try to locate further nesting aggregations.

5.1 Desk Study

In order to determine the ecology of the Sea Aster mining bee *Colletes halophilus*, existing literature was reviewed and various hymenopteran experts consulted, in addition to direct observations of the behaviour of the bee during this investigation, as this can be important for understanding the ecology of insects (Walton and Dent, 1997).

5.2 Site visits to locate additional nesting sites

Sites with historical records of *Colletes halophilus* were visited in order to try to identify additional nesting aggregations. Sites were visited between 10am and 5pm, when bees are more active, and on warm days with low wind speed (Edwards, 1996; Bowler *et al.*, 2009). Stands of Sea Aster, *Aster tripolium*, the main forage plant of *C. Halophilus* (Kuhlmann *et al.*, 2007; Hymettus, 2009), were observed for a minimum of 1 hour in order to establish the presence of *C. halophilus* (Personal Communication: Mike Edwards, 17th August 2013).

Once a sighting of the bee had been recorded, the surrounding area was explored to attempt to locate any nesting aggregations within a 600m radius, the max foraging distance of most solitary bees (Gathmann and Tscharrntke, 2002). Explorations to locate new nesting sites were made by walking around the area where the bee was sighted, looking for males searching for females, and also foraging females (Knowles, 2011). Searching was limited to south facing slopes and/or bare ground areas, as these are considered the preferred nesting

habitat type for mining bees (Klemm, 1996; Westrich, 1996; Greer, 1999; Bowler *et al.*, 2009). Sites with the presence of nest holes similar to those of *C. halophilus* were watched for 20 minutes in order to confirm activity of the bee at these sites (Bowler *et al.*, 2009). Confirmed nesting aggregations were then surveyed using standardised field work sheets, which recorded a range of variables as discussed in the section 'Nest site survey'.

5.3 Nesting aggregations

The following section gives a description of the three confirmed nesting aggregations, which will represent both man-made (Coalhouse Fort and Walsh's mount) and natural habitats (Colne Point Sites A and B).

Colne Point SSSI – Essex Wildlife Trust

Colne Point Essex Wildlife Trust Nature Reserve was first visited on the 26th August 2013, shortly after the first emergence had been observed by Bob Seago, the Essex Wildlife Trust reserve warden working there. Colne Point nature reserve (Grid reference: TM 099125) (Grid reference obtained using a Garmin Etrex handheld GPS: Liberty House, Bulls Copse Road, Southampton, SO40 9LR) is a Site of Special Scientific Interest (SSSI) currently owned and protected by Essex Wildlife Trust (Plate 1). The 683 acre reserve lies at the mouth of the Colne Estuary and is comprised of a shingle ridge which encloses a substantial area of saltmarsh habitat through which Ray Creek flows (Essex Wildlife Trust, 2013).



Plate 5 Sea Aster stands at Colne Point Nature Reserve, with the warden's hut in the background. Copyright Kara Alicia Hardy.

Colne Point nature reserve is situated south of Brightlingsea, 15km south east of Colchester on the eastern bank of the Colne Estuary (Natural England, 2013) (Figure 2).

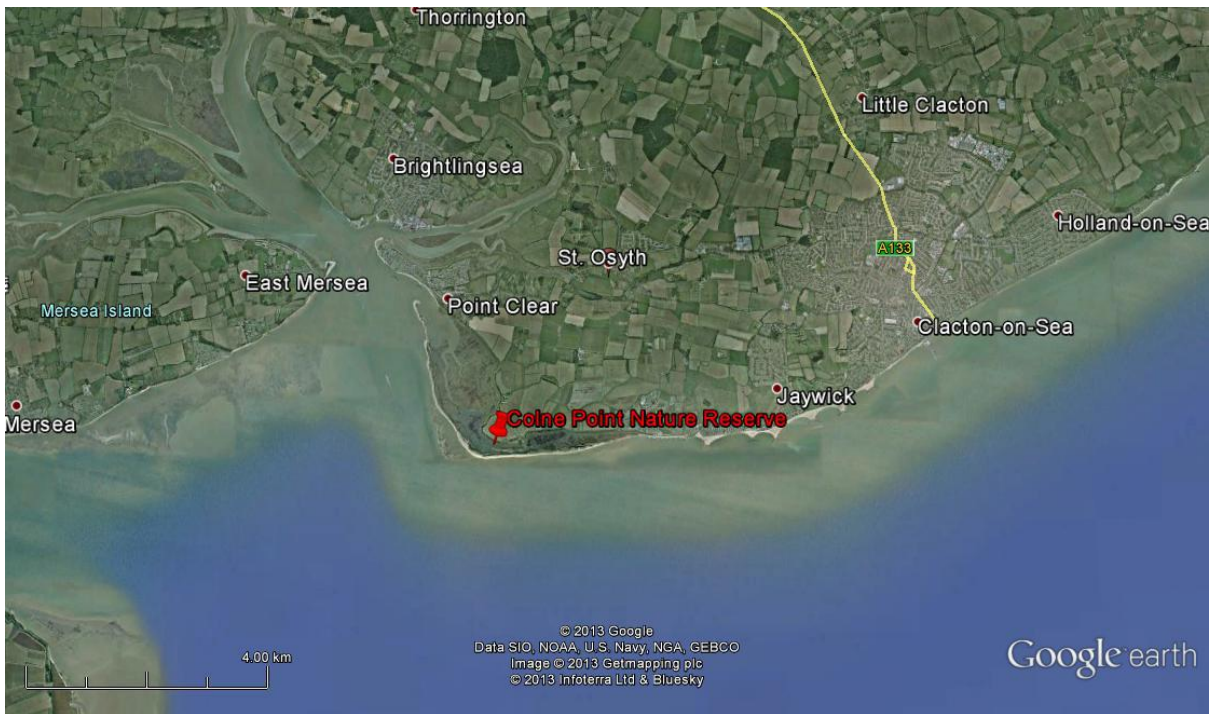


Figure 2 Location of Colne Point Nature Reserve nest site. Source: Google Earth (2013) Data SIO, NOAA, US Navy, NGA, GEBCO; Getmapping plc; Infoterra Ltd & Bluesky (License information: <http://www.google.com/permissions/geoguidelines/attr-guide.html>).

Colne Point is a typical example of saltmarsh habitat in Essex, supporting nationally scarce plants such as Golden Samphire *Inula crithmoides* and Small Cord-grass *Spartina maritima* (Essex Wildlife Trust, 2013). This site is important for many different invertebrates including an array of spiders, beetles and moths (*ibid.*). The sandy substrate, of which this site comprises, provides ideal nesting habitat to a number of solitary bees and wasps including the rare Sea Aster mining bee *Colletes halophilus* (Personal Observation 26th August 2013).

The site consists of large nesting aggregations located within two distinct habitat types. The first (Colne Point Site A) comprised a stretch of open sandy ground at the edges and to either side of a public footpath (Plate 6) located at the margins of upper saltmarsh areas and Marram Grass *Ammophila arenaria* sand dunes (Colne Point Site A).



Plate 6 Nesting site A at Colne Point Nature Reserve, bees are nesting both sides of this public footpath. Copyright Kara Alicia Hardy.

In addition, a second aggregation (Colne Point Site B) was found within the Marram Grass sand dune area (Plate 7) lying contiguous to large stands of Sea Aster, *Aster tripolium*.



Plate 7 Nesting site B located at Colne Point Nature Reserve, bees nesting in open areas besides Sea Aster. Copyright Kara Alicia Hardy.

Coalhouse Fort Park SSSI – Thurrock Council

This site was first visited on the 29th August 2013, not long after the first emergence had been observed by Ray Reeves, the Ranger working there. Coalhouse Fort Park (TQ 690768) is a SSSI, and also a special protection area (SPA) and Ramsar site (Thurrock Council, 2010), which is located approximately 400metres south of East Tilbury Village, lying contiguous to the River Thames (Thurrock Council, 2013) (Figure 3). The study site is located in an area to the north east of the fort, formerly known as East Tilbury silt lagoons, which were formed with the laying of river dredging's around 30 years ago (Reeves, 2012).



Figure 3 Location of Coalhouse Fort Park SSSI, nest site labelled in red. Source: Google Earth, 2013 (License information: <http://www.google.com/permissions/geoguidelines/attr-guide.html>).

The site has subsequently dried out and developed over the years, which has left an interesting mosaic of habitat types, which support a diversity of different plant and animal species (Reeves, 2012). The site comprises calcareous grassland, species-rich grassland, rough grassland with seasonally wet areas, semi-stressed grassland, reed beds, willow coppices and lichen heath, all of which lie contiguous to the vast stand of Sea Aster, *Aster tripolium*, which dominates the salt marsh area to the southeast of this site (*ibid.*). It is the presence of large areas of salt marsh (Thurrock Council, 2010) which makes this site suitable for the Sea Aster mining bee (Plate 8).



Plate 8 Large stands of Sea Aster at Coalhouse Fort as seen from the nesting aggregation site. Copyright: Kara Alicia Hardy.

The rangers at Coalhouse Fort have been managing certain areas of the site on an annual basis in order to create opportunities for this bee and other rare invertebrates (Thurrock Council, 2010). This involves strimming an area of grassland, close to the stand of *Aster tripolium*, in a rectangular shape and as short as possible, whilst leaving thin strips of longer grass approximately 2 inches in width, at intervals of approximately 1m (Plate 9).



Plate 9 Novel management by ranger Ray Reeves (Thurrock Council) at Coalhouse Fort in East Tilbury. Copyright: Kara Alicia Hardy.

Aggregates site – East Tilbury

The aggregates site was visited on the 22nd September 2013. This site (Grid reference: TQ 6877), a construction aggregates site, is located to the north west of Coalhouse Fort and sits within a farmed landscape to the east of Princess Margaret Road, East Tilbury, and west of the River Thames (Plate 10).

The site is a busy industrial yard which re-grades various construction aggregates and consists of a variety of substrates, including sands and gravels, which are piled up across the site (Personal Communication: Ray Reeves, 29th September 2013). The site experiences various levels of vehicular disturbance on a daily basis.



Plate 10 Walsh's aggregates yard located on land adjacent to Coalhouse Fort, East Tilbury. Copyright: Kara Alicia Hardy.

The area of interest is a pile of Thanet sand which has been left relatively undisturbed for over 9 years, leading to the area being vegetated naturally over the years and colonised by various invertebrate species, including *C. halophilus*. Hereafter this site will be referred to as Walsh's mount (Plate 11).



Plate 11 Nesting aggregation site located at Walsh's Yard (Walsh's Mount), East Tilbury. Copyright: Kara Alicia Hardy.

Several visits were made to each nesting aggregation site in order to collect the relevant habitat data required to support this investigation.

5.4 Nest Site Survey

Nesting aggregations of *Colletes halophilus* were surveyed in order to collect habitat data that would describe certain attributes that may determine site selection by these mining bees.

Bee population

The number of nest burrows is a good estimate of population (Hart and Huang, 2012), therefore, in order to obtain a comparable measure of bee abundance at each site, *Colletes halophilus* nest burrows were counted within quadrats to calculate the nest burrow density per square metre and averaged to get a comparable value for each site (Edwards, 1996; Personal Communication: Adrian Knowles, 24th July 2013). Nest burrows were identified by the size, shape, habitat and presence of fresh soil piles (Bowler *et al.* 2009). This will provide a surrogate measure for the population at each site (Personal Communication: Alan Roscoe, 25th November 2013).

Forage resource

Due to the limited foraging distance of most solitary bees (Zurbuchen *et al.*, 2010), the distance between nesting aggregation and nearest stand of Sea Aster, *Aster tripolium*, will be recorded as part of the desktop study. Pollen sources are important in maintaining bee populations (Potts *et al.*, 2005) therefore the size of the foraging resource present will also be recorded.

Microclimate

Temperature data loggers (Thermochron ibutton DS1922L: Maxim Integrated, 160 Rio Robles, San Jose, CA 95134, United States) were used in order to measure the temperature at ground level in order to record the microclimate as arthropods may experience it (Jones *et al.*, 2006). Data loggers were set up on the 30th August 2013 at each nesting aggregation. Loggers were positioned at ground level in the centre of the nesting aggregation (Plate 12) in order to reduce any impacts from edge effects (Pihlaja *et al.*, 2006) and were left in situ until the 9th October 2013 when surveying for the bee had finished. In order to establish differences in the microclimate of the nesting site in comparison to the ambient temperature, weather data will be taken from the Writtle weather station; data supplied by Writtle College (hereafter Writtle weather station will be referred to as WWS). Optimum period (10:00 – 17:00) mean daily temperature was calculated for each site. Data loggers were not left at Walsh's Mount.



Plate 12 Temperature data logger holder set at ground level at Colne Point Nature Reserve. Copyright: Kara Alicia Hardy.

Topography

Topography influences the distribution of plants and animals (Potts *et al.*, 2005), therefore the slope of the nest was measured using a clinometer (Invicta Trigger Action Clinometer: NHBS, 2-3 Wills Road, Totnes, Devon, TQ9 5XN) to help give a more three dimensional description of the nesting sites. The aspect of the nesting sites were also recorded, as this may influence the microclimates which invertebrates can often be very sensitive to (Ausden and Drake, 2006; Philip Wheeler *et al.*, 2011). Any distinct micro-topographical features were also photographed.

Wind speed

An anemometer (Skywatch Atmos Rotating Cup Anemometer ANF-275-100T: LabShop, Unit 1A, Rivergreen Business Centre, Queen's Meadow, Hartlepool, Cleveland, TS25 2DL), was used to measure the wind speed within each quadrat at ground level, and at the height of 1.5m in order to determine any sheltering effects that surrounding vegetation may be having on the nest site.

Vegetation sampling

Vegetation sampling was conducted at each nest site in order to determine the type of cover and other habitat attributes that can be found at each site. A belt transect method was used, which involved placing a 1m² quadrat at regular intervals (5 paces) in a line (Countryside Information, 2013). Vegetation and bare ground cover (%) were estimated within each quadrat and, where possible, vegetation was identified to the level of species.

Soil sampling

Soil compaction can be an important parameter to consider in ground nesting bees (Klemm, 1996; Potts *et al.*, 2005), as penetrability can hinder their burrowing activities (Heneberg, 2011). Therefore a penetrometer (Soil Compaction Tester: DICKEY-john Corporation, AS Communications LTD, Cambridgeshire, PE19 5DQ) was used to measure the level of compaction at each site. The penetrometer penetrated the ground and measurements were taken within each quadrat at both 3 and 6 inches as *C. halophilus* nest depth has been noted at a depth of approximately 4inches (Personal Communication: Ray Reeves, 30th August 2013).

Soil texture is also an important characteristic in site selection for mining bees (Potts *et al.*, 2005), therefore to identify the type of substrate, or dominant soil texture, that could be found at each nest site, soil samples were taken from the piles of soil that had been excavated by nesting *Colletes halophilus* (Personal Communication: Alan Stubbs, 13th August 2013) and assessed by geologist, Alan Stubbs, from Buglife.

Photographic evidence

Photographs of the nesting aggregation site, proximate forage areas and micro-topographical detail will be taken throughout the study period in addition to any features of interest that may be considered important.

Risk assessment

A thorough risk assessment was conducted prior to each visit.

5.5 Medmerry managed realignment case study

A site visit to the Medmerry managed realignment scheme with Mike Edwards was conducted on the 18th August 2013 to assess the status of a small population of *C. halophilus* that may be negatively impacted by the project. This will be in order to establish actions that may be able to mitigate for the imminent breach of the sea wall and its potential consequences for the colony that is present (Personal Communication: Mike Edwards, 24th July, 2013). This will provide an additional short study which should complement the overall report.

5.6 Limitations to this investigation

Due to the limited number of nesting aggregations found, generalisations may not be entirely relevant for all individuals of *Colletes halophilus* at all sites where they could be found, as they only represent a small sample of the total population. However, this investigation will give us information regarding opportunities that *C. halophilus* may take advantage of and, therefore, its potential response to various factors. In addition, searches for nesting areas were mainly limited to 'suitable habitat' i.e. south-facing areas of bare ground/ minimum vegetation cover, which may result in nesting aggregations being overlooked in areas that don't fit the typical description (Knowles, 2011). Therefore, it must be kept in mind that there is a possibility that *C. halophilus* may be nesting in atypical conditions that were not discovered during this investigation.

5.7 Data analysis

All data analysis performed using PAST version 2.12 (Hammer *et al.*, 2001), Paleontological Statistics software package for education and data analysis. Statistical significance measured with *p* values lower than <0.05 and <0.01, and <0.001 indicated high significance. Nesting aggregations will hereafter be referred to as the following: Walsh's mount = WM, Coalhouse Fort = CHF, Colne Point Site A = CPA and Colne Point Site B = CPB.

6.0 Survey results

During this investigation *Colletes halophilus* were recorded at a total of seven sites on the East Anglian coast, Thames estuary area, both in East Anglia and north Kent, and also on the east coast of Kent (Figure 4). All sites comprised large areas of Sea Aster. However, thorough searches were conducted at all sites, and nesting aggregations were only found at three of these sites.

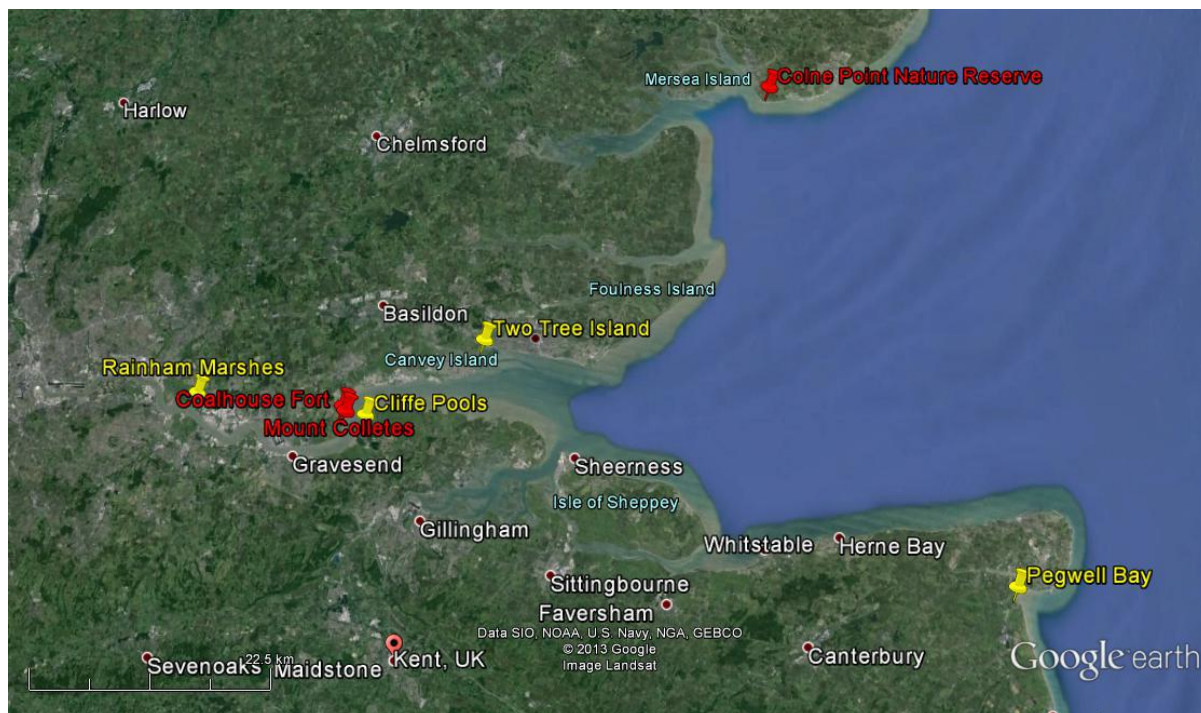


Figure 4 Locations of sites where *Colletes halophilus* were present (yellow labels) and the nesting aggregations identified during this investigation (red labels). Source: Google Earth, 2013; Data SIO, NOAA, US Navy, NGA, GEBCO, Google Image Landsat (License information: <http://www.google.com/permissions/geoguidelines/attr-guide.html>).

Additional sites were visited in search of the bee (and nesting aggregations), including Brancaster Beach in Norfolk, several sites along the Thames estuary, and also the Kent and East Anglian coast, unfortunately these visits did not yield either the presence of the bee or any potential nesting aggregations.

Factors that may be influencing the lack of nesting sites include a lack of suitable nesting areas, i.e. open, bare ground (10 out of 12 sites). In addition, 3 of the 12 sites no longer had stands of Sea Aster due to quite recent development. Highly vegetated and highly compacted clay sea walls were present at 7 of the 12 sites, potentially reducing opportunities for *Colletes halophilus* (Appendix 1).

There is also a possibility that *Colletes halophilus* were present but the bees may have been nesting in smaller, less noticeable, aggregations, or perhaps nest sites were in areas with restricted public access and were therefore out of the survey area. 2 of the 12 sites, i.e. Cliffe Pools and Brancaster Beach, had plenty of Sea Aster and suitable nest sites, however the large area to search meant it was possible that *Colletes halophilus* nests were overlooked.

Access to historic sites, such as Dagenham and Gravesend, also proved difficult due to the large presence of industrial sites and limited public access along the waterside.

6.1 Bee population – Man-made vs. natural habitats

Kruskal Wallis (with Mann Whitney pairwise comparison), which compares count data with three or more samples (Fowler *et al.*, 1998; Field *et al.*, 2007), explored any differences between the sample populations of all nesting aggregations. There was highly significant statistical difference between the sample populations ($p < 0.001$) (WM: 20; CHF: 2.6; CPA: 12.5; CPB: 9.3) (Figure 5).

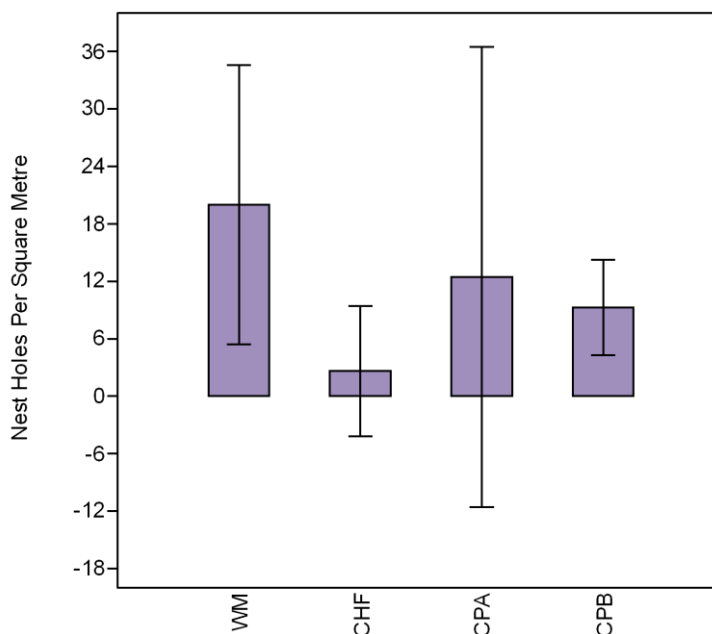


Figure 5 Difference between nest holes per square metre between each nesting site.

Post-hoc Mann Whitney pairwise testing was applied which identified highly significant statistical differences between WM and CHF ($p < 0.001$) and CPB ($p < 0.01$), but no difference was found between WM and CPA ($p > 0.05$). There was a statistically significant difference between CHF and CPA ($p < 0.05$) and CPB ($p < 0.01$). No statistically significant difference was found between CPA and CPB ($p > 0.05$). Higher numbers of nest holes were found at WM, followed by CPA, then CPB, with the lowest numbers found at CHF.

6.2 Forage resources

All nesting aggregation sites CPA, CPB, CHF and WM had large areas of Sea Aster, with approximately 2 acres at CPA and CPB, and approximately 20 acres in the vicinity of CHF and WM. CPA, CPB and CHF nest site locations were within 10m of the stands of Sea Aster, whilst WM was approximately 300m from the Sea Aster stands.

6.3 Microclimate

Kruskal Wallis testing was also used to compare the daily mean between each nesting site and Writtle weather station data. Highly significant statistical differences were found between all sites ($p < 0.001$) (CHF: 26.3; CPA: 23.2; CPB: 21.4; WWS: 17.2) (Figure 6).

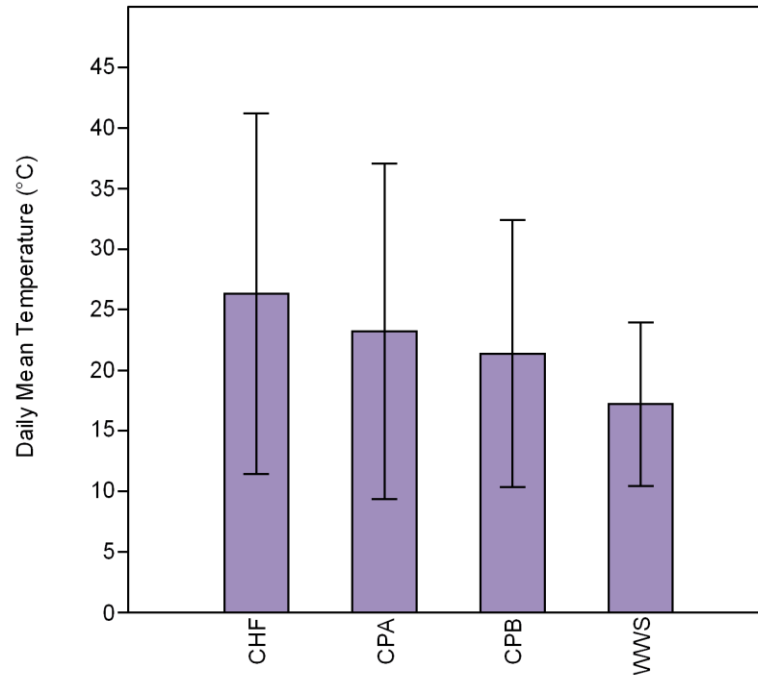


Figure 6 Differences between the mean daily temperature (C°) between nesting sites, Coalhouse Fort (CHF), Colne Point site A and site B (CPA and CPB) and Writtle weather station data (WWS).

Post hoc Mann Whitney pairwise testing was also applied. Highly significant statistical differences were found between all sites ($p < 0.001$). It can be seen that all nesting aggregation sites experienced higher local temperatures than the ambient temperatures recorded at the Writtle weather station (WWS), with the highest temperatures found at CHF.

6.4 Topography – slope and aspect

Generally the slopes of the sites at Coalhouse Fort and the two sites at Colne point were level ($0^\circ - 15^\circ$). However, at a finer scale, variable topography could be seen. At Colne Point this was mainly as a result of disturbance by rabbits, and at Coalhouse Fort digging by dogs had created variable topography. It could be seen that quite a number of *C. halophilus* immediately took advantage of these opportunities to burrow in these areas of exposed earth (Plate 13).



Plate 13. Bare ground areas and variable topography caused by rabbit burrowing disturbance which *Colletes halophilus* have exploited.

Copyright: Kara Alicia Hardy.

At a finer scale, at the edges of the pathway, small vertical faces could be seen (Plate 14), and it was at these locations that higher numbers of nesting burrows were also seen.



Plate 14 Miniature vertical cliffs at Colne Point which *Colletes halophilus* have been readily exploiting. Copyright: Kara Alicia Hardy.

Root systems may provide a level of stabilisation to the sandy substrate (Lee, 2011), which was preferred by *C. halophilus* (Plate 15).



Plate 15 *Colletes halophilus* female returning from a foraging trip with a pollen and nectar load, Plant roots potentially providing stability to tunnel construction. Copyright: Kara Alicia Hardy.

In addition, at both Colne Point and Coalhouse Fort, when counting nest holes, it was noticed that they dominated the edges of these open areas, with nest burrows maintained closer to the longer vegetation. This

was duly recorded and a T-Test was performed on the data in order to see if this was as significant as it seemed to be.

Statistically significant differences were found between the numbers of nest burrows located at the edge of open areas and those found elsewhere at CPA (edge: 12.5; other: 4.1, $p < 0.05$) (Figure 7). Higher numbers of nest holes were found at the edge of open areas.

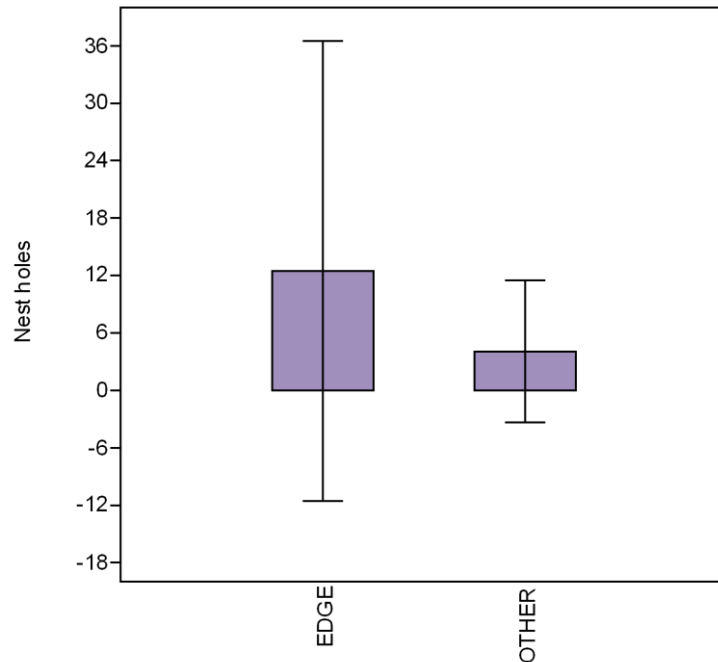


Figure 7 Difference between the numbers of nest holes located at the edges of these open habitats compared with the core areas at Colne Point nest site A.

No statistically significant difference was found, although only marginally at CPB (edge: 5.9; other: 3.4, $p < 0.06$) (Figure 8); no difference was found between sample numbers of nest holes at the two types of locations.

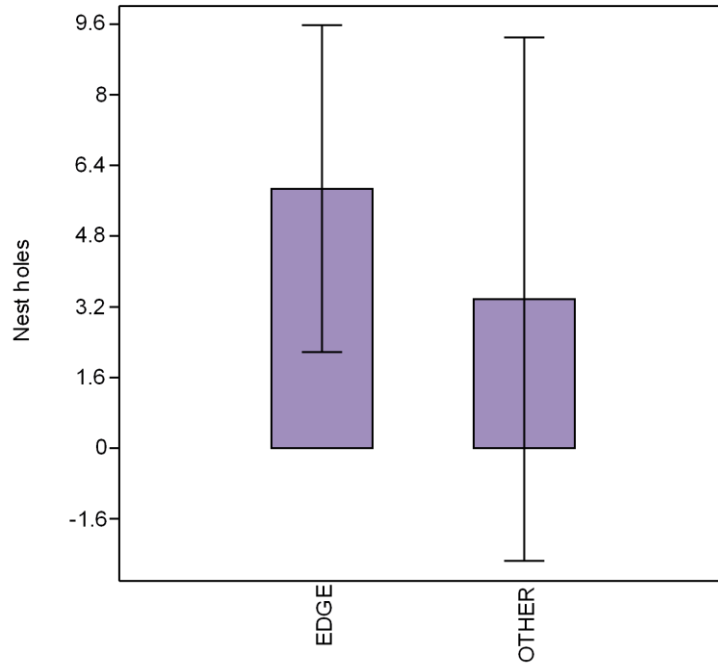


Figure 8 Difference between the numbers of nest holes located at the edges of these open habitats compared with the core areas at Colne Point nest site B.

No statistically significant difference was found at CHF (Edge: 2; other: 0.6, $p > 0.05$ (Figure 9)); no difference was found between the sample number of nest holes located at the two types of location.

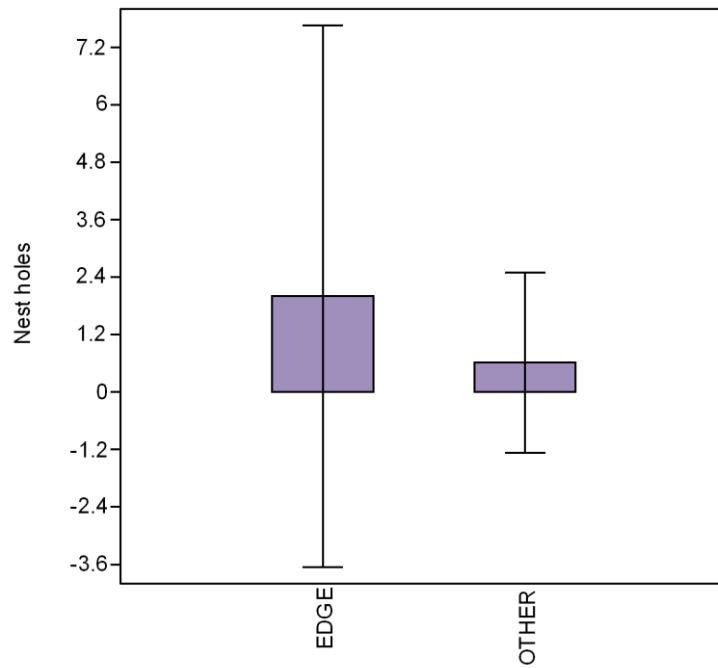


Figure 9 Difference between the numbers of nest holes located at the edges of these open habitats compared with the core areas at Coalhouse Fort.

The nesting aggregation at Walsh's Mount was very different, with an overall slope of approximately 45°. Upon closer inspection, small-scale variability could be seen, ranging from angles of 35° to 70°; nest holes were seen across the entire southern and south east side of the site (Plate 16).



Plate 16 Nesting aggregation at Walsh's Mount; nest burrows found across the entire site. Copyright: Kara Alicia Hardy.

6.5 Wind speed

A Wilcoxon test was used to identify any differences between the wind speed taken at ground level and the wind speed taken at a height of 1.5m. A highly significant difference was found between the wind speed at ground level, and at a height of 1.5m ($p < 0.001$) (Figure 10). The following figure shows that the wind speed at ground level was almost non-existent compared with the wind speed at height, which suggests that nesting aggregations were located in positions that offered an element of shelter.

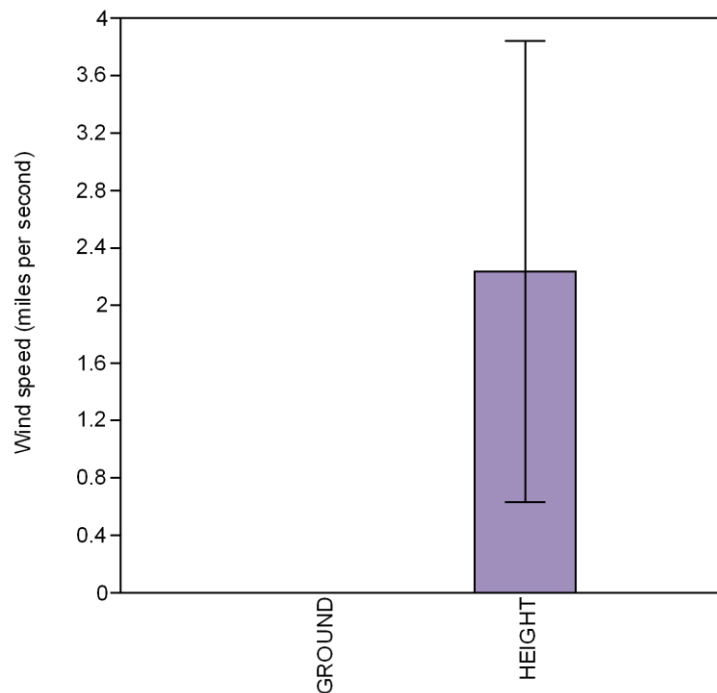


Figure 10 Differences between the wind speeds (m/s) recorded at ground level and at a height of 1.5m; with all sites combined.

6.6 Vegetation sampling

The plant composition at Colne Point consisted of typical salt marsh plants, such as Shrubby Seablite (*Suaeda vera*), Sea Purslane (*Halimione portulacoides*) and Rock Sea Lavender (*Limonium binervosum*). Coalhouse Fort comprised plants such as species of Clover (*Trifolium* sp.), Birds Foot Trefoil (*Lotus corniculatus*), Cats Ear (*Hypochaeris radicata*), Dandelion (*Taraxacum* sp.) and Yarrow (*Achillea millefolium*). Walsh's Mount consisted of plants very similar to those found at Coalhouse Fort, except for the Yarrow and species of Clover, but also comprised of additional species, such as Scentless Mayweed (*Tripleurospermum inodorum*) and Bristly Oxtongue (*Helminthotheca echioides*). Common plant species such as Grass sp. and Moss sp. were found across all sites.

A Spearman's rank correlation (non-parametric) statistical test was applied to the data to identify if there was any correlation between the population surrogate (nest holes per square metre) and vegetation and bare ground cover.

A significant, though weak positive correlation ($r_s: 0.49, p < 0.01$) was found between the sample population and bare ground cover of all sites combined (Figure 11). It can be seen that the higher the percentage cover of bare ground, the higher the numbers of nest holes found.

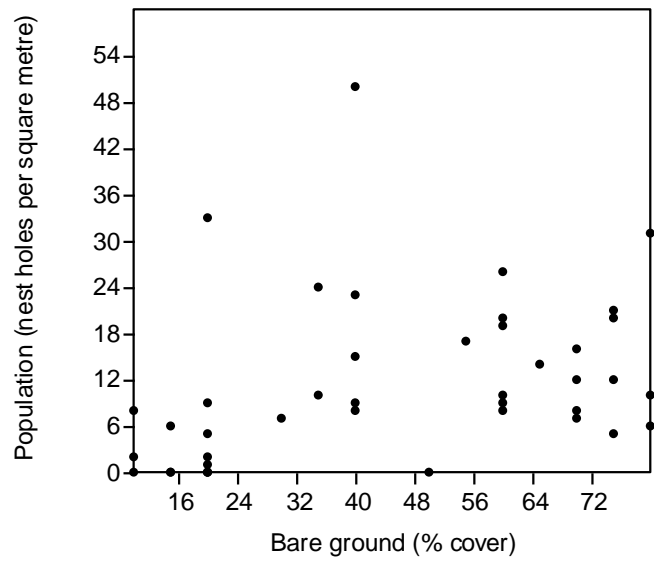


Figure 11 Correlation between the population (nest holes per square metre) and the percentage cover of bare ground.

In addition, a highly significant negative correlation ($r_s: -0.66, p < 0.001$), was found between the sample population and percentage grass cover of all the sites combined (Figure 12). It can be seen that the higher the percentage grass cover, the lower the number of nest holes found.

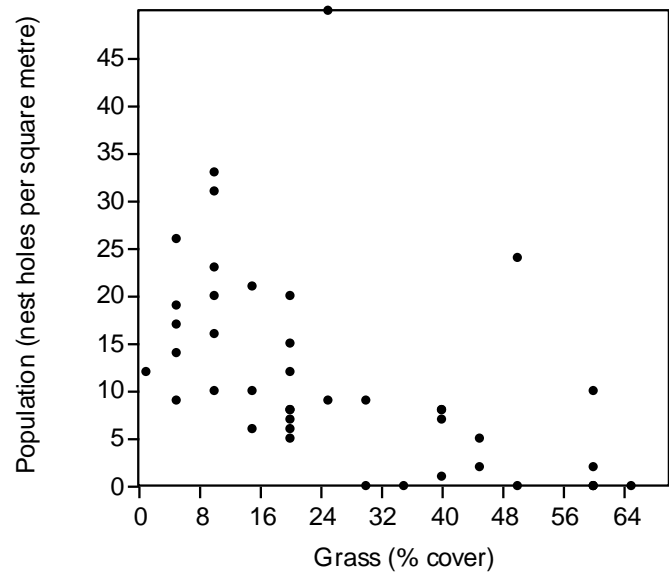


Figure 12 Correlation between the population (nest holes per square metre) and the percentage cover of grass.

6.7 Soil sampling

Soil samples were analysed by geologist Alan Stubbs from Buglife. CHF consisted of soils ranging from very fine sand – fine sand – sandy silt – silt, however higher number of samples contained very fine sand making this the dominant soil texture found at this site. CPA consisted of soils of predominantly silt, with some samples of very fine sand. CPB consisted of soils with predominantly very fine sand. WM was almost completely made up of very fine (Thanet) sand (Figure 13). Only a trace of organic mud was found at any of the sites.

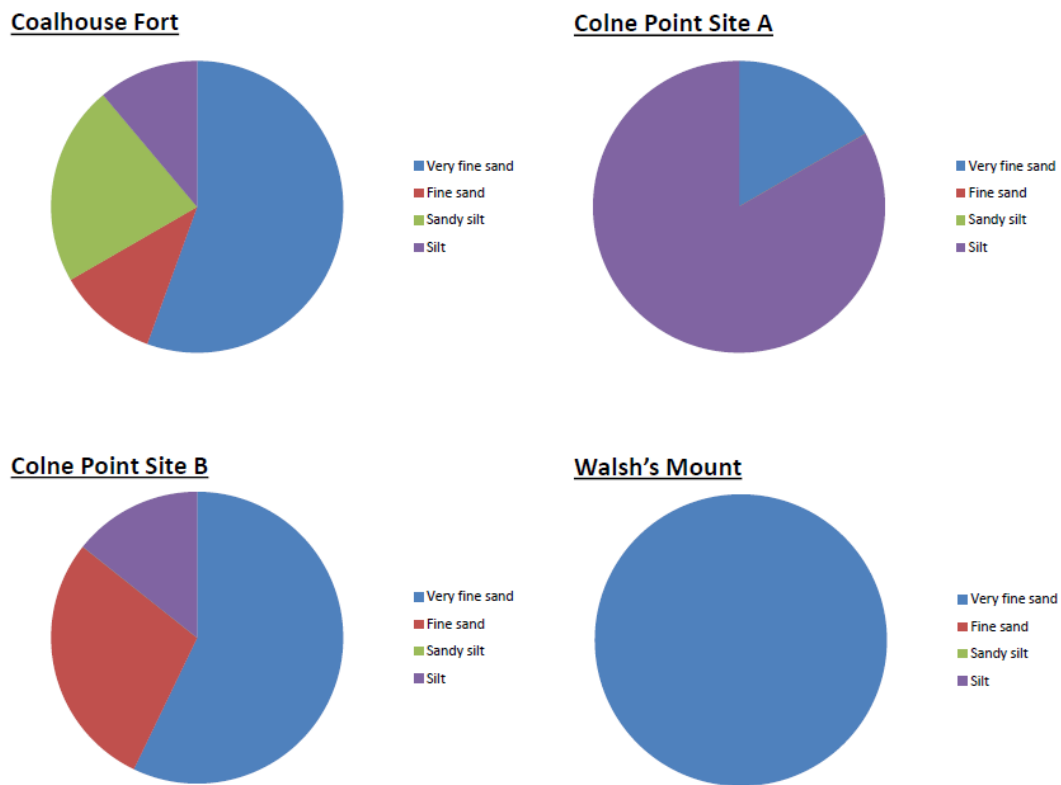


Figure 13 The dominant soil texture, as described by geologist Alan Stubbs, that is present at each site.

A Kruskal Wallis test was used to identify differences between the levels of soil compaction at each nesting aggregation site for measurements taken at 3" and 6". A highly significant statistical difference was found between all samples taken at a depth of 3" (CHF: 209.2, CPA: 89.2, CPB: 96.2, WM: 0; $p < 0.001$) (Figure 14).

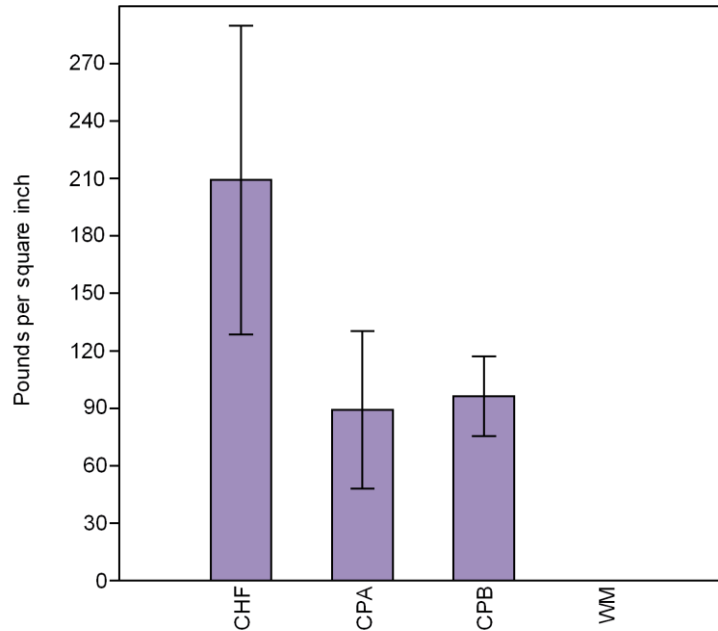


Figure 14 Differences between the levels of compaction (psi) measured at each site at a depth of 3".

Post-hoc Mann-Whitney pairwise testing indicated that there were highly significant differences between CHF and CPA, CPB and WM ($p < 0.001$). However, no difference was found between CPA and CPB ($p > 0.05$). It is apparent that the soil at CHF was highly compacted compared to the other three samples. CPA and CPB experienced medium levels, whilst soils at WM were not at all compacted.

At a depth of 6", a highly significant statistical difference was found between samples at all sites (CHF: 300, CPA: 253.8, CPB: 183.7, WM: 0; $p < 0.001$) (Figure 15).

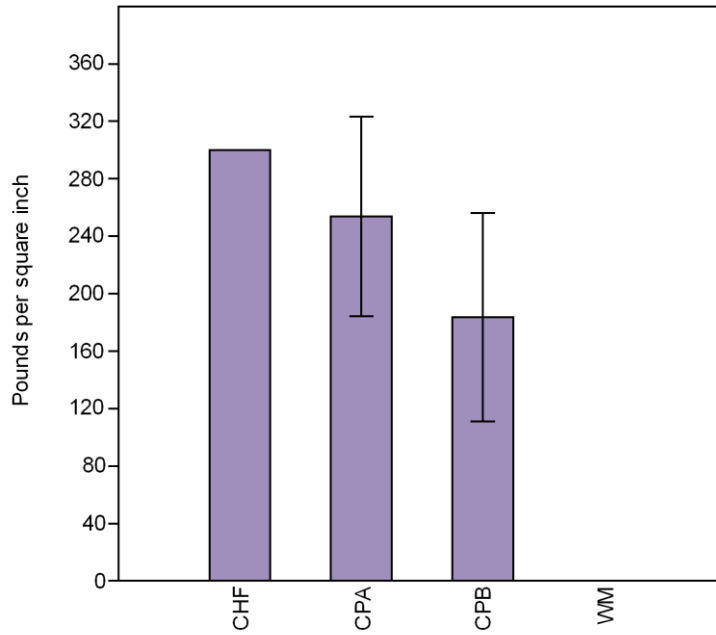


Figure 15 Differences between the levels of compaction (psi) measured at each site at a depth of 6".

Post-hoc Mann Whitney pairwise testing indicated that there was highly significant differences between CHF and CPA, CPB and WM ($p < 0.001$). However, there was only significant difference between CPA and CPB ($p < 0.01$). It can be seen that the soil compaction at CHF was higher than all other samples, followed by CPA, then CPB; soil compaction at WM was non-existent.

It can be seen that soil compaction increased after the 3" depth, which indicates that the top soil at CHF, CPA and CPB were looser, compared with the compaction at a depth of 6", whilst WM is made entirely of loose soil.

7.0 Medmerry managed realignment case study

Medmerry is located in Sussex, southern England, along the coastline considered to be one of the most vulnerable areas at risk of flooding due to climate change and associated sea level rise (Environment Agency, 2013). In order to reduce the flood risk in this area the process of managed realignment has been implemented inland from Selsey to Bracklesham in West Sussex (*ibid.*).

Managed realignment, involves the creation of new sea wall defences further inland, while existing seawalls are breached and tidal inundation is allowed to flood behind them (Luisetti *et al.*, 2011; Friess *et al.*, 2012; Environment Agency, 2013). This has the potential to create or restore salt marsh habitats, in particular, intertidal salt marsh, which can increase opportunities for flood alleviation, climate change mitigation and biodiversity through the creation of sustainable coastal defences, carbon sinks and fish nursery areas (Kadiri *et al.*, 2011; Morris, 2011; Buglife, 2013). Managed realignment at Medmerry also has the potential to negatively impact on various species through the loss of existing habitat.

A small nesting aggregation of *Colletes halophilus* may be particularly affected as the post-breach flooding will inundate the nest site location (Personal Observation 18th August 2013). Mike Edwards (BWARS), Tim Callaway (RSPB), and I visited the Medmerry site in order to investigate potential actions to mitigate for the habitat loss resulting from the managed realignment.

The following actions have now been implemented which may provide additional opportunities for this and other species:

- Firstly a banked area adjacent to the nesting site, at a site which will be safe from flooding, was cleared of vegetation in order to provide bare ground areas, which are preferred by ground nesting aculeates (Evans and Potts, 2013). It is hoped that *C. halophilus* will exploit these safer nesting areas (Personal Communication: Tim Callaway, 30th August 2013).
- In addition, nesting containers have been left near the pre-existing nest site, which are plastic containers with sand and drainage holes in the bottom and will provide further nesting resources for this bee. Once the sea wall breach is underway these nesting containers can be moved to an area at less risk of flooding, thus providing further nesting opportunities with low flood risk for *C. halophilus*.
- Lastly, in order to provide sustainable forage resources for this bee, areas of Sea Aster will be moved with a bulldozer in order to create raised 'faults' of the bees preferred food source. By saving as much Sea Aster as possible this will provide pollen and nectar sources for many invertebrate species, and may enable faster regeneration of salt marsh areas through the presence of existing salt marsh plants (Erfanzadeh *et al.*, 2010).

The success, or not, of these actions will not be apparent until next year when *C. halophilus* emerge yet again at the end of August 2014. The results may be particularly important in providing evidence to support invertebrate mitigation techniques for future managed realignment schemes.

8.0 Discussion

Habitat loss and fragmentation as a result of anthropogenic activities, such as agriculture, has negatively impacted on bee species around the world (Williams and Kremen, 2007). This has led to a greater interest in the specific habitat requirements of individual species, particularly in artificial and natural habitats, in order to tailor management techniques to individuals (Bowler *et al.*, 2009).

Colletes halophilus, a rare and endangered bee, has been discovered persisting, and thriving, in both man-made and natural habitats (Knowles, 2011; Evans and Potts, 2013). Walsh's Mount, one such artificial habitat (simply a pile of sand), is home to a particularly strong nesting population compared with any other found during this investigation, which further strengthens the idea that *C. halophilus* will happily exploit man-made as well as natural habitats. Coalhouse Fort, situated very close to Walsh's mount, held the lowest numbers of all sites visited, which may be due to flooding events that occurred on the site during the summer last year (2012) (Personal Communication: Ray Reeves, 30th August 2013). This may have inundated the nesting aggregation to the point that many of the broods may have perished and resulted in lower numbers emerging this year (*ibid.*). Another possibility is that *C. halophilus* were opting to use Walsh's Mount instead of the available man-made site at Coalhouse Fort. The reason for this is unclear, but it could suggest a preference for larger aggregations, which would result in higher mating opportunities. Alternatively, it may indicate certain advantages within the habitat that may be allowing the persistence and abundance of this species in deference to the smaller man-made sites present.

Available food resources are a key limiting factor of native bees (Westrich, 1996; Potts *et al.*, 2005), and the presence of sufficient forage is particularly important in maintaining bee populations (*ibid.*). A common denominator across all nesting aggregation sites was the presence of large stands of Sea Aster, ranging from over 2 acres at Colne Point, to the presence of over 20 acres in the vicinity of Coalhouse Fort and Walsh's Mount. All nesting sites were within approximately 300m of the forage resource, highlighting the main advantage of locations supporting *C. halophilus* populations. It may be important to consider that Michaelmas daisy flowers, a later flowering plant, has recently been spreading from gardens and onto roadside verges (Personal Observation, 10th September 2013) and brownfield sites (Personal Communication: Steven Falk, 13th December 2013). This may provide additional opportunities for this late emerging species and potentially increase its distribution further inland (*ibid.*).

Micro-habitat characteristics have an impact on the way arthropods respond to their environment (Roslin *et al.*, 2009; Lessard *et al.*, 2011), as these small-sized ectotherms are notably sensitive to their thermal environment (Noordijk *et al.*, 2010). The microclimate of all nesting aggregations experienced higher temperatures compared with the ambient temperature taken from Writtle weather station (the nearest available data to all sites), which suggests that *C. halophilus* selects nesting sites which are significantly warmer than the ambient temperature. It is important to note that Writtle weather station data may not represent the changeable nature of the weather on the Estuary and therefore it is difficult to make broad generalisations (Personal Communication: Jamie Robins, 9th December 2013). However, ground-nesting invertebrates often require warm locations for their brood, in order to enable faster development of eggs and larvae (Goulson, 2003; Macadam *et al.*, 2013) and this may be why *C. halophilus* were nesting in these warmer locations.

Local topographical variation can also impact on the microclimates of habitats due to the sheltering features that are sometimes present (Geiger, 1950; Philip-Wheater *et al.*, 2011). *Colletes halophilus* have been found at both sites with little or no slope, to sites with a more heterogeneous topography, which suggests that the slope of nesting sites selected is less important than other factors, such as food and temperature. However, it is important to note that higher numbers were found at Walsh's Mount, where the topographic variation was much more prevalent suggesting that *C. halophilus* may prefer nesting sites which are more variable. Furthermore, where pits and mounds were present there was an apparent predilection to these topographical

features which may be providing additional opportunities. Raised areas can provide increased incidences of solar radiation, while pits will be sheltered to some extent from external environmental conditions (Goulson, 2003), thus providing potential reasons for their nest site selection. Animal disturbance in the form of rabbit burrows and holes dug by dogs were also highly utilised by *C. halophilus* and provided structural diversity often attractive to invertebrates (Falk, 1991; Macadam *et al.*, 2013; Personal Observation: 15th September 2013).

Many ground-nesting bee species prefer soft ground which is stabilised by plant roots and mosses (Personal Communication: Steven Falk, 13th December 2013), which may explain the significant preference displayed by *Colletes halophilus* to the edges of bare ground areas where an element of vegetation was present. This may also explain why the managed site created by Ray Reeves at Coalhouse Fort was being exploited. There is also the chance that nesting by distinct vegetation may be providing a landmark for these animals which are guided by celestial orientation and landmarks (Kirkwood, 1929; Gathmann and Tschardt, 2002). This technique that bees use to navigate using landmarks could also be an important factor in the higher numbers found at Mount Colletes, as this larger nesting area may provide a useful marker that these bees can detect from afar.

Nesting by vegetation, may also provide an element of protection from the wind and may therefore help enable a warmer microclimate and better flying conditions for *C. halophilus*. There was a significant difference in the wind speed at ground level compared to that found at a height of 1.5m, which may support the suggestion that *C. halophilus* nests in areas less exposed to the effects of wind. It has also been suggested that the root structures of certain plant species, such as Marram Grass, can provide an element of stability to the soil which may be another reason why *C. halophilus* choose to burrow in these sparsely vegetated areas (Lee, 2011). However, finer grasses such as fescues, may be more important for *C. halophilus*, as Marram grasses are often restricted to areas with highly mobile sands (Personal Communication: Steven Falk, 13th December 2013). It is important to consider the fact that ground-nesting species are thought to scent mark their nesting areas, which may be an important factor in their apparent preference to nest in large aggregations (Personal Communication: Steven Falk, 13th December 2013). This may be the reason that they nest in areas with an element of vegetation present, on which to mark, and may explain their absence in areas of apparently suitable habitat.

The plant composition varied across nesting sites, which suggests that *C. halophilus* is less affected by the composition of the vegetation as opposed to the amount of vegetation cover present. It can be seen that bare ground areas were utilised more by *C. halophilus* and therefore may provide more opportunities for nesting. Fewer species were found in areas with a higher percentage cover of grass. This may be due to the higher insolation experienced by bare ground areas, absent of dominant grasses (Woods, 2011; Gedge *et al.*, 2012), and possibly offers easier access for mining their nesting burrows. This may also explain why nesting aggregations were not discovered in many of the sites visited throughout this investigation, which were comprised of large areas of Sea Aster, but with highly vegetated clay sea walls.

Typically, very fine sandy soils were found across all sites, with the occasional sandy or silt substrate found and with very little organic matter present. Soils with few nutrients and that drain well are unlikely to be comprised of many competitive grass species (Woods, 2011), which could explain why *C. halophilus* are found in these types of soils. Higher populations were also found at Walsh's Mount, a site comprised entirely of very fine sands, and therefore further supporting the notion that *C. halophilus* prefers nesting in soils of very fine sands. Variable levels of compaction were experienced across all sites, which suggest that *C. halophilus* can utilise sites that are quite heavily compacted (Up to 300 psi) as well as sites with very little compaction at all. However, considerably higher numbers were found at Walsh's Mount, the site whose compaction levels were non-existent, suggesting that *C. halophilus* have a preference for less compacted loose soils, which may be easier to burrow into. Fine sands are also sands which are non-windblown and may increase the substrates stability within nesting sites; no sites comprised substrates of typically windblown sands, i.e. 100% sand grains.

Highly compacted (well over 300 psi) areas were also a common denominator at most of the sites visited during this investigation where *C. halophilus* was absent.

This investigation has confirmed that *Colletes halophilus* are able to adapt to and exploit both man-made habitats as well as natural habitats, as long as certain key elements are present; the main limiting factors for bees, which are available forage and suitable nesting sites. The most popular site found during this investigation was Walsh's Mount, a large pile of Thanet sand. However, it is unclear whether this was due to the looser soils found, the larger aggregation present, the high percentage cover of bare ground, or the effects of these factors combined. There are also other historical factors which will impact on the presence of *C. halophilus* such as the habitats age, its history of disturbance and its continuity (Personal Communication: Steven Falk, 13th December 2013). It is also important to highlight the fact that although Walsh's Mount was the most populous, its temporary nature makes it potentially the most vulnerable, and the loss of this mound of sand could potentially wipe out an entire generation. This large population may also be allowing the persistence of the larger metapopulation of this region, and its vulnerability to extirpation could result in much larger losses to this species.

Additionally, there is always the possibility for individuals of a species to alter their historic, 'known' behaviour, and act in unexpected ways, such as changing their foraging and nesting habits (Personal Communication: Steven Falk, 13th December 2013). Therefore, with the reduction in available salt marsh habitats and associated food (i.e. Sea Aster) (IUCN, 2013), but an increase in both distribution and abundance of other flowering plants at the same time of year, such as Michaelmas Daisy, *C. halophilus* may surprise us and 'switch' to another forage source like this. This would have the potential to offer opportunities much farther and wider than at present, increasing both its abundance and distribution (Personal Communication: Steven Falk, 13th December 2013).

9.0 Conclusion

Colletes halophilus, a rare and endangered bee of salt marshes, can be found in large numbers at various sites in Essex, utilising both man-made and natural habitats (Knowles, 2011). Major threats to this species include both development and sea level rise, however, it can also be seen that a lack of management may also pose a problem for this species, as suitable nest sites are often not readily available in areas where its food plant is present.

Mitigation for climate change involves managed realignment, as mentioned previously, which can provide additional areas of salt marsh but may not provide nesting habitats which are of utmost importance for the persistence of this species. Furthermore, development has the potential to destroy nesting sites and forage sites and has already reduced these available habitats in the past, particularly in the Thames Estuary area, an area so important not only for bees, but biodiversity in general (Knowles, 2010). Therefore, it is suggested that invertebrate mitigation measures are implemented during new development projects (wildlife-friendly developments) in order to provide options for various species, including *C. halophilus* (in those areas adjacent to Sea Aster). Appropriate invertebrate surveying for *C. halophilus* and other species, must be carried out in advance so that the impact of the development on species can be monitored and mitigated for if necessary. It would also be beneficial if nesting creation preceded the commencement of the development project, in order to allow the optimum establishment of a site, so that as many species as possible colonise it in advance of work.

Nesting creation would also be useful in areas where large stands of Sea aster are present and so could optimise the available opportunities for this species in as many locations as possible. This may help *C. halophilus* populations colonise previously unoccupied areas and increase the connectivity between

populations, thus reducing the isolation of various populations. The abundance of *C. halophilus* exhibited at Walsh's Mount may make this population particularly important, as it may be playing a strong role in the metapopulation dynamics of this area. However, its temporary nature makes it vulnerable to future development, and loss of this large population could impact on a much larger-scale. Therefore, continued management of Coalhouse Fort to increase populations there, may strengthen the overall population situated in the surrounding area, and through emigration may bolster numbers further up and down this Thames Estuary area. In addition, the creation of small nesting mounds throughout the coastline in this area, perhaps supported by the RSPB, may help provide stepping stones for *C. halophilus* and other ground nesting species.

Optimum nesting habitats would comprise areas with increased insolation that may provide warmer areas for this species, such as south-facing slopes, raised banks, and cliff sides with sparse vegetation, which may provide shelter from the wind or may stabilise excavated tunnels. In addition, heterogeneous topography which provides structural diversity will also provide sheltering features that could beneficially alter the microclimates as these small animals experience them, thereby offering more opportunities. Raised nesting sites which are located on south facing slopes will be warmer due to the increased insolation experienced, which supports the creation of banked nesting areas for invertebrates. Banked areas will also allow the bees to nest in an area with a reduced risk of inundation from any heavy rains and associated flooding that they might experience. These attributes were all present at Walsh's Mount, which proved to be by far the most successful site found for *C. halophilus*. Nesting sites situated close to the food source will reduce the period spent commuting by the female of the species and can increase the number of offspring produced at a site (Williams and Kremen, 2007), which suggests that any nest creation is implemented as close to the food resource as possible.

Colletes halophilus has shown its ability to utilise man-made habitats such as those situated at Coalhouse Fort and Walsh's Mount, which could prove particularly important due to the fact that it is highly unlikely that urban development will ever stop (McIntyre and Hostetler, 2001). Therefore any ideas or management designs that we can use to try to foster biodiversity within these environments may help the continued persistence of this and other invertebrate species. This is of particular importance at this time when so many species are being lost to us.

10.0 Recommendations

Please see attached 'management guidance sheet'.

11.0 Suggestions for further studies

This investigation was only conducted over one season; however, effects of management may require more than one generation to manifest (Parker and MacNally, 2002), which suggests that additional studies could prove useful. Therefore it is suggested that continued monitoring of these known populations is undertaken in order to attempt to fully understand these bees. It would be particularly interesting to know their level of fidelity to a site, and also to identify if there is a limited time span in which *Colletes* will utilise a nesting site. In addition, further investigations to find additional nesting sites in order to fully understand the adaptable nature of this bee to particular conditions may help provide insights into its possible future in its current and future locations. Additionally, an investigation into the success of the managed realignment project at Medmerry, where mitigation measures have been carried out this year to ensure the continued survival of *C. halophilus* in this area, will help guide future schemes.

Understanding the movement patterns of the population at Walsh's Mount, and its influence regarding the metapopulation dynamics of the region, could prove particularly useful in confirming its importance. This could include the identification of movement patterns between Walsh's Mount and Coalhouse Fort, which could have implications for providing additional mitigation measures to reduce the local threat to this bee.

With regards to the possibility that *C. halophilus* might 'switch' to Michaelmas daisy in the future (Personal Communication: Steven Falk, 13th December 2013). Additional investigations into the use by *C. halophilus* of cultivated aster flowers in adjacent gardens to current nesting sites may help to provide additional options for this bee.

Finally, DNA testing of associated cuckoo bees, *Epeolus* spp., may be useful in determining its taxonomic relationship and status and thereby contribute to, and increase our knowledge of this rare bee.

12.0 Acknowledgements

I would like to take this opportunity to thank the many people who were involved in making this investigation possible. Firstly a massive 'Thank you' to People's Trust for Endangered Species (PTES), who funded this project through their grant giving scheme. I would also like to thank everyone at Buglife who have helped me during this investigation, particularly Jamie Robins, Alan Stubbs and Steven Falk, in addition to Sarah Henshall and Vicky Kindemba. I'd like to extend a big thanks to Alan Roscoe of Writtle College who has supported me tremendously throughout this study and also to Writtle College for the use of various pieces of equipment during this summer. Several hymenopteran experts were contacted during this investigation and I would also like to thank each individual for their information and feedback. Thanks to Adrian Knowles, Simon Saxton and Tim Strudwick. Peter Harvey and Mike Edwards, were particularly kind and helpful, the former for his help confirming the identity of several specimens, and the latter for extending his home to me so that I could spend time at the managed realignment scheme at Medmerry. I would like to direct a big thank you to various people at the Royal Society for the Protection of Birds (RSPB), including Tim Callaway at Medmerry, Andy Daw at Cliffe Pools, Andrew Gouldstone at Rainham Marshes and Paul Charlton at Old Hall Marshes. I'd like to also thank The Wildlife Trust, in particular David Smart and Carole Mander who directed me to various reserve wardens who have each been very helpful. I'd like to thank Mark Bridges at Two Tree Island who took time out of his evening to show me around his site, Nick MacFarlane at Shoeburyness and Bob Seago at Colne Point, who guided me around his wonderful site. Finally, I'd like to send huge thanks to Ray Reeves (Thurrock Council), the ranger at Coalhouse Fort, who has given me great advice and help throughout this investigation. Thank you all.

13.0 References

- Ausden, M. and Drake, M. (2006) 'Invertebrates', in W. J. Sutherland (ed.) *Ecological Census Techniques: A Hand Book (2nd edition)*. Cambridge: Cambridge University Press, 214 – 249.
- Belisle, R. A. (2011). *Microstructure and Chemical Composition of Colletes halophilus Nest Cell Linings*. MPhil Thesis. University of Bath, United Kingdom.
- Bowler, J., Sears, J. and Hunter, J. (2009) 'Recent research on the Northern Colletes Mining Bee *Colletes floralis* Eversmann', *The Glasgow Naturalist*, **25**, 43 – 49.
- Buglife (2009) *Planning for Brownfield Biodiversity: A Best Practice Guide*. Peterborough: Buglife.
- Buglife (2010) *Brownfields England's Rainforests*. Peterborough: Buglife.
- Buglife (2011) *Action Update 18 – Winter 2011*. Peterborough: Buglife.
- Buglife (2013) *Salt Marsh* [www document]
www.buglife.org.uk/conservation/adviceonmanagingbaphabitats/coastalsaltmarsh (Accessed 1st April 2013).
- BWARS (2012a) *Colletes halophilus verhoeff, 1943* [www document]
www.bwars.com/index.php?q=bee/colletidae/colletes-halophilus (Accessed 19th April 2013).
- BWARS (2012b) *Epeolus variegatus Linnaeus, 1758* [www document]
<http://www.bwars.com/index.php?q=bee/apidae/epeolus-variegatus> (Accessed 30th July 2013).
- Cane, J. H. (2001) 'Habitat fragmentation and native bees: a premature verdict?', *Ecology and Society* [online], **5**, (Accessed 23rd July 2013). Available from the World Wide Web:
<http://www.ecologyandsociety.org/vol5/iss1/art3/manuscript.html>.
- Countryside Information (2013) *Ecological Sampling Methods: Belt Transect Method* [www document]
<http://www.countrysideinfo.co.uk/4howto.htm> (Accessed 31st May 2013).
- Davies, E. S., Reid, N. Paxton, R.J (2012) 'Quantifying forage specialization in polyphagic insects: the polylectic and rare solitary bee, *Colletes floralis* (Hymenoptera: Colletidae)', *Insect Conservation and Diversity*, **5**, 289 – 297.
- Dicks, L. V., Showler, D. A. and Sutherland, W. J. (2010) *Bee Conservation: Evidence for the Effects of Interventions*, Synopses for Conservation Evidence. Exeter: Pelagic Publishing.
- Dicks, L. V., Ashpole, J. E., Danhardt, J., James, K., Jönsson, A., Randall, N., Showler, D. A., Smith, R. K., Turpie, S., Williams, D. and Sutherland, W. J. (2013) *Farmland Conservation: Evidence for the Effects of Interventions in northern and western Europe*, Synopses For Conservation Evidence. Exeter: Pelagic Publishing.
- Edwards, M. (1996) 'Optimizing Habitats for Bees in the United Kingdom – A Review of Recent Conservation Action', in A. Matheson, S. L. Buchmann, C. O'Toole, P. Westrich, and I. H. Williams (eds.) *The Conservation of Bees*. London: Academic Press, 35 – 45.
- Environment Agency (2013) *Medmerry Managed Realignment Scheme* [www document]
<http://www.environment-agency.gov.uk/homeandleisure/floods/109062.aspx> (Accessed 3th July 2013).
- Erfanzadeh, R., Garbutt, A., Pétilion, J., Maelfail, J. and Hoffmann, M. (2010) 'Factors affecting the success of early salt marsh colonizers: Seed availability rather than site suitability and dispersal traits', *Plant Ecology*, **206**, 335 – 347.

- Essex Field Club (2013) *Species Account for Colletes halophilus* [www document]
<http://www.essexfieldclub.org.uk/portal/p/Species+Account/s/Colletes%20halophilus> (Accessed 26th May 2013).
- Essex Wildlife Trust (2013) *Colne Point Nature Reserve* [www document]
<http://www.essexwt.org.uk/reserves/colne-point> (Accessed 15th July 2013).
- Evans, R. L. and Potts, S. G. (2013) *Iconic Bees: East England – Sea Aster Mining Bee*. Reading: University of Reading.
- Eyre, M. D. and Rushton, S. P. (1989) 'Quantification of conservation criteria using invertebrates', *Journal of Applied Ecology*, **26**, 159 – 171.
- Falk, S. (1991) *A Review of the Scarce and Threatened Bees, Wasps and Ants of Great Britain*. Peterborough: Nature Conservancy Council.
- Field, R. G., Gardiner, T., Mason, C. F. and Hill, J. (2007) 'Agri-environment schemes and butterflies: The utilisation of two metre arable field margins', *Biodiversity and Conservation*, **16**, 465 – 474.
- Fowler, J., Cohen, L. and Jarvis, P. (1998) *Practical Statistics for Field Biology*. Chichester: John Wiley and Sons.
- Friess, D. A., Spencer, T., Smith, G. M., Möller, I., Brooks, S. M. and Thomson, A. G. (2012) 'Remote sensing of geomorphological and ecological change in response to saltmarsh managed realignment, The Wash, UK', *International Journal of Applied Earth Observation and Geo-information*, **18**, 57 – 68.
- Gathmann, A. and Tscharrntke, T. (2002) 'Foraging range of solitary bees', *Journal of Animal Ecology*, **71**, 757 – 764.
- Gedge, D., Grant, G., Kadas, G., Dinham, C. (2012) *Creating Biodiverse Green Roofs for Invertebrates*. Peterborough: Buglife.
- Geiger, R. (1950) *The Climate Near the Ground*. Cambridge, Massachusetts, USA: Harvard University Press.
- Goulson, D. (2003) *Bumblebees: Their Behaviour and Ecology*. Oxford: Oxford University Press.
- Greer, L. (1999) *Alternative Pollinators: Native Bees*. Arkansas: ATTRA.
- Hammer, Ø., Harper, D. A. T. and Ryan, P. D. (2001) 'PAST: Palaeontological Statistics software package for education and data analysis. *Palaeontological Electronica* [online]. **4**, [Accessed 12th January 2013]. Available from the World Wide Web: www.folk.uio.no/ohammer/past.
- Harris, L. F and Johnson, S. D. (2004) 'The consequences of habitat fragmentation for plant-pollinator mutualisms', *International Journal of Tropical Insect Science*, **24**, 29 – 43.
- Hart, N. H. and Huang, L. (2012) 'Monitoring nests of solitary bees using image processing techniques', 19th International Conference of Mechatronics and Machine Vision in Practice, Auckland, New Zealand, 28 – 30 November 2012, 1 – 4.
- Heneberg, P. (2011) 'Soil Penetrability, Effect on Animal Burrowing', in J. Gliński, J. Horabik and E. Lipiec (eds.), *Encyclopedia of Agrophysics*. The Netherlands: Springer.
- Heneberg, P., Bogusch, P. and Řehounek, J. (2012) 'Sandpits provide critical refuge for bees and wasps (Hymenoptera: Apocrita)', *Journal of Insect Conservation*, **17**, 473 – 490.

Hymettus (2009) *Colletes halophilus*, a bee of salt marshes, Midhurst: Hymettus, The UK Aculeate Conservation Group.

IUCN (2013) *The IUCN Red List of Threatened Species* – *Colletes halophilus* [www document] <http://www.iucnredlist.org/details/13306686/0> (Accessed 16th August 2013).

JNCC (2010) *UK Priority Species* – *Colletes halophilus* Verhoeff, P. M. F. 1944 [www document] http://jncc.defra.gov.uk/_speciespages/2192.pdf (Accessed 30th June 30th April 2013).

Jones, J. C., Reynolds, J. D. and Raffaelli, D. (2006) 'Environmental Variables', in W. J. Sutherland (ed.), *Ecological Census Techniques: A Handbook* (2nd edition). Cambridge: Cambridge University Press, 87 -185.

Kadiri, M., Spencer, K. L., Heppell, C. M. and Fletcher, P. (2011) 'Sediment characteristics of a restored saltmarsh and mudflat in a managed realignment scheme in southeast England', *Hydrobiologia*, **672**, 79 – 89.

Kirkwood, P. (1929) 'The biology and behaviour of mining bees, *Anthophora abrupta* and *Entechnia taurea*', *Psyche*, **36**, 155 – 181.

Klemm, M. (1996) 'Man-Made Bee Habitats in the Anthropogeneous Landscape of Central Europe – Substitutes for Threatened or Destroyed Riverine Habitats' in A. Matheson, S. L. Buchmann, C. O'Toole, P. Westrich and I. H. Williams (eds.) *The Conservation of Bees*. London: Academic Press, 17 – 34.

Knowles, A. (2010) *Colletes halophilus* in East Anglia – Draft Report, Unpublished Report to Hymettus Ltd.

Knowles, A. (2011) *Nest Site Preferences of Colletes halophilus* in East Anglia, Unpublished Report to Hymettus Ltd.

Kuhlmann, M., Else, G. R., Dawson, A. and Quicke, D. L. J. (2007) 'Molecular, biogeographical and phenological evidence for the existence of three western European sibling species in the *Colletes succinctus* group (Hymenoptera: Apidae)', *Organisms, Diversity and Evolution*, **7**, 155 – 165.

Lee, P. (2011) *Hymettus Ltd: Research Report for 2011*. Midhurst, West Sussex: Hymettus.

Lessard, J., Sackett, T. E., Reynolds, W. N., Fowler, D. A. and Sanders, N. J. (2011) 'Determinants of the detrital arthropod community structure: The effects of temperature and resources along an environmental gradient', *Oikos*, **320**, 333 – 343.

Loss, S. R., Terwilliger, L. A. and Peterson, A. C. (2011) 'Assisted colonisation: Integrating conservation strategies in the face of climate change', *Biological Conservation*, **144**, 92 – 100.

Luisetti, T., Turner, R. K., Bateman, I. J., Morse-Jones, S., Adams, C. and Fonseca, L. (2011) 'Coastal and marine ecosystem services valuation for policy and management: Managed realignment case studies in England', *Ocean and Coastal Management*, **54**, 212 – 224.

Macadam, C., Bairner, S. and Cathrine, C. (2013) *Open Mosaic Habitats on Previously Developed Land: Survey and Recommendations for Habitat Planning and Management in Scotland*. Inverness: Scottish Natural Heritage.

McIntyre, N. E. and Hostetler, M. E. (2001) 'Effects of urban land use on pollinator (Hymenoptera: Apoidea) communities in a desert metropolis', *Basic Applied Ecology*, **2**, 209 – 218.

Morris, R. (2011) *Managed Realignment – A Sediment Management Perspectives*. Hull: Bright Angel Coastal Consultants.

- Natural England (2013) Colne Estuary (SSSI) [www document] http://www.naturalengland.org.uk/ourwork/conservation/geodiversity/englands/sites/local_ID30.aspx (Accessed 16th July 2013).
- NBN (2013) *Colletes halophilus Taxonomic and Designation Information* [www document] www.data.nbn.org.uk/speciesinfo/taxonomy.jsp?searchTerm=colleteshalophilu&spkey=NHMSYS0000875714 (Accessed 12th April 2013).
- Noordijk, J., Schaffers, A. P., Heijerman, T., Boer, P., Geichman, M. and Sýkora, K. V. (2010) 'Effects of vegetation management by mowing on ground-dwelling arthropods', *Ecological Engineering*, **36**, 740 – 750.
- Parker and MacNally, R. (2002) 'Habitat loss and fragmentation threshold: An experimental evaluation of impacts on richness and total abundances using grassland invertebrates', *Biological Conservation*, **105**, 217 – 229.
- Philip Wheater, C., Bell, J. R. and Cook, P. A. (2011) *Practical field Ecology: A Project Guide*. Chichester: John Wiley and Sons.
- Pihlaja, M., Kaivula, M. and Niemala, J. (2006) 'Response of boreal carabid beetle assemblages (Coleoptera: Carabidae) to clear cutting and top soil preparation', *Forest Ecology and Management*, **222**, 182 – 190.
- Potts, S. G., Vulliamy, B., Roberts, S., O'Toole, C., Dafni, A., Ne'eman, G. and Willmer, P. (2005) 'Role of nesting resources in organising diverse bee communities in a Mediterranean landscape', *Ecological Entomology*, **30**, 78 – 85.
- Reeves, R. (2012) *Coalhouse Fort Park: Higher Level Stewardship Management Plan*. Thurrock: Thurrock Council.
- Robins, J., Henshall, S. and Farr, A. (2013) *The State of the Brownfields in the Thames Gateway*. Peterborough: Buglife.
- Rooijackers, E. F. and Sommeijer, M. J. (2009) 'Gender specific brood cells in the solitary bee *Colletes halophilus* (Hymenoptera: Colletidae)', *Journal of Insect Behaviour*, **22**, 492 – 500.
- Roslin, T., Avomaa, T., Leonard, M., Luoto, M. and Ovaskainen, O. (2009) 'Some like it hot: Microclimate variation affects abundance and movements of a critically endangered dung beetles', *Insect Conservation and Diversity*, **2**, 232 – 241.
- RSPB (2010) *Scrape Creation for Wildlife*. Bedfordshire: RSPB.
- Thurrock Council (2010) *News Archive – Rangers are Busy Bees at Coalhouse* [www document] www.thurrock.gov.uk/news/content.php?page=story&10=3771 (Accessed 20th May 2013).
- Thurrock Council (2013) *Coalhouse Fort and Park* [www document] <https://www.thurrock.gov.uk/coalhouse-fort-and-park/overview> (Accessed 30th July 2013).
- Westrich, P. (1996) 'Habitat Requirements of Central European Bees and the Problems of Partial Habitats', in A. Matheson, S. L. Buchmann, C. O'Toole, P. Westrich and I. H. Williams (eds.), *The Conservation of Bees*. London: Academic Press, 1 – 16.
- Williams, N. M. and Kremen, C. (2007) 'Resource distribution among habitats determine solitary bee offspring production in a mosaic landscape', *Ecological Applications*, **17**, 910 – 921.

Williams, N. M., Crone, E. E., Roulston, T. H., Minckley, R. L., Pucker, L. and Potts, S. G. (2010) 'Ecological and life history traits predict bee species responses to environmental disturbances', *Biological Conservation*, **143**, 2280 – 2291.

Winfree, R., Williams, N. M., Dushoff, J. and Kremen, C. (2007) 'Native bees provide insurance against ongoing honey bee losses', *Ecology Letters*, **10**, 1105 – 1113.

Woodcock, B. A. and Pywell, R. F. (2010) 'Effects of vegetation structure and floristic diversity on detritivore, herbivore and predatory invertebrates within calcareous grasslands', *Biodiversity Conservation*, **19**, 81 – 95.

Woods, R. (2011) *Conservation in Action: Habitat Created and Enhanced for Scarce Brownfield Invertebrates in the Tees Valley*. Redcar, North Yorkshire: Industry Nature Conservation Association.

Zurbuchen, A., Landert, L., Klaiber, J., Müller, A., Hein, S. and Dorn, S. (2010) 'Maximum foraging ranges in solitary bees: only few individuals have the capacity to cover long foraging distances', *Biological Conservation*, **143**, 669 – 676.

14.0 Appendices

Appendix 1 Record of sites visits made through the summer of 2013.

Surveyor:	Kara Hardy
Date:	2 nd September 2013
GPS co-ordinates:	TM244 296 - Dovercourt, Harwich
Ambient temperature:	28°C
1 hour observation of aster stands – bee detected:	No
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No
Active nest holes detected:	No
Notes: Clay sea walls, very few open areas. Bare ground areas are as a result of human recreation, i.e. pathway, and is therefore highly compacted, well over 300psi.	
Surveyor:	Kara Hardy
Date:	4 th September 2013
GPS co-ordinates:	TQ588 793 Chafford Hundred, Thurrock
Ambient temperature:	28°C
1 hour observation of aster stands – bee detected:	N/A
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No
Active nest holes detected:	No
Notes: Recent development has reduced suitable nesting habitat to the point that there are very few opportunities for nesting for this bee.	
Surveyor:	Kara Hardy
Date:	12 th September 2013
GPS co-ordinates:	TQ930 842 Shoeburyness, Southend on Sea
Ambient temperature:	23°C
1 hour observation of aster stands – bee detected:	No – very little aster present.
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	Yes
Active nest holes detected:	No
Notes: Limited available Sea Aster. Very few bare ground areas. Recent development has reduced the habitat available for this species.	
Surveyor:	Kara Hardy
Date:	20 th September 2013
GPS co-ordinates:	TL957 121 Old Hall Marshes, Maldon
Ambient temperature:	18°C
1 hour observation of aster stands – bee detected:	No
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No
Active nest holes detected:	No
Notes: Plenty of Sea Aster but few bare ground areas or sparsely vegetated south facing banks. Clay sea walls are highly compacted and heavily vegetated.	
Surveyor:	Kara Hardy
Date:	24 th September 2013

GPS co-ordinates:	TQ468 826 Ripple Nature reserve, Dagenham
Ambient temperature:	21°C
1 hour observation of aster stands – bee detected:	N/A – access to riverside restricted by large-scale developments
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No
Active nest holes detected:	No
Notes: Dagenham sites inaccessible due to large scale development, leaving only the small nature reserve as a possible location for the bee. No Sea Aster in sight. Very few opportunities in this area for nesting or foraging.	
Surveyor:	Kara Hardy
Date:	25 th September 2013
GPS co-ordinates:	TQ732 850, Fobbing Marshes, Fobbing
Ambient temperature:	22°C
1 hour observation of aster stands – bee detected:	No
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No - few bare ground areas.
Active nest holes detected:	No
Notes: Sea Aster available. Very few nesting sites present, obvious recent grazing along the clay sea walls. Highly vegetated banks.	
Surveyor:	Kara Hardy
Date:	26 th September 2013
GPS co-ordinates:	TQ545 787, Rainham Marshes
Ambient temperature:	18°C
1 hour observation aster stands – bee detected:	Yes
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No
Active nest holes detected:	No
Notes: Sea Aster available, however very few bare ground nesting sites present. Highly compacted clay sea walls which are also highly vegetated. Possibility that <i>Colletes</i> is not nesting in public areas	
Surveyor:	Kara Hardy
Date:	27 th September 2013
GPS co-ordinates:	TQ826 850, Two Tree Island, Leigh on Sea
Ambient temperature:	18°C
1 hour observation of aster stands – bee detected:	Yes
Thorough search of suitable nesting sites:	Yes – very few bare ground areas present.
Nest holes detected:	No
Active nest holes detected:	No
Notes: Sea Aster present, however very few suitable nesting sites are present. Highly vegetated and highly compacted clay sea walls do not offer many opportunities for CH.	
Surveyor:	Kara Hardy
Date:	27 th September 2013
GPS co-ordinates:	TQ770 836, Northwick, Canvey Island
Ambient temperature:	18°C
1 hour observation of aster stands – bee detected:	N/A
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No

Active nest holes detected:	No
Notes: Highly industrialised area with very few opportunities for ground nesting bees, particularly problematic is the absence of Sea Aster.	
Surveyor:	Kara Hardy
Date:	29 th September 2013
GPS co-ordinates:	TQ690 778, Walsh's yard, East Tilbury
Ambient temperature:	19°C
1 hour observation of aster stands – bee detected:	N/A
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	Yes
Active nest holes detected:	Yes
Notes: Nesting aggregation found.	
Surveyor:	Kara Hardy
Date:	29 th September 2013
GPS co-ordinates:	TQ692 778, Coalhouse Fort (new nest sighting)
Ambient temperature:	19°C
1 hour observation of aster stands – bee detected:	N/A
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	Yes
Active nest holes detected:	No CH detected
Notes: Sea Aster present, nesting aggregations also found. Highly likely that CH were using the nesting holes, but presence was not detected during that particular visit.	
Surveyor:	Kara Hardy
Date:	30 th September 2013
GPS co-ordinates:	TQ713 772, Cliffe Pools, Medway
Ambient temperature:	19°C
1 hour observation of aster stands – bee detected:	Yes
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	Yes
Active nest holes detected:	No
Notes: Sea Aster available and vast areas of bare ground areas present, however no nesting aggregation was detected during this visit. The presence of Sea Aster and suitable nesting sites, in addition to its proximity to Coalhouse Fort (across the river from it) suggests that CH are nesting there but were not detected during this particular visit.	
Surveyor:	Kara Hardy
Date:	1 st October 2013
GPS co-ordinates:	TR343 630, Pegwell Bay, Ramsgate.
Ambient temperature:	17°C
1 hour observation of aster stands – bee detected:	Yes
Thorough search of suitable nesting sites:	Yes – very few open areas.
Nest holes detected:	No
Active nest holes detected:	No
Notes: Sea Aster available, however very few suitable nesting sites were present. Highly compacted clay sea walls which were highly vegetated. River dredging's available on site with the potential to move them into a more southerly facing location to attract CH.	
Surveyor:	Kara Hardy

Date:	5 th October 2013
GPS co-ordinates:	TF761 448, Brancaster Beach, Norfolk.
Ambient temperature:	16°C
1 hour observation of aster stands – bee detected:	No
Thorough search of suitable nesting sites:	Yes
Nest holes detected:	No
Active nest holes detected:	No
Notes: Sea Aster present. Plenty of sparsely vegetated and open areas, however possibly too much areas to cover and therefore CH was not detected at this time.	