The restoration of intertidal habitats for non-breeding waterbirds through breached managed realignment

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Declaration

This thesis and the data presented in it are the result of my own research except where collaborative work has been duly acknowledged. No part of this work has been submitted to any other institution in application for a higher degree.

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September 2007

Abstract

Conservation of intertidal habitats in the UK is vital in order to continue to support nationally and internationally important populations of non-breeding waterbirds. Historic reclamation for agriculture and industry has resulted in the loss and degradation of large areas of these intertidal habitats in estuaries and they continue to be threatened by sea-level rise. Managed realignment is one method which is increasingly being used to restore intertidal habitats. As managed realignment is a relatively new restoration technique, the extent to which knowledge of the biology of estuaries is applicable to managed realignment sites is unclear. Habitat restoration is often unsuccessful or incomplete, so a detailed knowledge of both the natural system and the characteristics of restored systems will usually be necessary to recreate fully-functional estuarine habitats.

This thesis focuses on Nigg Bay Managed Realignment Site (Nigg Bay MRS), the first managed realignment site in Scotland, and follows the first four years of ecological development to gain an understanding of how breached realignment can be used to restore intertidal habitats to support non-breeding waterbirds. This thesis has six major aims: (i) to describe the development of saltmarsh, (ii) to describe the development of intertidal flat, (iii) to describe the colonisation by non-breeding waterbirds (iv) to determine how tidal cycle and weather affect patterns of waterbird use, (v) to determine which factors affect the spatial distribution of waders and finally (vi) to determine the patterns of use by individual birds.

Four summers after the re-establishment of tidal conditions, almost all of the saltmarsh species recorded on the nearby saltmarsh had colonised Nigg Bay MRS, although recognisable communities had yet to establish. Three winters after the re-establishment of tidal conditions in Nigg Bay MRS, the sediments had a significantly smaller particle size and higher organic matter content compared to the fine sands of the adjacent intertidal flats. The intertidal invertebrate community also differed from the adjacent intertidal flats. Nigg Bay MRS attracted large numbers of non-breeding waterbirds and supported each of the most common wader and wildfowl species present in the wider estuary. Nigg Bay MRS performs a number of important functions for non-breeding waterbirds by: (i) providing a foraging and resting habitat when the tide is absent and intertidal sediments in Nigg Bay are exposed; (ii) providing a foraging resource as the tide passes over the intertidal sediments within the site once the intertidal flats in Nigg Bay are inundated; and (iii) providing a high tide roosting site. On days with low temperatures and high wind speeds, more waterbirds use Nigg Bay MRS, suggesting that it is likely to be providing sheltering benefits. Nigg Bay MRS also provides top-up feeding habitat. The factors that often influence the spatial distributions of waders in estuaries appear to be operating within Nigg Bay MRS. Wader densities are greater on the intertidal flats when they are accessible than on the saltmarsh. Wader densities are also greatest close to creeks and drainage channels, possibly due to higher invertebrate densities, more accessible prey or sheltering benefits. Colour-ringing and radio-tracking of Common Redshank established that Nigg Bay MRS has a subset of regular users, including both adults and juveniles, and the wader assemblage at night may differ from the assemblage during the day.

These findings are discussed in terms of the implications for locating, designing and managing future managed realignment projects.

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Contents

Chapter 1

Introduction to non-breeding waterbirds, intertidal habitats and managed realignment

1.1 Rationale

Each winter, intertidal estuarine habitats in the UK support about 1.7 million waders (Charadriidae and Scolopacidae) and 1.4 million wildfowl (Anatidae) (Pollitt *et al*. 2003). Relatively small resident populations are supplemented by waders and wildfowl migrating south along the 'East Atlantic Flyway' from the high Arctic (Figure 1.1). An estimated 15.5 million waders migrate along the East Atlantic Flyway each autumn (Stroud *et al*. 2004).

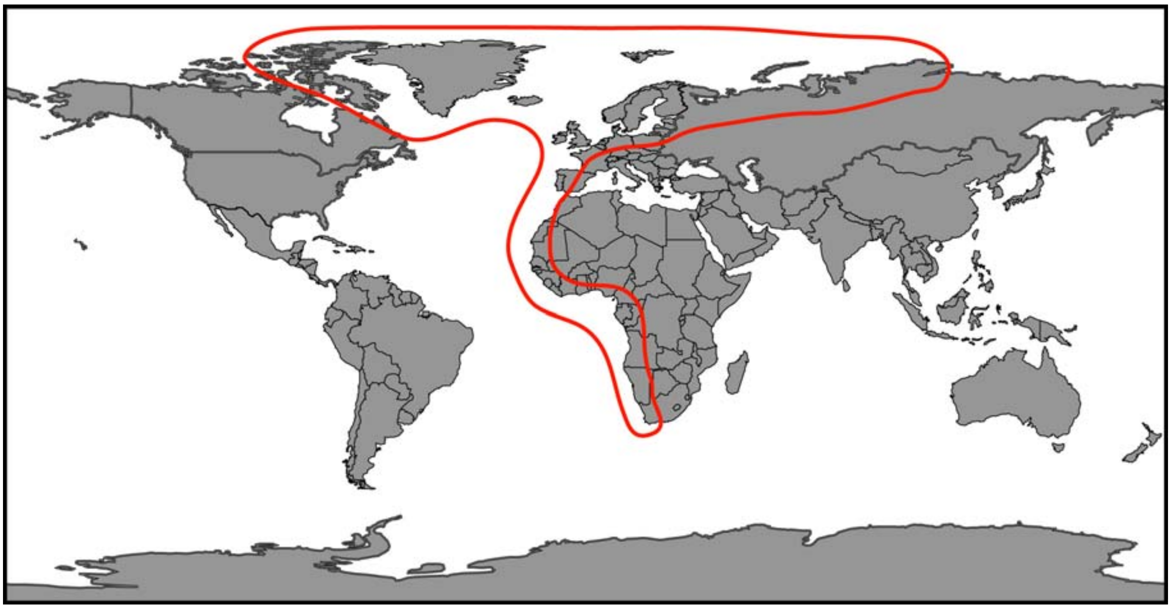


Figure 1.1: Location of the East Atlantic Flyway.

In addition to providing essential stopover sites for those birds migrating further south, the UK supports many birds throughout the winter (Wernham *et al*. 2002). Many wetlands support populations of national (1% or more of the estimated British population) and/or international (1% or more of the estimated global population or regularly supports 20,000 or more waterbirds) importance (Kershaw & Cranswick 2003;

Rehfisch *et al*. 2003). Waterbirds wintering in the UK benefit from the mild Atlantic climate and large tidal ranges, which mean that the intertidal flats rarely freeze (Clark 2006). The most important sites for non-breeding waterbirds in the UK (those regularly supporting more than 100,000 waterbirds) (Figure 1.2) coincide with major UK estuarine habitats, comprising large areas of intertidal flats and saltmarsh (Pollitt *et al*. 2003).

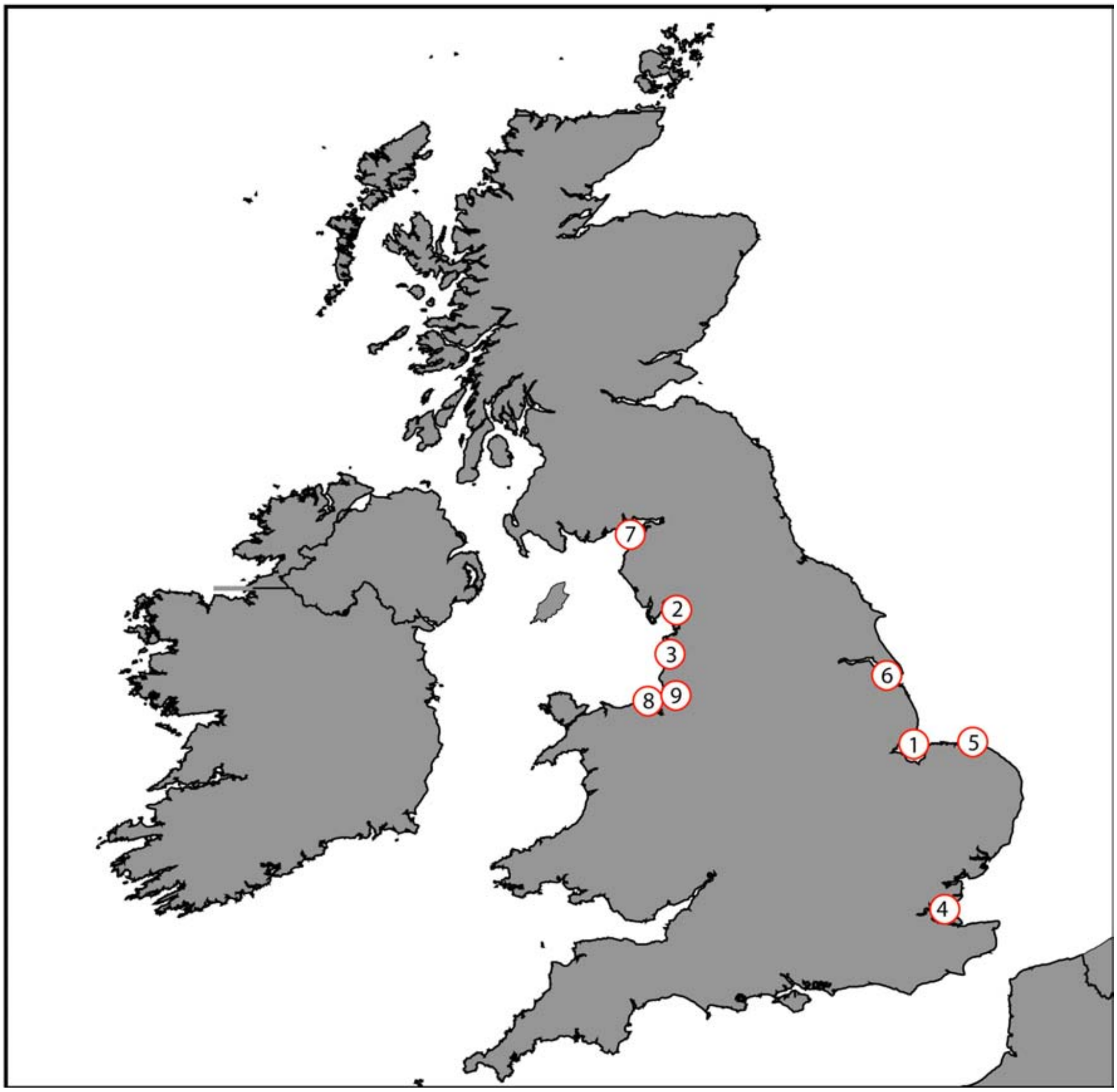


Figure 1.2: Sites regularly supporting more than 100,000 waterbirds (based on Wetland Bird Survey data from winter 1996/1997 to 2000/2001, Pollitt *et al*. 2003). Sites are ranked in descending order according to the average number of waterbirds: (1) The Wash, (2) Morecambe Bay, (3) Ribble Estuary, (4) Thames Estuary, (5) North Norfolk Coast, (6) Humber Estuary, (7) Solway Estuary, (8) Dee Estuary and (9) Mersey Estuary.

Conservation of intertidal habitats in the UK is vital in order to continue to support the nationally and internationally important populations of non-breeding waterbirds. Historic reclamation for agriculture and industry has resulted in the loss and degradation of large areas of these intertidal habitats in estuaries (Davidson *et al*. 1991, Moser *et al*. 1996) and they continue to be threatened by sea-level rise (IPCC 2001). Managed realignment is one method which is increasingly being used to restore intertidal habitats (Atkinson *et al*. 2001). As managed realignment is a relatively new restoration technique, the extent to which knowledge of the biology of estuaries is applicable to managed realignment sites is unclear. Since habitat restoration is often unsuccessful or incomplete (Wheeler *et al*. 1995; Gilbert & Anderson 1998; Wade & Joyce 1998; Perrow & Davy 2002a, 2002b; Andel & Aronson 2005; Stanturf & Madsen 2005; Bobbink *et al*. 2006), a detailed knowledge of the characteristics of both natural and restored systems will usually be necessary to recreate fully-functional estuarine habitats.

1.1.1 The tidal cycle

An understanding of the tidal cycle is important for this thesis because it causes predictable patterns of inundation and exposure of the intertidal zone. Invertebrates and plants that inhabit the intertidal zone must be able to tolerate periods of tidal inundation and exposure, while waders and wildfowl experience changes in the area of accessible feeding and roosting habitat.

Tides occur due to the significant gravitational attraction exerted on the oceans by both the sun and the moon (Levington, 2001). The extent of the tide is largely determined by the difference in gravitational attraction on either side of the earth. On the side closer to the moon the gravitational attraction pulls water towards the moon, while on the opposite side of the earth there is a corresponding bulge due to the centrifugal force of the earths spin producing two areas of high tide. Between the bulges there are areas of depression producing two areas of low tide. As the moon passes over the earth once per day, generally there are two low tides and two high tides per day.

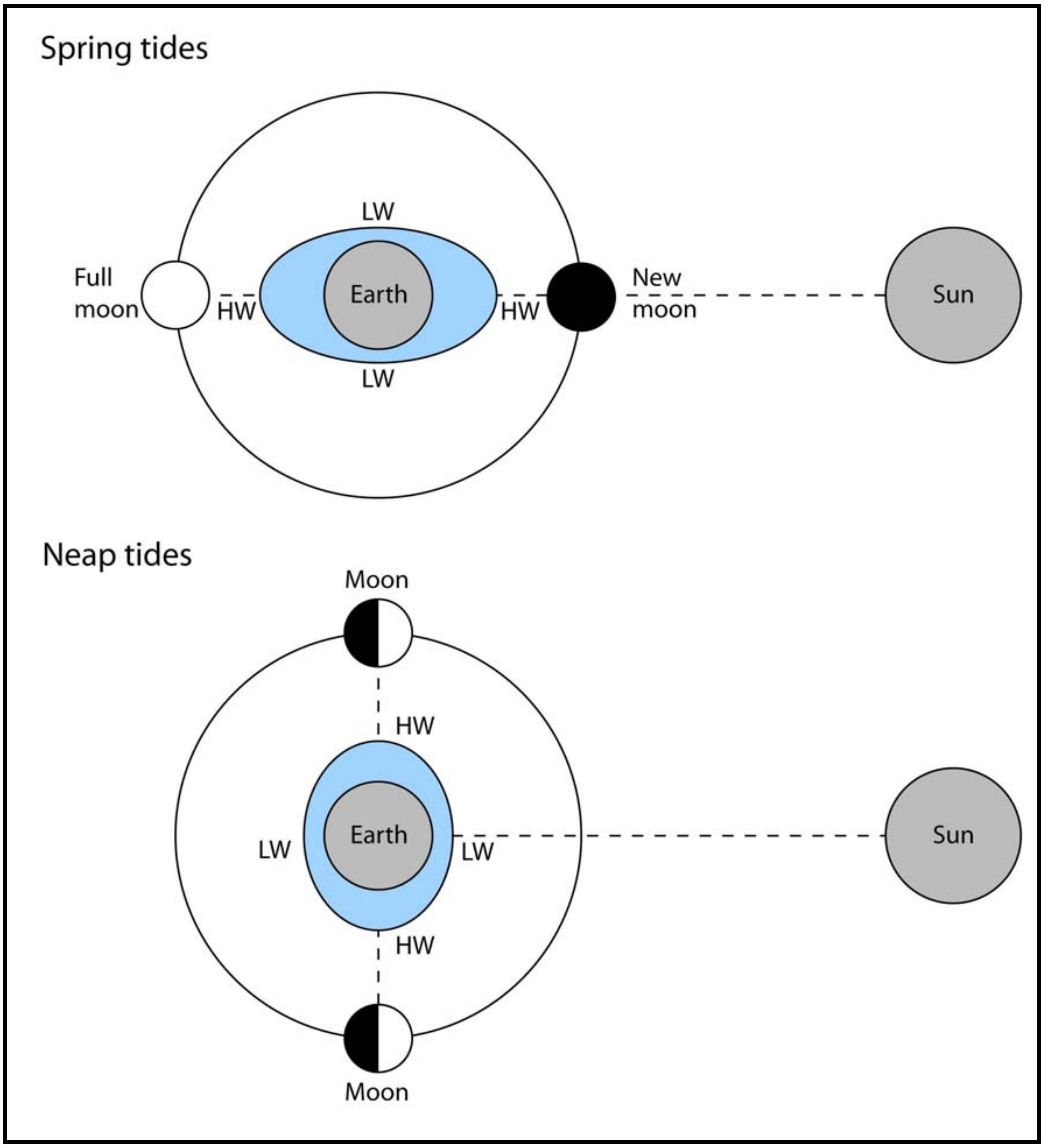


Figure 1.3: Action of tidal forces at different alignments of the sun and moon. HW = High Water and LW = Low Water

When the sun, earth and moon are aligned the gravitational force exerted by the sun amplifies that of the moon and maximal tidal range (Spring tide) is achieved (Figure 1.3). When the sun, earth and moon form a right angle the gravitational effects act in opposite directions and minimal tidal range (Neap tide) is achieved (Figure 1.3) Two spring tides and two neap tides occur each lunar month (approximately 29.5 days).

Although astronomical data are important in tidal predictions, detailed local knowledge is required to predict times and heights for specific locations. Prevailing weather conditions may affect both the timing and height of the actual high and low water and may extend the tidal range beyond the highest and lowest astronomical tides.

1.1.2 Intertidal habitats which support non-breeding waterbirds

Intertidal flat in the UK is estimated to cover 270,000 ha (Department of the Environment 1994). Intertidal flats are formed from sediments deposited in low-energy environments. They are often formed from fine sediments (i.e. silts and clays) which have high organic matter content, although sandier sediments are deposited in areas of increased wave activity. Intertidal flats support a high density of intertidal invertebrates. Intertidal invertebrate species show a range of habitat preferences, including position on the shore, substrate type, organic matter content, oxygen concentration, tidal strength, exposure and salinity (Anderson 1972). The lower limit of a species in the tidal frame is usually determined by the presence of predators or interspecific competition, whereas the upper limit is often controlled by physiological limits on the species' tolerance of extremes of temperature and exposure (Levinton 2001).

Saltmarsh in the UK is estimated to cover 45,500 ha (Department of the

Environment 1994). Saltmarsh develops in the presence of tidal flooding above the level of Mean High Water Neap (MHWN) tides. Saltmarsh succession (halosere) is largely determined by elevation relative to the tidal frame (Crooks *et al*. 2002), as different species have different levels of tolerance to saltwater (Hill *et al*. 1999). Saltmarsh succession is initiated when pioneer species, such as Glasswort *Salicornia europaea*, Annual Sea-blite *Suaeda maritima* and Common Cord-grass *Spartina anglica*, which can withstand frequent submergence in saltwater, colonise the intertidal flat. These species trap sediments, thereby increasing the surface elevation and altering the sediment characteristics, creating favourable conditions for species which are less tolerant of submergence in saltwater, such as Saltmarsh Grass *Puccinellia maritima* and Sea-purslane *Halimione portulacoides*. The resulting saltmarsh shows a transition from lower (most salt-tolerant species), through middle, to upper (least salt-tolerant species) saltmarsh with increasing elevation in the tidal frame (Table 1.1 and Figure 1.4). The National Vegetation Classification (NVC) (Rodwell 2000) describes 28 saltmarsh communities which occur in mainland Britain, the Isle of Man, the Isles of Scilly and the Scottish Isles (Table 1.1). However, the number of saltmarsh communities declines with increasing latitude (Rodwell 2000).

Table 1.1: Saltmarsh zonation (Long & Mason 1983) and distribution of NVC communities (Rodwell 2000). Elevations are shown for Mean High Water (MHW) and Mean Low Water (MLW) for Neap (N) and Spring (S) tides.

Zone	NVC	Elevation (m OD)				
Mudflat	3	MLWS	(-0.6)	:	MHWN	(1.2)
Lower saltmarsh	13	MHWN	(1.2)	:	MHW	(1.7)
Middle saltmarsh	9	MHW	(1.7)	:	MHWS	(2.2)
Upper saltmarsh	3	> MHWS	(>2.2)			

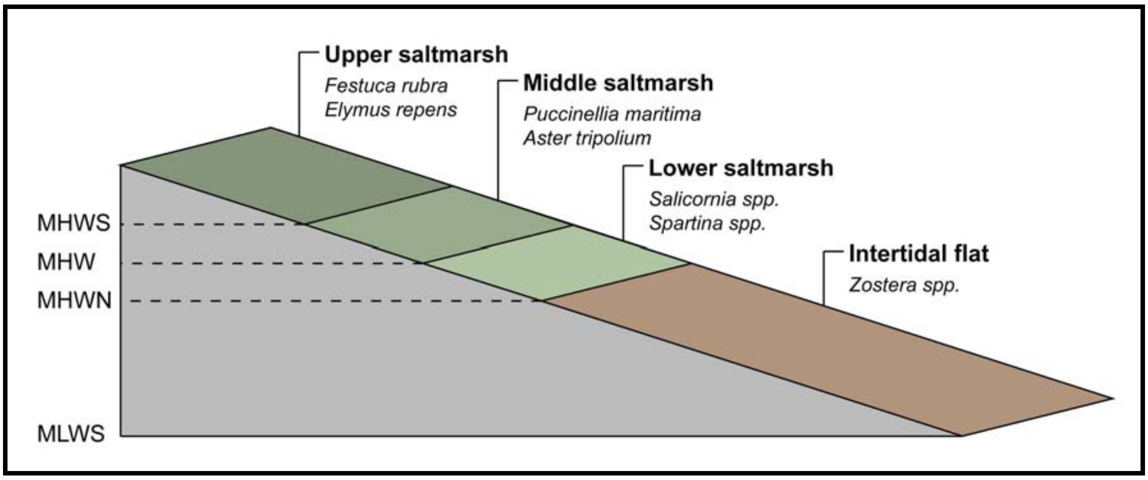


Figure 1.4: Saltmarsh zonation showing representative vegetation species.

In addition to supporting non-breeding waterbirds, saltmarsh supports wintering passerines such as Twite *Carduelis flavirostris* and Snow Bunting *Plectrophenax nivalis* (Brown & Atkinson 1996) and provides breeding sites for wader species such as Common Redshank *Tringa totanus*, Northern Lapwing *Vanellus vanellus* and Common Snipe *Gallinago gallinago* (Norris *et al*. 1997; Milsom *et al*. 2002). Saltmarshes support around 45% of the population of Common Redshank breeding in Great Britain (Brindley *et al*. 1998).

Intertidal flats and saltmarsh perform several further important functions (Vernberg 1993; Levin *et al*. 2001): (i) providing feeding, refuge and nursery areas for fish and decapod crustaceans (Rountree & Able 1992; Peterson & Turner 1994; West & Zedler 2000; Minello *et al*. 2003); (ii) dissipating wave energy and playing an important role in coastal defence (King & Lester 1995; Möller & Spencer 2002; Cooper 2005); (iii) sequestering pollutants including phosphorus, ammonium, nitrates and heavy metals (Jimenez-Carceles *et al*. 2006) and (iv) providing foraging areas for livestock (Jensen 1985).

It is important to determine whether saltmarsh colonisation in managed realignment sites proceeds in the same way as in estuarine areas and to determine whether the intertidal invertebrate species that are abundant on intertidal flats are able to colonise and establish within managed realignment sites. When planning managed realignment projects, consideration should be given to the timescales involved in the establishment of saltmarsh and intertidal invertebrate communities, particularly where intertidal habitats are being created to mitigate for future losses of existing habitats.

1.1.3 Use of intertidal flat and saltmarsh habitats by non-breeding waterbirds

1.1.3.1 Activities undertaken by waterbirds

Waders, and many wildfowl species, feed on a range of intertidal invertebrates, including molluscs, crustaceans and polychaete worms, which are abundant on the intertidal flats (Skagen & Oman 1996). Waders selectively forage for the most profitable prey, i.e. the species and size classes of prey that provide the highest net rate of energy return (Goss-Custard 1977a; Rippe & Dierschke 1997; Dierschke *et al*. 1999; Arcas 2004; Ieno *et al*. 2004; Santos *et al*. 2005) and usually feed in areas of highest prey density (Goss-Custard *et al*. 1977b, 1977c; Bryant 1979). On the Tagus Estuary, Portugal, for example, 44% of birds fed less than 5 m from the edges of drainage channels (i.e. just 12% of the available area) where invertebrate prey were most abundant (Lourenço *et al*. 2005).

Waders use various methods to detect their prey. For example, some use predominantly tactile foraging, probing the surface to detect prey, while others use predominantly visual foraging, targeting individuals emerging from burrows or following tracks of invertebrates which move over the intertidal flats (Barbosa 1995). Tactile foragers usually feed in dense flocks and move slowly over the intertidal flats, while visual foragers usually feed individually or in loose flocks and move rapidly over the intertidal flats. When waders forage at high density, interference between individuals can result in a reduced feeding rate (Triplet *et al*. 1999; Yates *et al*. 2000) and force birds to use less-preferred feeding areas (Goss-Custard. 1977c). The burrowing depth of invertebrates affects their accessibility to waders. The majority of intertidal invertebrates live beneath the maximum depth that the longest bills can probe (Zwarts & Wanink 1993). The larger individuals of any given species tend to burrow more deeply than smaller individuals (Zwarts & Wanink 1993). The most accessible invertebrates tend to have a relatively poor body condition and may therefore represent marginal prey (Zwarts & Wanink 1991). Some wildfowl species, such as Eurasian Wigeon *Anas penelope*, are herbivorous and feed on saltmarsh grasses, seeds, algae and eel grass (Mathers & Montgomery 1996).

When their foraging grounds become inundated, most waders and some wildfowl species congregate at roost sites on upper intertidal habitats, including saltmarsh, where they sleep, preen or forage. Other wildfowl species loaf (non-foraging activity on the water) on open water. Roost sites can vary from those used occasionally by a few birds to sites used regularly by hundreds or thousands of birds (Colwell *et al*. 2003). Choice of roost site is often governed by wind speed and the ability of roosts to provide shelter (Peters & Otis 2007) although the risk of predation may also be an important factor (Rosa *et al*. 2006). Choice of roost site may differ between day and night as the relative importance of the factors affecting roost selection change (Rogers *et al*. 2006). Roost sites are often located close to foraging areas to minimise the energetic costs associated with flying (Dias *et al*. 2006; Rogers *et al*. 2006). Many potential foraging areas may not be used due to the lack of a nearby roost (Dias *et al*.

2006). Some species, such as Eurasian Curlew, are more roost-faithful than others, such as Red Knot, as has been shown in studies on the Moray Firth, Scotland (Rehfisch *et al*. 2003), and the Wash, England (Rehfisch *et al*. 1996).

When managed realignment is used to restore intertidal habitats for waterbirds it is essential to determine whether the restored habitats meet the requirements of the target wader and wildfowl species. This will involve ensuring that profitable invertebrate prey (or vegetation) is present for foraging birds and that sheltered and safe roost sites are provided for roosting birds.

1.1.3.2 How disturbance may affect waterbird activities

Predation by raptors and foxes is a threat to waterbirds in many intertidal areas. On the Tyninghame Estuary, Scotland, for example, 90% of the juvenile population of Common Redshank was taken by raptors in two winters (Cresswell & Whitfield 1994). Waders can minimise their risk of predation by foraging in more open habitats where there is less cover from which predators could launch a surprise attack. Human activities such as dog walking and wildfowling also cause disturbance to waterbirds (Madsen & Fox 1995; Fox & Madsen 1997).

Waders and wildfowl often respond to disturbance by flying to less-disturbed areas, which can result in a loss of feeding time and depletion of energy reserves. In more harsh winters, disturbance can lead to a reduced fitness. Modelling has shown that in winters with good feeding conditions Eurasian Oystercatcher *Haematopus ostralegus* can be disturbed up to 1.0-1.5 times per hour before their fitness is reduced. However, in winters with poor feeding conditions this reduces to 0.2-0.5 times per hour (Goss-Custard *et al*. 2006b). Clearly, when selecting and engineering sites for managed realignment, consideration should be given to minimising disturbance of any waterbirds that may use the site for foraging or resting.

1.1.3.3 How the tidal cycle may affect waterbird activities

Patterns of behaviour of waterbirds in intertidal habitats are closely related to the tidal cycle (Siegel-Causey 1991; Hotker 1995; Fasola & Biddau 1997; Blanco 1998; Granadeiro *et al*. 2006), which causes predictable changes in the accessible area of the intertidal zone. In general, foraging becomes restricted to progressively smaller areas of the upper intertidal flats on the rising tide, and when these become submerged, the birds move to their roosting or loafing sites. This pattern is reversed as the tide ebbs, although foraging patterns may differ between flow and ebb tides (Bryant & Leng 1975).

Waterbird species have two responses to the movement of the tide line. Some species are predominantly tide "followers" and follow the tide edge closely as it moves across the intertidal flats. Intertidal invertebrates depend on water for foraging, dispersal and breeding, and are often active in the shallow water at the tide edge where they are relatively easy for birds to detect. The Mud Shrimp *Corophium volutator*, the preferred prey of Common Redshank (Goss-Custard 1977b), only moves to the surface in areas of wet sand or mud (Colwell & Landrum 1993). Kelsey & Hassall (1989) showed that invertebrates in softer, wetter sediments were more accessible to Dunlin *Calidris alpina* foraging on the Wash since these sediments were more easily penetrated by their bills. Other species are predominantly "non-followers" and spend more time in areas away from the tide edge. Whether a species is a tide "follower" or a "non-follower" varies between and even within locations. Within the Tagus Estuary, Portugal, for example, Dunlin are tide "followers" (Granadeiro *et al*. 2006) whereas in the Wadden Sea in late summer they tend to be “non-followers” (Nehls & Tiedemann 1993). Species that may be tide “followers” on the flow tide are often “non-followers” on the ebb tide, as they stay behind feeding in areas of wet mud or at creek edges (Bryant & Leng 1975).

When managed realignment is being used to restore intertidal habitats for waterbirds, it is important to establish whether the restored habitat is functioning as a natural extension of the estuary. As managed realignment sites are usually situated high in the tidal frame, they would be expected to be used by more birds once the lower intertidal flats are inundated.

1.1.3.4 How weather may affect waterbird activities

Waterbird behaviour can be affected by weather on a seasonal basis or in the shorter term. Most waders winter south of the 0 ºC January isotherm. Weather can affect the distribution of waterbirds on a wide geographic scale. In warmer winters, for example,, seven out of nine wader species had smaller wintering populations in the generally milder southwest of the UK while in colder winters, a greater proportion of these species remained in the east of the UK (Austin & Rehfisch 2005).

In harsher weather, the metabolic requirements of waders and wildfowl are greater. Low temperatures coupled with high wind speeds can lead to significant wind chill, increasing the likelihood of starvation. Although some species are able to regulate their body mass to reduce their risk of starvation (Mitchell *et al*. 2000; Kelly *et al*. 2002), waders are more likely to be found dead in winter than at other times of the year (Goss-Custard *et al*. 1977a). Of the waders wintering in British and other European estuaries, Common Redshank suffers the highest mortality during severe weather

(Pilcher *et al*. 1974; Davidson & Clark 1985; Clark *et al*. 1993). Severe winter weather can result in major mortality events, which may impact on local population sizes (Baillie 1980; Clark *et al*. 1993; Clark 2004). Significantly reduced annual survival rate due to severe winter weather has been reported for Common Redshank on the Moray Firth (Swann & Etheridge 1989; Insley *et al*. 1997).

Adverse weather conditions may affect the ability of birds to detect prey. At lower temperatures, intertidal invertebrates may be less active and may burrow more deeply in the sediments (Pienkowski 1983; McGowan *et al*. 2002; Beauchamp 2006), going beyond the depth that most bills can penetrate. When the intertidal flats become frozen, sediments may become impenetrable. Rainfall also decreases prey detectability to waders (Pienkowski 1983; Selman & Goss-Custard 1988). Poor visibility, caused by low light levels or wind disturbance, may negatively affect birds which rely on sight to detect their prey (Verkuil *et al*. 2003).

In poor weather conditions, waterbirds may struggle to meet their daily energy demands on the intertidal flats when they are accessible during daylight hours. In order to meet their metabolic requirement, birds must increase their rate of energy intake by eating more and/or reduce their energy expenditure by reducing their activity levels or exposure to the weather. Common Redshank in the Ythan Estuary, Scotland, consumed less than 50% of their daily requirement when feeding on the estuary in daylight hours, and the balance had to be met by feeding at night or feeding on surrounding fields at high tide, when the intertidal feeding areas were inaccessible (Goss-Custard 1969). Similarly, in the Tees Estuary, England, waders extended their feeding time by feeding on peripheral wetland sites when the intertidal flats were inundated (Davidson & Evans

1986). Smaller birds lose heat more easily than larger birds since they have a higher surface area to volume ratio. They therefore have to feed more to compensate for the loss (Calder 1974; Goudie & Piatt 1991). On the Wash, smaller wader species including Red Knot *Calidris canatus*, Dunlin and Common Redshank spent over 95% of the available daylight hours feeding in winter (Goss-Custard *et al*. 1977a).

Waterbirds need to balance their risk of starvation against the risk of predation (Lima 1986; McNamara & Houston 1990; Houston & McNamara 1993; Hilton *et al*. 1999). Heavy birds require more energy to fly and are less manoeuvrable, making them more vulnerable to predator attack (Witter & Cuthill 1993). In more favourable seasons, therefore, when there may be less pressure on finding enough to eat, birds may shed fat reserves and choose to forage in less-profitable feeding habitats, where these coincide with a lower risk of predation. When weather conditions are more severe, feeding becomes a greater priority and birds may store more fat and choose to forage in more-profitable feeding habitats, even if the risk of predation is higher. On the Tyninghame Estuary, Scotland, when the risk of starvation was higher for Common Redshank foraging on the mudflat, more birds moved to the saltmarsh where the energy intake was 23% higher and the thermoregulatory costs were 40% lower, but the chance of being attacked by an Eurasian Sparrowhawk *Accipiter nisus* was 21 times higher (Yasue *et al*. 2003).

As harsh weather conditions increase waterbird mortality in estuaries, it would be useful to establish whether the creation of managed realignment sites can help to reduce the susceptibility of waterbirds to starvation, perhaps through providing more sheltered conditions and providing additional feeding time once the adjacent intertidal flats become inundated (i.e. top-up feeding).

1.1.3.5 Individual bird use of intertidal habitats

Studies of individuals have been used to identify waterbird migration routes by linking the breeding grounds, stop-over sites and wintering grounds of individual birds (Gudmundsson & Lindstrom 1992; Summers 1994; Butler *et al*. 1996; Wernham *et al*. 2002; Perkins *et al*. 2007). Understanding of waterbird migration has been further enhanced through studies investigating the duration of stop-overs (Figuerola & Bertolero 1998; Pfister *et al*. 1998; Nebel *et al*. 2000; Lehnen & Krementz 2005), timing of departure (Green *et al*. 2002; Battley *et al*. 2004; Battley *et al*. 2005; O'Hara *et al*. 2005; Verkuil *et al*. 2006) and site fidelity between years (Tomkovich & Soloviev 1994; Burton & Evans 1997; Perkins *et al*. 2007).

The ability to identify individual waterbirds is valuable in local studies investigating how different areas of intertidal habitat are used both temporally and spatially (Symonds & Langslow 1984; Drake *et al*. 2001; Butler *et al*. 2002; Takekawa *et al*. 2002). The findings of such studies have potentially important implications for the conservation of nationally and internationally important populations of waders and wildfowl. Colour-ringing and radio-tagging have both been used in studies of Common Redshank in Cardiff Bay, Wales, investigating both winter site fidelity (Burton 2000) and the fate of birds displaced by the creation of a barrage (Burton *et al*. 2006). Radio-tracking has also been used to show that Common Redshank on the Severn Estuary, Wales (Burton & Armitage 2005), and Red Knot on the Rio Negro, Argentina (Sitters *et al*. 2001), use different areas of intertidal feeding habitat at night compared to during the day. Monitoring usage patterns by individuals will be particularly important in assessing the success of habitat creation and restoration schemes, including managed realignment, to restore intertidal habitat for waterbirds (Atkinson *et al*. 2001).

In the context of studies of managed realignment, individual marking can be used to infer the source of colonists for the restored habitat, whether they are birds re-distributed from the adjacent intertidal area or are new settlers. Individual marking can also provide an insight into whether restored habitats have a regular and exclusive clientele or, alternatively and more likely, show the links between the birds using restored habitats and the foraging and roosting habits of birds elsewhere in the estuary.

1.1.4 Intertidal habitat loss and its impact on non-breeding waterbirds

Both intertidal flat and saltmarsh are an important resource for non-breeding waterbirds in the UK, yet these intertidal habitats are in decline. In the UK around 43,000 ha of saltmarsh has been reclaimed in the last 300 years (Davidson *et al*. 1991). Historically, large areas of saltmarsh were enclosed and drained for agriculture. For example, 23% of estuaries and 50% of saltmarshes have been drained since Roman times (Davidson *et al*. 1991; Moser *et al*. 1996). In 1946, the War Commission was responsible for the conversion of 90% of grazing marsh to agricultural land (May 2003). More recently, small areas of saltmarsh have been reclaimed for developments such as industrial facilities, ports, transport infrastructure, waste disposal and marinas.

Intertidal habitats are also being lost through natural processes (Harmsworth & Long 1986; Burd 1992; Cooper *et al*. 2001; Pye 2000; Wal & Pye 2004). Erosion accounts for the loss of about 100 ha of saltmarsh in the UK every year (Atkinson *et al*. 2004) and the probable loss of intertidal flats and saltmarsh in England by 2013 is predicted to be 10,000 ha (4% of the resource) and 2,750 ha (8% of the resource), respectively (Pye & French 1993). In some locations, erosion may be exacerbated by reduced sediment supply (Sabatier *et al*. 2006), while in other locations the presence of hard defences, which prevent the natural landward migration of saltmarsh, may result in coastal squeeze (Pethick 2001; Doody 2004). Global climate-change models predict a rise in relative sea level and an increase in frequency and severity of storm surges which are likely to cause increased rates of erosion in the future (IPCC 2001). Predictions for sea-level rise by 2080 range from 19-79 cm for the coast of SE England and from 1-19 cm for the coast of NE Scotland (Hulme *et al*. 2002). Sea-level rise is more pronounced in SE England and less so in NE Scotland due to the isostatic adjustment of the UK in response to the last ice age (Peltier *et al*. 2002).

Reduction or degradation of intertidal habitats, particularly around estuaries, is likely to cause population declines amongst waterbirds (McLusky *et al*. 1992; Goss-Custard *et al*. 1995, 2006a; Galbraith *et al*. 2002; Durell *et al*.; 2005; Stillman *et al*. 2005; Burton *et al*. 2006; Clark 2006). Intertidal habitat loss is expected to impact upon bird populations if the bird numbers in the area concerned are already close to carrying capacity (Goss-Custard 1985). In such cases, the exact impact of habitat loss will be affected by the ability of displaced birds to find and adapt to new sites (Figure 1.5). The creation of tidal barrages in estuaries can halve the tidal range, thereby reducing the intertidal area available for foraging birds (Clark 2006). Following the impoundment of Cardiff Bay, around 300 Common Redshank were displaced to the Severn Estuary (Burton *et al*. 2006). However, these displaced birds apparently did not adapt well to the new site as they experienced poor body condition and a 44% increase in mortality rate. Similarly, although 25% of Eurasian Oystercatcher displaced by the closure of the Grevelingen Estuary, Netherlands, initially settled into the nearby Roggenplaat area, this influx apparently exceeded the carrying capacity as there was a sharp decline in numbers by the following winter and only 6% of the displaced Eurasian Oystercatchers settled in the long-term (Lambeck *et al*. 1989). Within a population, the impact of habitat loss may vary due to individual specialisations in diet and feeding method relating to age and sex, and the impact on population size is likely to be greater if habitat loss affects a particular age or sex group more than another (Durell 2000). Habitat loss is likely to be more problematic for species which are site faithful as they are less likely to adapt successfully to alternative sites. Most waders, for example, show high site fidelity to the estuary that they settled on in their first winter (Clark 2006). Continued intertidal habitat loss may have detrimental consequences for nationally and internationally important non-breeding waterbird populations.

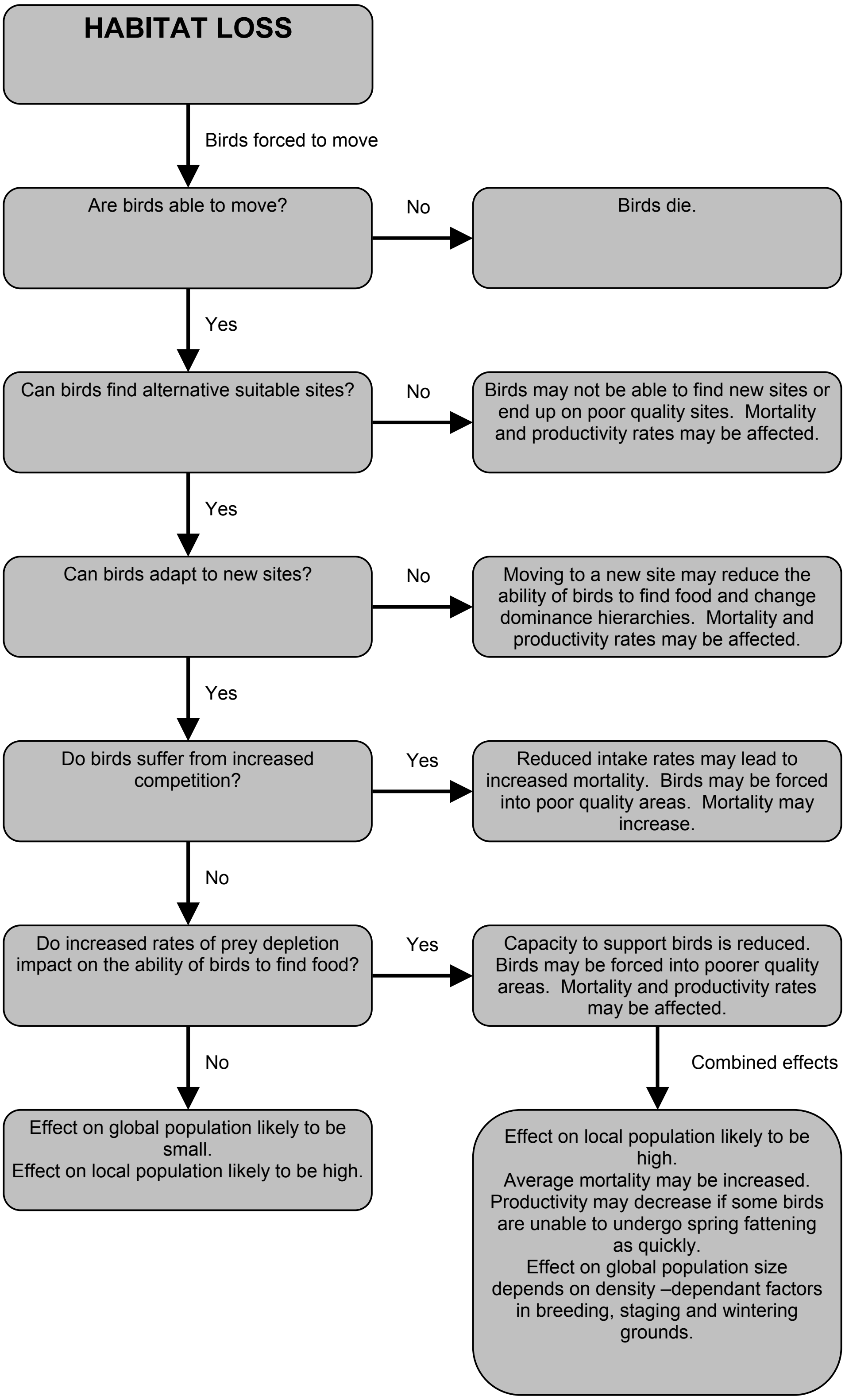


Figure 1.5: How intertidal habitat loss may affect non-breeding waterbird populations (from Atkinson *et al.* 2001).

1.1.5 Restoring intertidal habitats

In recognition of their ecological importance, many intertidal habitats have received greater protection through site designations under national and international law (Table 1.2). Important Bird Areas (IBAs), identified by BirdLife International, form a network of key sites providing suitable breeding, stop-over and wintering sites along the flyways of migratory species. Reserves, including Local Nature Reserves (LNRs), National Nature Reserves (NNRs) and reserves owned by non-governmental organisations (NGOs), including the Royal Society for the Protection of Birds (RSPB), Wildfowl and Wetlands Trust (WWT) and Wildlife Trusts, are also managed for the conservation of habitats and wildlife. Natura 2000 and Ramsar sites are designated under international legislation, and can only be developed if there is an overriding public interest. Where such sites are adversely affected by development, then compensatory habitats must be created.

In 1994, the *Biodiversity: the UK Action Plan* (Department of the Environment 1994) was launched in response to the 1992 Rio Convention on Biological Diversity. The UK Biodiversity Action Plan (BAP) includes habitat action plans for both coastal saltmarsh and mudflats. The objectives of the Coastal Saltmarsh BAP include ensuring no further net loss of saltmarsh and creating a further 40 ha per year to replace the 600 ha lost between 1992 and 1998. The objectives of the Mudflat BAP include maintaining at least the present extent and regional distribution of the UK's mudflats, and creating and restoring enough intertidal area over the next 50 years to offset predicted losses due to rising sea level in the same period.

Table 1.2: Designations affecting intertidal habitats.

Designation	Legislation	Remit	Scope
Area of Outstanding Natural Beauty (AONB)	1949 National Parks and Access to the Countryside Act	Conserve natural beauty including wildlife, physiographic features, cultural heritage, landscape and scenery.	UK (excluding Scotland)
Wetland of International Importance (Ramsar site)	1971 Ramsar Convention	Conservation and wise use of wetlands	Global
Special Protected Area (SPA)	1979 EC Wild Birds Directive	Areas of the most important habitat for rare and migratory birds within the European Union.	European
Site of Special Scientific Interest	1981 Wildlife and Countryside Act	Sites providing protection for the best examples of the UK's flora, fauna, or geological or physiographical features	UK
Special Area of Conservation (SAC)	1992 EC Habitats Directive	Areas best representing the range and variety within the European Union of habitats and (non-bird) species	European
Natura 2000 site (SPA & SAC)	1992 EC Habitats Directive	Assure the long-term survival of Europe's most valuable and threatened species and habitats.	European

However, intertidal habitats pose particular problems for restoration (Atkinson *et al*. 2001): (i) they are topographically and ecologically complex; (ii) they support many species of animals, some of which require specific habitats and linkages to other habitats; and (iii) they exist and evolve within dynamic coastal settings which are subject to changing tidal levels, salinities and long-term forcing factors associated with sea-level rise and climate change.

One of the most widely used restoration techniques is managed realignment (Section 1.1.6). In addition, a range of other methods has been used (Hughes & Paramor 2004). Enhanced sedimentation involves constructing groynes or sedimentation fields to encourage mudflat accretion (Pye & French 1993). Foreshore recharge involves pumping dredged material onto a containment site (Streever 2000; Bolam & Whomersley 2005). Transplantation of saltmarsh plants from donor sites or plants propagated in glasshouses and seeding (Brooke *et al*. 1999) has been widely adopted to restore saltmarsh in the USA (Bergen *et al*. 2000; Broome & Craft 2000; Zedlar *et al*. 2003) and Australia (Burchett *et al*. 1998; Seliskar 1998; Kay 2004), but within the UK, experimental transplantation has only been undertaken at a relatively small number of sites (Garbutt *et al*. 2006). Intertidal habitat restoration schemes have had varying degrees of success in creating habitats with similar vegetation, invertebrate and waterbird communities as nearby reference sites (ABP 1998; Atkinson *et al*. 2001).

Intertidal habitat restoration involves the loss or degradation of other habitats. Predictions for the next 50 years suggest that while managed realignment of 12,500 ha will lead to a net gain of 770 ha of intertidal habitat in England and Wales, this is likely to be at the expense of 4,000 ha of freshwater and brackish habitat (Lee 2001). Often the land either side of an embankment will already be designated under the Habitats Directive and, as it is illegal to allow any developments which might threaten either of the habitats (Pethick 2002), it is often difficult to know how best to proceed to maximise conservation or other related goals.

1.1.6 Managed realignment

Managed realignment, also referred to as managed retreat, coastal setback or 'depoldering' (in mainland Europe), is a 'soft' engineering technique which allows the sea to flood previously enclosed land and promotes the creation of intertidal habitats. Managed realignment can take a number of forms (Burd 1995): (i) the entire embankment may be removed (banked realignment); (ii) a section of the embankment may be removed to create a single or multiple breaches (breached realignment); (iii) a section of the embankment may be lowered to provide a spillway; or (iv) reverse freshwater sluices may be installed to allow the inflow of sea water. These latter two methods are often referred to as regulated tidal exchange (RTE).

The most appropriate method will depend on the desired outcome of the project, the budget and the site characteristics. Where the desired outcome is the development of saltmarsh, breached realignment and RTE provide relatively sheltered conditions, which promote sediment accretion and plant colonisation (Pontee *et al.* 2006). In contrast, banked realignment creates relatively exposed conditions, which inhibit saltmarsh development. Although this method has been less widely adopted, it was implemented at the Welwick Managed Realignment Site on the Humber Estuary, England, which aims to create compensatory mudflat (Pontee *et al*. 2006). Where managed realignment is being adopted as a cost-effective solution to coastal defence, RTE and breached realignment are likely to be favoured over banked realignment as less earth needs to be moved, thereby lowering the cost. A potential drawback of RTE (and, to a lesser extent, breached realignment) in terms of habitat creation/compensation is reduced ecological connectivity with the wider estuary (Pontee *et al*. 2006). From a flood defence perspective, tide levels (and consequently flood risk) may not be significantly reduced and the site may be less able to respond to future changes as sea levels rise (Pethick 1993; Townend & Pethick 2002). Over time, however, breached realignments may provide greater connectivity with the wider estuary if the embankment is removed by erosion. Some managed realignment schemes have adopted a staged approach to the re-establishment of tidal conditions by using a combination of methods. At Abbott's Hall, England, tidal conditions were first restored to the site in 1996 when two pipes were installed in the embankment (Diack 1998); six years later five breaches were made in the embankment, thereby extending the range of the tidal influence (May 2003). At Ziesetal, Denmark, tidal conditions were first restored in 1995 when the embankment was breached; four years later the entire embankment was removed (Grunwald 2002; Zander 2002).

There are also many sites where natural breaching of embankments has occurred (Burd *et al*. 1994). For example, the floods of 1953 resulted in 12,000 breaches of flood defences along the east coast of England (Baxter 2005), some of which were never repaired. While such sites can provide natural analogues of how intertidal habitat development might proceed at breached realignment sites (French 1999), limited ecological monitoring data are available. One notable exception is the Scheldt Estuary, Netherlands, where a breach in 1990 resulted in the development of tidal marsh (Eertman *et al*. 2002). Data on the vegetation, invertebrates and birds colonising the site were collected over ten years following the breach. A more recent natural breach occurred in 1996 when a storm breached a shingle ridge at Porlock, England, and this provided another excellent opportunity to study intertidal habitat formation (Doody & Randall 2003).

This thesis focuses on the use of breached realignment to restore intertidal habitats. This has been the most widely used technique in the UK to date, being employed in several locations, mostly in the estuaries of SE England (Table 1.3), and has also been used elsewhere in Europe, particularly in Germany and the Netherlands (Wolters *et al*. 2005).

Table 1.3: Details of breached managed realignment sites in the UK from 1991 to December 2006 (adapted from Wolters *et al*. 2005).

Site name	Location	Area (ha)	Year	Month	Years embanked	Land use[1]	Main reason[2]	Design (number and size of breaches)	Drainage[3]	Elevation (m MHWN)	Tidal range (m)	Monitoring[4] V	I	B
Northey Island B	Blackwater Estuary	0.8	1991	Aug	118	A,F	2	1 (20 m)	I	0.7-1.6	4.8	Y	N	N
Pawlett Hams	River Parrett, Somerset	4.8	1994		—	—	2	1	—	2.7-3.7	11.1	Y		
Orplands	Blackwater Estuary	40	1995	Apr	175	A,F	1	2 (40 m & 50 m)	III	0-2.5	4.7	Y	Y	Y
Tollesbury	Blackwater Estuary	21	1995	Aug	150	A	2	1 50 m)	I	-0.6-1.5	4.7	Y	Y	Y
Brancaster West	North Norfolk Coast	7.5	1996		—	F	2	1	—	—	6.5			
Lantern Marshes	Orfordness, Suffolk	37	1999		—	—	—	—	—	—	—			
Chaldock Marsh	Chichester Harbour	—	1999		~200	—	—	1	—	—	4.4			
Thornham Point	Chichester Harbour	—	—			—	—	1	—	—	4.4			
Pillmouth	River Torridge, Devon	—	2000	Jul	>200	A	2	3	II	—	7.0			
Trimley	Orwell Estuary	16	2001		—	—	—	1	—	—	3.6			
Freiston	The Wash	66	2002	Aug	19	A	1	3	II, III	0.8-1.6	6.4	Y	Y	Y
Hullbridge	Blackwater Estuary	12	2002	Nov	—	—	—	—	—	—	4.7			
Abbots Hall	Blackwater Estuary	115	2002	Oct	—	A	1	5	—	—	4.7			
Nigg Bay	Cromarty Firth	25	2003	Feb	~50	P	1	2 (20 m & 20 m)	II	0.3-1.8	3.7	Y	Y	Y
Paull Holme Strays	Humber Estuary	70	2003	Sep	—	A,P	1,2	2	—	—	6.4	Y	Y	Y
Wallasea C	Crouch Estuary	115	2005	Jul	—	A	1	1	—	—	—	Y	Y	Y
Chowder Ness	Humber Estuary	12	2006	Jul										
Alkborough	Humber Estuary	440	2006	Sep	—	—	1	1	—	—	6.4			

[1] A = arable; P = pasture; F = freshwater grazing.
[2] 1 = habitat creation/compensation; 2 = flood defence.
[3] I = superficial; II = drainage ditches; III = artificial creeks.
[4] V= Vegetation; I = Invertebrates; B = Birds.

1.2 Aims of the present study

The process of restoring intertidal habitats is complex and poorly understood (Section 1.1.5). As managed realignment is still a relatively new restoration technique, the extent to which knowledge of the biology of estuaries is applicable to managed realignment sites is not yet known. It is important to study schemes in order to learn which sites are the most amenable to restoration and to establish timescales of colonisation by saltmarsh vegetation, intertidal invertebrates and non-breeding waders and wildfowl.

This thesis focuses on Nigg Bay Managed Realignment Site (Nigg Bay MRS) (Chapter 2), the first managed realignment site in Scotland, and follows the first four years of ecological development to gain an understanding of how breached realignment (Section 1.1.6) can be used to restore intertidal habitats to support non-breeding waterbirds.

The results of sediment, vegetation, intertidal invertebrate and non-breeding waterbird monitoring are presented for the first three winters and four summers following the re-establishment of tidal conditions. Temporal and spatial patterns in the use of Nigg Bay MRS are established, and colour-ringing and radio-tagging are used to provide an insight into how Nigg Bay MRS and the wider estuary are used by individual birds. The findings are discussed in terms of the implications for locating and design of future managed realignment projects.

1.2.1 Thesis outline

Chapter 2: The study Site

This chapter provides an introduction to Nigg Bay and the Nigg Bay MRS, highlighting the importance of the area to non-breeding waterbirds.

Chapter 3: Patterns of saltmarsh colonisation over four years in Nigg Bay Managed Realignment Site

Saltmarsh succession in estuaries is relatively well understood. However, the extent to which this knowledge applies to managed realignment sites is less certain. The majority of UK managed realignment schemes to date have been undertaken in southern England, where the saltmarsh communities are more species rich. This study provides a unique opportunity to investigate colonisation at a site in north Scotland, where the available pool of colonists is considerably reduced. The aim of this chapter is to describe the development of saltmarsh in Nigg Bay MRS to address the following questions: Which saltmarsh species colonised Nigg Bay MRS? What was the temporal pattern of colonisation? What was the source of the colonists? How was colonisation affected by position in the tidal frame? How did NVC communities compare with those of a nearby reference site? How did colonisation compare with that of other UK managed realignment sites?

Chapter 4: The development of intertidal flats in Nigg Bay Managed Realignment site: sediment characteristics and colonistation by invertebrates

Intertidal flats and the invertebrate communities that they support provide an important resource for feeding waterbirds. Intertidal flats in breached managed realignment sites generally develop in more sheltered conditions compared to intertidal flats on the open estuary. However, the extent to which the sediment characteristics and the colonising invertebrate community differ between managed realignment sites and estuaries is poorly understood. The aim of this chapter is to describe the development of intertidal flats in Nigg Bay MRS to address the following questions: How do sediment particle size and organic matter content compare between Nigg Bay MRS and a nearby reference site? How do these sediment characteristics change with position on the shore? Which intertidal invertebrates colonised Nigg Bay MRS? What was the temporal pattern of colonisation? What were the ages/sizes of the colonising species? How does the intertidal invertebrate assemblage of Nigg Bay MRS compare with the reference site? Does Nigg Bay MRS support profitable prey for waterbirds?

Chapter 5: Patterns of colonisation of Nigg Bay Managed Realignment Site by non-breeding waterbirds

Managed realignment sites have the potential to create valuable saltmarsh and intertidal flat habitats for non-breeding waterbirds, however, there have been few studies specifically investigating this issue. When managed realignment is being used as a conservation tool it is important to ensure that the conditions are appropriate to support the species of interest. The aim of this chapter is to describe the colonisation of Nigg Bay MRS by non-breeding waterbirds to address the following questions: Which wader and wildfowl species colonised Nigg Bay MRS? What was the temporal pattern of colonisation? How does the waterbird assemblage compare with that of Nigg Bay? How many birds have benefited from the creation of Nigg Bay MRS? How did colonisation compare with that of other UK managed realignment sites?

Chapter 6: How tidal cycle and weather affect patterns of use of Nigg Bay Managed Realignment Site by non-breeding waterbirds

Patterns of waterbird activity in estuaries are influenced by the tidal cycle and prevailing weather conditions. As managed realignment sites are often created at sites higher in the tidal frame they might be expected to be used in similar ways to upper intertidal flat and saltmarsh habitats. Waterbird activity is usually greatest on the upper intertidal flats at higher tidal states when the lower intertidal areas are inundated and no longer accessible for feeding. As the metabolic requirements of waterbirds increase in harsher weather conditions, they may be expected to seek out sheltered sites and increase their energy intake. The aim of this chapter is to determine how the tidal cycle and weather affect waterbird use of Nigg Bay MRS by addressing the following questions: Which activities (foraging, resting, loafing) do waterbirds undertake in Nigg Bay MRS? How does the role of Nigg Bay MRS as a resource for non-breeding waterbirds change in response to temporal variations in tide and weather? How do temporal patterns of behaviour vary across species?

Chapter 7: Spatial patterns of use of Nigg Bay Managed Realignment Site by non-breeding waders

On an estuarine scale, non-breeding wader distributions have been shown to be primarily affected by invertebrate prey distributions and predation risk. However, managed realignment sites are often small relative to the area of existing intertidal flat and the extent to which these, and other, factors operate to determine distributions at this scale is unknown. The aim of this chapter is to determine which factors affect the spatial distributions of waders Nigg Bay MRS by addressing the following questions: What is the spatial distribution of waders on Nigg Bay MRS? How do spatial distributions vary through the tidal cycle? What factors affect the spatial distribution of waders on Nigg Bay MRS? What is the relative importance of these factors? How do spatial patterns vary across species?

Chapter 8: Use of Nigg Bay Managed Realignment Site and Nigg Bay by individually marked birds

Although it is informative to investigate the use of a site at the population level, many questions can only be addressed through observations of individual birds. Through identifying individuals we can determine how different areas are linked temporally and spatially. The aim of this chapter is to determine the use of Nigg Bay MRS by individual birds to address the following questions: Does Nigg Bay MRS have a regular and exclusive clientele? What is the age structure of the birds present? Which other areas of intertidal habitat are used by the individuals which use Nigg Bay MRS? Is Nigg Bay MRS used at night?

Chapter 9: Restoration of intertidal habitats: Conservation management indicators from the Nigg Bay Managed Realignment Project

This chapter provides a summary of the main findings of the thesis and discusses implications for conservation management.

Chapter 2

The study site

Nigg Bay, on the Cromarty Firth (part of the Moray Firth estuarine complex), is the location of the first managed realignment site in Scotland and the first UK site to be located in a sand-dominated estuary. As the Moray Firth is of international importance (Section 1.1) to non-breeding waterbirds, the creation of this managed realignment site provides an excellent opportunity to investigate the effectiveness of breached realignment (Section 1.1.6) in restoring intertidal habitat for non-breeding waterbirds.

2.1 Location, geomorphology, sediments and tidal regime

Nigg Bay is situated on the northern shore of the Cromarty Firth in Ross-shire, Scotland (Figure 2.1). The Cromarty Firth, a deep, narrow inlet of the Moray Firth, separates the mainland of Easter Ross from the Black Isle and extends approximately 28 km from its mouth, between the headlands known as the Sutors, west then south west to Dingwall.

The Cromarty Firth is a deep glacial trough which was created during the last ice age and flooded as sea levels rose. Nigg Bay lies in a shallow hanging valley of the main glacial trough. Significant post-glacial deposition has resulted in sediment depths of up to 60 m towards the head of the Firth, while depths in Nigg Bay reach over 9 m (Babtie Shaw & Morton 1969). Surveys in Nigg Bay have demonstrated that the sediments largely consist of fine sands (Raffaelli & Boyle 1986, Rendall & Hunter 1986).

The tide levels for two locations on the Cromarty Firth are shown in Table 2.1. The mean spring tidal range at Invergordon is 3.7 m.

Figure 2.1: Map of the Moray Firth estuarine complex. The location of Nigg Bay is indicated by red shading.

Table 2.1: Tide data for Cromarty and Invergordon on the Cromarty Firth (Admiralty Data 2002). Tide levels are given as m above Ordnance Datum.

Tide type	Cromarty	Invergordon
Lowest astronomical tide	No data	-2.3
MLWS	-1.4	-1.5
MLWN	-0.4	-0.6
MHWN	1.3	1.2
MHWS	2.2	2.2
Highest astronomical tide	No data	2.8

2.2 Importance to non-breeding waterbirds

The Moray Firth (Figure 2.1) is the most northerly extensive estuarine complex in Europe. The Inner Moray Firth, Dornoch Firth and Cromarty Firth combined regularly support over 100,000 waterbirds (Pollitt *et al*. 2003). The Moray Firth lies at the north-west limit of the winter range of many waterbird species. It is therefore of major strategic importance, providing both a first and last stop-over site for migrating birds and, in severe weather, serves as an important cold-weather refuge. Nigg Bay holds internationally important populations of Bar-tailed Godwit *Limosa lapponica* and Greylag Goose *Anser anser*, and nationally important populations of Common Redshank *Tringa totanus*, Eurasian Curlew *Numenius arquata*, Red Knot *Calidris canatus*, Whooper Swan *Cygnus cygnus*, Eurasian Wigeon *Anas penelope*, Northern Pintail *Anas acuta*, Greater Scaup *Aythya marila* and Red-breasted Merganser *Mergus serrator* (Trubridge & Chisholm 1999). At any one time, Nigg Bay may hold up to 80% of the wintering waders and wildfowl within the Cromarty Firth (Chisholm *et al*. 2004). The waders and wildfowl which visit the Moray Firth in winter breed in Canada, Greenland, Iceland, the Faeroes, Orkney, Shetland, Scandinavia and Russia (Symonds & Langslow 1986).

In recognition of its significance to internationally important populations of wintering and passage wildfowl, the firths and bays of the Moray Basin have been designated an Important Bird Area (Section 1.1.5). The Cromarty Firth has been designated as a Site of Special Scientific Interest (SSSI) and a National Nature Reserve (NNR), while Nigg Bay has been designated as a Special Protection Area (SPA) under the EC Wild Birds Directive and as a Wetland of International Significance under the Ramsar Convention (Section 1.1.5). Nigg Bay also forms part of Nigg and Udale Bays

RSPB Reserve, which covers 1586 ha and comprises intertidal flat, saltmarsh and wet grassland habitats.

2.3 Disturbance

Disturbance has the potential to impact bird numbers in the Moray Firth (Section 1.1.3.2), although wildfowling pressure in winter 2005-2006 (Crowther & Elliott 2006) was found to have been reduced compared with levels in winter 1992-1993 (Hancock 1993). In Nigg Bay, wildfowling activity occurred during each month of the winter (October-February) (Crowther & Elliott 2006). Nigg Bay attracts a small number of (mostly local) regular wildfowlers that operate individually and also visiting wildfowlers, who are often in groups comprising two or three individuals. The majority of wildfowlers target geese when they leave (at dawn) or arrive (at dusk) at their roost sites. Other recreational activities such as bird-watching, dog-walking and recreational walking which also occur on the reserves may cause disturbance during daylight hours (Crowther & Elliott 2006).

2.4 Intertidal habitat loss in Nigg Bay

Land claim and sea-level rise, which lead to large-scale and permanent loss of intertidal areas, are important conservation problems in Scottish estuaries (Raffaelli 1992).

Large areas of intertidal habitat have been lost from Nigg Bay over the last century. Between 1947 and 1997, 39.4 ha (36%) of saltmarsh were lost from the head of Nigg Bay (Johnstonova & Cowie 2001). The loss of 25.47 ha (23%) of saltmarsh was attributable to the reclamation of Meddat Marsh (Figure 2.2b) in the 1950s but, as this was the last of the marshland bordering Nigg Bay to be reclaimed, the remaining loss of 13.93 ha (13%) is likely to have been due to erosion. The mean rate of saltmarsh erosion in upper Nigg Bay between 1947 and 1997 was 0.068 ha yr^{-1}. Between 1970 and 1979, 93 ha of intertidal habitat was reclaimed in the lower area of Nigg Bay for the construction of an oil terminal and oil rig fabrication yard (Figure 2.2c). The construction of the oil terminal and fabrication yard is likely to have altered the dynamics of Nigg Bay as a whole and may have accelerated rates of erosion. The construction of the embankment enclosing Meddat Marsh may also have increased erosion rates in the upper areas of Nigg Bay.

a)

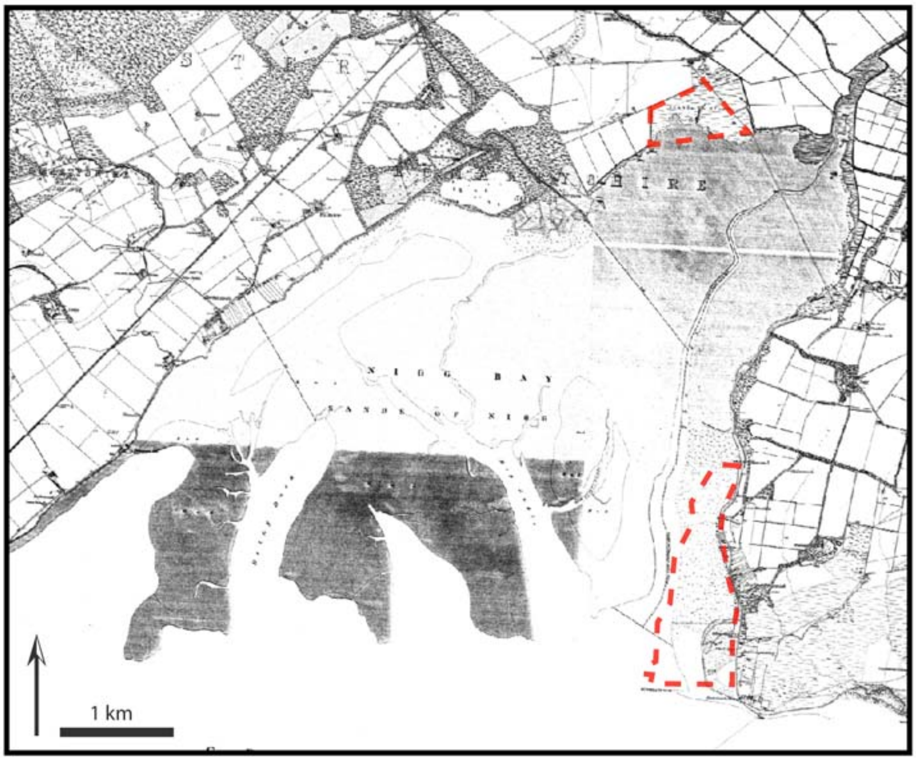


Figure 2.2: Maps from (a) 1880/1881, (b) 1959/1960 and (c) 2002 showing the major intertidal loss that has occurred since 1880 including the reclamation of Meddat Marsh and the construction of Nigg oil terminal and oil rig fabrication yard. Continues overleaf.

b)

c)

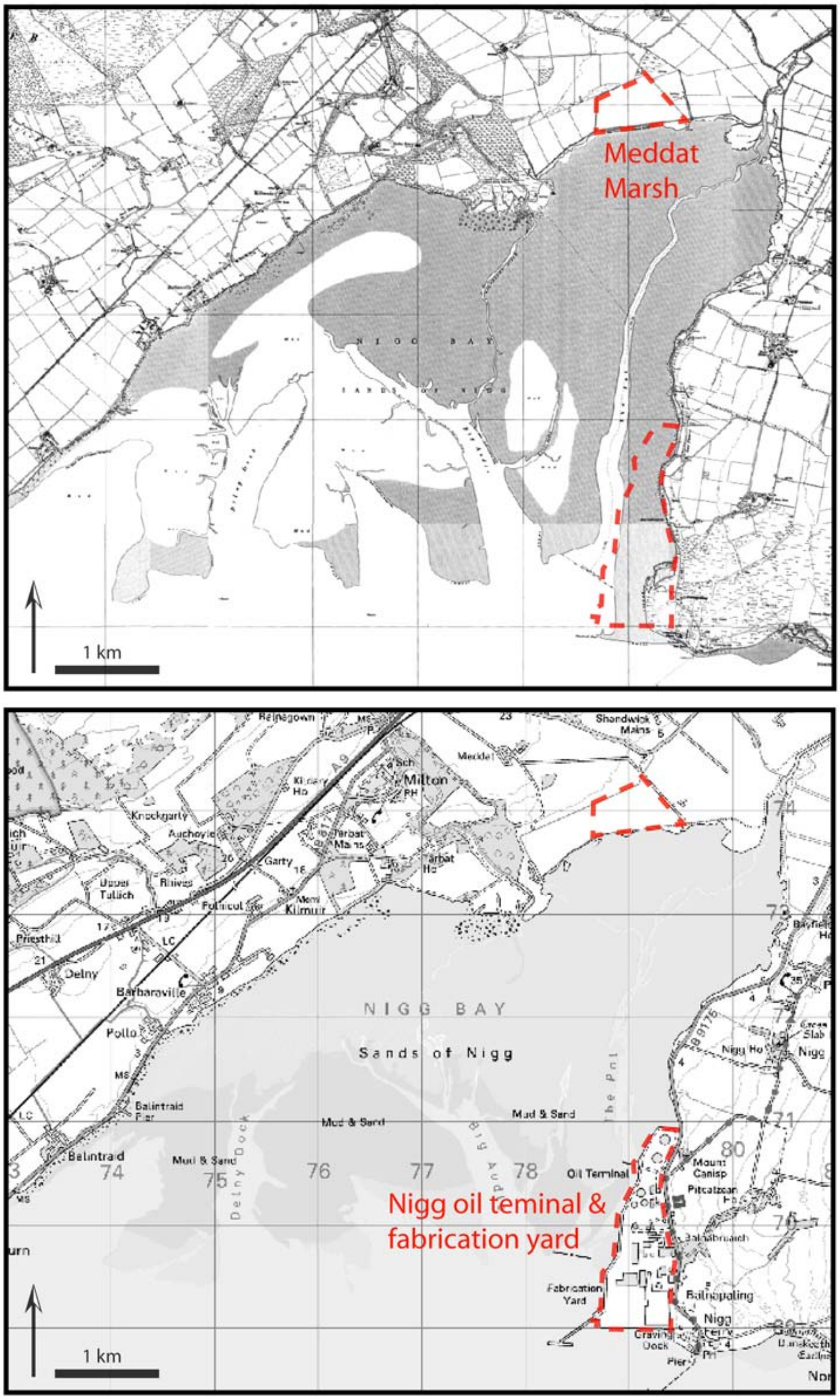


Figure 2.2 continued.

2.5 Nigg Bay Managed Realignment Project

2.5.1 Acquisition of the site

The site known as Meddat Marsh (Figure 2.2) was purchased by the RSPB in 2001, as a suitable site to implement the first managed realignment project in Scotland. This was an excellent opportunity to try to recreate important intertidal habitats that had previously been lost to erosion and development in Nigg Bay (Section 2.4). When the RSPB purchased the site the southern embankment was already damaged from coastal erosion and wave action (Figure 2.3), and was likely to have breached naturally within a few years.

Figure 2.3: The eroding southern embankment prior to breaching. RSPB.

2.5.2 Aims of the Nigg Bay Managed Realignment Project

The Nigg Bay Managed Realignment project mainly came about through opportunity (Chisholm *et al*. 2004). The aims of the Nigg Bay Managed Realignment project included creating intertidal flats to provide foraging habitat and creating saltmarsh to provide roosting and breeding habitat for waterbirds.

2.5.3 Suitability of Meddat Marsh for managed realignment

Following the enclosure of previously intertidal sites, anthropogenic activities often alter the physical and chemical characteristics of sediments (Hazelden & Boorman 2001). Drainage for agriculture may result in the lowering of sites relative to the adjacent saltmarsh and extensive physical activities, such as ploughing, may significantly alter the topography of sites and disrupt relict creek systems. Chemicals (including nitrates, phosphates and heavy metals, applied as fertilisers, pesticides and herbicides) may accumulate in the sediments.

Meddat Marsh was particularly amenable to managed realignment as it had been reclaimed relatively recently compared to other managed realignment sites in the UK (Table 1.3). Since being reclaimed, Meddat Marsh had been used as rough pasture. Cultivation had been attempted in a small area in the north east corner, but the rest of the site had never been ploughed. No fertiliser had been applied in Meddat Marsh in the previous five years and historical fertiliser use had comprised minimal application of ammonium nitrate. Meddat Marsh had therefore not been extensively altered, either physically or chemically. It had retained an estuarine morphology, was suitably positioned in the tidal frame (1.5 m – 3.5 m OD), had a gentle slope (1:250) and a relict creek system.

2.5.4 The design

A design and impacts study (Babtie Group 2002) was undertaken to assess the hydrodynamic, ecological and geomorphologic impacts of the proposed realignment, and to identify the most appropriate design (Section 1.1.6) to promote the establishment of both saltmarsh and mudflat habitats. This study proposed a breached realignment involving the creation of at least two 20 m wide breaches in the southern embankment aligned with the relic drainage channels. Under this design the managed realignment site was predicted to develop low (including pioneer marsh and mudflats), middle and upper saltmarsh (Figure 2.4).

Figure 2.4: Predicted post-realignment saltmarsh zonation. [dark green] = Upper marsh; [green] = Middle marsh; and [pale green] = Lower marsh (including pioneer marsh and mudflats. From Babtie Group (2002).

2.5.5 Engineering works

Prior to breaching, the pre-existing secondary defence was strengthened (Figure 2.5a) and two culverts in the west and east embankments were blocked to isolate the site hydrologically from the adjacent farmland (Figure 2.5b). Based on the findings of the design and impacts study, two 20m wide breaches were created in the southern embankment (Figure 2.5c).

a)

b)

c)

Figure 2.5: The engineering works in progress: (a) the upgraded secondary defence, (b) blocking one of the culverts and (c) breaching the southern embankment to create the west breach gap. RSPB.

2.5.6 Breaching the southern embankment

On 11th and 12th February 2003 two eroding sections of the southern embankment were breached, allowing the field to flood at high water (Figure 2.6), creating Nigg Bay MRS (Figure 2.7).

Figure 2.6: The first tide that entered Nigg Bay Managed Realignment Site following breaching. View looking along the southern embankment across the east breach gap, with Nigg Bay to the left and Nigg Bay Managed Realignment Site to the right. RSPB.

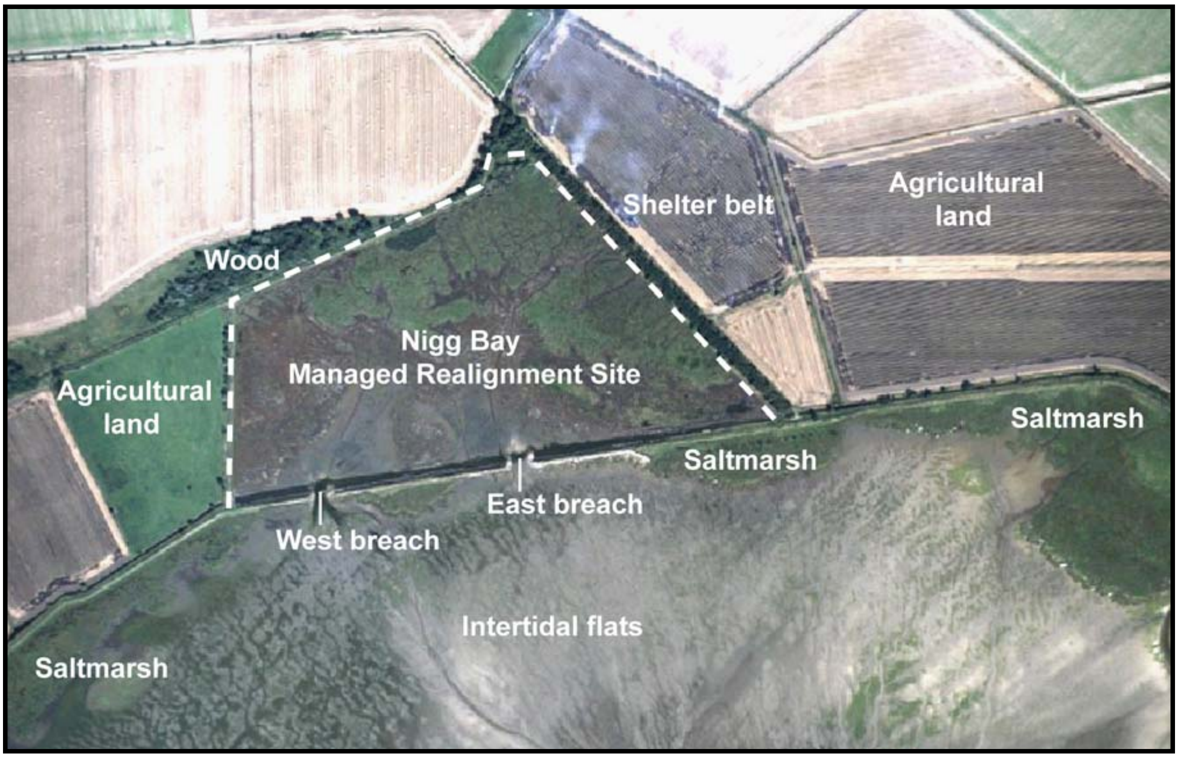


Figure 2.7: Nigg Bay Managed Realignment Site. Aerial photograph taken in September 2003, seven months after the reintroduction of tidal conditions. The dashed line indicates the secondary defence. NERC ARSF.

Chapter 3

Patterns of saltmarsh colonisation over four years in Nigg Bay Managed Realignment Site.

3.1 Introduction

Saltmarsh is important to waterbirds as foraging, roosting and breeding habitat (Section 1.1.3), but in the UK is being lost at a rate of 100 ha per year (Section 1.1.4). It has been estimated that sea-level rise will result in the loss of 2,750 ha of saltmarsh in the UK between 1993 and 2013. To offset this loss and compensate for historic losses, the UK BAP (Biodiversity Action Plan) has set a target to restore or create 140 ha of saltmarsh per year (Section 1.1.5). Managed realignment is one method by which this can be achieved (Section 1.1.6). Managed realignment can also be used to create saltmarsh as compensation for Natura 2000 and Ramsar sites which are adversely affected by development (Section 1.1.5).

A simple measure of success of saltmarsh creation through managed realignment is whether the communities that develop ultimately resemble those of local saltmarsh. The success in achieving this may be determined by comparing the species composition and NVC communities (Rodwell 2000) of the created saltmarsh with that of a nearby reference site. Most colonists are expected to arrive in a managed realignment site via dispersal from local saltmarsh (Huiskes *et al.* 1995). However, sites that were reclaimed relatively recently may have a viable seed bank providing an alternative source of colonists (Thompson *et al.* 1997). Classic saltmarsh succession proceeds as pioneer species promote sediment accretion which raises the elevation and creates conditions suitable for less salt-tolerant species (Section 1.1.2). In managed realignment sites there is often a pre-exiting range of elevations, potentially providing conditions suitable for colonisation by species traditionally viewed as mid- and late-successional species.

This chapter investigates the development of saltmarsh in Nigg Bay MRS and attempts to answer the following questions: Which saltmarsh species colonised Nigg Bay MRS? What was the temporal pattern of colonisation? What was the source of the colonists? How was colonisation affected by position in the tidal frame? How did NVC communities compare with those of a nearby reference site? How did colonisation compare with that of other UK managed realignment sites?

3.2 Methods

3.2.1 Botanical monitoring within Nigg Bay Managed Realignment Site

A vegetation survey was undertaken at Meddat Marsh in June 2001, two summers prior to the re-establishment of tidal conditions, to provide a baseline against which future changes in vegetation within Nigg Bay MRS could be measured (Mchaffie 2002). Sixty permanent quadrats were chosen, distributed in two sets of five rows, each containing six quadrats (Figure 3.1, Appendix 1). All rows were on a bearing of 260°W, approximately parallel with the southern embankment, and the position of quadrats in each row was randomised. All quadrat locations were marked with a post to allow re-sampling of the same area in subsequent years.

The 1 m^2 quadrat was usually sampled 1 m to the northeast of the marker post unless there was a topographic reason, such as the presence of a creek, for an alternative position. Percentage cover of species in each quadrat was recorded. The total percentage cover for each quadrat could exceed 100% because ground-covering and taller plant species could cover the same surface area. The vegetation survey was repeated within Nigg Bay MRS in the four summers post-breach (Table 3.1).

Table 3.1: Details of the summer vegetation surveys in Nigg Bay Managed Realignment Site showing time relative to the breaching of the southern embankment and month in which the survey was undertaken.

Summer	Year	Summers since breach	Month
S0	2001	-2	Jun
S1	2003	1	Sep
S2	2004	2	Jun
S3	2005	3	Jun
S4	2006	4	Jun

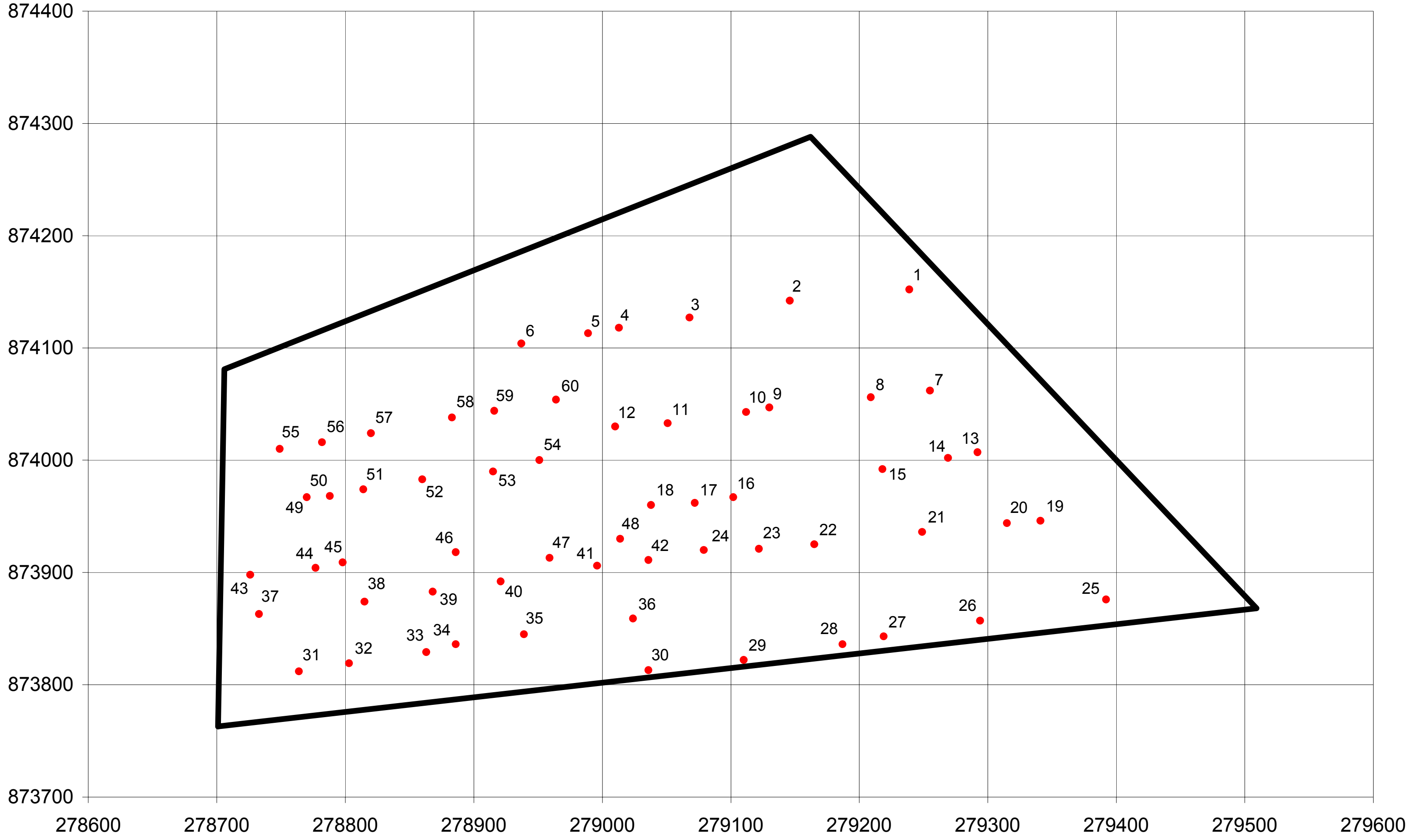


Figure 3.1: Locations of vegetation quadrats within Nigg Bay Managed Realignment Site.

3.2.2 Botanical monitoring of a reference saltmarsh

In July 2006, a quadrat-based vegetation survey was undertaken on the saltmarsh adjacent to Nigg Bay MRS to provide a reference against which the developing saltmarsh in Nigg Bay MRS could be compared. Quadrats (n=109) were chosen on 14 transects which ran due south from the embankment bordering Nigg Bay to a northing of 873,730 m BNG (Figure 3.2, Appendix 2). The percentage cover of each species in the 1 m^2 quadrat was recorded.

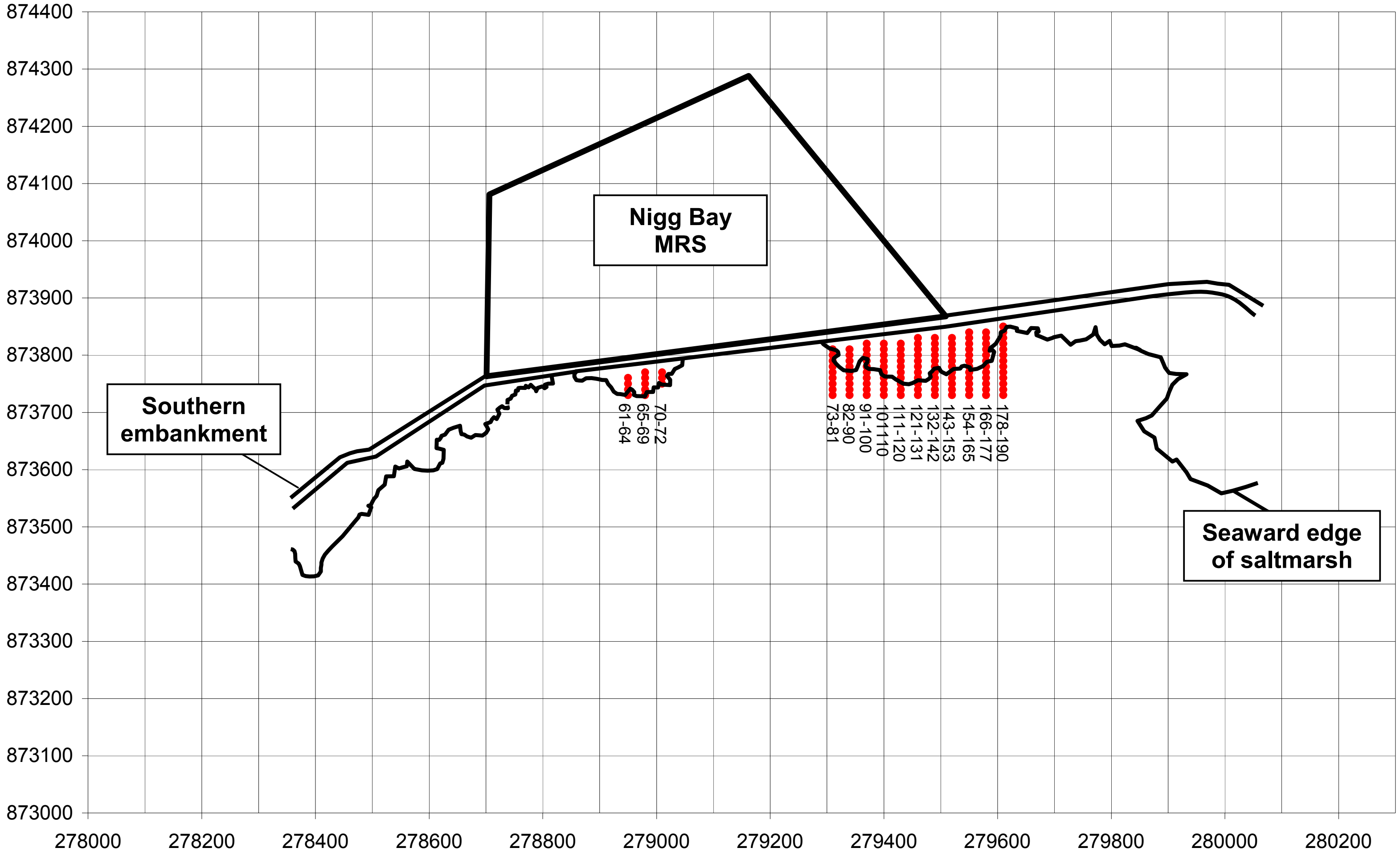


Figure 3.2: Location of vegetation quadrats on the reference saltmarsh adjacent to Nigg Bay Managed Realignment Site.

3.2.3 Elevation survey

In July 2006, elevation data were collected for the centre of each vegetation quadrat, both within the Nigg Bay MRS and on the reference saltmarsh, using differential GPS (Leica System 300 Dual Frequency Real-time Differential GPS). These data were used to determine the position of each quadrat relative to MHWS based on admiralty data for the Cromarty Firth.

3.2.4 Data analysis

3.2.4.1 Reference saltmarsh

Quadrats below 1.5 m OD (n = 19) were excluded from the analysis to enable direct comparison with Nigg Bay MRS. MAVIS (Smart 2000) was used to determine the NVC community (Rodwell 2000) for the saltmarsh as a whole and for each of three saltmarsh zones (Table 1.1). MAVIS computes the Czekanowski similarity coefficient for species frequency data by comparing the field data with published synoptic tables. In this study, 50% was used as the threshold for which a match was established, as a coefficient greater than 50% is considered to be an acceptable match (Grootjans *et al*. 1996). The sampling points were grouped into 0.1 m elevation bands and for each saltmarsh species, the proportion occurring in each elevation band was calculated for each year. Overall percentage coverage was also calculated for each saltmarsh species.

3.2.4.2 Nigg Bay Managed Realignment Site

The data for each year were analysed to determine the proportion of quadrats with greater than 50% dead vegetation and/or mud/bare ground. The species richness of: (i) herbs; (ii) grasses, rushes and sedges; and (iii) saltmarsh plants was calculated for Nigg Bay MRS as a whole and for the areas above and below MHWS. WinTWINS (Hill & Šmilauer 2005) was used to classify the quadrat data for each year into discrete groups for which NVC communities were derived using MAVIS. WinTWINS classifies species and samples, producing an ordered two-way table of their occurrence. The process of classification is hierarchical; samples are successively divided into categories, and species are then divided into categories on the basis of the sample classification. The quadrats were grouped into 0.1 m elevation bands and the proportion of each saltmarsh species occurring in each band was calculated for each year. Overall percentage coverage was calculated for each saltmarsh species. Wilcoxon's signed ranks tests, the nonparametric equivalent of a paired *t*-test, were used to compare percentage of cover of each saltmarsh species between pairs of years (S1-S2, S2-S3, S3-S4 and S1-S4). To reduce the chance of false positives (Type I statistical error) Bonferroni correction was used to adjust *P*.

3.3 Results

3.3.1 Botanical monitoring of the reference saltmarsh

Percentage abundance of the species recorded in each of the quadrats is presented in Appendix 3. Sea Arrowgrass *Triglochin maritima* was also present on the reference saltmarsh but was not recorded in any of the quadrats. The most likely NVC community derived by MAVIS was SM13b *Puccinellia maritima* saltmarsh community with a *Glaux maritima* sub-community (Table 3.2). The frequency of species varied across the three saltmarsh zones with all species except Sea Sandwort *Honkenya peploides* occurring in at least two of the saltmarsh zones. The abundance of species at each sampling point also varied across the three saltmarsh zones (Figure 3.3). Five species (Thrift *Armeria maritima* [83%], Sea Aster *Aster tripolium* [69%], Common Saltmarsh Grass *Puccinellia maritima* [66%], Glasswort *Salicornia sp*. [82%] and Annual Sea-blite *Suaeda maritima* [94%]) were most abundant in the middle saltmarsh zone while three species (Halberd-leaved Orache *Atriplex hastata* [85%], Sea-milkwort *Glaux maritima* [65%] and Sea Plantain *Plantago maritima* [60%]) were most abundant in the upper saltmarsh zone. *Salicornia sp.* (78%) abundance was greatest between 1.7 and 1.8 m OD while 85% of *Suaeda maritima* occurred between 2.0 and 2.1 m OD. Two species (Sea-purslane *Atriplex littoralis* and Common Scurvygrass *Cochlearia officinalis*) were relatively evenly distributed between the middle and upper saltmarsh zones. The density of Greater Sea-spurrey *Spergularia media* decreased with increasing elevation across the three saltmarsh zones.

Table 3.2: The frequency of saltmarsh species and the NVC community derived for each saltmarsh zone of the reference saltmarsh using MAVIS.

Type of species*	Lower (n = 11)	Middle (n = 29)	Upper (n = 50)	All (n = 91)
V		*Aster tripolium*		
IV	*Salicornia sp.*	*Cochlearia officinalis*	*Atriplex littoralis* *Aster tripolium* *Cochlearia officinalis* *Festuca rubra*	*Aster tripolium*
III	*Aster tripolium*	*Atriplex littoralis* *Festuca rubra* *Plantago maritima* *Puccinellia maritima*	*Plantago maritima*	*Atriplex littoralis* *Cochlearia officinalis* *Festuca rubra* *Plantago maritima*
II	*Puccinellia maritima*	*Glaux maritima* *Salicornia sp.*	*Glaux maritima* *Puccinellia maritima*	*Glaux maritima* *Puccinellia maritima*
I	*Atriplex littoralis* *Cochlearia officinalis* *Festuca rubra* *Glaux maritima* *Plantago maritima* *Suaeda maritima* *Spergularia media*	*Atriplex hastata* *Armeria maritima* *Elymus repens* *Suaeda maritima* *Spergularia media*	*Atriplex hastata* *Armeria maritima* *Elymus repens* *Honkenya peploides* *Suaeda maritima* *Spergularia media*	*Atriplex hastata* *Armeria maritima* *Elymus repens* *Honkenya peploides* *Suaeda maritima* *Spergularia media*
NVC community (Czekanowski similarity coefficient)	No match	SM13b (49.61)	SM13b (48.00)	SM13b (48.78)

* V = Community constant occurring in 81-100% of quadrats, IV = Community constant occurring in 61-80% of quadrats, III = Common or frequent species occurring in 41-60% of quadrats, II = Occasional species occurring in 21-40% of quadrats and I = Scarce species occurring in 1-20% of quadrats.

3.3.2 Botanical monitoring within Nigg Bay Managed Realignment Site

3.3.2.1 Vegetation cover

Prior to the re-establishment of tidal conditions, Meddat Marsh was used for rough-grazing and had been grazed by cattle in the summer months since at least 1968 (Babtie Group 2002). Grazing by cattle would have removed the more nutritious grasses and helped to maintain a heterogeneous sward. In the baseline survey (S0), all the quadrats sampled had 100% vegetation cover, comprised mainly of herbs and grasses (Appendix 4). Following the reintroduction of tidal conditions much of this vegetation cover was lost (Table 3.3), particularly from the areas of Nigg Bay MRS below MHWS.

Table 3.3: Percentage of quadrats within Nigg Bay Managed Realignment Site with greater than 50% dead vegetation and/or mud/bare.

Vegetation type	S0	S1	S2	S3	S4
All areas of site					
Dead vegetation	0	50	8	0	8
Mud/Bare	0	17	53	42	48
TOTAL:	0	67	61	42	56
Areas above MHWS					
Dead vegetation	0	17	11	0	28
Mud/Bare	0	0	0	6	0
TOTAL:	0	17	11	6	28
Areas below MHWS					
Dead vegetation	0	64	7	0	0
Mud	0	24	76	57	69
TOTAL:	0	88	83	57	69

3.3.2.2 Species richness

The baseline survey (S0) recorded plant richness in Meddat Marsh at 37 species, approximately 50% were herbs and the remaining 50% comprised grasses, rushes and sedges (Table 3.4). Two saltmarsh grasses (Creeping Bent *Agrostis stolonifera* and Couch *Elymus sp.*) were also recorded. In S1, species richness in Nigg Bay MRS declined to 25 species with most loss of species occurring from the areas below MHWS. Three saltmarsh species were recorded in the site for the first time. By S2 there had been no further substantial loss of terrestrial species and the number of saltmarsh species had increased to 11. By S4 the overall species richness had declined to 26 species as a result of the further loss of species from above MHWS.

Table 3.4: Species richness in Nigg Bay Managed Realignment Site.

Vegetation type	S0	S1	S2	S3	S4
All areas of site					
Herbs	18	12	11	11	8
Grasses, rushes and sedges	17	8	10	10	9
Saltmarsh plants	2	5	11	11	9
TOTAL:	37	25	32	32	26
Areas above MHWS					
Herbs	11	12	11	11	8
Grasses, rushes and sedges	8	8	10	10	9
Saltmarsh plants	2	2	2	4	6
TOTAL:	21	22	23	25	23
Areas below MHWS					
Herbs	14	2	0	0	0
Grasses, rushes and sedges	15	3	1	0	0
Saltmarsh plants	2	4	9	9	8
TOTAL:	31	9	10	9	8

3.3.2.3 NVC communities

The NVC communities inferred in Nigg Bay MRS are presented in Table 3.5. Prior to the reintroduction of tidal conditions, Meddat Marsh was classified as MG10 *Holcus lanatus - Juncus effusus* grassland with a similarity score of 52.24. When the sampling points were divided into two categories by WinTWINS, the two most likely communities were MG9 *Holcus lanatus - Deschampsia cespitosa grassland* and MG10. MG9, with a Czekanowski similarity coefficient of 44.52, occurred at 28 sites while

MG10, with a Czekanowski similarity coefficient of 60.34, occurred at 32 sites. Nine sampling points, located in the highest areas of the site (≥ 2.67 m OD) retained a mesotrophic grassland community throughout the course of the study. The NVC communities with the best match were MG10 and MG6 *Lolium perenne - Cynosurus cristatus* grassland. From S1, an increasing number of quadrats showed signs of developing saltmarsh but none of the specific communities derived by MAVIS was highly supported (i.e. Czekanowski similarity coefficient << 50%). The first sampling points inferred to be developing a saltmarsh community in S1 occurred at intermediate elevations in the site (1.98-2.48 m OD). Saltmarsh community development did not begin in the lowest areas of the site (≤ 1.73 m OD) until S3. MG11 *Festuca rubra - Agrostis stolonifera - Potentilla anserina* grassland occurred between 2.48 and 2.59 m OD in S3 and by S4 MG11 had expanded its range, although this community was not highly supported by MAVIS.

Table 3.5: NVC communities inferred in Nigg Bay Managed Realignment Site ordered by position in the tidal frame. Asterisks indicate communities with a Czekanowski similarity value greater than 50%. Quadrat numbers correspond with those in Figure 3.1. NVC names are coloured according to the type of community: mesotrophic grassland communities associated with poorly-drained permanent pastures, grass-dominated inundation communities and saltmarsh communities.

Quadrat	Elevation (m OD)	S0	S1	S2	S3	S4
5	2.87	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG6
14	2.85	MG9	MG10*	MG6* MG10*	MG10* MG6	MG6
4	2.80	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG6
6	2.79	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG6
13	2.76	MG10*	MG10*	MG6* MG10*	MG10* MG6	MG6
12	2.75	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG6
1	2.71	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG6
3	2.67	MG9	MG10*	MG6* MG10*	MG10* MG6	MG6
2	2.67	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG6
59	2.65	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG11
8	2.65	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG11
19	2.61	MG10*	MG10*	MG10	MG10* MG6	MG11
60	2.59	MG9	MG10 MG6	MG6* MG10*	MG11	MG11
11	2.56	MG10*	MG10 MG6	MG6* MG10*	MG11	MG11
22	2.51	MG9	MG10 MG6	MG6* MG10*	MG11	MG11
20	2.51	MG10*	MG10 MG6	MG10	MG11	MG11
15	2.48	MG10*	SM	MG10	MG11	MG11
58	2.47	MG9	MG10 MG6	MG6* MG10*	MG10* MG6	MG11
21	2.35	MG10*	SM	SM	SM	SM
25	2.35	MG10*	SM	SM	SM	SM
7	2.33	MG10*	SM	SM	SM	SM
10	2.28	MG9	—	—	SM	SM
26	2.22	MG9	—	SM	SM	SM
44	2.19	MG10*	—	SM	SM	SM
43	2.18	MG10*	—	—	SM	SM
49	2.18	MG10*	SM	SM	SM	SM
55	2.17	MG9	—	—	SM	SM
56	2.16	MG10*	—	—	SM	SM
17	2.15	MG9	—	SM	SM	SM
57	2.11	MG9	—	—	SM	SM
50	2.10	MG9	—	SM	SM	SM
51	2.08	MG10*	—	—	SM	SM
9	2.04	MG10*	SM	SM	SM	SM
45	2.03	MG10*	—	—	SM	SM
37	2.02	MG10*	—	—	SM	SM
48	2.02	MG10*	SM	—	SM	SM
54	2.00	MG10*	SM	SM	SM	SM
52	1.99	MG10*	—	SM	SM	SM
42	1.98	MG10*	SM	SM	SM	SM
38	1.94	MG10*	—	—	SM	SM
23	1.92	MG10*	—	SM	SM	SM
53	1.90	MG10*	—	—	SM	SM
31	1.87	MG10*	—	SM	SM	SM
35	1.85	MG9	—	—	SM	SM
18	1.80	MG9	—	—	SM	SM
47	1.78	MG9	—	—	SM	SM
39	1.75	MG10*	—	SM	SM	SM
40	1.73	MG9	—	—	SM	SM
32	1.71	MG9	—	—	SM	SM
36	1.71	MG9	—	—	SM	SM
46	1.71	MG9	—	—	SM	SM
30	1.70	MG10*	—	—	—	SM
41	1.64	MG10*	—	—	SM	SM
27	1.64	MG10*	—	—	SM	SM
24	1.63	MG10*	—	—	SM	SM
29	1.62	MG9	—	—	SM	SM
16	1.60	MG10*	—	—	SM	—
28	1.60	MG9	—	—	—	SM
34	1.57	MG10*	—	—	—	—
33	1.54	MG10*	—	—	SM	SM

3.3.2.4 Colonisation of saltmarsh species in relation to elevation in the tidal frame

Eleven saltmarsh species were recorded in Nigg Bay MRS between S1 and S4. Only two species (*Aster tripolium* and *Plantago maritima*) were recorded in every survey following the reintroduction of tidal conditions (Figure 3.3). Five species (*Atriplex littoralis*, *Puccinellia maritima*, *Salicornia sp.*, *Spergularia media* and *Suaeda maritima*) were recorded in all but the first survey and four species (*Armeria maritima*, *Atriplex hastate*, *Cochlearia officinalis* and *Glaux maritima*) were only recorded in a single survey. When they were first recorded in the site, the lowest elevation at which eight of the species occurred was 1.9-2.0 m OD. The four exceptions were *Armeria maritima* which colonised above 2.2 m OD, *Atriplex hastate* which colonised above 1.8 m OD, *Glaux maritima* which colonised above 2.3 m OD and *Puccinellia maritima* which colonised above 1.7 m OD. When they first colonised the site *Aster tripolium*, *Cochlearia officinalis*, *Glaux maritima* and *Plantago maritima* occurred exclusively within a 0.1 m elevation range, 1.9-2.0 m OD for all except *Glaux maritima* which colonised at 2.3-2.4 m OD, however, *Glaux maritima* and *Plantago maritima* only occurred at a single site. Other colonists occurred over wider elevation ranges, the widest being 1.0 m (1.9-2.9 m OD) for *Festuca rubra* and 0.7 m (1.7-2.4 m OD) for *Puccinellia maritima*. Over the course of the study, most species present in more than one survey expanded their elevation ranges. For three species (*Festuca rubra*, *Plantago maritima* and *Suaeda maritima*), the range over which the species occurred declined between one survey and another. By S4, *Aster tripolium* (60%), *Plantago maritima* (100%), *Puccinellia maritima* (68%), *Salicornia sp.* (70%) and *Suaeda maritima* (65%) were more abundant in the middle saltmarsh zone while *Atriplex littoralis* (75%), *Spergularia media* (76%) and *Festuca rubra* (93%) were more abundant in the upper saltmarsh zone.

The percentage cover of *Aster tripolium*, *Atriplex littoralis*, *Puccinellia maritima*, *Salicornia sp*. and *Suaeda maritima* in Nigg Bay MRS increased significantly over the course of the study (Tables 3.5 and 3.6). For *Atriplex littoralis*, *Puccinellia maritima* and *Salicornia sp*. coverage increased significantly between S3 and S4.

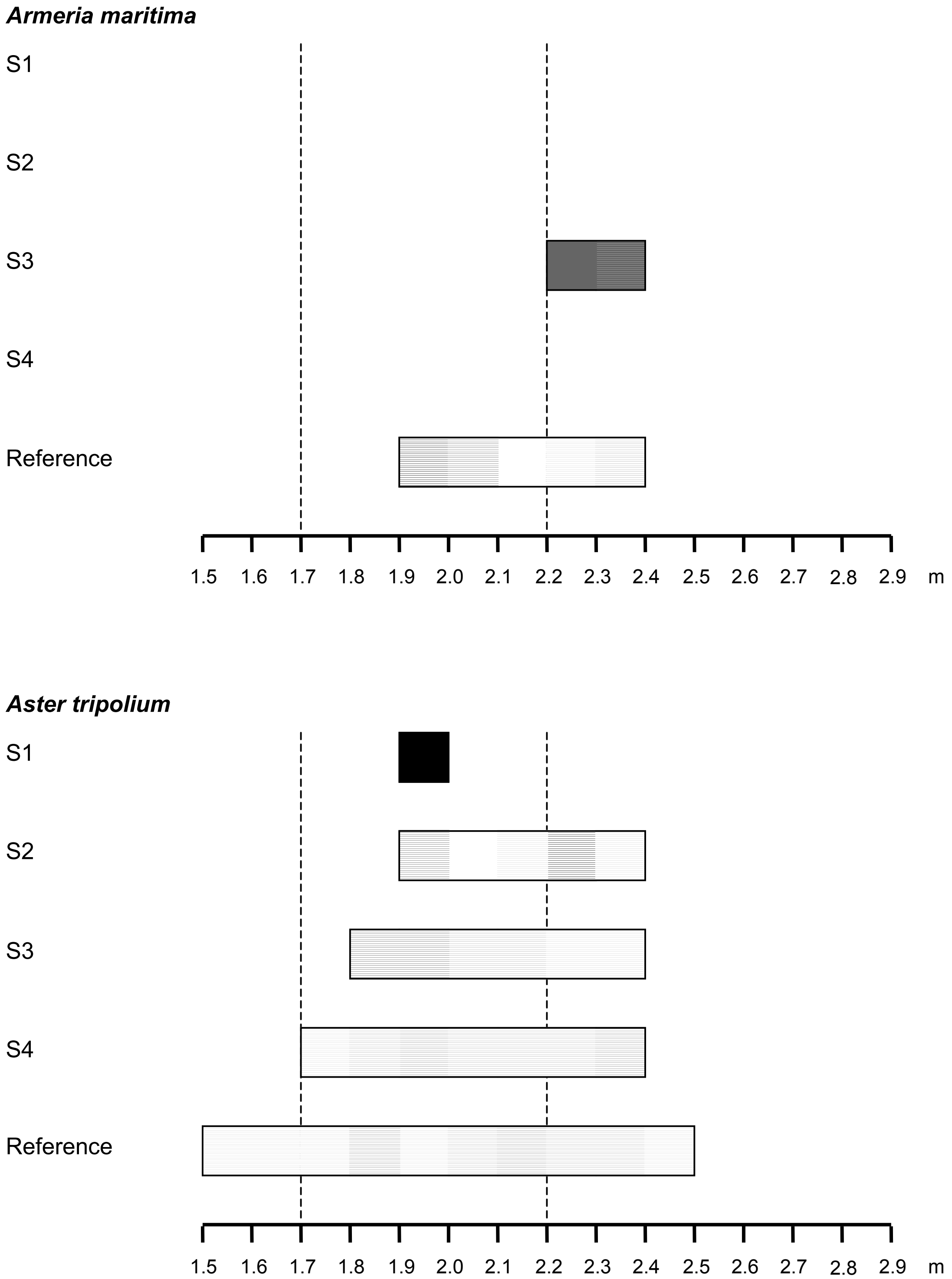
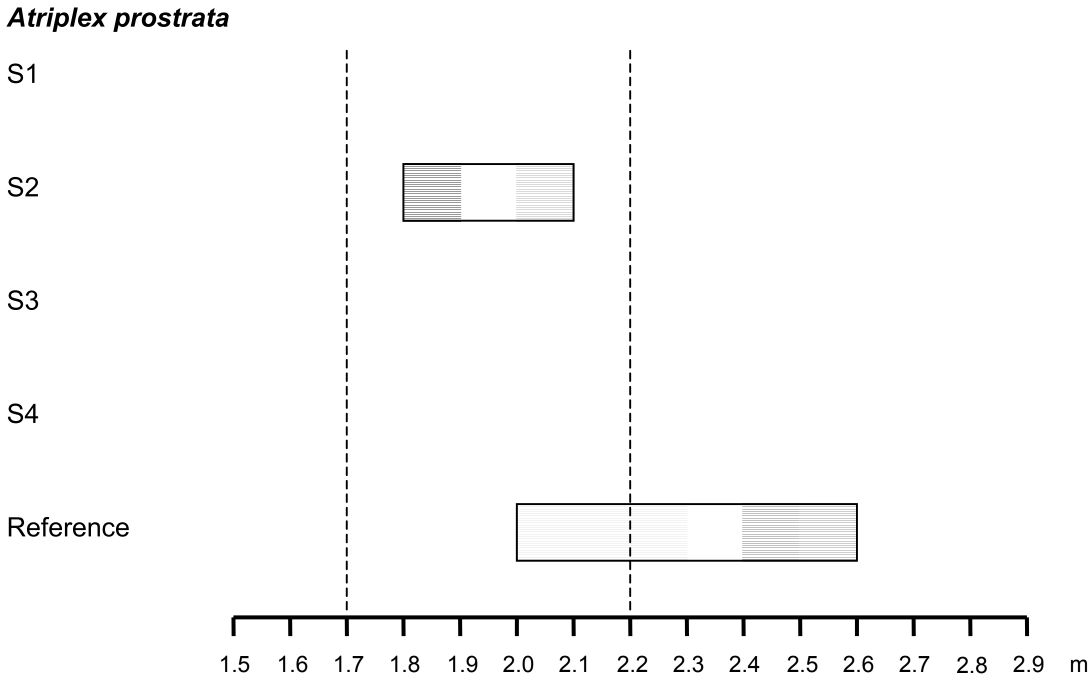
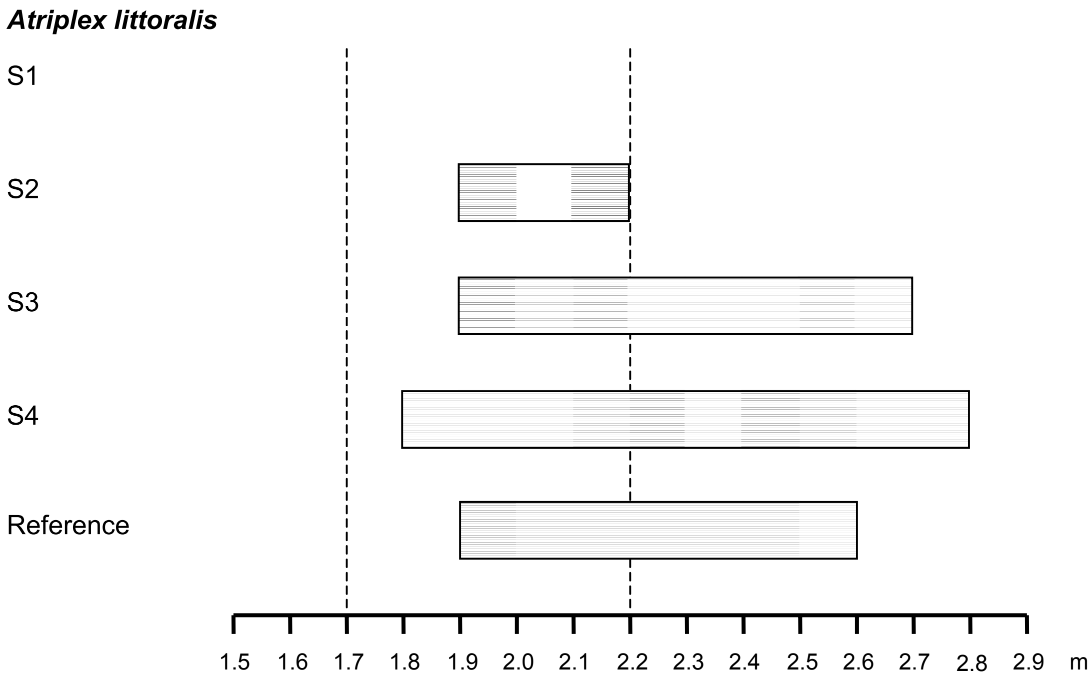


Figure 3.3: The distribution of saltmarsh species with elevation in the tidal frame in Nigg Bay Managed Realignment Site from S1-S4 and on the reference saltmarsh in S4. The dashed lines separate the lower, middle and upper saltmarsh zones. The length of the boxes indicates the elevation range occupied by each species and the shading indicates the proportion of each species found in each elevation category (0 % ▭, 0-10 % ▭, 10-20 % ▭, 20-30 % ▭, 30-40 % ▭, 40-50 % ▭ , 50-60 % ▭, 60-70 % ▭, 70-80 % ▭, 80-90 % ▭and 90-100 % ▭).





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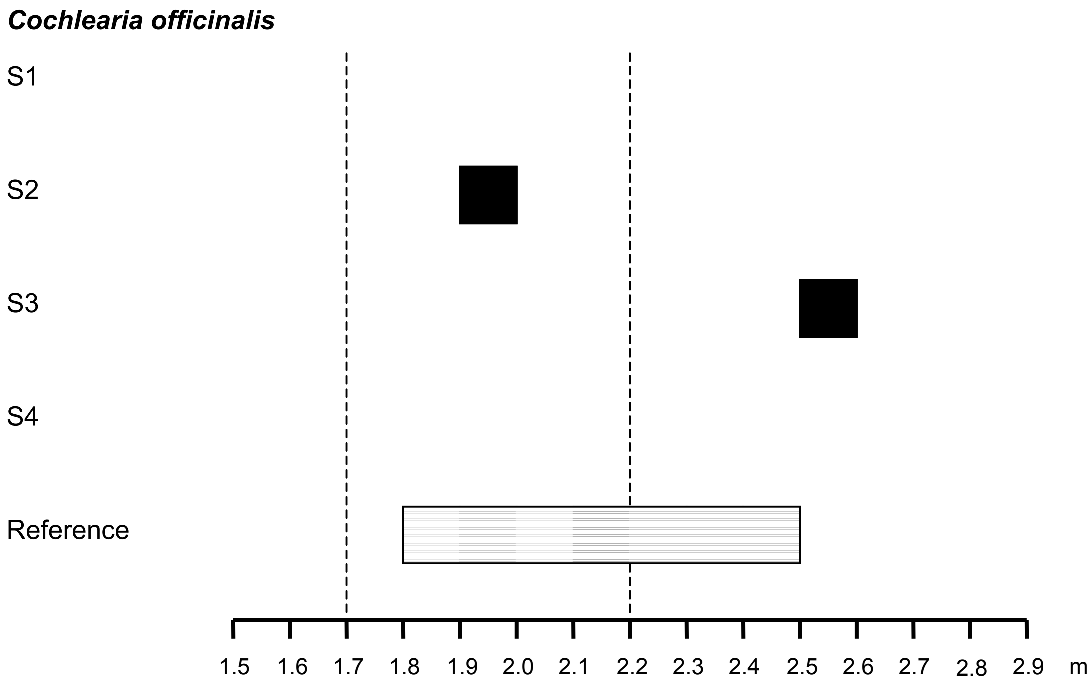


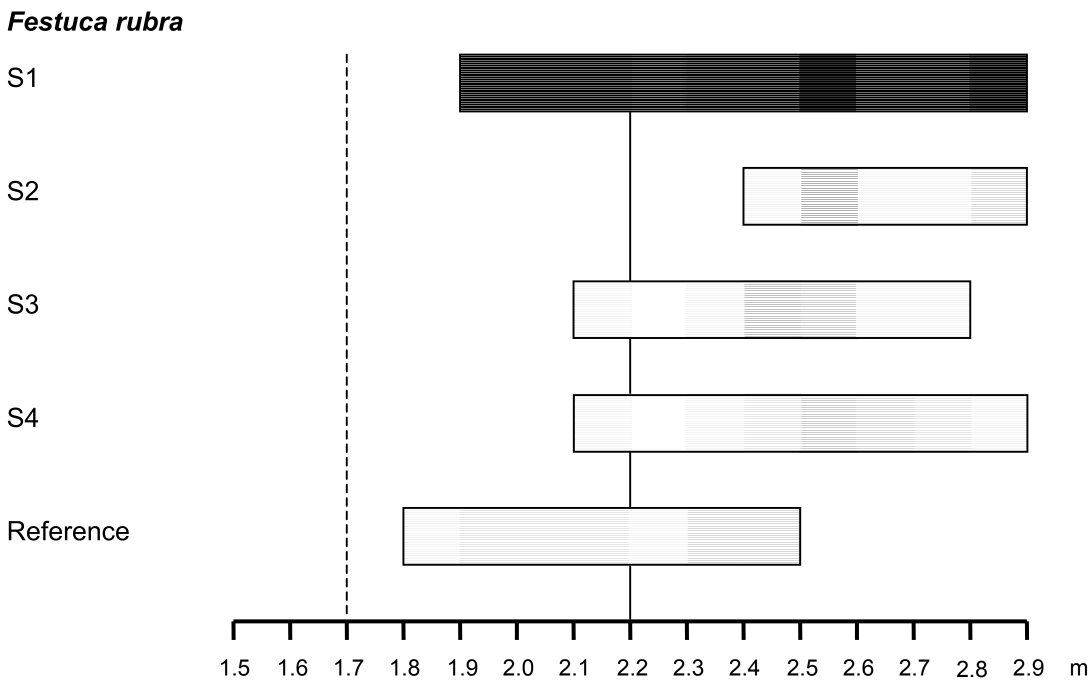
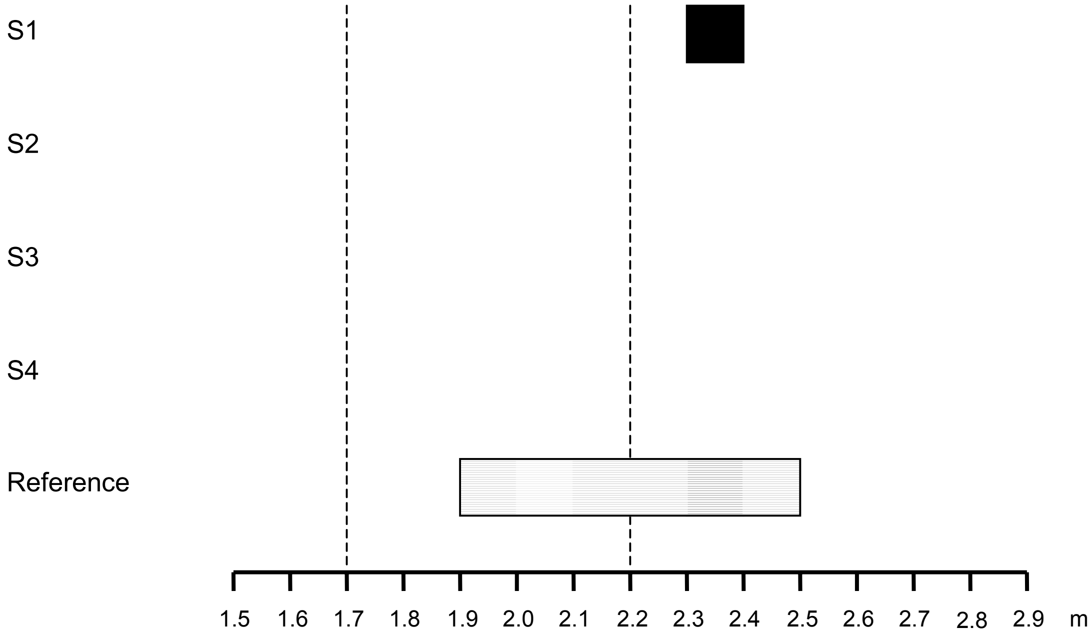


Figure 3.3 continued.

Glaux maritima



Plantago maritima

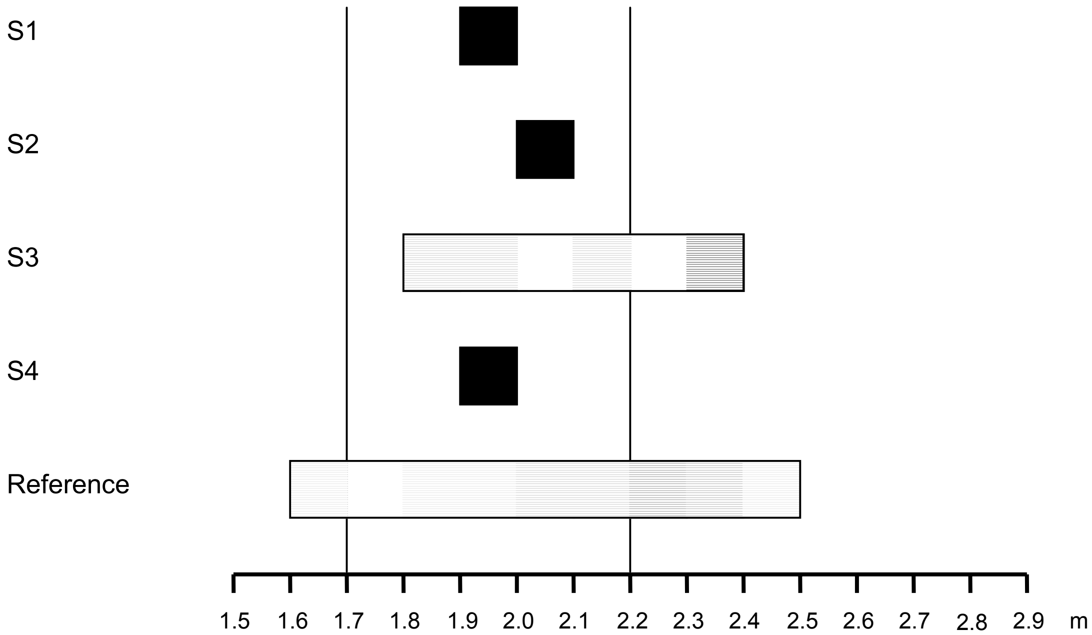
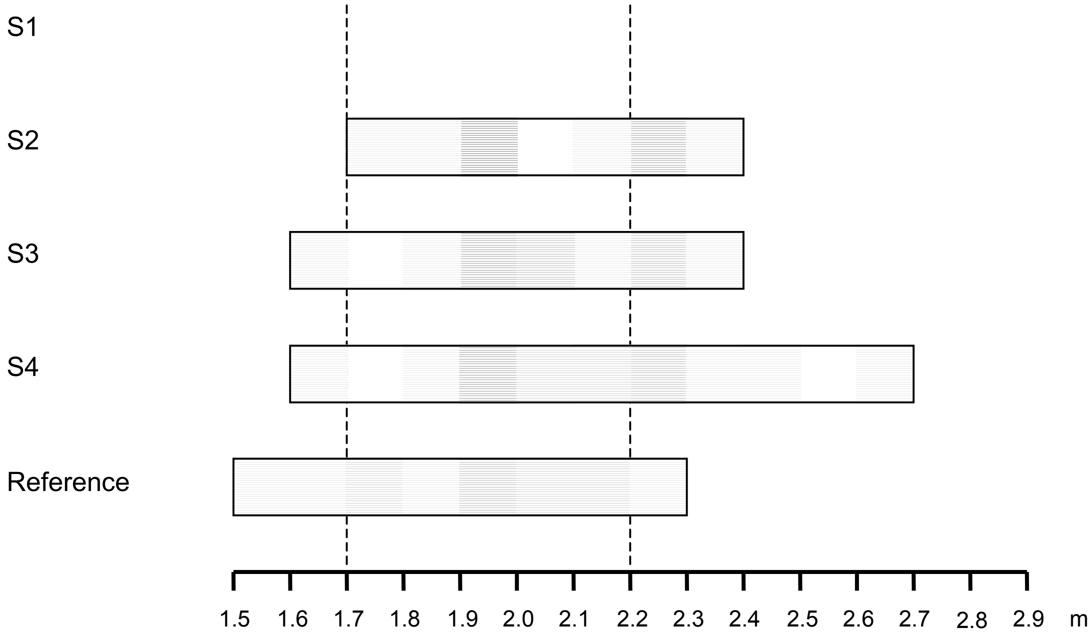


Figure 3.3 continued.

Puccinellia maritima



Salicornia sp.

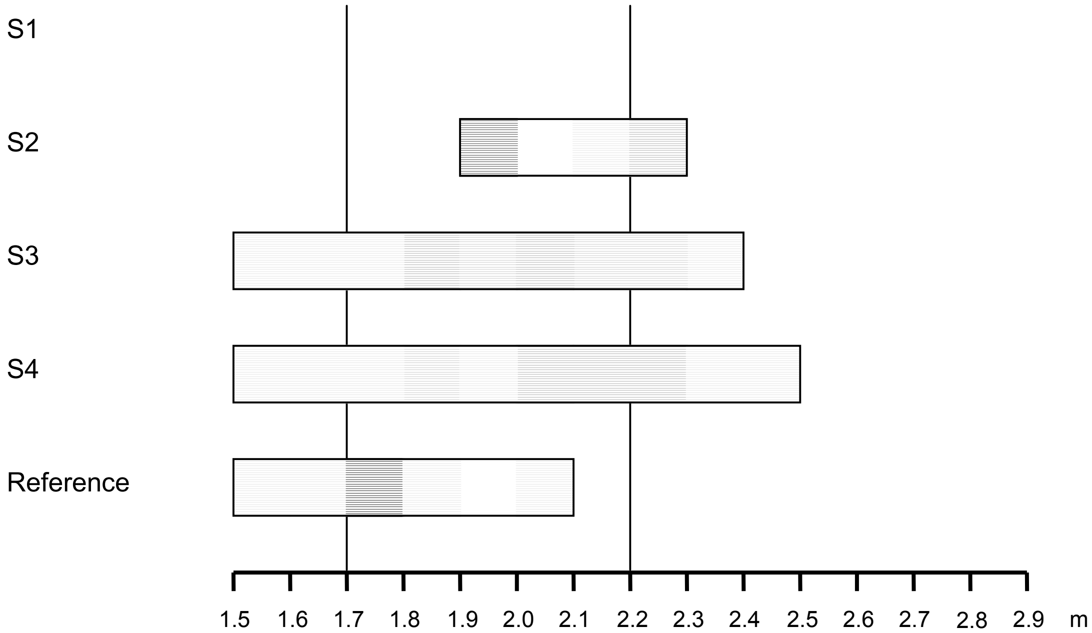
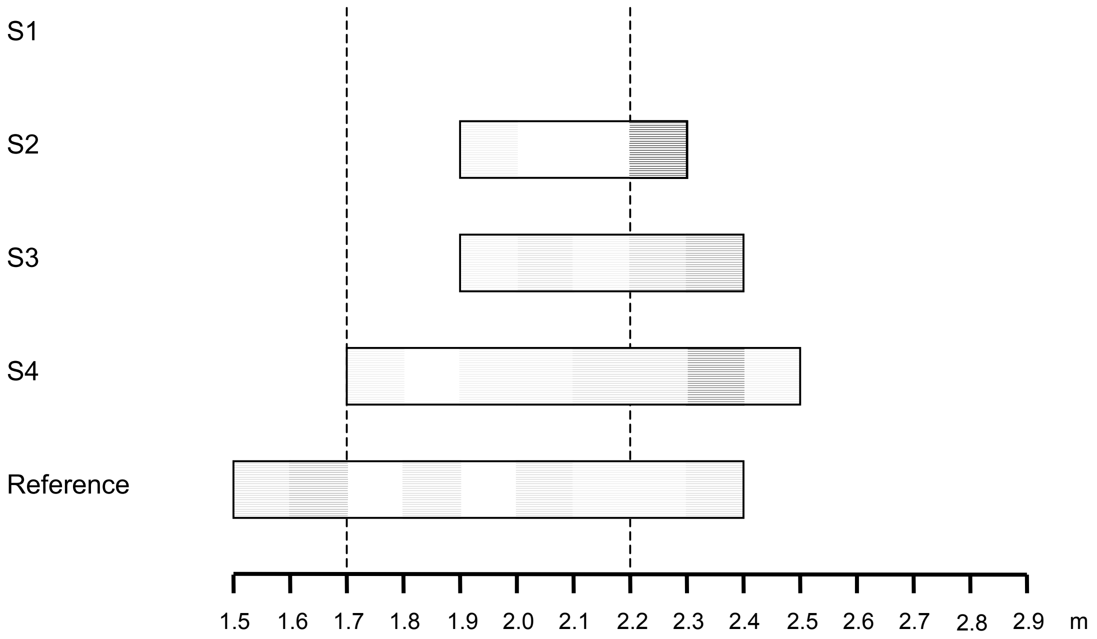


Figure 3.3 continued.

Spergularia media



Suaeda maritima

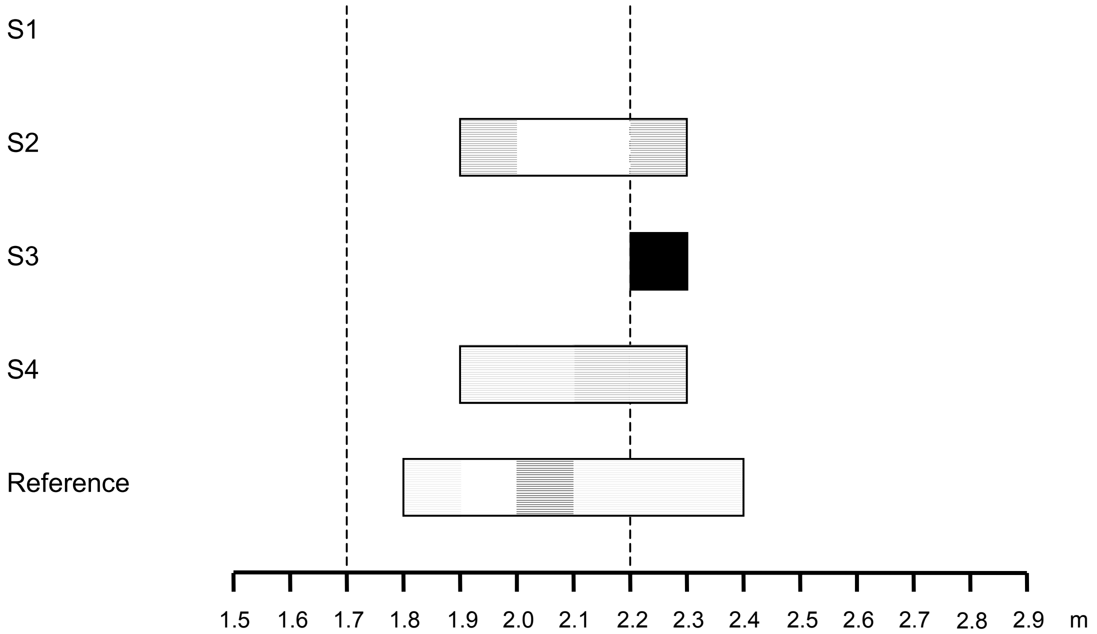


Figure 3.3 continued.

Table 3.5: Percentage cover of saltmarsh species within Nigg Bay Managed Realignment Site in the four summers following the re-establishment of tidal conditions in Meddat Marsh and on the reference saltmarsh in S4. Data are presented as means with 95% confidence levels.

Species	Reference	S1	S2	S3	S4
Armeria maritima	0.07 ± 0.07	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Aster tripolium	6.59 ± 2.49	0.0 ± 0.0	0.2 ± 0.3	0.7 ± 0.5	1.4 ± 0.8
Atriplex littoralis	6.93 ± 3.05	0.0 ± 0.0	0.1 ± 0.1	1.2 ± 0.7	0.5 ± 0.2
Atriplex prostrata	0.12 ± 0.10	0.0 ± 0.0	0.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Cochlearia officinalis	5.59 ± 2.05	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0
Festuca rubra	26.04 ± 5.95	1.9 ± 2.3	2.6 ± 2.7	2.7 ± 2.2	6.7 ± 3.7
Glaux maritima	7.70 ± 3.38	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Plantago maritima	9.88 ± 3.60	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.1 ± 0.1
Puccinellia maritima	12.24 ± 5.06	0.0 ± 0.0	0.4 ± 0.3	4.9 ± 2.9	10.4 ± 5.7
Salicornia sp.	0.54 ± 0.68	0.0 ± 0.0	0.1 ± 0.1	6.8 ± 3.4	7.6 ± 3.4
Spergularia media	0.26 ± 0.17	0.0 ± 0.0	0.1 ± 0.2	0.5 ± 0.4	1.0 ± 1.0
Suaeda maritima	0.73 ± 1.12	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.4 ± 0.2

Table 3.6: Between-year comparisons of vegetation cover in Nigg Bay Managed Realignment Site were made by performing Wilcoxon's signed ranks test on all quadrats. Changes significant at the 95% confidence level are indicated in bold.

Species	S1–S2		S2–S3		S3–S4		S1–S4	
	Z	*P*	*Z*	*P*	*Z*	*P*	*Z*	*P*
Armeria maritima	0.00	>0.05	-1.41	>0.05	-1.41	>0.05	0.00	>0.05
Aster tripolium	-1.83	>0.05	-2.20	**<0.05**	-3.02	**<0.05**	-4.02	**<0.05***
Atriplex littoralis	-1.34	>0.05	-3.74	**<0.05***	-1.27	>0.05	-4.16	**<0.05***
Atriplex prostrata	-1.34	>0.05	-1.34	>0.05	0.00	>0.05	0.00	>0.05
Cochlearia officinalis	-1.34	>0.05	0.00	>0.05	-1.00	>0.05	0.00	>0.05
Festuca rubra	-1.26	>0.05	-0.50	>0.05	-2.72	**<0.05**	-3.02	**<0.05**
Glaux maritima								
Plantago maritima	-0.45	>0.05	-1.63	>0.05	-1.29	>0.05	-1.34	>0.05
Puccinellia maritima	-2.95	**<0.05**	-3.97	**<0.05***	-2.63	**<0.05**	-4.46	**<0.05***
Salicornia sp.	-2.04	**<0.05**	-5.17	**<0.05***	-0.78	>0.05	-4.16	**<0.05***
Spergularia media	-1.34	>0.05	-1.85	>0.05	-0.20	>0.05	-3.17	**<0.05**
Suaeda maritima	-1.83	>0.05	-1.36	>0.05	-3.08	**<0.05**	-3.20	**<0.05***

* Asterisks indicate statistically significant differences ($P < 0.05$) when a Bonferroni correction is applied to adjust for multiple testing.

3.3.3 Comparison between the developing saltmarsh in Nigg Bay Managed Realignment Site and the reference saltmarsh

Of the eight species recorded in the surveys of both Nigg Bay MRS and the reference saltmarsh in S4, *Salicornia sp*. was the only species which had significantly greater coverage in Nigg Bay MRS than on the reference saltmarsh while four species (*Aster tripolium, Atriplex littoralis, Festuca rubra* and *Plantago maritima*) had significantly greater coverage on the reference saltmarsh than in Nigg Bay MRS. Three species (*Puccinellia maritima*, *Spergularia media* and *Suaeda maritima*) showed no significant differences in their coverage between Nigg Bay MRS and the reference saltmarsh (Table 3.5 and 3.7). The elevation ranges occupied by each species differed between Nigg Bay MRS and the reference saltmarsh.

Table 3.7: Comparisons of vegetation cover in Nigg Bay Managed Realignment Site and on the reference saltmarsh were made by performing a Mann-Whitney U test on all quadrats. Changes significant at the 95% confidence level are indicated in bold.

Species	U	*P*
Armeria maritima	2580.00	>0.05
Aster tripolium	1680.00	**<0.05***
Atriplex littoralis	1871.00	**<0.05***
Atriplex prostrata	2490.00	**<0.05**
Cochlearia officinalis	1200.00	**<0.05***
Festuca rubra	1616.50	**<0.05***
Glaux maritima		
Plantago maritima	1431.00	**<0.05***
Puccinellia maritima	2551.00	>0.05
Salicornia sp.	1215.00	**<0.05***
Spergularia media	2464.00	>0.05
Suaeda maritima	2427.00	>0.05

* Asterisks indicate statistically significant differences ($P < 0.05$) when a Bonferroni correction is applied to adjust for multiple testing.

3.3.4 Comparison between the colonisation of Nigg Bay Managed Realignment Site and the colonisation of other UK managed realignment sites

Table 3.8 collates the available data for several UK managed realignment sites.

Table 3.8: Saltmarsh species richness and presence/absence of species (common to Nigg Bay and Nigg Bay Managed Realignment Site) recorded at other UK managed realignment sites and on their respective reference saltmarshes. Stars indicate species that were present but were not recorded in the quadrats.

Managed realignment site	Survey	*Armeria maritima*	*Agrostis stolonifera*	*Aster tripolium*	*Atriplex prostrata*	*Atriplex littoralis*	*Cochlearia officinalis*	*Elymus sp.*	*Festuca rubra*	*Glaux maritima*	*Plantago maritima*	*Puccinellia maritima*	*Salicornia sp.*	*Spergularia media*	*Suaeda maritima*	*Triglochin maritima*	N
Nigg Bay	Reference	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	★	14
	Baseline	-	✓	-	-	-	-	✓	-	-	-	-	-	-	-	-	2
	1 2003	-	✓	✓	-	-	-	★	✓	✓	✓	-	★	-	-	-	7
	2 2004	-	✓	✓	✓	✓	✓	★	✓	-	✓	✓	✓	✓	✓	-	12
	3 2005	✓	✓	✓	★	✓	-	★	✓	-	✓	✓	✓	✓	✓	-	12
	4 2006	-	✓	✓	★	✓	-	★	✓	★	✓	✓	✓	✓	✓	-	12
Abbots	Reference																
Hall[1]	Baseline																
	1 Oct 1996	-	✓	-	✓	-	-	✓	-	-	-	✓	-	-	✓		5
	2 Aug 1997	-	✓	-	✓	✓	-	✓	-	-	-	✓	✓	-	✓		12
Havergate	Reference	-	-	✓	-	✓	-	-	-	-	-	✓	-	✓	✓	✓	10
Island[2]	Baseline	-	✓	-	✓	-	✓	✓	✓	-	-	-	✓		✓	-	
	1 2001	-	-	-	✓	-	-	✓	-	-	-	-	✓	-	✓	-	5
	2 2002	-	-	-	-	-	-	✓	-	-	-	-	✓	-	✓	-	4
	3 2003	-	-	-	-	-	-	✓	-	-	-	-	✓	-	✓	-	4
	4 2004	-	-	-	-	-	-	✓	-	-	-	-	✓	-	✓	-	5
Northey	Reference																
Island[3]	Baseline	-	✓	-	-	-	-	-	✓	-	-	-	-	-	-	-	2
	1 Jun/Jul 1992	-	✓	✓	✓	✓	-	✓	✓	-	-	✓	✓	-	✓	-	15
	2 Jun 1993	-	✓	✓	✓	✓	-	✓	✓	-	-	✓	✓	✓	✓	-	20
	3 Jul 1994	✓	✓	✓	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓	-	23
Orplands[1]	Reference																
	Baseline																
	1 Aug 1996	-	✓	-	✓	✓	-	✓	-	-	-	-	✓	✓	✓		10
	2 Aug 1997	-	✓	-	✓	✓	-	✓	-	-	-	✓	✓	✓	✓		11
Paull	Reference	-	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	-	✓	-	✓	
Holme	Baseline																
Strays[4]	1 July 2004	-	✓	✓	✓	✓	-	✓	✓	-	✓	✓	-	✓	-	-	
Saltram[1]	Reference																
	Baseline																
	1 1995	-	✓	✓	✓	-	-	✓	-	-	-	-	-	-	-	-	
	2 1996	-	✓	✓	✓	-	✓	✓	✓	-	-	-	-	-	-	✓	
	3 1997	-	✓	✓	✓	✓	✓	✓	✓	-	-	✓	✓	-	-	✓	
Tollesbury[5]	Reference	-		✓		✓	✓	✓		-	-	✓	✓		✓	✓	
	Baseline	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	1 1996	-		-	-	-	-	-		-	-	-	✓	-	-		1
	2 1997	-		-	-	-	-	-		-	-	-	✓	-	✓		4
	3 1998	-		✓	-	✓	-	-		-	-	✓	✓	-	✓		9
	4 1999	-		✓	-	✓	✓	-		-	-	✓	✓		✓		10
	5 2000	-		✓	-	✓	-	-		-	-	✓	✓	✓	✓		11
	6 2001	-		✓	✓	✓	-	✓		-	-	✓	✓	✓	✓		14

1 Diack (1998), 2 RSPB unpublished data, 3 Dagley (1995), 4 Brown & Garbutt (2004) and 5 Garbutt *et al*. (2006)

Most saltmarsh species in Nigg Bay MRS have colonised at lower elevations than at other UK sites (Figure 3.4).

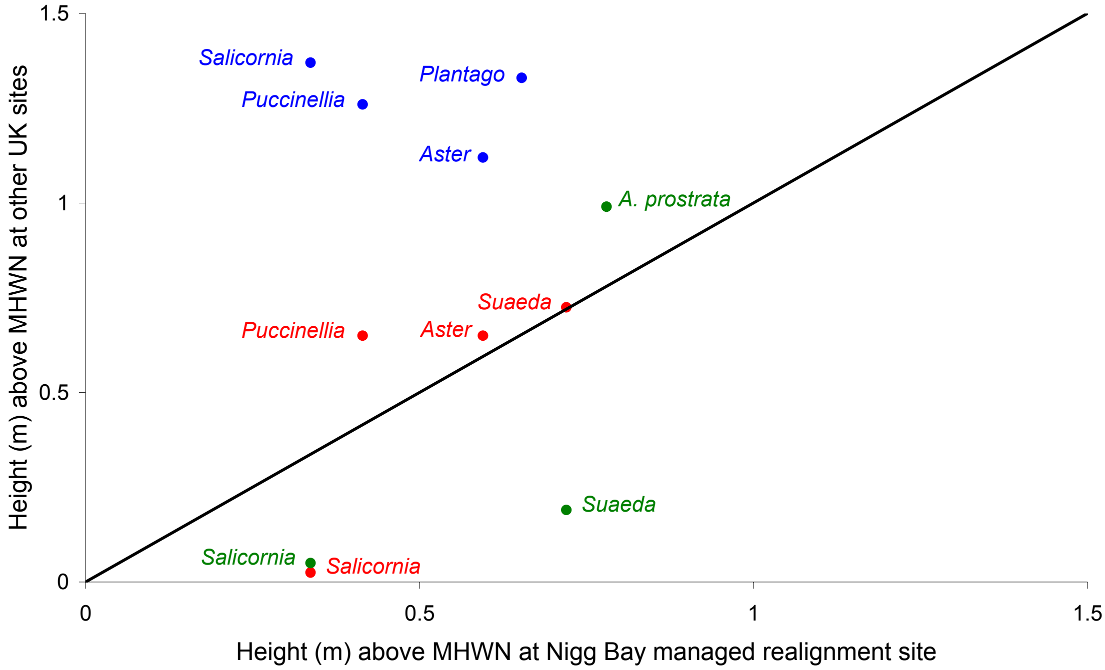


Figure 3.4: Lower elevation limits relative to MHWN of saltmarsh species within Nigg Bay Managed Realignment Site and other UK managed realignment sites: Havergate Island (Green), Paull Holme Strays (Blue) and Tollesbury (Red). Data were sourced from the available surveys detailed in Table 3.8. For each site, the lower elevation limits relative to MHWN were the lowest recorded in any post-breach survey.

3.4 Discussion

3.4.1 Reference saltmarsh

The reference saltmarsh adjacent to Nigg Bay MRS was classified as SM13b *Puccinellia maritima* saltmarsh community. This is the most widespread and extensive perennial community of the lower saltmarsh in the UK (Rodwell 2000) and might be expected to develop in the Nigg Bay MRS. The reference saltmarsh was species poor, which can be explained by its northerly position in the UK, since there is a progressive loss of species richness with increasing latitude (Rodwell 2000).

3.4.2 Botanical development within Nigg Bay Managed Realignment Site

3.4.2.1 Effect of breaching on pre-existing communities

Following the reintroduction of tidal conditions, much of the existing vegetation in Nigg Bay MRS died. The greatest loss occurred below MHWS where 88% of quadrats had more than 50% dead vegetation, mud or bare ground in S1. Of the species that were either constant or common species in the pre-breach communities (Common Bent *Agrostis capillaris*, Creeping Bent *Agrostis stolonifera*, Common Sedge *Carex nigra*, Yorkshire Fog *Holcus lanatus*, Soft Rush *Juncus effusus*, Meadow Buttercup *Ranunculs acris* and White Clover *Trifolium repens*) all except *Agrostis stolonifera* had an Ellenberg salinity value of zero (Hill *et al*. 1999) indicating that they were salt intolerant. The areas above MHWS, which were inundated relatively infrequently, remained largely unchanged throughout the course of the study. These areas continue to be grazed by cattle in the summer months to create a sward suitable for breeding waders, such as Common Redshank (Norris *et al*. 1997).

3.4.2.2 Colonisation by saltmarsh species

Colonisation of Nigg Bay MRS by saltmarsh species may have occurred through several routes: (i) via germination of seeds from the soil seed bank (Thompson *et al*. 1997), (ii) via dispersal of seeds and/or plant propagules by waterbirds through both endozoochory and ectozoochory (Figuerola & Green 2002; Sanchez *et al*. 2006) and (iii) via dispersal of seeds and/or plant propagules by wind and water (Huiskes *et al*. 1995).

As Nigg Bay MRS had not been intensively farmed prior to the reintroduction of tidal conditions (Section 2.5.3), it may have been expected to have retained a viable seed bank from which seeds would germinate when conditions were suitable. However, the reintroduction of tidal conditions apparently did not trigger a rapid response from the soil seed bank as species richness and coverage was low in S1. Germination from the seed bank may have been delayed by the presence of a smothering layer of dead vegetation and/or exceptionally warm/dry conditions. The soil seed bank may no longer have been viable due to the relatively long period since the site was reclaimed from the sea as the majority of saltmarsh species do not form a long-term persistent seed bank (Thompson *et al*. 1997; Wolters & Bakker 2002). At Freiston Shore Managed Realignment Site, Lincolnshire, for example, most saltmarsh species were absent from the soil seed bank within 30 years of the land being reclaimed (Wolters & Garbutt 2006).

Colonisation by wind-, tide- and waterbird-mediated dispersal would have been expected to have an associated lag between the breaching of the embankment and germination of seeds. Peak dispersal of diaspores occurs between September and December (Wolters *et al*. 2005) so there would have been limited opportunity for saltmarsh species to colonise Nigg Bay MRS prior to the survey being undertaken in September.

The increase in distribution of a given species within and between years may be explained by vegetative growth, successive opportunities for dispersal of seeds and propagules from the adjacent saltmarsh and, increasingly, by dispersal of seeds and propagules from newly established plants within Nigg Bay MRS. The percentage cover of *Aster tripolium*, *Atriplex littoralis*, *Puccinellia maritima*, *Salicornia sp*. and *Suaeda* *maritima* in Nigg Bay MRS increased significantly over the course of the study, which suggests that they were highly effective colonisers.

The saltmarsh species that colonised in S1 occurred at intermediate elevations in the site (1.98-2.48 m OD); where rapid die back, following the re-establishment of tidal conditions opened up the area for colonisation. Competition from terrestrial species is likely to have prevented species colonising at higher elevations. Saltmarsh development progressed towards lower elevations during the course of the study. In south-east England, Common Ragworm *Nereis diversicolor* has been found to limit plant colonisation at lower elevations (Paramor & Hughes 2004), however as this species was only present at relatively low densities in Nigg Bay MRS (Chapter 4), it is unlikely to have been a limiting factor. The higher level of disturbance, due to more frequent inundation, is more likely to have prevented plants from becoming established. Sediment accretion over the course of the study may have increased the elevation creating suitable conditions for colonisation. Unlike classic saltmarsh succession (Section 1.1.2), where mid- and late-successional species cannot colonise until sediment accretion has occurred, in Nigg Bay MRS these species were able to colonise early where elevation relative to the tidal frame was suitable. The presence of dead vegetation, particularly *Juncus effusus* may also have helped stabilise the sediment and create a suitable substrate for the colonising species. By the S3 and S4 surveys the areas of Nigg Bay MRS above MHWS were showing signs of changing from terrestrial communities towards more maritime communities since MG11 *Festuca rubra* - *Agrostis stolonifera* - *Potentilla anserina* grassland is an inundation community.

3.4.3 Comparison between the developing saltmarsh in Nigg Bay Managed Realignment Site and the reference saltmarsh

Prior to the reintroduction of tidal conditions to Meddat Marsh, the vegetation was still in transition from the saltmarsh that existed before reclamation, making assignment of NVC communities difficult (McHaffie 2002). As it can take more than 80 years for saltmarsh to establish fully (Smart 2005), it is not surprising that four summers on from the re-establishment of tidal conditions, the climax community present on the reference saltmarsh was absent from Nigg Bay MRS. Differences in elevation range, exposure and substrate between the Nigg Bay MRS and the reference saltmarsh will also explain differences in the vegetation.

The relatively high lower elevation limits of several species in Nigg Bay MRS compared with the reference saltmarsh may be explained by a number of factors. Poorly-drained sediments affect the establishment of saltmarsh species (Crooks *et al*. 2002). The finer sediments that have accumulated in the site since it was breached (Chapter 4) are likely to be less well-drained than the sandier sediments of Nigg Bay. The narrow breach gaps also appear to restrict the flow of ebb tide from the site so that there is a period when there is standing water in the lowest parts of the site after the tide has left (pers. obs.).

The highest areas of Nigg Bay MRS extend to over 2.9 m OD whereas the presence of the embankment has limited the highest elevation of the reference saltmarsh to about 2.5 m OD. As a result, the upper elevation limits of several species in Nigg Bay MRS were higher than on the reference saltmarsh.

The higher coverage of *Salicornia sp*. in Nigg Bay MRS compared to the reference saltmarsh may be explained by the high availability of unoccupied space and the absence of, or reduced, competition from other species. Wolters *et al*. (2006) found that *Salicornia sp*. was one of the first species to form a seedbank following de-embankment which may explain why this species was thriving in the site. Pioneer species such as *Salicornia* have been out-competed on the reference saltmarsh. Two species, *Armeria maritima* and *Atriplex prostrata* which were absent from the quadrats in Nigg Bay MRS were also uncommon on the reference saltmarsh, suggesting local conditions did not favour these species.

3.4.4 Comparison between the colonisation of Nigg Bay Managed Realignment Site and the colonisation of other UK managed realignment sites

A paucity of published studies on colonisation of UK managed realignment sites makes comparisons between sites difficult.

When comparing data for the first post-breach survey for different managed realignment sites it is important to consider the effect that the timing of breaching may have had on colonisation. Sites breached before September will experience peak diaspore dispersal in the same year (Wolters *et al*. 2005), whereas sites breached after September, may experience limited colonisation until the peak dispersal period the following year.

The species composition of a newly created managed realignment site is dependent on the composition of the adjacent saltmarsh (French 2006). As species composition of saltmarsh varies both locally and regionally, comparisons between managed realignment sites, particularly in different regions, are difficult to make. *Aster tripolium*, *Atriplex prostrata*, *Atriplex littoralis*, *Elymus sp*., *Salicornia sp*. *Spergularia* *media* and *Suaeda maritima* were present on many of the managed realignment sites within the first few years, however, suggesting that they are highly effective colonisers.

The peak number of species relative to nearby communities is likely to be reached sooner in a managed realignment if the adjacent saltmarsh is species poor. In general, the abundance of any one species is likely to be lower on a species-rich saltmarsh compared to a species-poor saltmarsh so the chance of any one species colonising the managed realignment site will be lower. Colonisation of Nigg Bay MRS has been rapid compared with colonisation of Tollesbury Managed Realignment Site (Tollesbury MRS), Essex (Garbutt *et al*. 2006). Only one species was recorded at Tollesbury in the first year after the sea wall was breached compared with seven in Nigg Bay MRS despite the shorter period between breaching and the survey in Nigg Bay MRS compared with Tollesbury MRS. Species richness stabilised at Nigg Bay MRS by the third survey whereas at Tollesbury MRS it was still increasing by the sixth year.

The elevation range of a managed realignment site will determine the number of species that can colonise. Sites with a greater range of elevation will be able to support more species with a greater range of salinity tolerances. If the elevation range of the managed realignment site differs considerably from that of the adjacent marsh then the species composition might be expected to be different. Havergate Island Managed Realignment Site (Havergate Island MRS) was lower in the tidal frame compared to the adjacent saltmarsh which would explain the presence of species such as *Salicornia sp*., which was absent from the adjacent saltmarsh, and the absence of *Atriplex littoralis*, which had ~57% cover on the adjacent saltmarsh (RSPB unpublished data).

The history of a site may also affect the rate of colonisation. Sites with residual salt in the soil, perhaps from before they were claimed from the sea, or which already experienced periodic inundation before the embankment was breached are already likely to support some 'saltmarsh' species which may give them a head start compared to sites that have not experienced inundation before breaching. Havergate Island MRS, experienced inundation prior to breaching and, as a result, already had nine saltmarsh species. However, four of these were lost by the first year following the breaching of the embankment.

Most saltmarsh species in Nigg Bay MRS have colonised at lower elevations than at other UK sites. Although Nigg Bay MRS is less well drained than the adjacent intertidal sediments, it may be better drained than other managed realignment sites. Meddat Marsh was enclosed relatively recently and has not been intensively farmed so less compaction of sediments is likely to have occurred. Also, Nigg Bay MRS has two breach gaps which will allow the site to drain more easily than sites with only a single or narrower gap(s). The pre-existing relict creek network and relic drainage channels will also aid de-watering.

3.5 Conclusion

Within four summers of the reintroduction of tidal conditions to Meddat Marsh, the Nigg Bay MRS had been successfully colonised by the majority of the saltmarsh species found on the reference saltmarsh. As the site was still in a dynamic phase of development, specific NVC communities could not be assigned. It is likely to be many more years before Nigg Bay MRS supports the same communities as the reference saltmarsh in Nigg Bay. Initial colonisation occurred at intermediate elevations in the site and subsequently spread to lower elevations over the course of the study, there were also indications that the higher areas of the site were beginning to develop a maritime community. Colonisation was relatively rapid compared to other UK managed realignment sites and the relatively well-drained nature of Nigg Bay MRS allowed saltmarsh plants to colonise at lower elevations.

Chapter 4

The development of intertidal flats in Nigg Bay Managed Realignment Site: sediment characteristics and colonisation by invertebrates

4.1 Introduction

Intertidal flats provide vital foraging habitat for waders and wildfowl (Section 1.1.3) yet the total area of mudflats in the UK is declining (Section 1.1.4). It has been estimated that sea-level rise will result in the loss of 10,000 ha of intertidal flat in the UK between 1993 and 2013. In order to halt this decline the UK BAP (Biodiversity Action Plan) has set a target of maintaining at least the present extent and regional distribution of mudflat in the UK (Section 1.1.5). To achieve this, areas of mudflats will need to be restored or created to offset future losses to development and sea-level rise. Managed realignment is one method by which this can be achieved (Section 1.1.6).

The quality of intertidal flat created through managed realignment as a foraging resource for waterbirds is dependent on the presence of profitable invertebrate prey. Waterbirds selectively forage on the species and size classes of prey that provide the highest net rate of energy return (Section 1.1.3.1). The invertebrate species that can be supported by an intertidal flat are, in turn, determined by elevation in the tidal frame and sediment characteristics such as particle size and organic matter content (Section 1.1.2). Intertidal flats created through breached managed realignment are likely to have formed in relatively sheltered conditions compared to those of the open estuary, allowing finer sediments to settle out of suspension.

This chapter investigates the development of intertidal flats in Nigg Bay MRS over three consecutive winters following the re-establishment of tidal conditions and attempts to answer the following questions: How do sediment particle size and organic matter content compare between Nigg Bay MRS and the reference site? How do these sediment characteristics change with position on the shore? Which intertidal invertebrates colonised Nigg Bay MRS? What was the temporal pattern of colonisation? What were the ages/sizes of the colonising species? How does the intertidal invertebrate assemblage of Nigg Bay MRS compare with the reference site? Does Nigg Bay MRS support profitable prey for waterbirds?

4.2 Methods

4.2.1 Sediment and invertebrate sampling

In January 2004, during the first winter following the re-establishment of tidal conditions at Meddat Marsh, a sediment and invertebrate survey was undertaken both within Nigg Bay MRS and on an adjacent reference intertidal flat. A total of 78 sampling points was selected, with 59 points in Nigg Bay MRS (Figure 4.1, Appendix 5) and 19 on the reference intertidal flats (Figure 4.2, Appendix 6).

Sediment (5 x 5 x 10 cm deep) and invertebrate (10 x 10 x 10 cm deep) cores were taken at each sampling point with a hand held corer; four cores (two sediment and two invertebrate) at each sampling point in the Nigg Bay MRS and seven cores (five sediment and two invertebrate) at each sampling point on the reference intertidal flats. Lugworm casts were counted within a 1 m^2 quadrat centred on the sampling point coordinates. The sediment and invertebrate survey was repeated in the subsequent two winters (Table 4.1) with the following modifications: In W2, only the lower areas of Nigg Bay MRS were sampled and three cores (one sediment and two invertebrate) were taken at each of 16 sites on reference intertidal flats (Appendices 3 and 4). In W3, the three west-east transects were sampled in Nigg Bay MRS and three cores (one sediment and two invertebrate) were taken at all 19 sites on the reference intertidal flats (Appendices 3 and 4).

As monitoring intertidal flat development was only one part of the whole research programme, compromises had to be made in terms of the choice of reference site, number of sampling points visited and number of samples taken in each year. The reference site was chosen because it abutted the saltmarsh on the adjacent intertidal flats. The close proximity to Nigg Bay MRS meant that it was convenient to survey and that data on waterbird use could be collected easily without separate trips being made to another locality, which could have caused disturbance to feeding birds.

Table 4.1: Descriptions of the three winters of study (W) referred to throughout the text.

Winter	Description
W1	Winter 2003/2004, the 1st winter following the re-establishment of tidal conditions
W2	Winter 2004/2005, the 2nd winter following the re-establishment of tidal conditions
W3	Winter 2005/2006, the 3rd winter following the re-establishment of tidal conditions

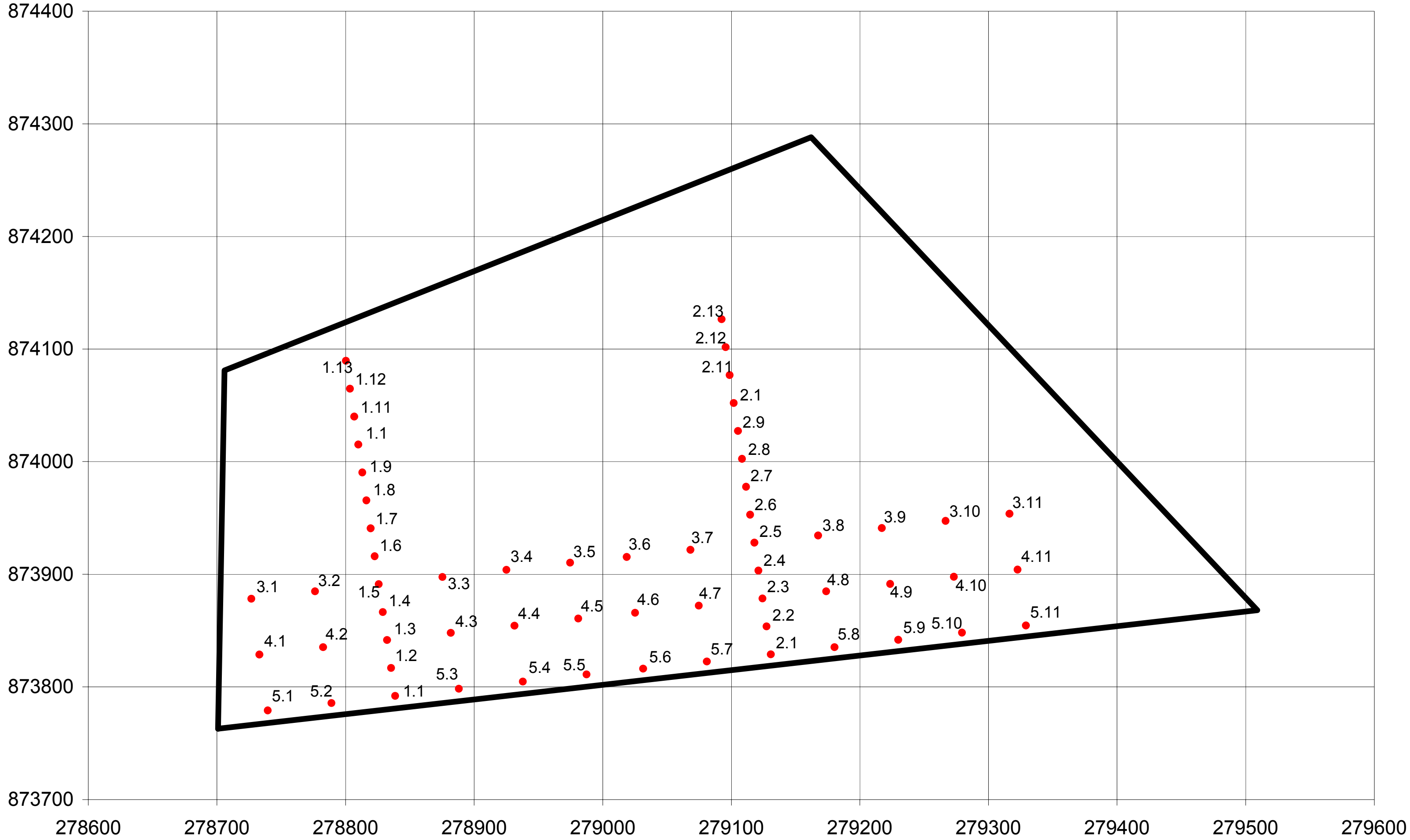


Figure 4.1: Locations of invertebrate sampling points in Nigg Bay Managed Realignment Site.

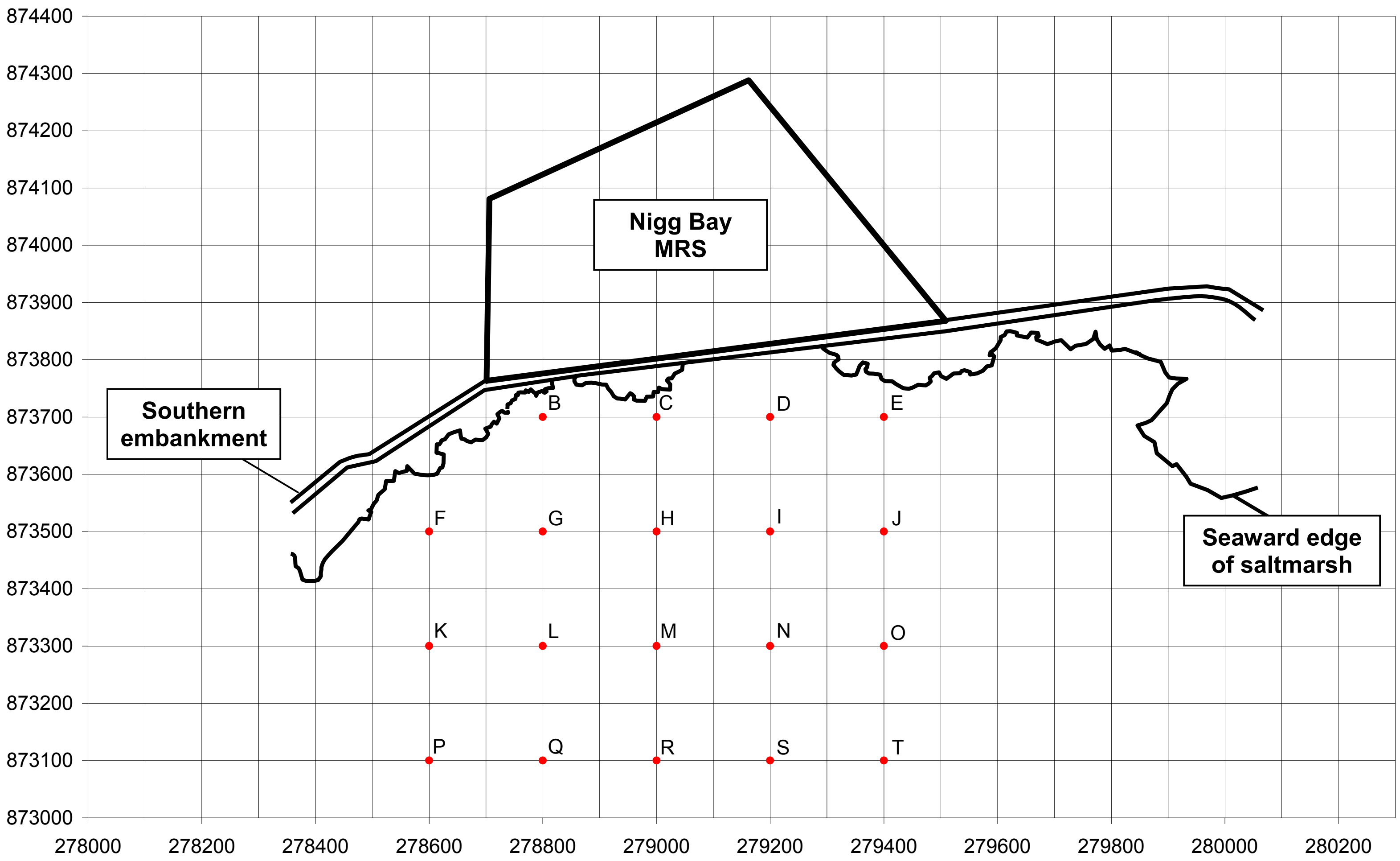


Figure 4.2: Locations of invertebrate sampling points on the reference intertidal flats.

4.2.2 Sediment particle size

Sediment particle size was analysed for samples collected in W1. Sediment particle size was measured using a Coulter LS 230 Laser Grain Sizer (Beckman Coulter Inc., California). The Coulter LS 230 Laser Grain Sizer uses a laser diffractometry method to size and count up to 10,000 individual particles in suspension per second (Coulter Inc. 1990). Its detection range is 0.04-2000 μm.

Prior to analysis with the Coulter LS 230 Laser Grain Sizer, each sample was passed through a 1 mm sieve to remove the coarse fraction (which was negligible in all samples). Calgon (10 cm^3) was added to each sample to reduce flocculation. Samples were placed on an automatic shaker for 1 h to aid particle dispersal. In order to distribute the particles in solution evenly, each sample was stirred using a magnetic stirrer before introduction to the Coulter Counter. The solution was introduced drop by drop into the cuvette using a pipette until the PIDS (Polarization Intensity Differential Scattering) registered about 40-50%. Each sample was analysed three times to account for any variation in the accuracy of the analysis. Arithmetic mean values were calculated from the output of these three runs.

An independent samples *t*-test was used to compare the modal particle size between Nigg Bay MRS and the reference intertidal flats for W1.

4.2.3 Sediment organic matter content

Organic matter content was analysed for each sample collected in W1 and W2. The percentage organic matter of each sample was calculated by mass loss on ignition. An air-dried subsample (~10 g) was dried in an oven at 105ºC for four hours. The mass of a clean, oven-dried porcelain crucible was recorded. The crucible was then half-filled with the oven-dried sediment sample before re-weighing. The crucible was placed in a furnace at 425ºC overnight then cooled in a desiccator before re-weighing.

Independent samples *t*-tests were used to compare the percentage organic matter between the Nigg Bay MRS and the reference intertidal flats for each winter. Paired samples *t*-tests were used to compare changes in the percentage of organic matter within each location (Nigg Bay MRS or reference intertidal flats) between winters.

4.2.4 Invertebrate analysis

Each invertebrate core was chilled and processed within 24 h of collection to minimise degradation and reduce the risk of predation by carnivores such as the ragworm *Hediste diversicolor*. Cores were wet-sieved through a 1 mm mesh and the residue was preserved in 70% ethanol. Samples were hand-sorted and invertebrates were counted and, where possible, identified to species level. Shell height of the laver spire shell *Hydrobia ulvae* and shell length of the Baltic tellin *Macoma balthica* were measured by placing each individual on 2 mm graph paper and assigned to size classes at 2 mm intervals. Size can be used to estimate the age of these species and allows inferences about colonisation to be drawn. The size of invertebrates can also affect their profitability to avian predators (Section 1.1.3.1).

Preliminary sampling in Nigg Bay MRS showed that estuarine invertebrates were not present above Mean High Water Springs (MHWS), so data from points above MHWS were excluded from analyses. Statistical analyses were performed for four species: the mud shrimp *Corophium volutator*, *Hydrobia ulvae*, *M. balthica* and *Hediste diversicolor*. Mann-Whitney *U* tests were performed to test for differences in the average densities of each of the invertebrate species between Nigg Bay MRS and the reference intertidal flats in each winter. Wilcoxon's matched-pair signed-ranks tests were performed to test for significant differences in the average density of each invertebrate species within a location (Nigg Bay MRS or reference intertidal flats) between winters. Kruskal-Wallis tests were performed to test for significant differences in the average density of each invertebrate species in various size classes within a location (Nigg Bay MRS or reference intertidal flats) for each winter. If Kruskal-Wallis tests gave a significant result, multiple comparisons tests were performed to determine which size classes were significantly different.

4.3 Results

4.3.1 Sediments

4.3.1.1 Particle size

The sediments on the reference intertidal flats were mostly fine sands, with particle sizes ranging from 168.8 µm to 324.3 µm (mean = 213.1 µm, SD = 43.5), while the sediments in Nigg Bay MRS were mostly silts, with particle sizes ranging from 21.69µm to 223.4 µm (mean = 79.5 µm, SD = 75.8). The particle size of the sediments in Nigg Bay MRS was significantly smaller than that of the reference intertidal flats (t = 6.068, $P < 0.001$, df = 29). There was a significant negative relationship with elevation for sediment particle size in both the reference intertidal flats ($r = 0.52$, $P < 0.05$) and Nigg Bay MRS ($r = 0.66$, $P < 0.01$) (Figure 4.3).

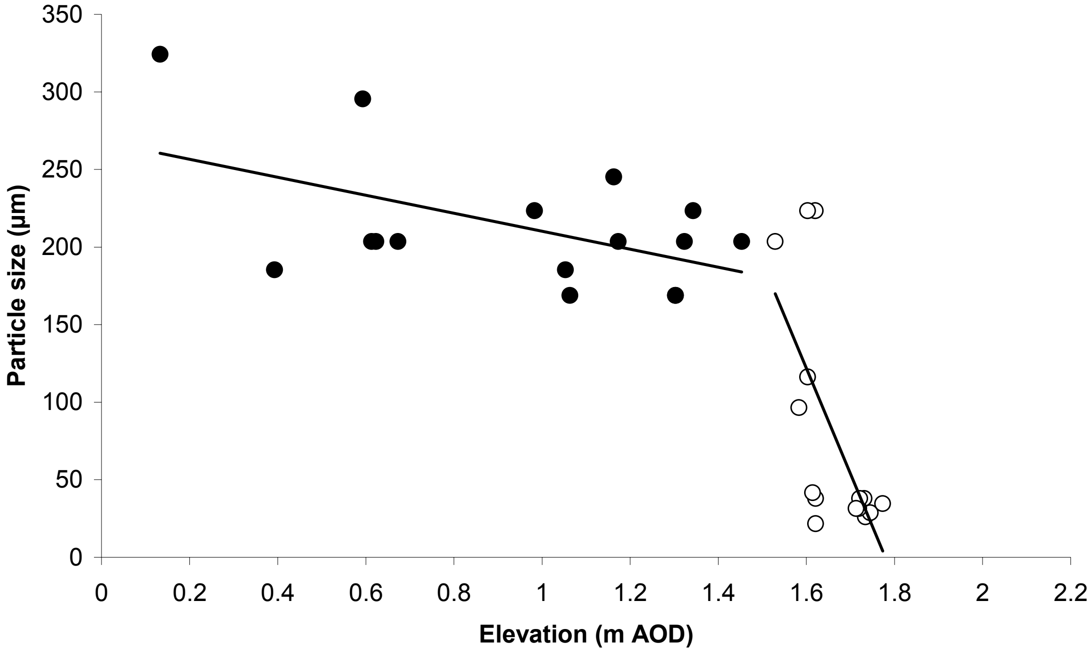


Figure 4.3: Relationship between particle size of the sediments and elevation in the tidal frame for sampling points in Nigg Bay Managed Realignment Site (open symbols) and reference intertidal flat (filled symbols) in W1. Significant relationships were found for the reference intertidal flats (y = -57.909x + 268.08 *r* = 0.52, *P* < 0.05) and for Nigg Bay MRS (y = -679.57x + 1209, *r* = 0.66, *P* < 0.01).

4.3.1.2 Organic matter content

The organic matter content of the sediments on the reference intertidal flats was less than 1% in every sample in both W1 and W2, whereas in Nigg Bay MRS it was as high as 46.6% and 27.2% in W1 and W2, respectively. The organic matter contents of the sediments in Nigg Bay MRS were significantly greater than those of the reference intertidal flats in both W1 (t = -7.547, P < 0.001, df = 30) and W2 (t = -6.963, P < 0.001, df = 30). Also, the organic matter content of the sediments in Nigg Bay MRS was significantly greater in W1 compared to W2 (t = 3.320, P < 0.01, df = 15). However, the organic matter content of the sediments of the reference intertidal flats was not significantly different between W1 and W2 (t = -0.930, P > 0.05, df = 15). In W1 the percentage of organic matter in the sediments of the reference intertidal flats showed a significant positive relationship with elevation in the tidal frame ($r = 0.68$, $P < 0.01$), although, this relationship was not detected in the following winter ($r = 0.38$, $P > 0.05$) (Figure 4.4). In W2 the percentage organic matter in the sediments of Nigg Bay MRS showed a significant positive relationship with elevation in the tidal frame ($r = 0.52$, $P < 0.05$), yet, this relationship was not detected for the previous winter ($r = 0.41$, $P > 0.05$) (Figure 4.4).

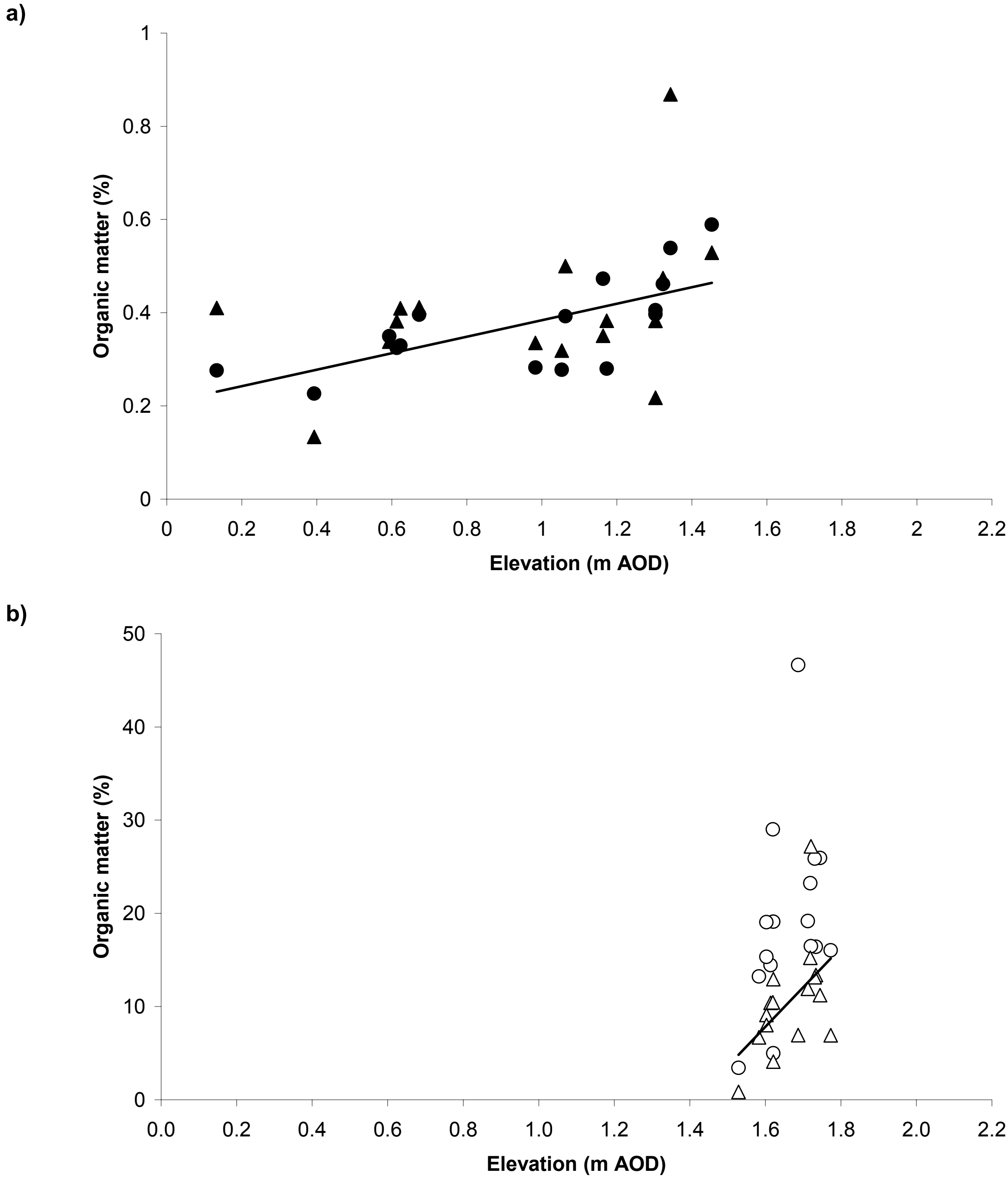


Figure 4.4: Relationship between percentage organic matter in the sediments and elevation in the tidal frame for sampling points in (a) reference intertidal flats and (b) Nigg Bay Managed Realignment Site in W1 (circles) and W2 (triangles). Significant relationships were found for the reference intertidal flats in W1 (y = 0.1768x + 0.2071, *r* = 0.68, *P* < 0.01) and for Nigg Bay Managed Realignment Site in W2 (y = 42.283x - 59.81, *r* = 0.52, *P* < 0.05).

4.3.2 Intertidal invertebrates

4.3.2.1 Species assemblage

Only four intertidal invertebrate species were consistently recorded in both Nigg Bay MRS and the reference intertidal flats each winter: *C. volutator*, *Hediste diversicolor*, *Hydrobia ulvae* and *M. balthica* (Table 4.2). Dipteran larvae were also recorded in both Nigg Bay MRS and on the reference intertidal flats each winter, however, as preliminary investigation found them to be present above MHWS in Nigg Bay MRS; they are not considered to be true intertidal invertebrates in this study. Further annelid species including the bristleworm *Pygospio elegans* and the lugworm *Arenicola marina*, the common cockle *Cerastoderma edule* and nematodes were recorded on the reference intertidal flats each winter, but were not recorded within Nigg Bay MRS during the study period. In W1 the number of *A. marina* casts on the reference intertidal flats ranged from 0-70 m^{-2} (mean = 15.4, SD = 16.7).

Table 4.2 Mean density and standard deviation of species recorded in Nigg Bay Managed Realignment Site (MRS) and reference intertidal flats (REF) in W1, W2 and W3.

	Species	**W1**		**W2**		**W3**	
		MRS	**REF**	**MRS**	**REF**	**MRS**	**REF**
Crustaceans	*Corophium volutator*	18 ± 146	26 ± 76	119 ± 271	1144 ± 3142	387 ± 1609	1158 ± 2242
	Crangon crangon					2 ± 13	3 ± 16
Molluscs	*Cerastoderma edule*		59 ± 118		47 ± 119		79 ± 163
	Hydrobia ulvae	957 ± 3734	12240 ± 8485	794 ± 2964	5404 ± 3609	192 ± 648	5408 ± 3427
	Macoma balthica	28 ± 93	942 ± 720	44 ± 175	369 ± 378	35 ± 157	737 ± 610
	Mytilus edulis		10 ± 37				
	Retusa				16 ± 45		
	Tellina tenuis		3 ± 17				
Worms	*Hediste diversicolor*	9 ± 51	36 ± 80	13 ± 34	78 ± 118	32 ± 81	95 ± 104
	Other		Present		Present		Present
Other	Nematodes		4789 ± 8750		2066 ± 2795		1997 ± 2921
	Dipteran larva	1 ± 12	1 ± 10	7 ± 38		77 ± 128	24 ± 88

4.3.2.2 Distribution

Hydrobia ulvae and *M. balthica* were both widespread on the reference intertidal flats; however, *C. volutator* and *Hediste diversicolor* were more patchily distributed, present at fewer than 50% of sampling points in at least one winter (Table 4.3). All the invertebrate species were patchily distributed in Nigg Bay MRS in every winter apart from *Hydrobia ulvae* in W1, which was present at 94% of sampling points (Table 4.3).

Table 4.3 Percentage of sampling points where selected invertebrate species were recorded in Nigg Bay Managed Realignment Site (MRS) and the reference intertidal flats (REF) in W1, W2 and W3.

Species	W1		W2		W3	
	MRS	REF	MRS	REF	MRS	REF
Corophium volutator	0	25	0	44	25	31
Hydrobia ulvae	94	100	25	100	56	100
Macoma balthica	31	100	6	100	38	94
Hediste diversicolor	13	56	0	69	25	44

4.3.2.3 Density

The average densities of *Hydrobia ulvae* and *M. balthica* were significantly lower in Nigg Bay MRS compared to the reference intertidal flats in every winter (Table 4.4). *C. volutator* densities were also significantly lower in the Nigg Bay MRS compared to the reference intertidal flats in W2 and *Hediste diversicolor* densities were lower in Nigg Bay MRS in both W1 and W2 (Table 4.4).

There was no significant change in density of *C. volutator* in Nigg Bay MRS between winters, despite the density of *C. volutator* on the reference intertidal flat being significantly greater in W2 and W3 compared to W1 (Table 4.5). There was a significant reduction in the density of *Hydrobia ulvae* between W1 and both W2 and W3 in both Nigg Bay MRS and on the reference intertidal flats (Table 4.5). There was a significant increase in the density of *M. balthica* in Nigg Bay MRS over the course of the study despite a significant reduction in the density of *M. balthica* on the reference intertidal flats (Table 4.5).

Table 4.4: Tests for significant differences in the density of invertebrates in Nigg Bay Managed Realignment Site (MRS) and reference intertidal flats (REF) in W1, W2 and W3.

Species	**W1**		**W2**		**W3**	
	Mann-Whitney *U* test		**Mann-Whitney *U* test**		**Mann-Whitney *U* test**	
	U	**diff[†]**	***U***	**diff[†]**	***U***	**diff[†]**
Corophium volutator	244		**72****	**MRS < REF**	233	
Hediste diversicolor	**166****	**MRS < REF**	**40*****	**MRS < REF**	217	
Hydrobia ulvae	**36*****	**MRS < REF**	**15*****	**MRS < REF**	**7*****	**MRS < REF**
Macoma balthica	**5*****	**MRS < REF**	**13*****	**MRS < REF**	**77.5*****	**MRS < REF**

[†] 'diff' indicates which location has the highest density of invertebrates for all cases where the difference is statistically significant.
* Asterisks indicate statistically significant differences (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

Table 4.5: Tests for significant differences in the density of invertebrates in Nigg Bay Managed Realignment Site (MRS) and reference intertidal flats (REF) between W1, W2 and W3.

Species	Wilcoxon's matched-pairs signed-ranks test between W1 and W2					
	MRS			**REF**		
	n	***Z***	**W diff**†	***n***	***Z***	**W diff**†
Corophium volutator	16	0.0		16	**-2.4***	**W2 > W1**
Hediste diversicolor	16	-1.3		16	-0.3	
Hydrobia ulvae	16	**-2.3***	**W1 > W2**	16	**-2.2***	**W1 > W2**
Macoma balthica	16	-1.0		16	**-3.4****	**W1 > W2**

Species	Wilcoxon's matched-pairs signed-ranks test between W2 and W3					
	MRS			**REF**		
	n	***Z***	**W diff**†	***n***	***Z***	**W diff**†
Corophium volutator	16	-1.8		16	-1.4	
Hediste diversicolor	16	-1.9		16	-0.2	
Hydrobia ulvae	16	-0.1		16	-1.1	
Macoma balthica	16	-1.5		16	**-2.4***	**W3 > W2**

Species	Wilcoxon's matched-pairs signed-ranks test between W1 and W3					
	MRS			**REF**		
	n	***Z***	**W diff**†	***n***	***Z***	**W diff**†
Corophium volutator	37	-1.4		19	**-2.4***	**W3 > W1**
Hediste diversicolor	37	-1.6		19	-0.9	
Hydrobia ulvae	37	**-2.5***	**W1 >W3**	19	**-3.0****	**W1 >W3**
Macoma balthica	37	**-2.0***	**W3 > W1**	19	**-2.0***	**W1 >W3**

† ' W diff' indicates which winter has the highest density of invertebrates for all cases where the difference is statistically significant.
* Asterisks indicate statistically significant differences (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

4.3.2.4 Distribution with elevation

On the reference intertidal flats, *Hydrobia ulvae* showed a significant relationship with elevation in the tidal frame, with significantly greater densities at higher shore levels in the W1 survey (r = 0.56, P < 0.01) (Figure 4.5), a relationship also recorded for *M. balthica* in W1 (r = 0.69, P < 0.001), W2 (r = 0.49, P < 0.05) and W3 (r = 0.51, P < 0.05) (Figure 4.6). No relationship with elevation was recorded for either *C. volutator* (Figure 4.7) or *Hediste diversicolor* (Figure 4.8) on the reference intertidal flats in any survey. In Nigg Bay MRS none of the species showed a significant relationship with elevation.

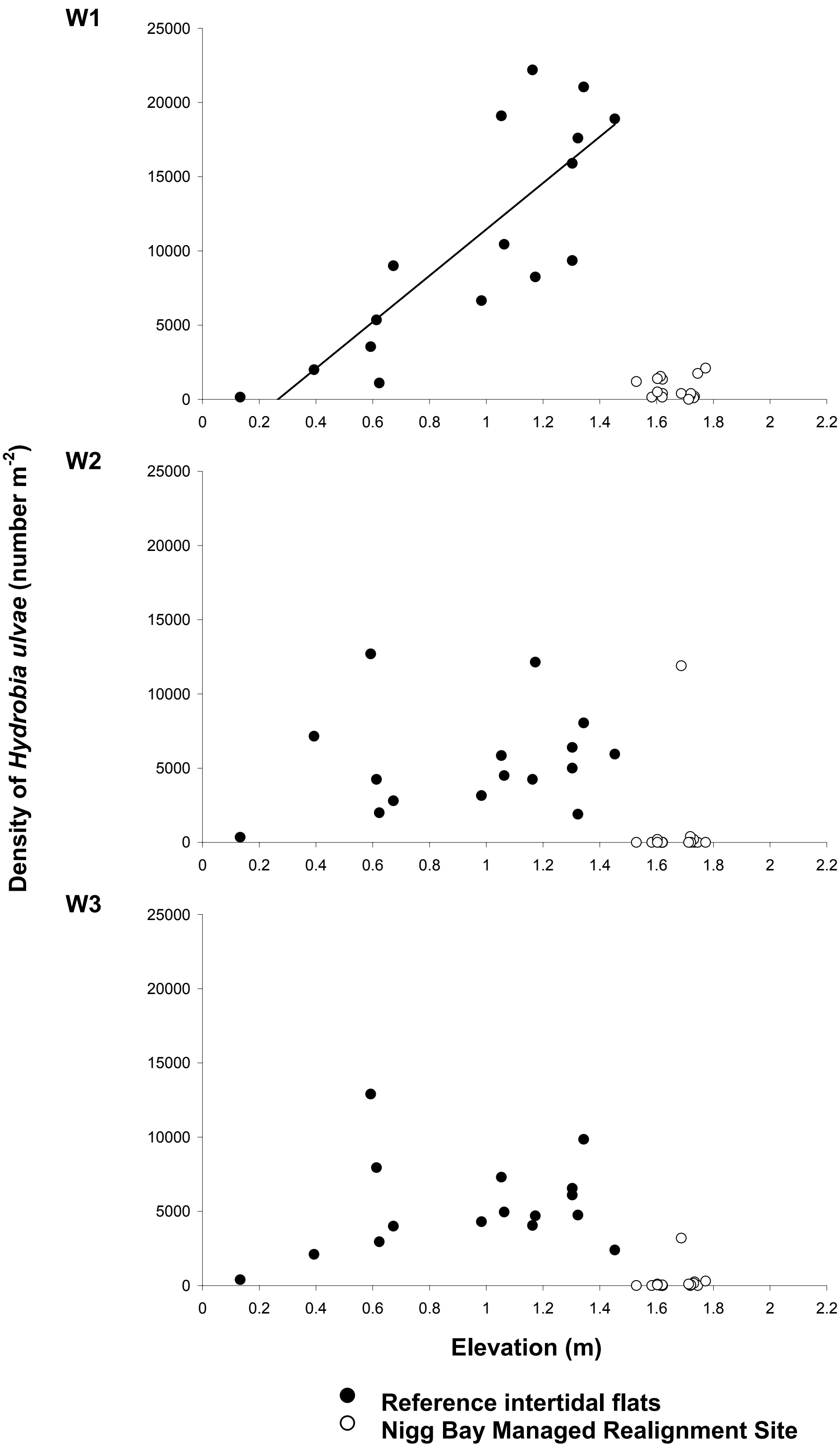


Figure 4.5: Distribution of *Hydrobia ulvae* with elevation. A significant relationship was found for the reference intertidal flats in W1 (y = 15602x - 4147.6, *r* = 0.82, *P* < 0.001).

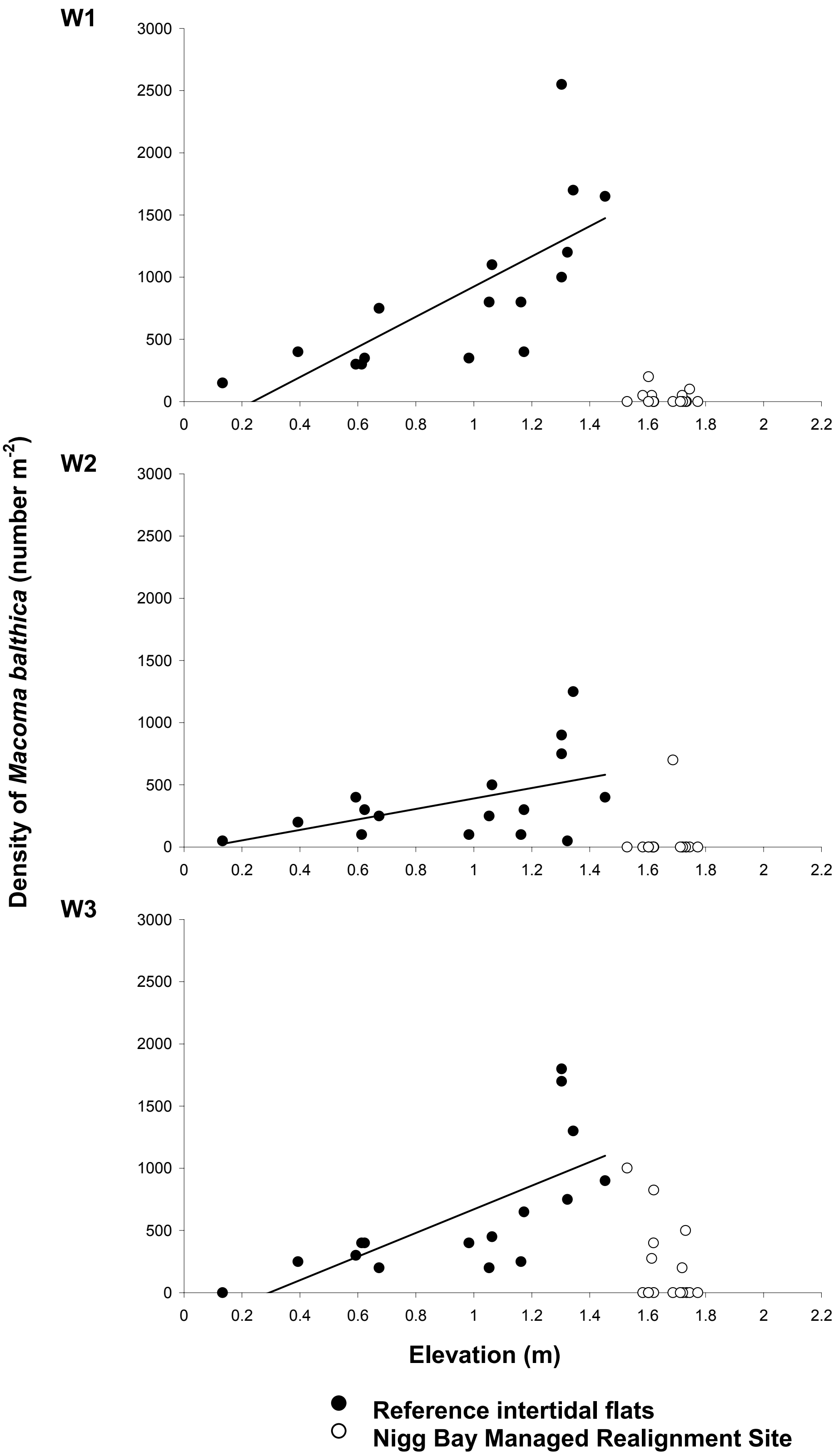


Figure 4.6: Distribution of *Macoma balthica* with elevation. Significant relationships were found for the reference intertidal flats in W1 (y = 1212.9x - 288.85, *r* = 0.72, *P* < 0.001), W2 (y = 420.93x - 30.819, *r* = 0.49, *P* < 0.05) and W3 (y = 949.97x - 279.88, *r* = 0.68, *P* < 0.01).

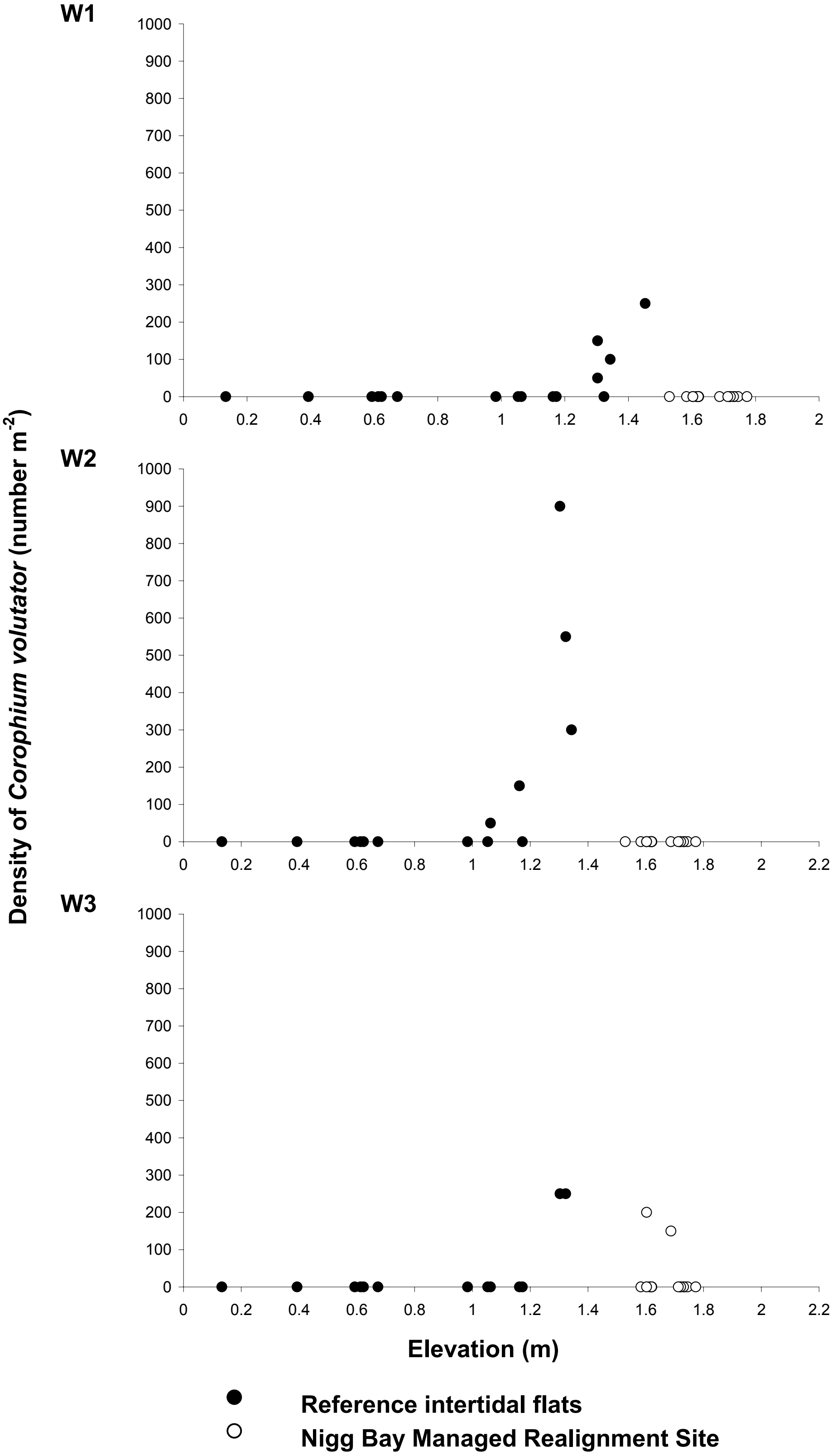


Figure 4.7: Distribution of *Corophium volutator* with elevation.

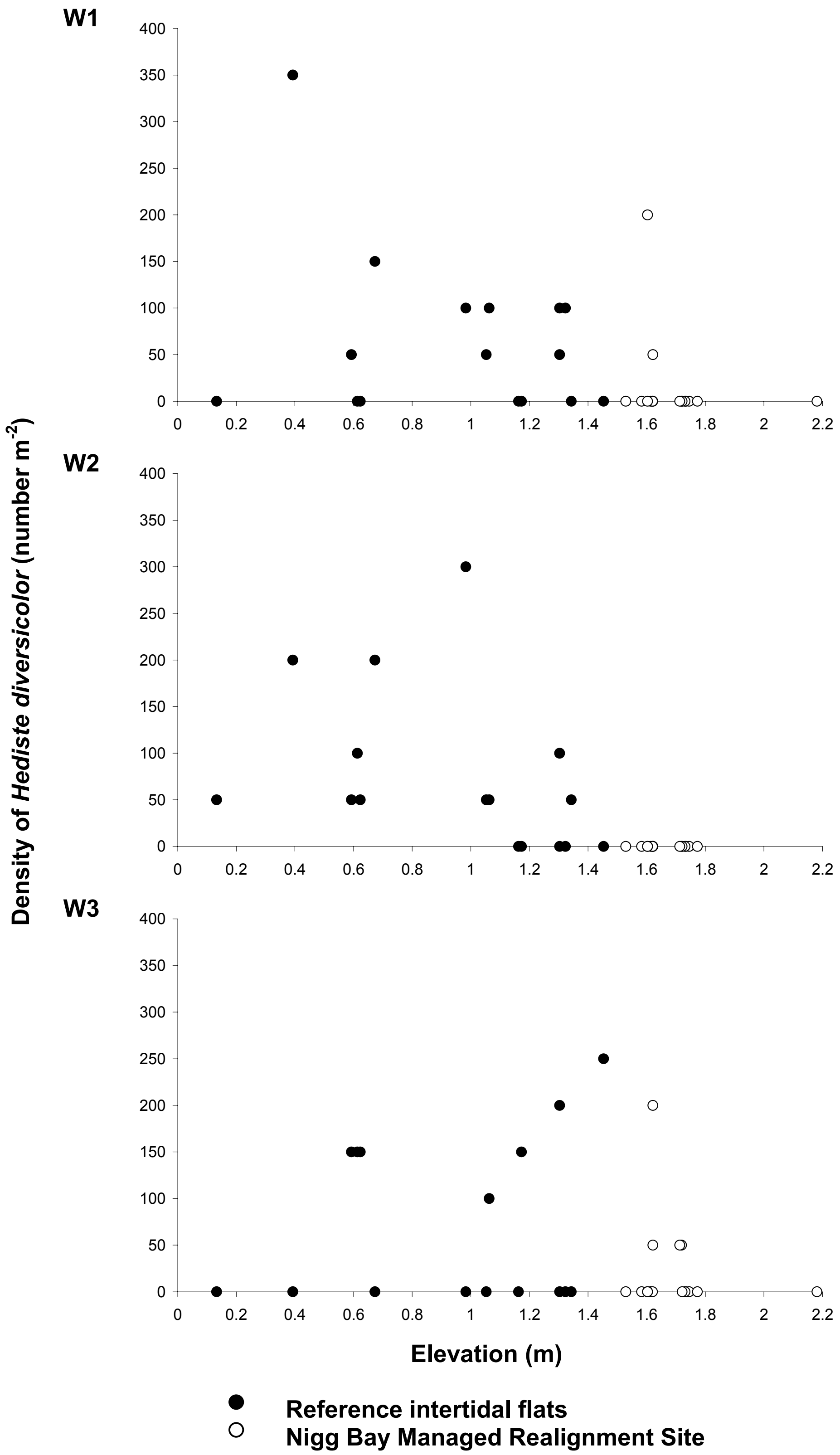


Figure 4.8: Distribution of *Hediste diversicolor* with elevation.

4.3.2.5 Size

The range of size classes of *Hydrobia ulvae* in Nigg Bay MRS and the reference intertidal flats remained the same throughout the study period (Figure 4.9). There were significantly more *Hydrobia ulvae* in the 2-4 mm size class in every winter (Table 4.6). Within Nigg Bay MRS there were no significant differences in the abundance of *Hydrobia ulvae* in each size class between winters (Table 4.6). The range of size classes for *M. balthica* in Nigg Bay MRS was smaller than on the reference intertidal flats (Figure 4.10). There were significantly more *M. balthica* in the 2-4 mm size class compared to the 12-14 mm size class in both W1 and W3 and significantly more in the 8-10 mm size class compared to the 12-14 mm size class in W2 (Table 4.7). Within Nigg Bay MRS there were no significant differences in the abundance of *M. balthica* in each size class between winters (Table 4.7).

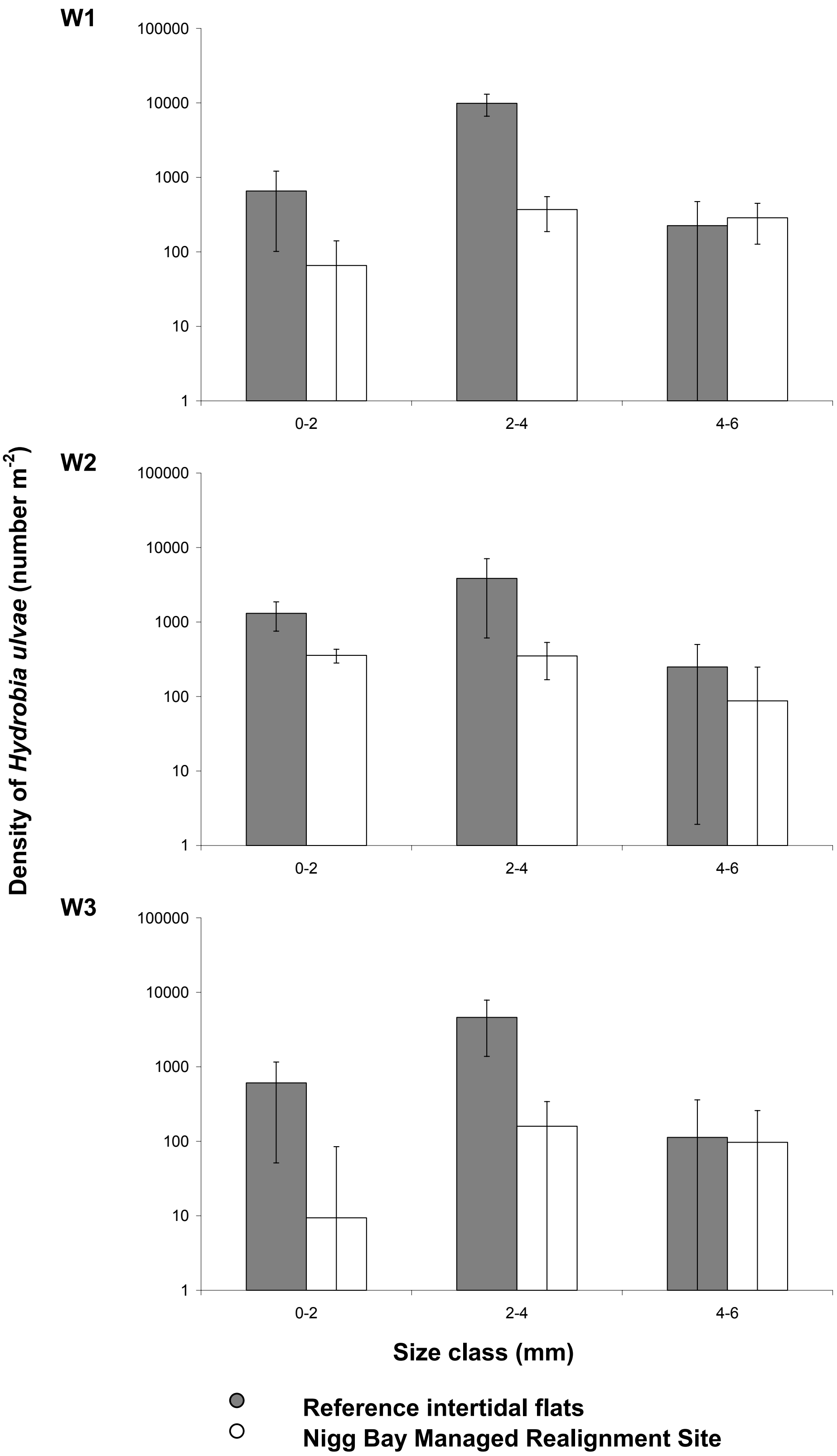


Figure 4.9: Average density of *Hydrobia ulvae* in each size class. Error bars show the 95% confidence limits.

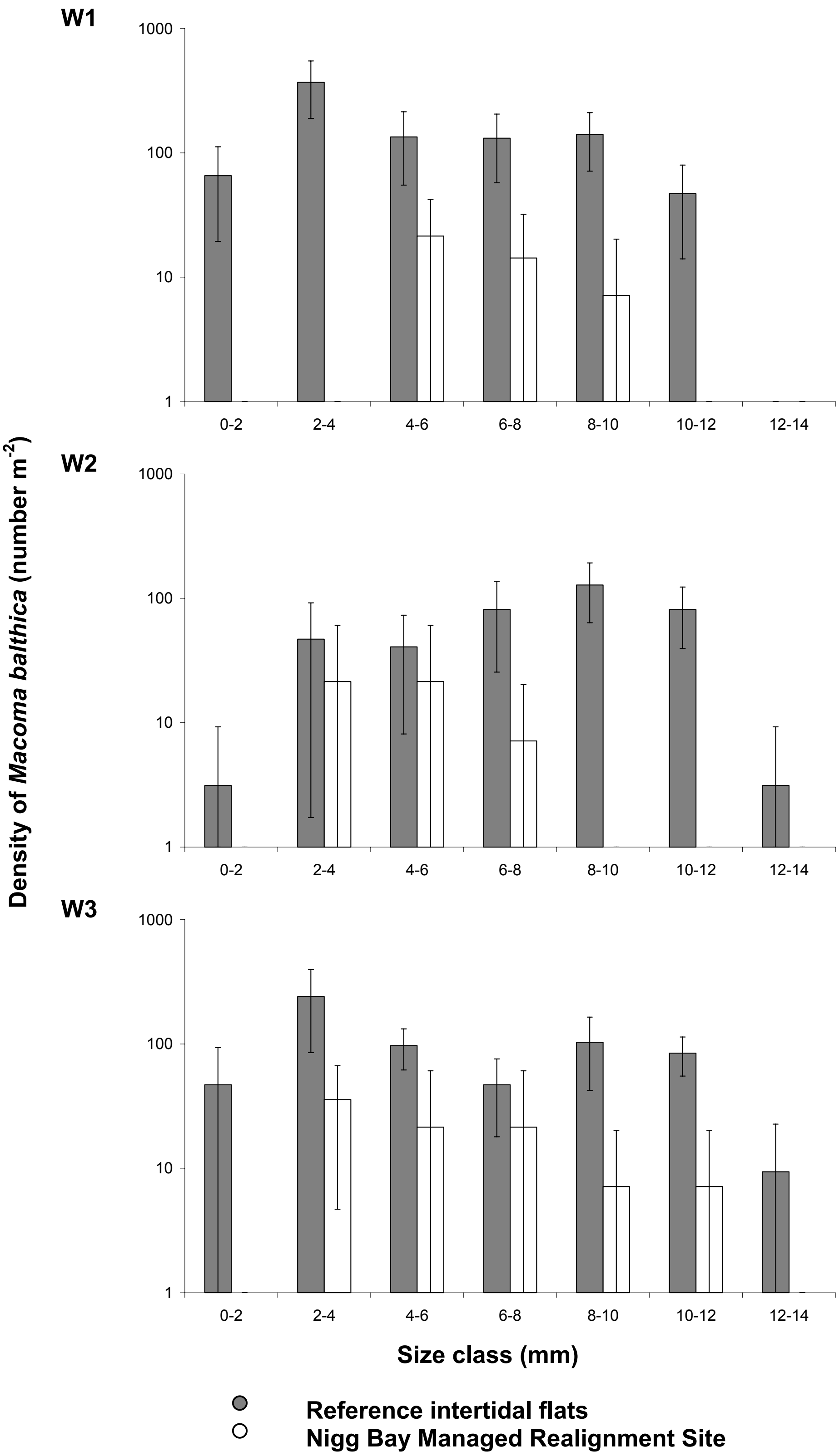


Figure 4.10: Average density of *Macoma balthica* in each size class. Error bars show the 95% confidence limits.

Table 4.6: Tests for significant differences in the density of *Hydrobia ulvae* in various size classes recorded in Nigg Bay Managed Realignment Site (MRS) and reference intertidal flats (REF) in W1, W2 and W3. Statistically significant values are emboldened.

Winter	Ref				MRS			
	Kruskal-Wallis test across TS0-3		Multiple comparison test		**Kruskal-Wallis test across TS0-3**		Multiple comparison test	
	n[§]	χ^2	***Q***	**SC diff**[†]	***n***[§]	χ^2	***Q***	**TS diff**[†]
W1	16	**28.6***	**3.85***	**2-4 > 0-2**	16	**13.2***		
			5.14*	**2-4 > 4-6**				
W2	16	**27.9***	**5.28***	**2-4 > 4-6**	16	2.0		
W3	16	**32.9***	**3.53***	**2-4 > 0-2**	16	4.8		
			5.69*	**2-4 > 4-6**				

§ *n* is the sum of the number of sampling points.
† 'SC diff' indicates which size class has the higher density of invertebrates where the difference is statistically significant.
* Asterisks indicate statistically significant differences ($P < 0.05$).

Table 4.7: Tests for significant differences in the density of *Macoma balthica* in various size classes recorded in Nigg Bay Managed Realignment Site (MRS) and reference intertidal flats (REF) in winters W1, W2 and W3. Statistically significant values are emboldened.

Winter	REF				MRS			
	Kruskal-Wallis test across TS0-3		Multiple comparison test		**Kruskal-Wallis test across TS0-3**		Multiple comparison test	
	n[§]	χ^2	***Q***	**SC diff**[†]	***n***[§]	χ^2	***Q***	**TS diff**[†]
W1	16	**44.59***	**6.05***	**2-4 > 12-14**	16	10.82		
W2	16	**41.9***	**4.74***	**8-10 > 12-14**	16	4.07		
W3	16	**29.1***	**4.35***	**2-4 > 12-14**	16	7.8		

§ *n* is the sum of the number of sampling points.
† 'SC diff' indicates which size class has the higher density of invertebrates where the difference is statistically significant.
* Asterisks indicate statistically significant differences ($P < 0.05$).

4.4 Discussion

Differences between the developing intertidal flats in Nigg Bay MRS and the reference intertidal flats need to be interpreted with caution as the adjacent area of intertidal flat sampled proved to be an unsuitable reference site. All the sampling points in the Nigg Bay MRS proved to be higher in the tidal frame than any of the sampling points on the reference intertidal flats, in spite of a visual impression of an elevated intertidal in the vicinity of the breaches. Detailed elevation data for the sampling points only became available from aerial surveys (LIDAR) once the baseline survey had been established and subsequent monitoring had been completed.

4.4.1 Sediment characteristics

4.4.1.1 Particle size

The particle size of the sediments within Nigg Bay MRS was significantly smaller than that of the adjacent intertidal flat. The sediments in Nigg Bay MRS were mostly silt, whereas those of the reference intertidal flats were mostly fine sand, supporting the findings of a previous studies of the sediments in Nigg Bay (Rafaelli & Boyle 1986; Rendall & Hunter 1986). As Nigg Bay MRS was created through breached rather than banked realignment (Section 1.1.6), this has created a more sheltered environment. Nigg Bay MRS does not experience strong wave activity and on spring tides the lower areas of the site are inundated for approximately five hours around high water (Babtie Group 2002) allowing fine particles to settle out of suspension.

4.4.1.2 Organic matter content

The organic matter content of the sediments within Nigg Bay MRS was significantly greater than that of the reference intertidal flats in both W1 and W2. The organic matter content of the sediments of the reference intertidal flats was comparable with that recorded in Nigg Bay and other areas of the Inverness, Cromarty and Dornoch Firths in a previous study (Rendall & Hunter 1986). Organic matter is usually associated with fine grained sediments such as those in the managed realignment site (see Section 4.4.1.1), so the sediments in Nigg Bay MRS are likely to have provided a large surface area for colonisation by micro-algae. Within Nigg Bay MRS the organic matter content was significantly higher in W1 compared to W2. The very high level of organic matter in W1 is not surprising given the large quantity of vegetation that had been killed following the re-establishment of tidal conditions (see Chapter 3). Fertiliser run-off may also have contributed to the high levels of organic matter, although no fertiliser had been applied in the five years prior to the reintroduction of tidal conditions. The lack of a relationship with elevation in the Nigg Bay MRS probably reflects the widespread dead vegetation in the areas below MHWS.

4.4.2 Invertebrate colonisation

4.4.2.1 Methods of colonisation

Invertebrates can colonise intertidal sediments by lateral movement through (burrowing) and on (crawling) the sediment or by settling from the water-column (Negrello-Filho *et al*. 2006). Invertebrates might also be transported to a site via attachment to other animals and birds or to flotsam (Charalambidou & Santamaría 2002; Figuerola & Green 2002; Green & Figuerola 2005).

The rate of colonisation will depend on the biology of the species concerned (Table 4.8). The early colonists are likely to be those that are most mobile, are short-lived and that have a long breeding season. *C. volutator* is a mobile species (Atkinson *et al*. 2001) and would have been able to move into Nigg Bay MRS from entry of the first tides. *Hydrobia ulvae* is able to float at the surface using a mucous raft when the intertidal flats are inundated (Jackson 2000) and has been found to migrate actively in the water column to exploit new resources (Armonies 1994), so mature individuals may have moved into Nigg Bay MRS shortly after it was created. Colonisation by larval *Hydrobia ulvae* in the first summer was also likely. Evans *et al*. (1998, 2001) found *M. balthica* at the Seal Sands (Teeside) Managed Realignment Site to be rare seven years after its creation and at Orplands (Essex) Managed Realignment Site, bivalves were not present in the first four years after the site was created, despite being abundant on the adjacent intertidal area (Atkinson *et al*. 2001, 2004). In these cases the substrate or other circumstances of the site would appear to have prevented rapid colonisation. Although, usually considered to be relatively immobile, *M. balthica* also colonised Nigg Bay MRS in the first year. Since *M. balthica* often reach maturity at 3-6 mm (Budd & Rayment 2001), it appears that some of the *M. balthica* that colonised Nigg Bay MRS in the first year were mature. This contrasts with colonisation of other managed realignment sites which were largely dependent on settlement of planktonic larvae (Atkinson *et al*. 2001). Reports of large scale sediment transport in Nigg Bay related to storm events (Raffaelli & Boyle 1986) suggest that the rapid appearance of mature *M. balthica* in the restored habitat could have resulted, at least in part, from wind or wave-driven immigration.

Table 4.8: The mobility of common intertidal invertebrates. Emboldened invertebrate species names indicate species found in Nigg Bay Managed Realignment Site. Shaded invertebrate species names indicate species that have previously been recorded in Nigg Bay (Raffaelli & Boyle 1986).

		Development	Mobility				
Category	**Invertebrate species**	**Planktotrophic**	**Non-motile**	**Drifter**	**Burrower**	**Crawler**	**Swimmer**
Poychaete worms	***Hediste diversicolor***				X	X	X
	Nephtys hombergii	X			X	X	X
	Arenicola marina				X		X
	Lanice conchilega	X			X		
Bivalve molluscs	*Cerastoderma edule*	X			X		
	Mytilus edulis	X	X				
	Macoma balthica	X			X		
	Mya arenaria	X			X		
Gastropod molluscs	***Hydrobia ulvae***	X		X		X	
	Littorina spp.	X				X	
Crustaceans	***Corophium spp.***				X	X	X
	Crangon crangon	X				X	X
	Carcinus maenas	X				X	

Sources: Ager (2006), Budd (2006), Budd & Hughes (2005), Budd & Rayment (2001), Jackson (2005), Tyler Walters (2002), Tyler Walters (2003), Tyler Walters (2005), Tyler Walters (2006), Neal (2007), Neal & Avant (2006) and Neal & Pizzolla (2007)

4.4.2.2 Invertebrate assemblages and densities in Nigg Bay Managed Realignment Site and reference intertidal flats.

The four most abundant invertebrate species in Nigg Bay MRS three years after the re-establishment of tidal conditions were also noted as colonists in the first year.

Hydrobia ulvae densities were significantly greater on the reference intertidal flats than in the developing flat in Nigg Bay MRS in every winter. *Hydrobia ulvae* densities in Nigg Bay MRS declined significantly after W1, which appears to reflect a reduction in the densities of *Hydrobia ulvae* on the reference intertidal flats. As long-term annual survey data for Nigg Bay are not available, it is not possible to determine whether the observed decline in densities was part of the natural population fluctuations or due to a one-off event. There are records of mass mortalities of *Hydrobia ulvae* caused by high temperatures triggering development of larval digenean trematodes within the snails (Jackson 2000). However, Met Office data for Kinloss indicated that the summers before W2 and W3 were no warmer than the summer before W1. Equally, as a surface dweller, *Hydrobia ulvae* might be expected to be affected more by a cold early winter than other species which are able to burrow deeply in the sediments to escape the cold. However, Met Office data for Kinloss also indicated that W2 and W3 were milder than W1. A further possibility is that the large scale sediment transport related to storm events, which has already been suggested as a factor in the dispersal of *M. balthica*, may be a cause of mass mortality of *Hydrobia ulvae* in Nigg Bay (Raffaelli & Boyle 1986).

M. balthica densities were also significantly greater on the reference intertidal flats than in the developing flat in Nigg Bay MRS in every winter. *M. balthica* densities in Nigg Bay MRS increased over the three years, despite a reduction on the reference intertidal flats, indicating a successful colonisation of the site by this species.

Possible reasons for differences in the invertebrate assemblage detected in the Nigg Bay MRS and the reference intertidal flats are discussed briefly below:

4.4.2.2.1 Time since breaching

Although invertebrates may colonise suitable habitats rapidly if a source of potential colonisers is available, species composition could be different from surrounding areas, even after 10-15 years (Atkinson *et al*. 2001). This is perhaps more likely where the physical conditions differ markedly from the reference intertidal flats, as at the sheltered Nigg Bay MRS.

4.4.2.2.2 Elevation in the tidal frame

On the reference intertidal flats, *M. balthica* showed a positive linear relationship with elevation in the tidal frame in every winter, while *Hydrobia ulvae* showed a positive linear relationship with elevation in the tidal frame in W1. Previous studies of the sediments and invertebrates of Nigg Bay found that tidal height was the most important factor governing the distribution and abundance of intertidal communities in Nigg Bay and that sediment characteristics were only weakly related to invertebrate distribution patterns (Raffaelli & Boyle 1986).

Invertebrate densities at mid-tide levels are expected to be greater than at sites higher in the tidal frame (McLusky 1989), so relationships between density and elevation in the tidal frame should be curvilinear. Intertidal invertebrate densities in Nigg Bay MRS would, therefore, be expected to be lower than the reference intertidal flats, even if the Nigg Bay MRS was functioning as a natural extension of the adjacent intertidal flat. However, the transition between the two areas should be gradual. Such a relationship was observed for *M. balthica* in W3.

4.4.2.2.3 Sediment characteristics

Sediment particle size has been shown to affect invertebrate colonisation and may account for the absence of certain species from Nigg Bay MRS. The lugworm, *Arenicola marina*, is usually abundant in fine or muddy sand and scarce or absent in fine muds and coarse sediments (Longbottom 1970). In Morecombe Bay, *A. marina* was scarce on the upper shore where particle size was less than 75 µm (Anderson 1972). Most sediments in Nigg Bay MRS were silts and therefore not suitable for this species. *M. balthica, Hediste diversicolor, Hydrobia ulvae* and *C. volutator* are typically associated with fine-grained sediments. Finer particles have a greater surface area to volume ratio and therefore usually have a greater amount of organic matter adsorbed on their surface which provides food for these species. Preference experiments have shown that some *C. volutator* prefer finer sediments (Meadows 1964) such as those present in Nigg Bay MRS. *C. volutator* inhabit permanent U-shaped burrows which are easier to maintain in finer sediments. Both *Hydrobia ulvae* and *Hediste diversicolor* have been associated with fine-grained sediments (Newell 1965; Anderson 1972). The sharp transition between the coarse sediments of Nigg Bay and the fine sediments of the Nigg Bay MRS, related in part to the strong spring-tidal currents in the vicinity of the breaches, is likely to have played a part in encouraging an equivalently sharp transition between species typical of fine- and coarse-grained sediments.

Increased sediment organic content has also been shown to affect macrofaunal colonisation of intertidal flats negatively (Bolam *et al*. 2004). The exceptionally high organic matter content of the sediments in Nigg Bay MRS may have caused hypoxic conditions due to the increased biological oxygen demand (BOD) of the sediments. While undertaking the sediment and invertebrate sampling the characteristic smell of hydrogen sulphide was clearly recognisable (pers. obs.). Sulphide combined with hypoxia is more toxic than hypoxia alone (Diaz & Rosenberg 1995). However, as the oxygen concentration of the sediments was not measured, the extent to which this may have been a factor affecting invertebrate colonisation cannot be determined. Densities of *C. volutator* and *Hediste diversicolor* are typically greater in areas of high organic matter (Yates *et al*. 1993) and *Hediste diversicolor* has been shown to be relatively resilient to poorly oxygenated sediments (Theede 1973). The high level of organic matter in the sediments of Nigg Bay MRS relative to the reference intertidal flats is likely to have created favourable conditions for colonisation by these species. *Hydrobia ulvae* has been classed as an opportunist; reaching high densities around areas of organic pollution (Pearson & Rosenberg 1978) but hypoxic conditions may have limited the densities.

The salinity of sediments and of overlying waters is likely to influence which invertebrates will colonise a site. Although this was not measured as part of this study it is likely that, due to its higher elevation in the tidal frame, the Nigg Bay MRS experienced greater freshwater runoff from surrounding habitat. *C. volutator* and *Hediste diversicolor* (Anderson 1972) both prefer areas with reduced salinity, which may partly explain the presence of these species in Nigg Bay MRS.

Heavily compacted sediments caused by earthmoving equipment have been cited as a reason for high mortality of colonists in some created sites since invertebrates were unable to bury in the sediment to escape harsh frosts (Evans *et al*. 1998). However, this was not an issue at Nigg Bay MRS.

4.4.3 Consequences for waterbird colonisation

Nigg Bay MRS supports *C. volutator*, *Hediste diversicolor*, *Hydrobia ulvae* and *M. balthica* which are the main food items in the diets of several waterbird species (see Table 4.9). This indicates that Nigg Bay MRS offers a suitable feeding habitat for these bird species.

It has been suggested that although invertebrates may be quick to colonise a newly created site, it may be some time before they grow to a size which makes their exploitation profitable to avian predators (Atkinson *et al*., 2001). Many bird species preferentially feed on relatively large size classes of prey, since these give the highest net rate of energy return. The preferred size classes of *Hydrobia ulvae* and *M. balthica* taken by a range of waterbirds is shown in Table 4.10. Given that many of the *Hydrobia ulvae* that have colonised Nigg Bay MRS are greater than 2 mm, and the *M. balthica* are less than 16 mm, there should be profitable prey size classes available for these species.

Waders on estuaries are usually aggregated in areas with abundant invertebrate food supplies (Bryant 1979). If choice of feeding habitat by birds was governed by prey density alone they might by expected to choose the adjacent intertidal area over the developing intertidal flat in Nigg Bay MRS. However, when the adjacent intertidal habitats become submerged at higher tidal states, and this choice is removed, Nigg Bay MRS may provide a valuable feeding habitat for these birds as an alternative to roosting or flying to distant, exposed sites (Chapter 5).

Table 4.9: The diets of selected waterbird species in winter. Emboldened invertebrate species names indicate species found in Nigg Bay Managed Realignment Site. Shaded invertebrate species names indicate species that have previously been recorded in Nigg Bay (Raffaelli & Boyle 1986). Invertebrate species that were identified as principal prey species for each waterbird in the original studies are shown in bold.

Category	Invertebrate species	Bar-tailed Godwit	Common Redshank	Common Shelduck	Dunlin	Eurasian Curlew	Eurasian Oystercatcher	Red Knot
Poychaete worms	***Hediste diversicolor***	x	**X**	x	**X**	**X**	x	x
	Nephtys hombergii		**X**		**X**	x		
	Arenicola marina	x				x	x	
	Scolops armiger				x	x		
	Lanice conchilega	x				**X**		
	Pygospio elegans				x			
Oligochaete worms			x		x			x
Bivalve molluscs	*Cerastoderma edule*		x		x	x	**X**	**X**
	Mytilus edulis			x	x	x	**X**	x
	Macoma balthica	x	**X**	x	**X**	**X**	**X**	**X**
	Scrobicularia plana	x				**X**	x	
	Tellina tenuis	x		x	x		x	x
	Mya arenaria			x		x	x	x
Gastropod molluscs	***Hydrobia ulvae***		**X**	**X**	**X**			**X**
	Littorina spp.		x	x	**X**		x	x
	Retusa obusata				x			x
	Rissoa parva				**X**			x
	Theodoxus			x	**X**			
Crustaceans	***Corophium spp.***		**X**	x	x			x
	Crangon crangon		**X**		x		x	x
	Carcinus maenas		**X**		x	**X**	x	x

Sources: Atkinson *et al*. (2001), Bryant (1979), Campbell *et al*. (1935), Davidson (1971), Dierschke *et al*. (1999), Drinnan (1958), Durell *et al*. (1993), Durrell & Kelly (1990), Evans *et al*. (1979), Goss-Custard (1966, 1969, 1977b, 1977d), Goss-Custard & Jones (1976), Goss-Custard *et al*. (1977b, 1977c), Olney (1965), Moreira (1994), Perez-Hurtado *et al*. (1997), Prater (1972), Worrall (1984).

Table 4.10: The preferred size classes of *Hydrobia ulvae* and *Macoma balthica* taken by waterbirds. Sources: Buxton & Young (1981), Goss-Custard *et al.* (1977b).

Waterbirds	Invertebrate size (mm)	
	Hydrobia	***Macoma***
Bar-tailed Godwit		9-11
Common Redshank	> 2	< 16
Common Shelduck	3-4.5	
Dunlin	2-3	
Eurasian Curlew		10-16
Eurasian Oystercatcher		11-13
Red Knot	> 2	< 16

4.5 Conclusion

The intertidal flats that have been restored in Nigg Bay MRS differ from those of the adjacent intertidal flats in terms of sediment characteristics and the invertebrate densities and assemblages that are supported. It is not possible to determine whether the observed differences are primarily due to the early stage of site development or other factors.

The sediments in Nigg Bay MRS have a higher silt content and are more organic-rich than those of the adjacent intertidal flats. This will be due, in part, to the higher elevation of the Nigg Bay MRS in the tidal frame, but the method of site creation is also likely to be a major contributing factor. Rather than banked realignment (which would have allowed the intertidal flat to develop as a continuation with the adjacent area) two small breach gaps were created, which provided sheltered conditions promoting the deposition of fine sediments. Following the re-establishment of tidal conditions the majority of vegetation below MHWS died and was left *in situ*. The presence of such large quantities of dead matter is likely to have caused greater inputs of nutrients into the system than would have been the case if the original vegetation had been removed prior to breaching. The elevation in the tidal frame as well as differences in sediments characteristics are likely to account for the lower invertebrate species richness and densities in Nigg Bay MRS relative to the reference intertidal flats.

However, the invertebrate species that have colonised Nigg Bay MRS are the preferred prey for many wader species. *Hydrobia ulvae* and *M. balthica* are of suitable size to make their exploitation profitable but unless densities and coverage of these species increase, Nigg Bay MRS is likely to be considered a lower quality feeding habitat.

Chapter 5

Patterns of colonisation of Nigg Bay Managed Realignment Site by non-breeding waterbirds

5.1 Introduction

The UK hosts non-breeding populations of migratory waders and wildfowl of national and international importance (Section 1.1). Many of these populations require large areas of intertidal habitat for feeding and roosting (Section 1.1.3); yet historic and recent losses of these wetlands to anthropogenic developments have been substantial (Section 1.1.4). Reduction or degradation of intertidal habitats, particularly around estuaries, is likely to cause population declines amongst waders and other waterbirds (Section 1.1.4) Some effects of habitat loss on estuaries could be mitigated by habitat creation and restoration (Section 1.1.5), particularly managed realignment (Section 1.1.6).

A simple measure of success of intertidal habitat creation through managed realignment is whether the waterbird assemblage that uses the site ultimately resembles that of the adjoining estuary. As the site develops, and invertebrates and saltmarsh plants become established, the waterbird species assemblage is likely to change and the site may be able to support a larger number of individuals.

This chapter investigates the first three winters of waterbird colonisation in Nigg Bay MRS and attempts to answer the following questions: Which wader and wildfowl species colonised Nigg Bay MRS? What was the temporal pattern of colonisation? How does the waterbird assemblage compare with that of Nigg Bay? How many birds have benefited from the creation of Nigg Bay MRS? How did colonisation compare with that of other UK managed realignment sites?

5.2 Methods

5.2.1 Wader and wildfowl monitoring in Nigg Bay

The Wetland Bird Survey (WeBS) is jointly run by the British Trust for Ornithology (BTO), the Joint Nature Conservation Committee (JNCC), the Royal Society for the Protection of Birds (RSPB) and the Wildfowl and Wetlands Trust (WWT). The aims of the survey are to monitor non-breeding waterbirds in the UK to: (i) identify population sizes; (ii) determine trends in numbers and distributions; and (iii) identify important sites for waterbirds. Monthly coordinated counts are undertaken at around 2000 sites distributed across a range of wetland habitats.

In Nigg Bay, WeBS counts are undertaken in October, December, January and February. Nigg Bay is divided into five sections and all the waterbirds within each section are counted in the three hours leading up to high tide. WeBS data for Nigg Bay were collated for the eight winters up to the end of the study (1998/1999 – 2005/2006).

WeBS data were used to calculate a mean number of each waterbird species for each month across the eight winters (**monthly long-term mean**) and a mean number of each waterbird species across all counts (**annual long-term mean**). One-way ANOVA with multiple comparisons tests (least significant difference, LSD) were performed to test for significant differences in the mean number of birds between months.

5.2.2 Wader and wildfowl monitoring in Nigg Bay Managed Realignment Site

Waterbirds were monitored during the first three winters following the re-establishment of tidal conditions (Table 5.1).

Table 5.1: Descriptions of the three winters of study (W) referred to throughout the text.

Winter	Description	Period of data collection
W1	Winter 2003/2004, the 1st winter post breach	Jan-Feb
W2	Winter 2004/2005, the 2nd winter post breach	Oct-Jan
W3	Winter 2005/2006, the 3rd winter post breach	Sep-Feb

Observations prior to the re-establishment of tidal conditions (D.M. Bryant, pers. comm.) showed that use of Meddat Marsh by waders and wildfowl was confined to occasional roosting by small numbers of Mallard *Anas platyrhynchos*, Teal *Anas crecca* and Eurasian Curlew *Numenius arquata* (< 5). Small numbers of Common Snipe *Gallinago gallinago* (< 10) occurred on the pasture but no systematic counts were undertaken. The analysis below assumes pre-breach wader and wildfowl numbers in Nigg Bay MRS were effectively zero.

Observations of waterbirds in Nigg Bay MRS began immediately following the re-establishment of tidal conditions. Three wader species were recorded on visits during late March, October and November 2003: Eurasian Curlew (0-3 birds); Eurasian Oystercatcher *Haematopus ostralegus* (0-2 birds); and Common Redshank *Tringa totanus* (1-57 birds). Detailed observations throughout the tidal cycle began in January 2004. On each of 16 days, the Nigg Bay MRS was visited between one and four times and the numbers of waders and wildfowl in the area below MHWS were recorded. In W2 and W3, Nigg Bay MRS was monitored throughout the diurnal tidal cycle and the numbers of waders and wildfowl in the area below MHWS recorded at 15 min intervals. In W2 data were collected over 47 d and in W3 over 21 d, including at least two spring tides and one neap tide each month.

Data for Nigg Bay MRS were analysed to determine the proportion of days that each wader and wildfowl species was recorded in the site during each month of W2 and

W3. For each day, the maximum number (**daily peak**) of each species recorded in Nigg Bay MRS in a single 15 minute period was calculated. From the daily peak numbers for each month of W2 and W3 a maximum (**monthly maximum peak**) and mean (**monthly mean peak**) were calculated. From the daily peak numbers for each winter (W2 and W3) a maximum (**annual maximum peak**) and mean (**annual mean peak**) were calculated. Kruskall Wallis tests with multiple comparisons tests were performed to test for significant differences in the daily peak numbers of each species between months.

5.2.3 Comparison between the waterbird assemblage in Nigg Bay Managed Realignment Site and that of Nigg Bay

Given that Nigg Bay MRS was high in the tidal frame, and each of the WeBS sections in Nigg Bay extended to the middle and lower intertidal flats, it was not considered appropriate to compare bird numbers and densities directly. As an alternative to direct comparison of bird densities, the proportions of Nigg Bay habitats occurring in the Nigg Bay MRS were calculated for comparison with the proportion of Nigg Bay birds in Nigg Bay MRS (Table 5.2). The habitat dimensions compared were saltmarsh (area and length of seaward edge) intertidal flat (area) and intertidal habitat between the Mean Low Water Spring (MLWS) and Mean High Water Spring (MHWS) tide levels (area). Under the assumption that habitats in Nigg Bay MRS were equivalent to those elsewhere in Nigg Bay, the expected proportion of birds in site would be equal to the proportion of the habitat. However, if Nigg Bay MRS was supporting a higher/lower proportion of birds it might suggest that it was a higher/lower quality habitat.

Table 5.2: Proportion of Nigg Bay habitats found in Nigg Bay Managed Realignment Site.

Habitat	Feature	Comparison	Nigg Bay	Nigg Bay Managed Realignment Site	Proportion of Nigg Bay habitat in Nigg Bay Managed Realignment Site (%)
Saltmarsh	Area	Area available to birds as high tide roost sites	63 ha	6.0 ha	9
Saltmarsh	Line	Length available to birds as high tide roost sites	6.7 km	1.2 km	15
Intertidal flats (MLWS to lower edge of saltmarsh)	Area	Area available to birds for feeding at low water on a spring tide	1000 ha	3.7 ha	< 1
Intertidal (MLWS-MHWS)	Area	Area available to birds at low water on a spring tide	1063 ha	9.7 ha	< 1

5.3 Results

5.3.1 Waterbirds in Nigg Bay

Sixteen wader and 18 wildfowl species were recorded in Nigg Bay WeBS counts between winters 1998/1999 and 2005/2006 (Table 5.3). Eurasian Wigeon *Anas penelope*, Mallard, Mute Swan *Cygnus olor*, Eurasian Oystercatcher, Common Redshank, Eurasian Curlew and Bar-tailed Godwit *Limosa lapponica* were recorded in Nigg Bay during each month of every winter from 1998/1999 and 2005/2006 (Table 5.3). In addition to the wader and wildfowl species, several Grey Heron *Ardea cinerea*, Great Cormorant *Phalacrocorax carbo* and European Shag *Phalacrocorax aristotelis* were frequently recorded and there were occasional occurrences of Common Guillemot *Uria aalge* and Red-throated Diver *Gavia stellata*.

Mean numbers of 4 waterbird species (Eurasian Wigeon, Eurasian Oystercatcher, Red Knot *Calidris canatus* and Dunlin *Calidris alpina*) exceeded 1000 individuals in at least one month, while mean numbers of 11 waterbird species (Common Redshank, European Golden Plover *Pluvialis apricaria*, Eurasian Curlew, Bar-tailed Godwit, Northern Lapwing *Vanellus vanellus*, Greylag Goose *Anser anser*, Mallard, Mute Swan, Common Shelduck *Tadorna tadorna*, Pink-footed Goose *Anser brachyrhynchus* and Northern Pintail *Anas acuta*) were between 100-1000 individuals in at least one month (Table 5.3). The remaining 19 waterbird species (8 waders and 11 wildfowl) were represented by a mean number of less than 100 individuals each month (Table 5.3).

The numbers of Eurasian Wigeon and Golden Plover, were significantly greater in October (Table 5.3) while numbers of Northern Pintail were significantly greater in December (Table 5.3). Common Shelduck numbers were significantly greater in December and January (Table 5.3). There was no significant difference between months in the numbers of the remaining waterbirds in Nigg Bay (Table 5.3).

Wader and wildfowl numbers in Nigg Bay are highly variable, with numbers of some species being up to ten times greater in some years than others. Numbers of several abundant species (Eurasian Curlew, Dunlin, Red Knot and Common Redshank) were lowest in the winter of 1999-2000 and highest in the winter of 2003-2004.

Table 5.3: Mean numbers of waders and wildfowl recorded in Nigg Bay during winters 1998-2006, based on WeBS high tide data. Numbers in parentheses denote the number of years that each species was recorded in Nigg Bay. WeBS counts were not undertaken in November. Results of one-way ANOVA and multiple comparisons tests are shown. Statistically significant values are emboldened.

	Annual long-term Mean	Monthly long-term mean				ANOVA	LSD
		Oct	Dec	Jan	Feb	*F*	Peak month
WILDFOWL							
Eurasian Wigeon[†]	2285	4867 (8)	2893 (8)	859 (8)	521 (8)	**9.0***	**Oct**
Common Shelduck	180	38 (7)	266 (8)	243 (8)	174 (8)	**20.5***	**Dec/Jan**
Greylag Goose	173	484 (3)	188 (6)	7 (3)	12 (2)	–	
Pink-footed Goose	168	27 (5)	431 (5)	24 (2)	189 (3)	–	
Mallard	107	111 (8)	135 (8)	105 (8)	75 (8)	0.7	
Northern Pintail	59	13 (5)	150 (6)	54 (6)	18 (3)	**5.2***	**Dec**
Mute Swan	49	43 (8)	50 (8)	49 (8)	55 (8)	0.3	
Common Teal	11	4 (2)	33 (4)	0 (1)	5 (3)	–	
Goldeneye	4	0 (2)	7 (7)	4 (5)	4 (4)	2.0	
Red-breasted Merganser	4	7 (5)	6 (6)	1 (2)	2 (4)	2.5	
Whooper Swan	3	5 (2)	2 (2)	1 (3)	5 (5)	–	
Tufted Duck	2	3 (1)	1 (1)	1 (1)	3 (3)	–	
Brent Goose	1	0 (0)	1 (1)	1 (1)	1 (1)	–	
Common Eider	1	1 (1)	0 (2)	0 (0)	2 (1)	–	
Long-tailed duck	1	0 (0)	1 (1)	0 (0)	1 (2)	–	
Barnacle Goose	0	0 (0)	0 (0)	0 (0)	0 (1)	–	
Shoveller	0	0 (0)	0 (0)	0 (0)	0 (2)	–	
White-fronted Goose	0	0 (0)	0 (1)	0 (0)	0 (0)	–	
WADERS							
Red Knot[‡]	1786	630 (7)	2098 (8)	2432 (8)	1984 (6)	2.3	
Dunlin	1367	390 (8)	2152 (8)	1659 (7)	1268 (8)	2.6	
Eurasian Oystercatcher	1007	1004 (8)	1083 (8)	889 (8)	1051 (8)	0.3	
Bar-tailed Godwit[‡]	806	418 (8)	947 (8)	882 (8)	978 (8)	0.9	
Common Redshank[†]	694	809 (8)	802 (8)	589 (8)	577 (8)	1.3	
Eurasian Curlew[†]	549	500 (8)	514 (8)	669 (8)	513 (8)	0.4	
Northern Lapwing	268	365 (8)	411 (8)	166 (8)	130 (6)	2.9	
European Golden Plover	243	581 (6)	248 (5)	114 (5)	28 (2)	**3.4***	**Oct**
Common Ringed Plover	21	18 (7)	33 (5)	17 (5)	14 (3)	0.9	
Grey Plover	7	16 (6)	5 (3)	5 (4)	2 (2)	–	
Ruddy Turnstone	6	2 (4)	4 (6)	6 (4)	10 (5)	1.2	
Common Snipe	1	1 (4)	1 (3)	1 (1)	1 (3)	–	
Black-tailed Godwit	0	1 (3)	0 (1)	0 (0)	0 (0)	–	
Common Greenshank	0	0 (1)	0 (2)	0 (0)	0 (0)	–	
Green Sandpiper	0	0 (1)	0 (0)	0 (0)	0 (0)	–	
Jack Snipe	0	0 (0)	0 (0)	0 (1)	0 (0)	–	

[†] Denotes species with a nationally important population in the Cromarty Firth.
[‡] Denotes species with an internationally important population in the Cromarty Firth..
* Asterisks indicate statistically significant differences ($P < 0.05$)

5.3.2 Waterbirds in Nigg Bay Managed Realignment Site

Twelve wader and 11 wildfowl species were recorded in Nigg Bay MRS during the course of the study (Tables 5.4-5.6). In addition to the wader and wildfowl species, Grey Heron and Little Grebe *Tachybaptus ruficollis* were frequently recorded and Great Cormorant were occasionally recorded.

Species richness and numbers of individuals were low in W1 (Table 5.4) but increased in subsequent winters (Tables 5.5-5.6). Species richness increased from three species (two waders, one wildfowl) in W1 to 19 (10 waders and 9 wildfowl) and 18 (9 waders and 9 wildfowl) species in W2 and W3, respectively (Table 5.7). Each of the species recorded in W1 was also recorded in the subsequent two winters. Of the 16 additional species recorded in W2, 5 waders and 6 wildfowl species were also recorded in W3. Four species were observed in the managed realignment site for the first time in W3.

Eurasian Curlew, Common Redshank and Eurasian Oystercatcher were the wader species most frequently observed in Nigg Bay MRS, the same three species as recorded in the first autumn after breaching. Eurasian Curlew was recorded on 100% of the days on which observations were made each month in both W2 and W3 (Tables 5.5-5.6). The percentage of days on which wildfowl species were recorded in Nigg Bay MRS fluctuated throughout each winter (Tables 5.5-5.6). In W2, wader species richness declined from nine species in October to five in January (Table 5.5). In W3, wader species richness fluctuated between five and seven species throughout the winter (Table 5.6).

Eight wader species were represented by > 10 individuals during the course of the study (Tables 5.4-5.6). In W1, only Common Redshank numbers exceeded five individuals (Table 5.4). The peak number of Bar-tailed Godwit, Eurasian Curlew, Dunlin and Red Knot recorded in Nigg Bay MRS increased over the three winters, while Golden Plover, Lapwing, Common Redshank and Common Snipe abundance was greatest in W2. Only three wildfowl species (Common Shelduck, Teal and Eurasian Wigeon) were represented by > 10 individuals during the course of the study (Tables 5.4-5.6). The peak number of each of these species in Nigg Bay MRS increased over the three winters. The minimum number of individual birds (across all waterbird species) recorded within Nigg Bay MRS rose from 62 in W1 to 2319 in W3 (Table 5.7).

In W3, significantly more Common Redshank ($\chi^2 = 12.2$, $P < 0.05$) and Eurasian Oystercatcher ($\chi^2 = 15.1$, $P < 0.05$) used Nigg Bay MRS during one month of the winter, but multiple comparisons tests were not able to determine which month. For other species, no significant difference in use of the Nigg Bay MRS between months was detected. The highest monthly maximum peak numbers of Bar-tailed Godwit, Eurasian Curlew, Dunlin, Red Knot and Common Redshank were recorded during December and January (Table 5.6).

Table 5.4: Monthly mean peak number (Mean) and monthly maximum peak number (Max) of each waterbird species recorded in Nigg Bay Managed Realignment Site in W1. The proportion (%) of the total number of days on which data were collected (indicated next to the name of the month) that each species was recorded in the managed realignment site is also shown. The month with the highest maximum peak number of each waterbird species is indicated by grey shading.

	Jan (12 d)			Feb (4 d)		
	Mean	**Max**	**%**	**Mean**	**Max**	**%**
Waders						
Bar-tailed Godwit						
Black-tailed Godwit						
Common Greenshank						
Common Redshank	10.5	48	42	73	200	100
Common Ringed Plover						
Common Snipe						
Dunlin						
Eurasian Curlew	1	3	58			
Eurasian Oystercatcher						
European Golden Plover						
Northern Lapwing						
Red Knot						
Wildfowl						
Common Shelduck						
Common Teal						
Eurasian Wigeon						
Goldeneye						
Greylag Goose						
Long-tailed Duck						
Mallard						
Mute Swan						
Pintail						
Red-breasted Merganser	0.1	1	8	0.3	1	25
Whooper Swan						

Table 5.5: Monthly Mean peak number (Mean) and monthly maximum peak number (Max) of each waterbird species recorded in Nigg Bay Managed Realignment Site in W2. The proportion (%) of the total number of days on which data were collected (indicated next to the name of the month) that each species was recorded in the managed realignment site is also shown. The month with the highest maximum peak number of each waterbird species is indicated by grey shading.

	Oct (23 d)			Nov (12 d)			Dec (6 d)			Jan (6 d)		
	Mean	Max	%	Mean	Max	%	Mean	Max	%	Mean	Max	%
Waders												
Bar-tailed Godwit												
Black-tailed Godwit												
Common Greenshank	0.3	2	26									
Common Redshank	58.7	171	100	62.8	147	100	59.0	122	83	86.3	172	100
Common Ringed Plover	0.0	1	9	0.2	2	25						
Common Snipe	5.2	28	65									
Dunlin	20.0	69	87	4.8	25	33	0.5	3	17	1.7	3	83
Eurasian Curlew	3.8	7	100	3.3	7	100	2.0	3	100	13.8	50	100
Eurasian Oystercatcher	2.1	6	91	0.9	2	67	2.5	4	100	0.3	1	33
European Golden Plover	6.1	11	100	0.3	1	33						
Northern Lapwing	3.3	45	43	0.4	5	8				0.3	2	17
Red Knot							0.2	1	17			
Wildfowl												
Common Shelduck	0.3	3	35	2.7	12	83	12.5	24	100	9.7	16	100
Common Teal	5.3	40	43									
Eurasian Wigeon	12.4	218	74	1.2	9	42						
Goldeneye				0.7	2	58	1.0	2	83	1.0	2	67
Greylag Goose				0.3	2	17	0.2	1	17			
Long-tailed Duck				0.5	1	50	0.7	1	83	0.5	1	50
Mallard	0.7	5	22	0.2	2	8						
Mute Swan												
Pintail												
Red-breasted Merganser	1.2	3	65	0.2	1	33	0.2	1	33	0.7	1	67
Whooper Swan	0.0	1	4									

Table 5.6: **Monthly Mean peak number (Mean) and monthly maximum peak number (Max) of each waterbird species recorded in Nigg Bay Managed Realignment Site in W3. The proportion (%) of the total number of days on which data were collected (indicated next to the name of the month) that each species was recorded in the managed realignment site is also shown. The month with the highest maximum peak number of each waterbird species is indicated by grey shading.**

	Sep (4 d)			Oct (4 d)			Nov (3 d)			Dec (3 d)			Jan (4 d)			Feb (3 d)		
	Mean	Max	%	Mean	Max	%	Mean	Max	%	Mean	Max	%	Mean	Max	%	Mean	Max	%
Waders																		
Bar-tailed Godwit	2.75	8	100	1.0	4	25	0.3	1	33	74.3	220	100	38.5	154	25			
Black-tailed Godwit				1.3	3	50	0.3	1	33									
Common Greenshank				0.3	1	25												
Common Redshank	1.0	3	75	12.5	30	100	28.0	41	100	69.3	160	100	21.0	56	75			
Common Ringed Plover	6.8	14	50															
Common Snipe										0.3	1	33						
Dunlin	4.0	11	50							53.3	160	33	1.3	5	25			
Eurasian Curlew	5.8	8	100	100.3	280	100	15.0	36	100	100.7	291	100	51.0	191	100	16.7	33	100
Eurasian Oystercatcher	4.8	8	100	4.8	7	100	4.7	5	100	2.7	4	100	0.3	1	25			
European Golden Plover																		
Northern Lapwing	6.0	17	75													3.7	11	33
Red Knot	0.3	1	25							36.7	110	33	62.5	250	25			
Wildfowl																		
Common Shelduck				0.3	1	25	12.7	19	100	19.7	34	100	17.8	47	50	3.0	9	33
Common Teal										22.7	50	100	97.3	150	100	13.3	23	100
Eurasian Wigeon	1.0	4	25	29.3	66	50	426.7	1000	67	310.0	480	67	88.0	200	75	33.3	100	33
Goldeneye							0.3	1	33	1.3	3	67	1.0	2	75	0.7	1	67
Greylag Goose																		
Long-tailed Duck																		
Mallard	0.5	2	25										0.5	2	25			
Mute Swan							0.3	1	33				2.3	9	25	0.7	2	33
Pintail							2.0	6	33									
Red-breasted Merganser				0.8	3	25				0.3	1	33						

Whooper Swan	1.5	6	25

Table 5.7: Species richness (*S*) and minimum total number of individuals (sum of peak numbers for each species) (*n*) of waders and wildfowl recorded in Nigg Bay Managed Realignment Site during W1, W2 and W3.

	W1		W2		W3	
	S	***n***	***S***	***n***	***S***	***n***
Waders	2	61	10	386	9	1093
Wildfowl	1	1	9	296	9	1226
All waterbirds	**3**	**62**	**19**	**688**	**18**	**2319**

5.3.3 Comparison between the waterbird assemblage in Nigg Bay Managed Realignment Site and that of Nigg Bay

In W3 Nigg Bay MRS supported an annual mean peak of between 0.3 and 8.9% and an annual maximum peak of between 0.8 and 53.0% of the annual long-term mean number of selected bird species (Table 5.8).

Table 5.8: Annual mean and maximum peak proportions of the long-term mean Nigg Bay populations of wader and wildfowl species supported by Nigg Bay Managed Realignment Site in W3.

	Annual mean peak (%)	Annual maximum peak (%)
Waders		
Bar-tailed Godwit	2.3	27.3
Common Redshank	2.9	23.0
Dunlin	0.6	11.7
Eurasian Curlew	8.9	53.0
Eurasian Oystercatcher	0.3	0.8
Red Knot	1.0	14.0
Waterfowl		
Common Shelduck	4.7	26.1
Eurasian Wigeon	5.8	43.8

5.4 Discussion

5.4.1 Waterbirds in Nigg Bay

The waterbird assemblage recorded in WeBS counts of Nigg Bay is typical of a sand-dominated estuary. The large numbers of Eurasian Oystercatcher, Common Redshank, Red Knot, Eurasian Curlew, Bar-tailed Godwit, Dunlin and Common Shelduck exploit the invertebrates of the intertidal flats (Anderson 1970; Rafaelli & Boyle 1986; Chapter 4) while Eurasian Wigeon exploit the extensive eelgrass beds of the Cromarty Firth (Rodwell 2000). Some species that were recorded in smaller numbers may have been under-represented in the WeBS counts. Common Snipe are notoriously cryptic when using standard WeBS counting methods, while in Nigg Bay Common Teal typically occur in the ditches behind the embankments and are less likely to be detected (pers. obs). Species occurring in small numbers on passage, such as Common Greenshank and Black-tailed Godwit, may be overlooked because their stop-overs are often brief (Lehnen & Krementz 2005). Some species, such as Greylag Goose, Pink-footed Goose, Northern Lapwing and European Golden Plover, spend time away from intertidal habitats (Fuller & Lloyd 1981; Paterson *et al*. 1989) and so counts of these species are likely to vary considerably from month to month and between years.

5.4.2 Waterbirds in Nigg Bay Managed Realignment Site

Waders on estuaries are usually aggregated in areas with abundant invertebrate prey (Bryant 1979). The main prey species of many waders (Chapter 4), including *Hydrobia ulvae*, *Macoma balthica*, *Hediste diversicolor* and *Corophium volutator*, were present in Nigg Bay MRS in W1, yet wader and wildfowl species richness was low. The densities of these invertebrates were lower than on the adjacent intertidal flats and other invertebrate species were scarce or absent, suggesting that food availability may have been limited. It has been suggested that although invertebrates may be quick to colonise a newly created site, it may be some time before they grow to a size which makes their exploitation profitable to avian predators (Atkinson *et al*. 2001). This does not appear to have been the case at Nigg Bay, however, since profitable *Hydrobia ulvae* and *Macoma balthica* occurred in Nigg Bay MRS site by W1 (Chapter 4). Waders and wildfowl may also have been slow to respond to availability of new habitat. Previous studies have shown that many species show high site fidelity between winters, particularly amongst adults (Metcalfe & Furness 1985; Insley *et al*. 1997; Burton 2000; Leyrer *et al*. 2006). However, fluctuations in numbers between months and winters within WeBS sections in Nigg Bay (data not presented) suggests that this is not repeated on a finer scale.

By W2 and W3, Nigg Bay MRS supported all of the most abundant species found in Nigg Bay and supported over 2000 individual waterbirds. Changes in the bird assemblage over the course of the study may partly be attributed to the site becoming more open as the southern embankment eroded at the breach gaps, increasing the ecological connectivity with Nigg Bay (Pontee *et al*. 2006) and reducing the perceived predation risk of species such as Bar-tailed Godwit, which prefer more open sites (Summers *et al*. 2002).

5.4.3 Comparison between the waterbird assemblage in Nigg Bay Managed Realignment Site and that of Nigg Bay

All of the species recorded in Nigg Bay MRS (except Little Grebe) were also recorded in Nigg Bay WeBS counts between winters 1998/1999 and 2005/2006. The proportion of the long-term mean number of birds expected in Nigg Bay MRS varied according to the habitat being compared (Table 5.2). When comparing the available feeding habitat i.e. the intertidal flats, Nigg Bay MRS would be expected to support < 1% of Nigg Bay birds. By W3 six of the eight waterbird species had exceeded this expectation. However, this comparison assumes that birds in Nigg Bay are distributed evenly across the entire intertidal flats and that this is a fixed area available throughout the tidal cycle. The actual area of intertidal flat varies throughout the tidal cycle and bird distributions across the available area will usually be determined by the distributions of their invertebrate prey (Goss-Custard *et al*. 1977b, 1977c; Bryant 1979), which are often patchy (Colwell & Landrum 1993; Lourenço *et al*. 2005). Furthermore, some wader species are tide followers feeding at high density along the tide edge as it progresses over the intertidal flats (Granadeiro *et al*. 2006).

When comparing the available roosting habitat, i.e. the saltmarsh, Nigg Bay MRS would be expected to support 9% or 15% of birds, depending on whether the comparison is of the saltmarsh area or length of seaward edge. Assuming even density at roost sites is probably an over-simplification as waders often have several roost sites, which are occupied at a high density (Colwell *et al*. 2003). Only one species, Eurasian Curlew, reached the proportion expected based on area of saltmarsh available for roosting. However, length of seaward edge is probably the most valid comparison, particularly for waders, which tend to roost along the seaward edge of the saltmarsh at high tide rather than distribute themselves evenly across it. Although mean proportions did not reach 15% for any species, there were occasions when the Nigg Bay MRS supported peak numbers greater than 15% of the long term mean numbers of Bar-tailed Godwit, Eurasian Curlew, Common Redshank, Common Shelduck and Eurasian Wigeon in Nigg Bay.

The significance of these occasional peaks, including half of the nationally important population of Eurasian Curlew, depends upon the cause. The timing of the peak numbers in Nigg Bay MRS do not correspond with significantly higher monthly means in Nigg Bay and are therefore likely to be attributable to redistribution of Nigg Bay birds. These birds may have been displaced from sites elsewhere in Nigg Bay by natural (Cresswell & Whitfield 1994) or human disturbance (Madsen & Fox 1995; Fox

& Madsen 1997; Crowther & Elliott 2006) or may be deriving particular benefits from using the managed realignment site at these times (Chapter 6).

5.4.4 Waterbird colonisation of other UK managed realignment sites

Comparisons between wader and wildfowl colonisation of the Nigg Bay MRS and other UK sites are hampered by a lack of published studies. The timing of site creation is likely to have implications for bird colonisation as recruitment of invertebrate prey into the managed realignment site by midwinter is likely to be greater in a managed realignment site breached earlier in the year compared to one breached at the onset of winter. At Orplands and Tollesbury Managed Realignment Sites (Essex), breached in April and August 1995 respectively, both Eurasian Curlew and Common Redshank colonised in the first year, as in Nigg Bay MRS, but Dunlin, which were not recorded in the Nigg Bay MRS until the second year, were also noted (Atkinson *et al*. 2004). Most species at Tollesbury and Orplands Managed Realignment Sites colonised in the second winter but Red Knot did not colonise until the fourth winter which was attributed to the spread of *M. balthica* across the site. Colonisation of Nigg Bay MRS by Red Knot in the third winter also coincided with *M. balthica* reaching expected densities (Chapter 4).

5.5 Conclusion

Three years post-breach, Nigg Bay MRS was supporting many of the most common wader and wildfowl species recorded in Nigg Bay and supported over 2000 individual waterbirds. The following chapters will investigate waterbird use of Nigg Bay MRS in more detail to understand how it is used both temporally (through the tide cycle and in relation to prevailing weather conditions, Chapter 6) and spatially (Chapter 7) and to gain an insight into how Nigg Bay MRS and the adjacent estuary are used by individual birds (Chapter 8).

Chapter 6

How tidal cycle and weather affect patterns of use of Nigg Bay Managed Realignment Site by non-breeding waterbirds

6.1 Introduction

Waterbird activities in intertidal habitats can be affected temporally by both the tidal cycle (Section 1.1.3.3) and prevailing weather conditions (Section 1.1.3.4). Although the energy intake rate of waders is often greater on lower intertidal flats, most of their energetic requirements are met on the upper intertidal flats, as these are accessible for longer periods (Section 1.1.3.3). Conservation of upper intertidal flats is therefore essential in order to continue to support nationally and internationally important populations of waterbirds (Section 1.1.5). Managed realignment can be used to restore upper intertidal flats for foraging habitat and saltmarsh for high-tide roosting sites (Section 1.1.6).

Where managed realignment is adopted to replace or supplement existing upper intertidal habitats it is important to establish whether they can support the same patterns of waterbird behaviour. Usage might be expected to be greater at higher tidal states, when the lower intertidal flats are inundated, and in harsher weather conditions, when the enclosed nature of the managed realignment site may provide sheltering benefits. Peak usage might be expected to occur when harsh weather conditions coincide with higher tidal states. At these times waterbirds may use the managed realignment site for top-up feeding, exploiting the additional foraging time to allow them to meet their increased energy requirements.

This chapter investigates the value of Nigg Bay MRS as habitat for non-breeding waterbirds and attempts to answer the following questions: Which activities (foraging, resting, loafing) are waterbirds undertaking in Nigg Bay MRS? How does the role of Nigg Bay MRS as a resource for non-breeding waterbirds change in response to temporal variations in tide and weather? How do temporal patterns of behaviour vary across species?

6.2 Methods

6.2.1 Wader and wildfowl monitoring

In W2 and W3 (Table 5.1), Nigg Bay MRS was monitored throughout the diurnal tidal cycle (except in W2 when quantitative data were not collected for the period when the intertidal sediments in the site were completely submerged). The number of individuals of each wader and wildfowl species in the area below mean high water springs (MHWS) was recorded at 15 min intervals (15 min observations). A note was also made of the activity undertaken by each individual bird, whether foraging, resting (all non-foraging activity, including roosting) or, in the case of waterfowl, loafing (non-foraging activity on the water). Data were collected on 47 days (from October to January, inclusive) in W2 and on 21 days (from September to February, inclusive) in W3, including at least two spring tides and one neap tide each month.

6.2.2 Data analysis

This study focussed on eight waterbird species common in Nigg Bay (Table 6.1). The eight species were divided into two groups, waders and wildfowl.

Table 6.1: Selected common over-wintering waterbird species in Nigg Bay. Species included are the six most abundant wader and two most abundant wildfowl species based on the long-term WeBS data for Nigg Bay (Chapter 5).

	Group	Species		Code*
Waterbirds	**Waders**	Bar-tailed Godwit	*Limosa lapponica*	BA
		Eurasian Curlew	*Numenius arquata*	CU
		Dunlin	*Calidris alpina*	DN
		Red Knot	*Calidris canatus*	KN
		Eurasian Oystercatcher	*Haematopus ostralegus*	OC
		Common Redshank	*Tringa totanus*	RK
	Wildfowl	Common Shelduck	*Tadorna tadorna*	SU
		Eurasian Wigeon	*Anas penelope*	WN

* Species notation follows the convention of the WeBS wader and wildfowl counts

The tidal cycle was divided into four tide states (TS0-TS3) according to the location of the tide line in relation to Nigg Bay MRS (Table 6.2). The tide was absent from the site (TS0) for the duration of the neap tidal cycle so TS1-TS3 only occurred during the spring tidal cycle.

Table 6.2: Descriptions of the four tide states (TS) referred to throughout the text.

Tide state	Position of the tide line in the managed realignment site	Proportion of Nigg Bay intertidal flats inundated (%)
TS0	Tide absent	< 99
TS1	Tide present and the intertidal sediments partially inundated	> 99
TS2	Tide present and the intertidal sediments fully inundated	100
TS3	Tide present and the developing saltmarsh partially inundated	100

6.2.2.1 Patterns through the tidal cycle

The data sets for both winters were analysed separately as there were significant differences in the number of birds using Nigg Bay MRS between the two winters (Chapter 5). As the purpose of this section of the chapter is to compare the proportional distribution of bird numbers between the four tide states (TS0-TS3), data for entire days on which a group or species was not recorded in Nigg Bay MRS were excluded from the subsequent analyses. This approach means that the analyses reflect the behaviour of each group and species for all days on which it was recorded in Nigg Bay MRS for at least part of the tidal cycle. From the 15 min observations for each group and species, a daily mean number of birds was calculated for each tide state (**daily tide state mean**) and for each activity (foraging, resting and loafing) at each tide state (**daily tide state activity mean**). The mean of the daily tide state means (**annual tide state mean**) and mean of the daily tide state activity means (**annual tide state activity mean**) were calculated for each winter (W2 and W3).

The majority of the data were highly positively skewed with many zero values. A nonparametric equivalent of the one-way ANOVA, the Kruskal-Wallis test with multiple comparisons, was performed to test for significant differences in the numbers of birds between tide states. As the Kruskal-Wallis test is an unpaired ranks test, it evaluates data against the null hypothesis that samples are taken from populations with the same median. This meant that it was a relatively weak test of the difference between skewed and non-skewed data, as a small number of large values have little influence on the sample median. An advantage of a relatively weak test of this kind is that the probability of Type I error (false positive) is reduced.

Wilcoxon's matched-pairs signed-ranks test, a nonparametric equivalent of the paired *t*-test, was also performed to compare the numbers of birds between specific pairs of tide states. As this is a paired test, and does not rely upon sample medians, it has greater statistical power when comparing skewed versus non-skewed data than the Kruskal-Wallis test. A limitation of this test is the requirement for a minimum of six pairs of data. As the data were paired, this test also went some way to control for confounding factors, such as variable weather conditions (which were analysed in

Section 6.2.2.2). To avoid the reduction in statistical power associated with multiple testing, a conservative approach was adopted and only one comparison was made per data set. Each comparison was chosen under the prior assumption that it would show the greatest difference, given the expected behaviour of the birds. Overall numbers of birds, and numbers foraging, were compared between TS0 and TS1, numbers resting were compared between TS0 and TS2 and numbers loafing were compared between TS0 and TS3.

The Mann-Whitney *U* test, a nonparametric equivalent of the independent samples *t*-test, was performed to compare the number of birds between W2 and W3 at both TS0 and TS1. As with the Kruskal-Wallis test, the null hypothesis is that samples are drawn from populations with the same median, so this will also be a relatively weak test of skewed versus non-skewed data.

6.2.2.2 Patterns in relation to weather

Daily weather data for Kinloss (supplied by the Met Office, UK) were collated for each day that observations were recorded in Nigg Bay MRS. The use of daily data has the disadvantage that it extends beyond the diurnal data collection period. However, bird behaviour is likely to be affected by these longer-term conditions, in addition to weather conditions at the time of observation. The variables considered were: day length, maximum temperature, minimum temperature, rainfall, minimum grass temperature, average wind speed and wind direction. Day length was calculated using a sunrise/sunset table for Nigg Bay (US Naval Observatory) and recorded to the nearest hour. For the purposes of analysis, wind direction was divided into northerly (270º to 89º, coded 0) and southerly winds (90º to 269º, coded 1). As weather variables are expected to be correlated, Principal Component Analysis (PCA) was performed. This method was favoured over the General Linear Model (GLM) approach since it allowed the weather data to be treated as continuous variables, rather than dividing each variable into discrete categories.

For the purposes of analysis of waterbird use of the Nigg Bay MRS in relation to weather, the tidal cycle was divided into two states, tide absent (TS0) and tide present (TS1-TS3). From the 15 min observations for each group and species, a daily maximum number of birds was calculated for each tide state (**daily tide state peak**) and for each activity (foraging, resting and loafing) at each tide state (**daily tide state activity peak**). The maximum of the daily tide state activity peaks (**annual tide state activity peak**) was calculated for each winter (W2 and W3).

Each component generated by the PCA was introduced as a variable into multiple regression analysis to determine which combination of weather conditions affected the peak number of individuals of each species in Nigg Bay MRS at each tide state.

6.2.2.3 Disturbance

On each day that observations were made in Nigg Bay MRS, potential human and natural disturbances were noted (Appendix 7). An unpaired *t*-test between days with and without disturbance established that disturbance events did not significantly affect the daily peak number of each species recorded in Nigg Bay Managed Realignment Site, so it was considered appropriate to treat days with and without disturbance as a single dataset in the above analyses. However, subtle effects of disturbance would not be revealed in this analysis.

6.3 Results

6.3.1 Principal component analysis of the weather data

PCA of the weather data generated three components accounting for 76.2% of the variation (Table 6.3). C1 (with a high positive weighting for day length, maximum temperature, minimum temperature and minimum grass temperature) accounted for 38.9% of the variation. C2 (with a high positive weighting for maximum temperature and wind direction and a high negative weighting for average wind speed) accounted for 21% of the variation. C3 (with a high positive weighting for wind speed and a high negative weighting for rainfall) accounted for 16.0% of the variation.

Table 6.3: Principal Component Analysis of the daily weather data for Kinloss (data supplied by the MET Office). Weightings of each of the measured variables for each component (C1, C2 and C3) are shown, together with the total variance explained by each component.

Weather variables	**Units**	**Component**		
		C1	**C2**	**C3**
Day length	h	**0.71**	0.26	-0.44
Maximum temperature	°C	**0.69**	**0.54**	0.03
Minimum temperature	°C	**0.89**	-0.02	0.27
Rainfall	mm	0.28	-0.39	**-0.58**
Minimum grass temperature	°C	**0.89**	-0.19	0.24
Average wind speed	kn	0.19	**-0.72**	**0.52**
Wind direction	N/S	-0.20	**0.64**	0.46
Variance explained (%)		38.9	21.0	16.3

6.3.2 Waterbirds

Waterbirds used Nigg Bay MRS throughout the tidal cycle (Figure 6.1a), however, numbers were significantly greater when the tide was present in W2 (TS1) and W3 (TS1-TS3) than when it was absent (TS0) (Table 6.4). In W3, numbers of both foraging and resting waterbirds were significantly greater when the tide was present (TS1 and TS2) than when it was absent (TS0) (Table 6.5).

6.3.3 Waders

Waders used Nigg Bay MRS for both foraging and resting throughout the tidal cycle (Figure 6.1b). In W2 and W3 significantly greater numbers of waders used Nigg Bay MRS when the tide was present but intertidal sediments were exposed (TS1) than when the tide was absent (TS0) (Table 6.4). In W3, numbers of foraging waders were significantly greater when the tide was present but intertidal sediments were exposed (TS1) than when the tide was absent (TS0) or when the tide was encroaching on the developing saltmarsh (TS3) (Table 6.5). There was a significant negative relationship between numbers of foraging waders when the tide was present in the site (TS1-TS3) and C2 (Table 6.6). More waders were recorded foraging in Nigg Bay MRS on colder days when there was a strong, northerly wind.

6.3.4 Wildfowl

Wildfowl used Nigg Bay MRS throughout the tidal cycle (Figure 6.1a). Numbers of wildfowl were significantly greater when the tide was present in W2 (TS1) and W3 (TS1-TS3) than when it was absent (TS0) (Table 6.4). In W3 numbers of foraging wildfowl were significantly greater when the tide was present (TS1-TS3) than when it was absent (TS0) (Table 6.5). There was a significant relationship between the number of birds resting in Nigg Bay MRS when the tide was absent (TS0) and weather (Table 6.6). However, it was not possible to determine with which component.

6.3.5 Individual species accounts

Peak numbers of foraging and resting birds of many species occurred when the maximum daily temperature was below the monthly average and when there was a strong north-westerly wind and snow, sleet or hail (Table 6.7).

6.3.5.1 Bar-tailed Godwit

Bar-tailed Godwit were not recorded in Nigg Bay MRS in W2 (Figure 6.2a) and in W3 they were recorded infrequently (Table 6.8). When present in the site, Bar-tailed Godwit fed in low numbers (average < 1 bird) at all stages of the tidal cycle (Figure 6.2b). Larger numbers (on average between 8.7 and 10.2 birds) were present as roosting flocks after the intertidal sediments in the site became submerged (TS2 and TS3) (Table 6.5).

6.3.5.2 Eurasian Curlew

Eurasian Curlew were recorded in Nigg Bay MRS in both W2 and W3 (Figure 6.2a) and in W3 were frequently recorded both foraging and resting at all tide states (apart from foraging at TS2) (Table 6.8). In W3 numbers of Eurasian Curlew were greater when the tide was present but intertidal sediments were exposed (TS1) than when the tide was absent (TS0) (Table 6.4). The average number of Eurasian Curlew using Nigg Bay MRS was greater in W3 than in W2 (Table 6.9). There was a significant negative relationship between numbers of Eurasian Curlew when the tide was absent (TS0) and C2 (Table 6.6). More Eurasian Curlew were recorded across all activities and foraging in Nigg Bay MRS on colder days when there was a strong, northerly wind.

6.3.5.3 Dunlin

Dunlin were recorded in Nigg Bay MRS infrequently in both W2 and W3 (Table 6.8). Dunlin typically used Nigg Bay MRS for foraging after the intertidal sediments had become submerged (TS2 and TS3) (Figure 6.2b).

6.3.5.4 Red Knot

Red Knot were not recorded in Nigg Bay MRS in W2 (Figure 6.2a) and were recorded infrequently in W3 (Table 6.8). Red Knot was the only species that did not use Nigg Bay MRS until the intertidal sediments had become submerged (TS2 and TS3) (Figure 6.2a). Apart from a small number of foraging individuals (average < 1 bird) before the tide encroached on the developing saltmarsh, all records were of resting birds (Figure 6.2b).

6.3.5.5 Eurasian Oystercatcher

Eurasian Oystercatcher were recorded in Nigg Bay MRS in W2 and W3 (Figure 6.2a). In W3, Eurasian Oystercatcher were frequently observed foraging and occasionally observed resting when the intertidal sediments in Nigg Bay MRS were exposed (TS0 and TS1) (Table 6.8). When the intertidal flats were submerged (TS2), Eurasian Oystercatcher used Nigg Bay MRS infrequently to feed and rest and were never present when the tide encroached on the developing saltmarsh (TS3) (Table 6.7). Eurasian Oystercatcher were only present in small numbers (average < 1 bird) (Figure 6.2a) and used Nigg Bay MRS mainly for foraging (Figure 6.2b), particularly when the intertidal sediments were exposed (TS0 and TS1) (Table 6.5).

6.3.5.6 Common Redshank

In W2 and W3 more Common Redshank used Nigg Bay MRS when the tide was present but intertidal sediments were exposed (TS1) than when the tide was absent (TS0) (Table 6.4). However, the average number of birds at both tide states was lower in W3 (Table 6.9). The average number of birds foraging in Nigg Bay MRS was greater as the tide advanced over the intertidal sediments in the site (TS1) than when the tide was absent (TS0) or when the tide was present in Nigg Bay MRS and encroaching on the developing saltmarsh (TS3) (Table 6.5). The average number of resting birds increased through the tidal cycle, with significantly more resting after the intertidal sediments had become submerged (TS2 and TS3) than when the tide was absent (TS0). There was a significant negative relationship between overall numbers of Common Redshank and numbers foraging when the tide was present (TS1-TS3), and C2 (Table 6.6). There was also a significant positive relationship between numbers of resting Common Redshank when the tide was present (TS1-TS3) and C2 (Table 6.6). More Common Redshank were recorded across all activities and foraging, but fewer were recorded resting, in Nigg Bay MRS on colder days when there was a strong, northerly wind.

6.3.5.7 Common Shelduck

Common Shelduck were recorded in Nigg Bay MRS in W2 and W3 (Figure 6.2a). In W3 Common Shelduck frequently used the managed realignment site for foraging and loafing when the tide was present (TS1-TS3), but rested in the site infrequently (Table 6.8). There were significant negative relationships between overall numbers of Common Shelduck and C1 (TS1-TS3) and C2 (TS0 and TS1-TS3) (Table 6.9). There were more Common Shelduck recorded in the managed realignment site on shorter, colder days when there was a strong, northerly wind.

6.3.5.8 Eurasian Wigeon

Eurasian Wigeon were recorded in Nigg Bay MRS in W2 and W3 (Figure 6.2a). In W3 Eurasian Wigeon frequently used Nigg Bay MRS for loafing when the tide was present in the site (TS1-TS3) and for foraging once the intertidal flat was submerged (TS2-TS3) (Table 6.8). The average number of Eurasian Wigeon was an order of magnitude greater in W3 than in W2 (Table 6.8 and Figure 6.2a).

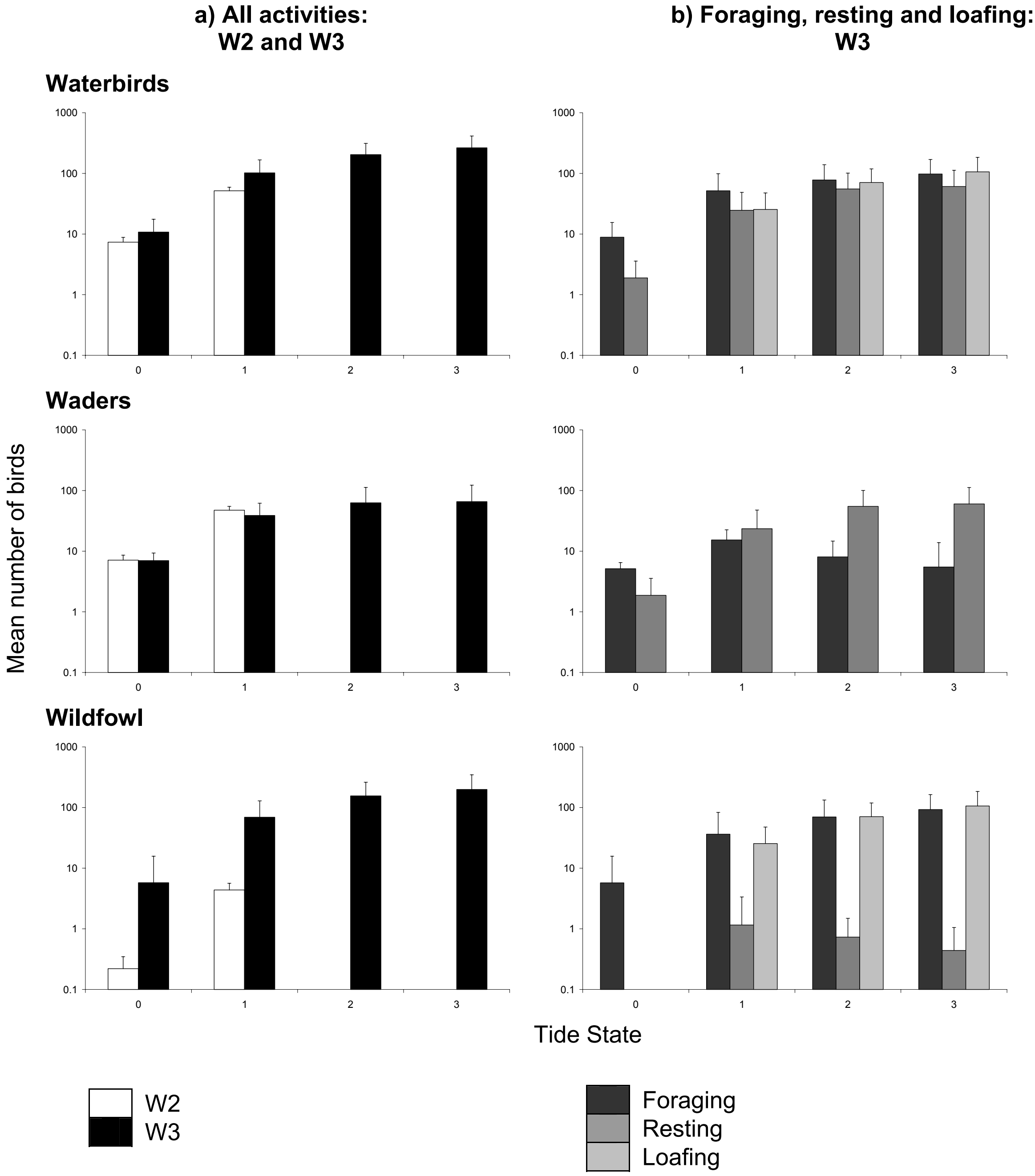


Figure 6.1: Variation in annual tide state mean numbers of waterbirds, waders and wildfowl in Nigg Bay Managed Realignment Site for W2 (TS0-TS1) and W3 (TS0-TS3). Annual tide state activity mean numbers of birds are also presented for W3. Error bars show the upper 95% confidence limits.

Table 6.4: Tests for significant differences in the annual tide state mean numbers of birds recorded in Nigg Bay Managed Realignment Site in W2 and W3. Statistically significant values are emboldened.

Category/species	W2			W3						
	Wilcoxon's matched-pairs signed-ranks test between TS0 and 1			**Kruskal-Wallis test across TS0-3**		Multiple comparison test		**Wilcoxon's matched-pairs signed-ranks test between TS0 and 1**		
	***n*[¶]**	***z***	**TS diff[†]**	***n*[§]**	χ^2	***Q***	**TS diff[†]**	***n*[¶]**	***z***	**TS diff[†]**
Waterbirds	32	**-4.9***	**TS1 > TS0**	52	**20.4***	**3.3***	**TS2 > TS0**	11	**-2.8***	**TS1 > TS0**
						3.9*	**TS3 > TS0**			
Waders	32	**-4.9***	**TS1 > TS0**	52	7.6			11	**-2.8***	**TS1 > TS0**
BA	0	—		27	4.4			3	—	
CU	32	-0.5		52	0.3			10	**-2.1***	**TS1 > TS0**
DN	23	**-3.9***	**TS1 > TS0**	12	5.5			1	—	
KN	1	—		14	—			0	—	
OC	22	-0.4		38	**16.4***	**3.9***	**TS0 > TS3**	8	-1.3	
RK	32	**-4.9***	**TS1 > TS0**	46	2.7			10	**-2.2***	**TS1 > TS0**
Wildfowl	32	**-4.2***	**TS1 > TS0**	43	**18.8***	**3.5***	**TS2 > TS0**	9	**-2.7***	**TS1 > TS0**
						3.8*	**TS3 > TS0**			
SU	20	**-3.8***	**TS1 > TS0**	35	**19.2***	**2.7***	**TS1 > TS0**	8	**-2.5***	**TS1 > TS0**
						3.6*	**TS2 > TS0**			
						3.7*	**TS3 > TS0**			
WN	15	**-2.8***	**TS1 > TS0**	41	**17.4***	**3.4***	**TS2 > TS0**	8	**-2.5***	**TS1 > TS0**
						3.8*	**TS3 > TS0**			

¶ *n* (Wilcoxon's matched-pairs signed-ranks test) is the number of days on which paired data were collected.
§ *n* (Kruskal-Wallis test) is the sum of the number of tide states on which observations were made.
† 'TS diff' indicates which tidal state has the higher number of birds for all cases where the difference is statistically significant.
* Asterisks indicate statistically significant differences ($P < 0.05$).
— Indicates statistical analysis could not be undertaken because there were fewer than six pairs.

Table 6.5: Tests for significant differences in the annual tide state activity mean numbers of birds recorded in Nigg Bay Managed Realignment Site in W3. Statistically significant values are emboldened.

Category/ species	Foraging							Resting							Loafing						
	Kruskal-Wallis test across TS0-3		Multiple comparison test		**Wilcoxon's matched-pairs signed-ranks test between TS0 and 1**			**Kruskal-Wallis test across TS0-3**		Multiple comparison test		**Wilcoxon's matched-pairs signed-ranks test between TS0 and 2**			**Kruskal-Wallis test across TS0-3**		Multiple comparison test		**Wilcoxon's matched-pairs signed-ranks test between TS0 and 3**		
	n[§]	χ^2	Q	TS diff[†]	n[¶]	z	TS diff[†]	n[§]	χ^2	Q	TS diff[†]	n[¶]	z	TS diff[†]	n[§]	χ^2	Q	TS diff[†]	n[¶]	z	TS diff[†]
Waterbirds	52	7.3			11	**-2.2***	**TS1 > TS0**	52	**10.1***	**3.2***	**TS2 > TS0**	11	**-2.9***	**TS2 > TS0**							
Waders	52	**11.7***	**3.4***	**TS1 > TS3**	11	**-2.1***	**TS1 > TS0**	52	**8.3***	**2.9***	**TS2 > TS0**	11	**-2.9***	**TS2 > TS0**							
BA	27	3.2			3	—		27	**12.3***	**2.8* 3.3***	**TS2 > TS1 TS2 > TS0**	5	—								
CU	52	**25.2***	**4.1* 4.0***	**TS0 > TS2 TS0 > TS3**	10	-0.6		52	1.9			8	**-2.4***	**TS2 > TS0**							
DN	12	3.3			1	—		12	3.5			1	—								
KN	13	—			0	—		13	—			2	—								
OC	38	**20.0***	**3.3* 3.8***	**TS0 > TS2 TS0 > TS3**	8	-1.1		38	6.2			5	—								
RK	45	**8.2***	**2.8***	**TS1 > TS3**	10	**-2.2***	**TS1 > TS0**	45	**11.7***	**2.8* 2.7***	**TS2 > TS0 TS3 > TS0**	7	**-2.4***	**TS2 > TS0**							
Wildfowl	43	**13.8***	**3.0* 3.2***	**TS2 > TS0 TS3 > TS0**	7	**-2.4***	**TS1 > TS0**	43	3.3			5	—		43	**25.5***	**3.0* 4.0* 4.5***	**TS1 > TS0 TS2 > TS0 TS3 > TS0**	10	**-2.8***	**TS3 > TS0**
SU	35	6.4			7	**-2.2***	**TS1 > TS0**	35	6.7			4	—		35	**20.4***	**2.7* 3.5* 4.0***	**TS1 > TS0 TS2 > TS0 TS3 > TS0**	8	**-2.5***	**TS3 > TS0**
WN	41	**13.1***	**2.8* 3.2***	**TS2 > TS0 TS3 > TS0**	4	-1.8		41	0.9			1	—		41	**21.7***	**3.8* 4.2***	**TS2 > TS0 TS3 > TS0**	10	**-2.8***	**TS3 > TS0**

¶ *n* (Wilcoxon's matched-pairs signed-ranks test) is the number of days on which paired data were collected.
§ *n* (Kruskal-Wallis test) is the sum of the number of tide states on which observations were made.
† 'TS diff' indicates which tidal state has the higher number of birds for all cases where the difference is statistically significant.
* Asterisks indicate statistically significant differences ($P < 0.05$).
— Indicates statistical analysis could not be undertaken because there were fewer than six pairs.

Table 6.6: Results of multiple regression analysis to investigate relationships between the daily tide state peak numbers of birds recorded in Nigg Bay Managed Realignment Site and weather components (C1, C2 and C3) at TS0 and TS1-3 in W2 and W3.

Category/species	All activities				Feeding				Resting				Loafing			
		ANOVA	*t* -test			ANOVA	*t* -test			ANOVA	*t* -test			ANOVA	*t* -test	
	n¶	*F*	*t*	C†	*n*§	*F*	*t*	C†	*n*§	*F*	*t*	C†	*n*§	*F*	*t*	C†
TS0																
Waterbirds	61	0.1			20	0.2			20	2.4						
Waders	61	1.0			20	1.5			20	2.5						
BA	9	0.6			9	0.7			9	0.1						
CU	61	**3.3***	**-2.9 ***	**C2**	20	**3.7***	**-3.2 ***	**C2**	20	2.7						
DN	31	2.2			3	—			3	—						
KN	5	0.7			3	—			3	—						
OC	46	1.6			14	0.8			14	0.9						
RK	57	0.2			16	3.0			16	0.2						
Wildfowl	54	0.5			13	0.3			13	**6.2***			13	1.4		
SU	35	**2.9***	**-2.6 ***	**C2**	11	2.0			11	**5.8***			11	0.5		
WN	33	0.6			11	0.3			11	1.6			11	1.6		
TS1-3																
Waterbirds	49	1.0			11	0.3			11	2.9						
Waders	49	2.7			11	**17.0***	**-5.5 ***	**C2**	11	2.7						
BA	6	2.1			6	0.6			6	2.0						
CU	49	0.8			11	0.7			11	1.4						
DN	29	2.3			3	—			3	—						
KN	5	1.0			3	—			3	—						
OC	37	1.4			8	0.3			8	2.0						
RK	47	**6.2***	**-3.6 ***	**C2**	10	**9.8***	**-2.8 ***	**C2**	10	**21.5***	**5.8***	**C2**				
Wildfowl	48	0.5			10	0.1			10	0.2			10	0.3		
SU	37	**7.1***	**-4.3 ***	**C1**	9	2.0			9	0.3			9	2.5		
			-2.1 *	**C2**												
WN	27	1.2			10	0.1			10	0.1			10	0.2		

¶ *n* (all activities) is the number of days on which data were collected in both winters 2004-2005 and 2005-2006.
§ *n* (feeding, resting and loafing) is the number of days on which data were collected in winter 2005-2006.
† C indicates which of the weather components is significantly related to the number of birds for all cases where the multiple regression is statistically significant.
* Asterisks indicate statistically significant differences ($P < 0.05$).
— Indicates statistical analysis could not be undertaken.

Table 6.7: Annual tide state activity peak numbers of birds recorded in Nigg Bay Managed Realignment Site together with the tidal state and weather conditions recorded at Kinloss in W3. Asterisks indicate below average temperatures, greater than average wind speeds and greater than average rainfall.

Sp.	Activity	Peak	Month	Tide	Day length	Max temp (ºC)	Min temp (ºC)	Min grass temp (ºC)	Wind speed (kn)	Wind dir	Rain (mm)	Snow/ sleet**	Hail**	Gale**
BA	F	31	Jan	TS3	7	6.7*	5.8	1.7	8	SW	0.0			
	R	220	Dec	TS3	7	3.6*	2.9	1.0	19*	NW	0.4	✓	✓	
CU	F	13	Nov	TS0	7	6.0*	2.5*	0.7	21*	NW	9.6*	✓	✓	✓
	R	297	Dec	TS2	7	3.6*	2.9	1.0	19*	NW	0.4	✓	✓	
DN	F	173	Dec	TS3	7	3.6*	2.9	1.0	19*	NW	0.4			
	R	3	Jan	TS3	7	6.7*	5.8	1.7	8	SW	0.0			
KN	F	10	Dec	TS2	7	3.6*	2.9	1.0	19*	NW	0.4	✓	✓	
	R	243	Jan	TS2	7	6.7*	5.8	1.7	8	SW	0.0			
OC	F	8	Oct	TS0	10	17.8	6.8*	1.2*	6	S	7.6*			
	R	3	Nov	TS2	8	5.7*	0.5*	-1.5*	8	SW	0.0			
RK	F	109	Dec	TS2	7	3.6*	2.9	1.0	19*	NW	0.4	✓	✓	
	R	61	Dec	TS3	7	3.6*	2.9	1.0	19*	NW	0.4	✓	✓	
SU	F	24	Jan	TS2	7	6.7*	5.8	1.7	8	SW	0.0			
	R	8	Nov	TS2	9	13.9	5.8	2.8	4	SE	1.0			
	L	25	Jan	TS3	7	6.7*	5.8	1.7	8	SW	0.0			
WN	F	555	Nov	TS1	9	13.9	5.8	2.8	4	SE	1.0			
	R	45	Feb	TS1	9	9.5	4.6	-0.3	10	SW	0.0			
	L	509	Nov	TS3	9	13.9	5.8	2.8	4	SE	1.0			

** Snow, sleet or hail fell or a gale (mean wind speed reached 34 knots or more) occurred within the last 24 hours from 0000 GMT.

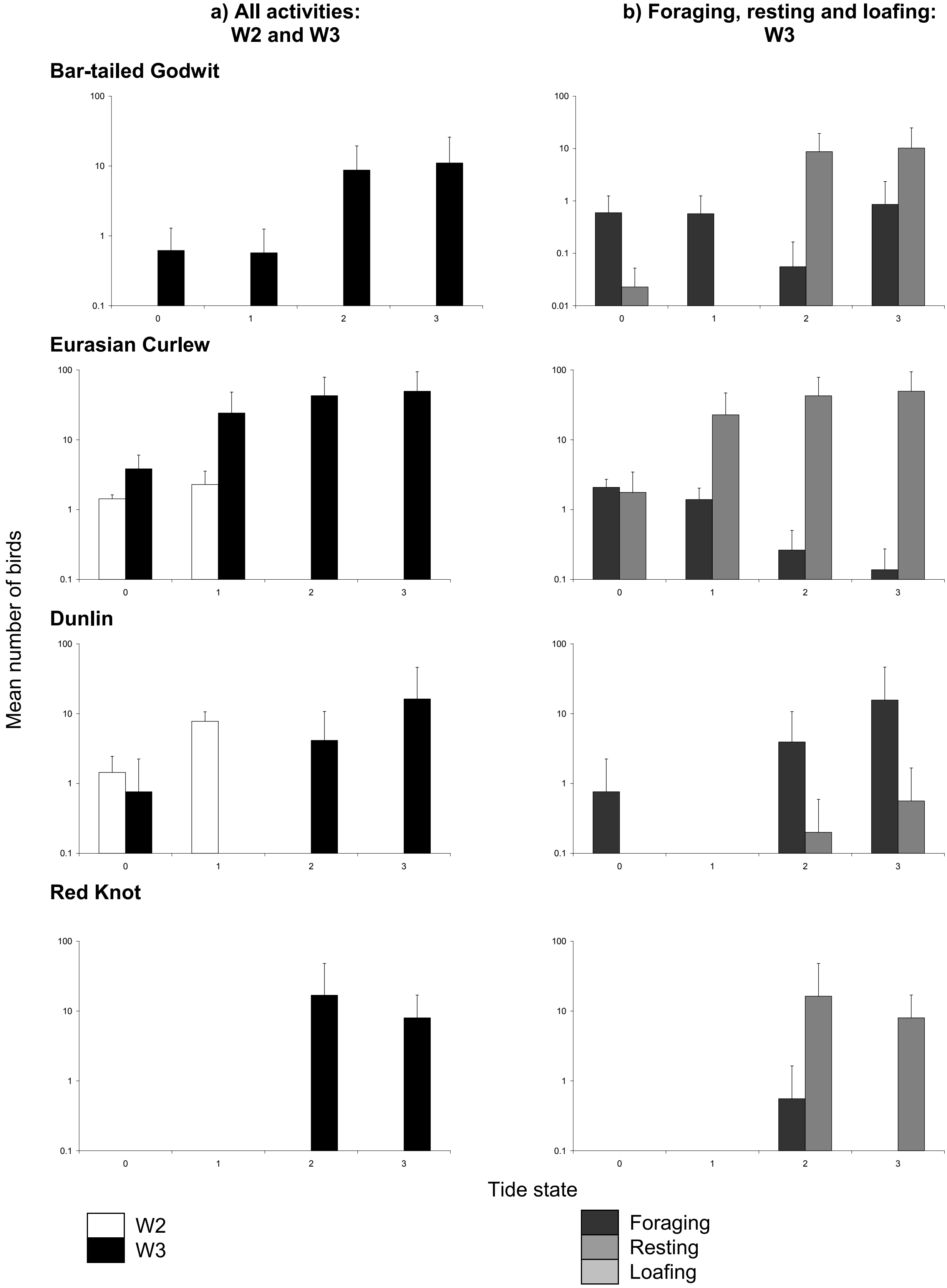


Figure 6.2: Variation in annual tide state mean numbers of selected wader and wildfowl species in Nigg Bay Managed Realignment Site in W2 (TS0-TS1) and W3 (TS0-TS3). Annual tide state activity mean numbers of birds are also presented for W3. Error bars show the upper 95% confidence limits. Continues overleaf.

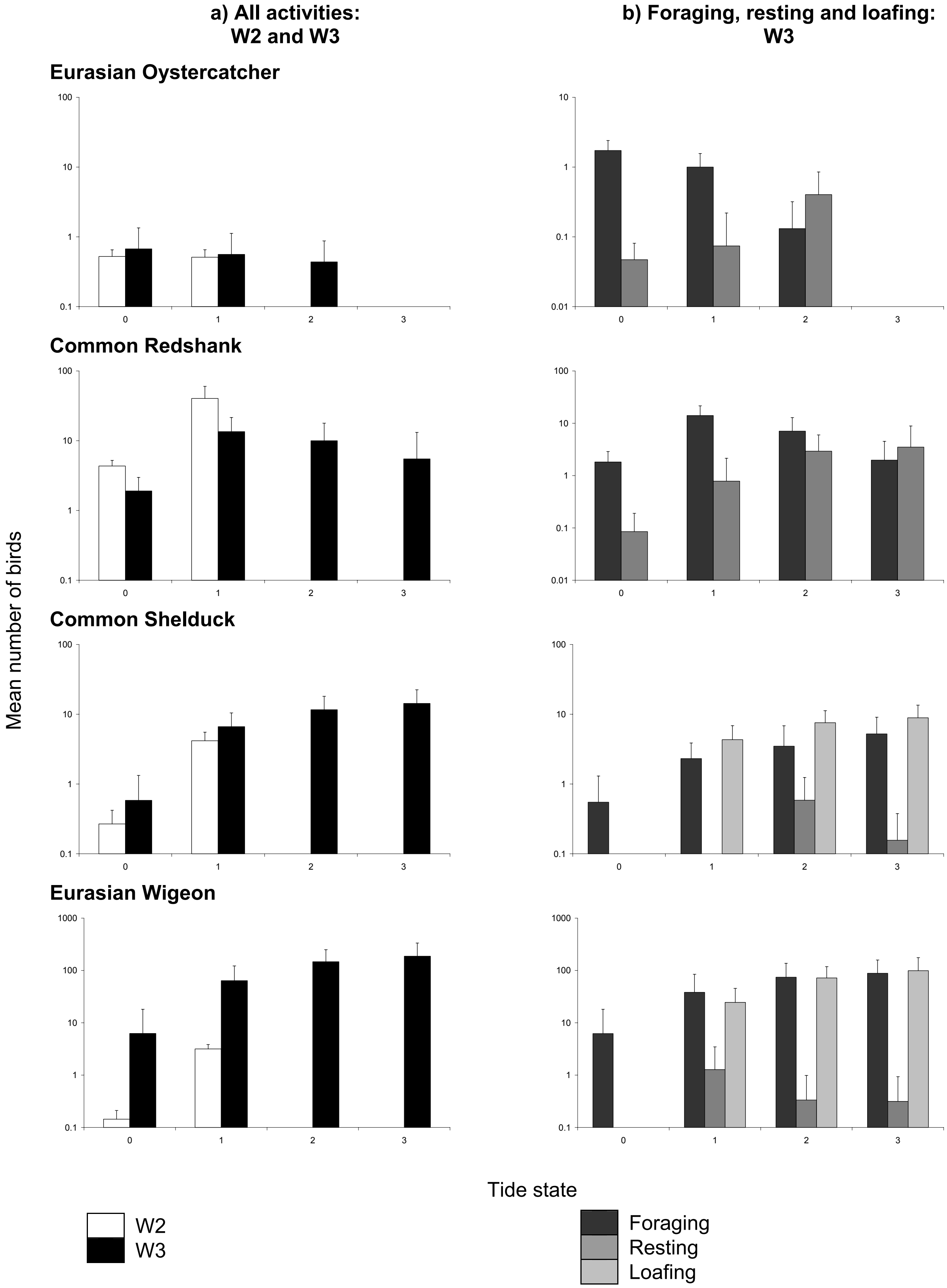


Figure 6.2: Continued.

Table 6.8: Percentage of days on which each wader and wildfowl species was recorded in Nigg Bay Managed Realignment Site at each tide state in W3.

Species	Behaviour	Tide state			
		TS0	TS1	TS2	TS3
BA	Foraging	30	20	9	20
	Resting	15	0	45	30
CU	Foraging	**90** ‡	**90** ‡	36	**50**‡
	Resting	**75** ‡	**70** ‡	**64** ‡	**80**‡
DN	Foraging	5	0	18	10
	Resting	0	0	9	10
KN	Foraging	0	0	9	0
	Resting	0	0	18	20
OC	Foraging	**65** ‡	**60** ‡	18	0
	Resting	35	10	27	0
RK	Foraging	**80** ‡	**80** ‡	**64**‡	40
	Resting	25	30	**64**‡	**70**‡
SU	Foraging	20	**70** ‡	**55**‡	**50**‡
	Resting	10	0	36	20
	Loafing	5	**70** ‡	**64**‡	**80**‡
WN	Foraging	10	40	**73**‡	**90**‡
	Resting	5	20	9	10
	Loafing	5	**70** ‡	**82** ‡	**100**‡

‡ Indicates tide states at which a species was recorded on at least 50% of days on which observations were made, which was taken as an indication that the species was a regular user of the managed realignment site.

Table 6.9: Tests for significant differences in the annual tide state mean numbers of each wader and wildfowl species recorded in the managed realignment site during W2 and W3.

Species	Mann-Whitney *U* test between W2 and W3					
	TS0			TS1		
	n¤	*t*	W diff†	*n*¤	*t*	W diff†
BA	9	—		9	—	
CU	61	**-2.7***	**W2 < 3**	50	**-3.3***	**W2 < 3**
DN	31	0.7		31	—	
KN	5	—		7	—	
OC	46	**-4.9***	**W2 < 3**	40	**-2.5***	**W2 < 3**
RK	57	**3.4***	**W2 > 3**	48	**5.3***	**W2 > 3**
SU	35	-0.8		35	-1.1	
WN	33	-1.5		27	**-2.7***	**W2 < 3**

¤ *n* is the number of days on which data were collected.
† 'W diff' indicates which winter has the higher number of birds for all cases where the difference is statistically significant.
* Asterisks indicate statistically significant differences ($P < 0.05$).
— Indicates no analysis undertaken due to the species being absent at TS0 or TS1 in at least one winter.

6.4 Discussion

Nigg Bay MRS was used by waterbirds throughout the diurnal tidal cycle, showing that it provides a resource for non-breeding waterbirds over-wintering in Nigg Bay. The number of waterbirds using Nigg Bay MRS varied throughout the tidal cycle, with greater numbers when the tide was present than when the tide was absent. This pattern was reflected in both wader and wildfowl numbers. Waders used Nigg Bay MRS for foraging and resting while wildfowl also loafed, with the numbers of birds undertaking each of these activities varying through the tidal cycle.

6.4.1 Three types of resource

6.4.1.1 A foraging and resting resource while the tide is absent

As an upper intertidal area, the tide is usually absent from Nigg Bay MRS for the duration of the neap tidal cycle and present for a relatively short period during the spring tidal cycle. Each species (except Red Knot) used Nigg Bay MRS in relatively small numbers throughout the period when the tide was absent, despite the availability of intertidal flats elsewhere in Nigg Bay. This could reflect a lower competitive status among these individuals (Chapter 7), meaning that they are unable to establish themselves on preferred sites in the wider Nigg Bay. From a conservation perspective, the regular presence of a small number of individuals over the long periods when the tide is absent from the site may represent an equivalent (or greater) benefit to the populations of these species in Nigg Bay to the presence of a large number of individuals over the short periods when the tide is present.

Eurasian Curlew and Common Shelduck were the only species whose numbers in Nigg Bay MRS were related to weather conditions when the tide was absent from the site (TS0). Both of these species used the site more on colder days when there was a strong, northerly wind (C2) with Eurasian Curlew using it more for feeding. Several other studies have found wind to have a strong influence on wader behaviour (Baker 1974; Dugan 1981; Burger 1982; Pienkowski 1983; Wishart & Sealy 1986; McConkey & Bell 2005). This suggests that Nigg Bay MRS provided a relatively sheltered area for these birds at low tide where they could continue feeding while minimising their energy expenditure on thermoregulation. Against this view, the large body size (and associated small surface area to volume ratio) of Common Shelduck and Eurasian Curlew means that they are expected to be relatively robust to harsh weather conditions (Calder 1974; Goudie & Piatt 1991) and less likely to require sheltered habitats than smaller species. However, in addition to shelter, the enclosed nature of Nigg Bay MRS may increase perceived predation risk, as was found at Seal Sands Managed Realignment Site (Evans *et al*. 2001) and Tollesbury Managed Realignment Site (Atkinson *et al*. 2004). The large body size of these species may make them less vulnerable to attack by avian predators, allowing them to exploit the shelter of Nigg Bay MRS during harsh weather conditions.

6.4.1.2 A foraging resource as the tide passes over the intertidal sediments

Although waders used Nigg Bay MRS for foraging throughout the tidal cycle, the number of foraging waders was greater when the tide was present in the site but intertidal sediments were exposed (TS1) than when the tide was absent (TS0) or present and encroaching on the saltmarsh (TS3). As the tide rises, waders are restricted to progressively smaller areas of the upper intertidal flats. As the lower limit of saltmarsh in Nigg Bay MRS is higher than that of the reference saltmarsh in Nigg Bay (Chapter 2), Nigg Bay MRS is one of the last areas of intertidal flat in Nigg Bay to become inundated and one of the first areas to become exposed after high water. It therefore provides supplementary foraging habitat for waterbirds while intertidal flats elsewhere in Nigg Bay are inundated, as was the case at created intertidal flats at Seal Sands (Evans *et al*. 1979). The larger number of foraging waders in the site when the tide is advancing over the areas of intertidal sediment may also be explained by the fact that some wader species are tide "followers" (Granadeiro *et al*. 2006), and feed at the tide edge throughout the duration of the tidal cycle where they take advantage of increased intertidal invertebrate activity.

The number of foraging wildfowl was also greater when the tide was present in the site (TS1-TS3) than when it was absent (TS0). Although wildfowl may loaf on areas of open water as the tide rises, like waders, they require exposed areas of intertidal sediments or shallow water, such as that available in Nigg Bay MRS, to continue foraging.

As the number of waders foraging in Nigg Bay MRS when the tide was present (TS1-3) was greater on colder days with a strong, northerly wind (C2), this suggests that the site may be functioning as a top-up feeding site. Once the intertidal flats in Nigg Bay become inundated, there is a period when intertidal sediments within Nigg Bay MRS are still accessible. Although this window of time is relatively short, it may be critical, particularly for smaller species. On the Wash, for example, Red Knot, Dunlin and Common Redshank spent over 95% of the available daylight hours feeding in winter (Goss-Custard *et al*. 1977a). Common Redshank suffers the highest mortality during severe weather (Pilcher *et al*. 1974; Davidson & Clark 1985; Clark *et al*. 1993) and has previously been affected by severe winters on the Moray Firth (Swann &

Etheridge 1989; Insley *et al*. 1997). Common Redshank appear to be using Nigg Bay MRS for top-up feeding, as more used the site on colder days when there was a strong, northerly wind (C2), when there would be a greater requirement for them to continue feeding once the adjacent intertidal flats were inundated.

6.4.1.3 A high tide roosting site

Waders used Nigg Bay MRS for resting throughout the tidal cycle, however, the number of resting waders was greater when the tide was present and the intertidal sediments were submerged (TS2) than when the tide was absent (TS0). Whilst ever intertidal flats are accessible, the majority of birds feed on the intertidal flats (Blanco 1998), but when the sediments become submerged, birds are forced to stop feeding or move to higher ground where they can roost or continue feeding until the intertidal sediments are once again exposed. On the three occasions that Dunlin occurred in the site when the tide was present, the maximum peak number occurred when the tide was encroaching on the developing saltmarsh (TS3), the maximum daily temperature was below the monthly average and there was a strong north-westerly wind. Dunlin have been reported to spend high tide in flight, to minimise the chance of being attacked by a raptor (Hotker 2000; Dekker & Ydenberg 2004). However, when the risk of starvation is greater they appear to be taking greater risks by feeding in Nigg Bay MRS, where the enclosed nature of the site means that the predation risk is likely to be higher.

As the number of Common Redshank resting in Nigg Bay MRS when the tide was present (TS1-3) was greater on colder days with a strong, northerly wind (C2) this suggests that the site may also be providing a sheltered roosting site for this species. By roosting in sheltered habitats at high tide, birds may reduce their energy expenditure (Peters & Otis 2007).

6.4.2 Patterns of behaviour

The species recorded in Nigg Bay MRS can be placed into one or several of six groups according to patterns of behaviour in the site through the tidal cycle: (i) tide-edge foragers; (ii) high-tide foragers; (iii) high-tide roosters; (iv) high-tide dabblers; (v) high-tide deserters; and (vi) low-tide users.

6.4.2.1 Tide-edge foragers

In contrast to Common Redshank on the Tagus Estaury, Portugal (Granadeiro *et al*. 2006), Common Redshank in Nigg Bay commonly follow the tide edge throughout the tidal cycle, as on the Forth Estuary (Warnes *et al*. 1980) where they presumably take advantage of the increased invertebrate activity (Colwell & Landrum 1993), and this pattern was continued into the managed realignment site. There is an influx of foraging Common Redshank as the tide enters and advances over the intertidal sediments in Nigg Bay MRS. Common Shelduck were also recorded foraging in the shallow water as it was passing over the intertidal sediments in the site. This species tends to use wet exposed flats at lower tide states but follows the tide edge towards high water (Bryant & Leng 1975).

6.4.2.2 High-tide foragers

While Common Redshank used Nigg Bay MRS largely for foraging while the intertidal sediment was exposed, foraging continued after the intertidal sediments were submerged, showing that the developing saltmarsh (Chapter 2) in Nigg Bay MRS also provided foraging habitat. In the Tyninghame Estuary, Scotland, the energy intake of Common Redshank was 23% higher on the saltmarsh than the mudflat, however, the mudflats were usually preferred because of the reduced risk of predation (Yasue *et al*. 2003). Dunlin were also occasionally recorded foraging on the developing saltmarsh areas in Nigg Bay MRS when the intertidal sediments were no longer exposed. Both Common Redshank and Dunlin have been identified as species usually requiring additional feeding time (Davidson & Evans 1986). Eurasian Wigeon mostly used Nigg Bay MRS for foraging and loafing once the intertidal sediments were inundated. Eurasian Wigeon are herbivorous (Durant *et al*. 2006) and at low tidal states, feed on the extensive beds of *Zostera spp*., *Salicornia spp*., and *Enteromorpha* algae which are present in the Cromarty Firth (Rodwell 2000). In Nigg Bay MRS they are likely to have fed on *Salicornia spp*., *Puccinellia maritima*, and seeds although this was not directly observed (Owen 1973; Owen & Thomas 1979; Mayhew 1988; Durant *et al*. 2006).

6.4.2.3 High-tide roosters

In W3, numbers of Eurasian Curlew were greater when the tide was present but intertidal sediments were exposed (TS1) than when the tide was absent (TS0). At this time, the average number of resting birds was about ten times greater than when the tide was absent (although there was no increase in average number of foraging birds), suggesting that Eurasian Curlew were forming pre-roosting flocks, and that Nigg Bay MRS was used principally as a high-tide roost (Colwell *et al*. 2003). This is supported by the fact that there were more birds resting and fewer birds foraging in the site when the intertidal sediment became submerged (TS2) than when the tide was absent (TS0). Bar-tailed Godwit and Red Knot occasionally used Nigg Bay MRS for high-tide roosting.

6.4.2.4 High-tide dabblers

In order to continue foraging when the intertidal flats are inundated, herbivorous dabbling ducks must either move to areas of shallow water where they can continue to graze on the intertidal flats or they must move onto the adjacent saltmarsh to graze on grasses. Such habitats are available in Nigg Bay MRS (Chapter 3) and were used by Common Teal *Anas crecca* (data not presented).

6.4.2.5 High-tide deserters

Eurasian Oystercatcher used Nigg Bay MRS infrequently when the intertidal flats become submerged and never once the tide encroached on the developing saltmarsh. Eurasian Oystercatcher in Nigg Bay tend to roost in tight flocks (pers. obs.), so it is likely that these birds leave the site to join larger roosting flocks elsewhere in Nigg Bay.

6.4.2.6 Low tide user

With the exception of Red Knot, each of the species that have been placed into the groups above also used Nigg Bay MRS in small numbers for both foraging and resting when the tide was absent. It is possible that birds using Nigg Bay MRS at this time are excluded from better foraging sites elsewhere in Nigg Bay (Goss-Custard 1977c). Resting activity in Nigg Bay MRS when the tide was absent, may, in part, be due to digestive bottlenecks, which restrict the rate of food intake. Kersten & Visser (1996) demonstrated that Eurasian Oystercatchers are forced to disrupt their foraging at regular intervals to allow the digestive tract to process the food. Digestive bottlenecks have also been described for Eurasian Wigeon foraging on *Salicornia sp*. (Durant *et al*. 2006). Alternatively, food may become less available at lower tidal states due to drying of the substrate (Prater 1972; Smith 1974; Goss-Custard 1977d; Grant 1984). While this will be influenced by time since the tide fell, invertebrate behaviour (and hence waterbird responses) will also be affected by rainfall, temperature, sun and wind.

6.5 Conclusion

Nigg Bay MRS is used by waterbirds for foraging, resting and (in the case of wildfowl) loafing at all stages of the tidal cycle, however, the number of individuals of each species present at any time is affected by tide state and prevailing weather conditions. At lower tidal states (when the tide was absent form Nigg Bay MRS and intertidal flats elsewhere in Nigg Bay were accessible), Nigg Bay MRS was used by a small number of birds for both foraging and resting. Numbers of Eurasian Curlew and Common Shelduck were greater on colder days with a strong northerly wind, indicating that the enclosed nature of the Nigg Bay MRS may have provided a more sheltered habitat, allowing birds to conserve energy. As the tide entered and advanced over the intertidal sediments of Nigg Bay MRS, there was an influx of foraging birds, which were likely to be taking advantage of the increased invertebrate activity along the tide edge. On colder days with a strong northerly wind the numbers of waders and, in particular, Common Redshank were greater, suggesting that Nigg Bay MRS may have been used as a top-up feeding site when energy demands were high. Birds that were unable to meet their energy demands when the intertidal flats of Nigg Bay were still exposed may have benefited from the additional foraging time that Nigg Bay MRS provided. Nigg Bay MRS also functioned as a regular high tide roost for some species, with peak numbers of resting individuals of each wader species occurring when temperatures were below average and when snow, sleet or hail had fallen within the last 24 hours.

Chapter 7

Spatial patterns of use of Nigg Bay Managed Realignment Site by non-breeding waders

7.1 Introduction

On an estuarine scale, non-breeding wader distributions have been shown to be primarily affected by invertebrate prey distributions (Section 1.1.3.1), predation risk (Section 1.1.3.2) and the tidal cycle (Section 1.1.3.3). Invertebrate prey distributions are largely determined by elevation in the tidal frame and the proximity to creeks, while perceived predation risk has been linked to the amount of cover afforded to predators by features such as embankments and tall vegetation.

Managed realignments sites are often relatively small and enclosed compared to the adjacent estuary, so the extent to which spatial factors influence wader distribution at this scale is not known. An understanding of how waders distribute themselves within managed realignment sites relative to different physical and biological features will be useful as it may be used to inform design and management of future managed realignment projects.

This chapter investigates the spatial use of Nigg Bay MRS by non-breeding waders and attempts to answer the following questions: What is the spatial distribution of waders in Nigg Bay MRS? How do spatial distributions vary through the tidal cycle? What factors affect the spatial distribution of waders in Nigg Bay MRS? What is the relative importance of these factors? How do spatial patterns vary across species?

7.2 Methods

7.2.1 Wader monitoring

During W3 (Table 5.1) Nigg Bay MRS was monitored on 21 days (including at least two spring tides and one neap tide each month) from the beginning of September until the end of February. The site was scanned at 15 minute intervals (relative to the predicted high tide times for the Cromarty Firth) and the positions of all waders (Table 6.1) to the south of a bisecting fence (approximately corresponding to MHWS; Figure 7.1) were recorded on an aerial photograph of the site and a note was made of whether each individual was foraging or resting. Foraging and resting wader distributions were investigated at four different tidal states, TS0-TS3 (Table 6.2).

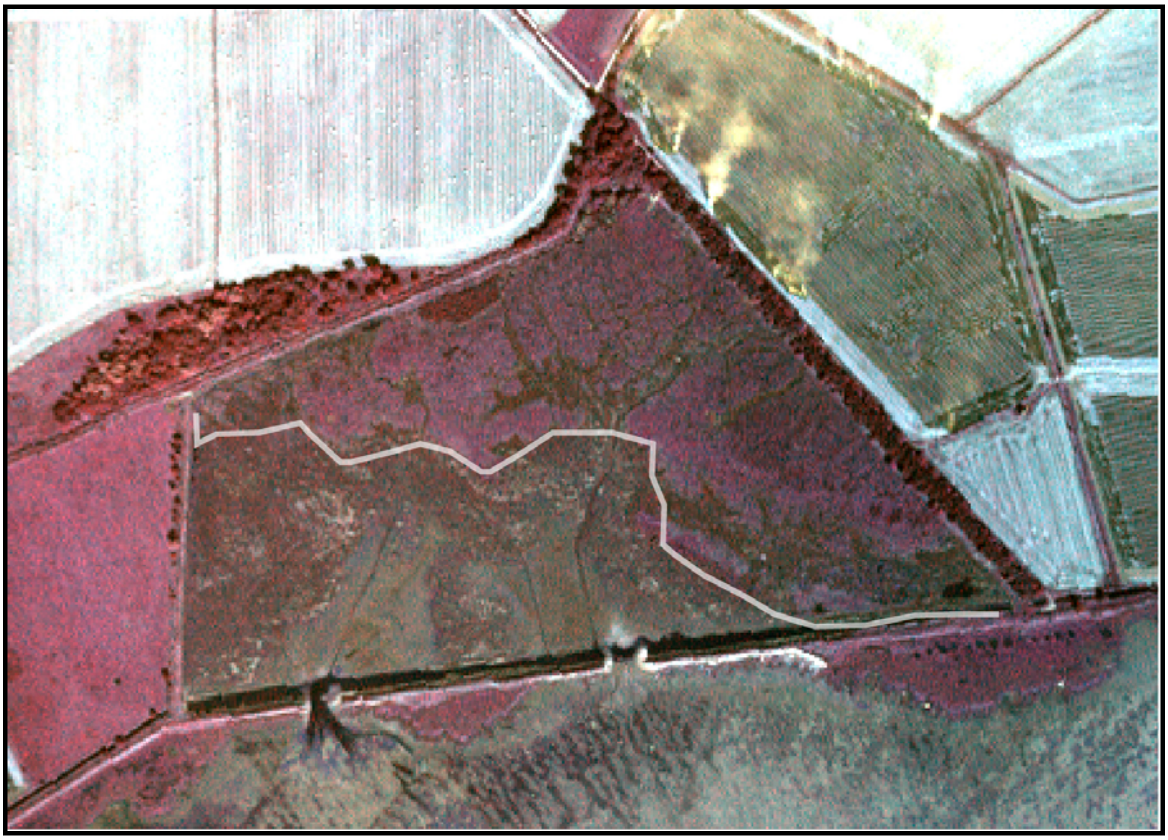


Figure 7.1: Fence in Nigg Bay Managed Realignment Site. The spatial distributions of waders using the area to the south of the fence were mapped in W3.

7.2.2 Data preparation

7.2.2.1 Wader data

The wader data were digitised in ArcMap™ (ESRI, California), by creating a layer for each 15 minute observation with each individual wader represented by a single point feature. Each point (i.e. each individual bird) had an associated species name, activity (foraging or resting) and tide state (TS0, TS1, TS2 or TS3). Point density maps were then created for each of several queries (Table 7.1) with an output cell size of 10 m and a neighbourhood of 1 cell. The point density rasters were converted to ASCII format and manipulated using custom Perl scripts to ensure that cells that were outside Nigg Bay MRS or to the north of the bisecting fence were removed and zeros were added to cells without values. Calculated densities for each 10 m cell were used in subsequent analyses.

Table 7.1: Queries for which point density rasters were created in ArcMap™.

Species	Activity	Tide state				
		All	TS0	TS1	TS2	TS3
All Waders	foraging	X				
	resting	X				
BA	foraging	X	X	X	X	X
	resting	X	X	X	X	X
CU	foraging	X	X	X	X	X
	resting	X	X	X	X	X
DN	foraging	X	X	X	X	X
	resting	X	X	X	X	X
KN	foraging	X	X	X	X	X
	resting	X	X	X	X	X
OC	foraging	X	X	X	X	X
	resting	X	X	X	X	X
RK	foraging	X	X	X	X	X
	resting	X	X	X	X	X

7.2.2.2 Physical feature data

The embankments, breach gaps, fence and major creeks were digitised in ArcMap™, by creating a layer for each feature. Euclidean distance was then calculated for each 10 m cell for each feature. Topographic (m OD) and vegetation (total % cover) point data were interpolated using ordinary kriging and an output cell size of 10 m. The rasters for each feature were also converted to ASCII format and manipulated using custom Perl scripts.

7.2.2.3 Invertebrate data

Invertebrate data for W3 were digitised in ArcMap™, by creating a layer for each of the species in Nigg Bay MRS (Chapter 4). Each invertebrate site sampled was represented by a circle on the map, with the area of the circle proportional to the density of the sampled invertebrate.

7.2.3 Data analysis

7.2.3.1 Problems of spatial autocorrelation, pseudoreplication and spatial scale

Spatial autocorrelation is the correlation between two observations of a measured variable based on their spatial location (Griffith 1992). Spatial autocorrelation can lead to pseudoreplication, which occurs when interdependent observations are treated as independent observations, and can lead to exaggerated estimates of statistical significance (Hurbert 1984). For the analyses in this chapter (Section 7.2.3.2), the rasters were subsampled by randomly selecting 25% of the cells, in order to reduce spatial autocorrelation and pseudoreplication. As sub-sampling will not eliminate these problems, statistically significant differences still need to be interpreted with caution.

Spatial scale can also cause problems in spatial statistics. For example, different species may respond to their habitat at different spatial scales (Graf *et al*. 2005; Holland *et al*. 2005). In this study, different wader species may select habitat at different spatial scales. For the analyses in this chapter (Section 7.2.3.2), the data were analysed at a range of spatial scales.

7.2.3.2 Analyses

Principal Components Analysis (PCA) and pairwise Pearson's correlations were performed between the physical features to identify significant associations. Mann-Whitney *U* tests were undertaken to determine whether the component scores extracted by PCA differed between those areas with and without different wader species at TS0. Mann-Whitney *U* tests were also undertaken to determine, for areas which each wader species used at TS0, whether the densities were significantly different below and above

1.7 m OD (the transition between lower and middle saltmarsh zones, Long & Mason 1983) and within and beyond 10 m of creeks. *G*-tests were undertaken to determine whether the presence of each foraging wader species was significantly associated with the presence of invertebrate prey (*Corophium volutator*, *Hydrobia ulvae*, *Hediste diversicolor*, *Macoma balthica* and all species combined) at a range of scales: 0.01 ha (single 10 x 10 m cell), 0.09 ha (single 10 x 10 m cell with 1 cell border) and 0.25 ha (single 10 x 10 m cell with 2 cell border). A nonparametric equivalent of the one-way ANOVA, the Kruskal-Wallis test with multiple comparisons, was performed to test for significant differences in the spatial distribution of Eurasian Curlew and Common Redshank between tide states in relation to the components extracted by PCA.

7.3 Results

7.3.1 Physical features

The physical features which were expected to affect wader distributions in Nigg Bay MRS were elevation (Figure 7.2), vegetation cover (Figure 7.3), proximity to breach gaps (Figure 7.4), proximity to embankments (Figure 7.5), proximity to the fence (Figure 7.6) and proximity to creeks (Figure 7.7). There were significant correlations between all of the physical features in Nigg Bay MRS, except between the distance from creeks and both distance from the fence and from the embankments (Table 7.2). PCA of the physical features generated two components, accounting for 78.4% of the variation (Table 7.3). C1 (with a high positive weighting for distance from breaches, elevation, distance from embankments and vegetation cover and a high negative weighting for distance from fence) accounted for 59.8% of the variation. C2 (with a high positive weighting for distance from creeks) accounted for 18.6% of the variation.

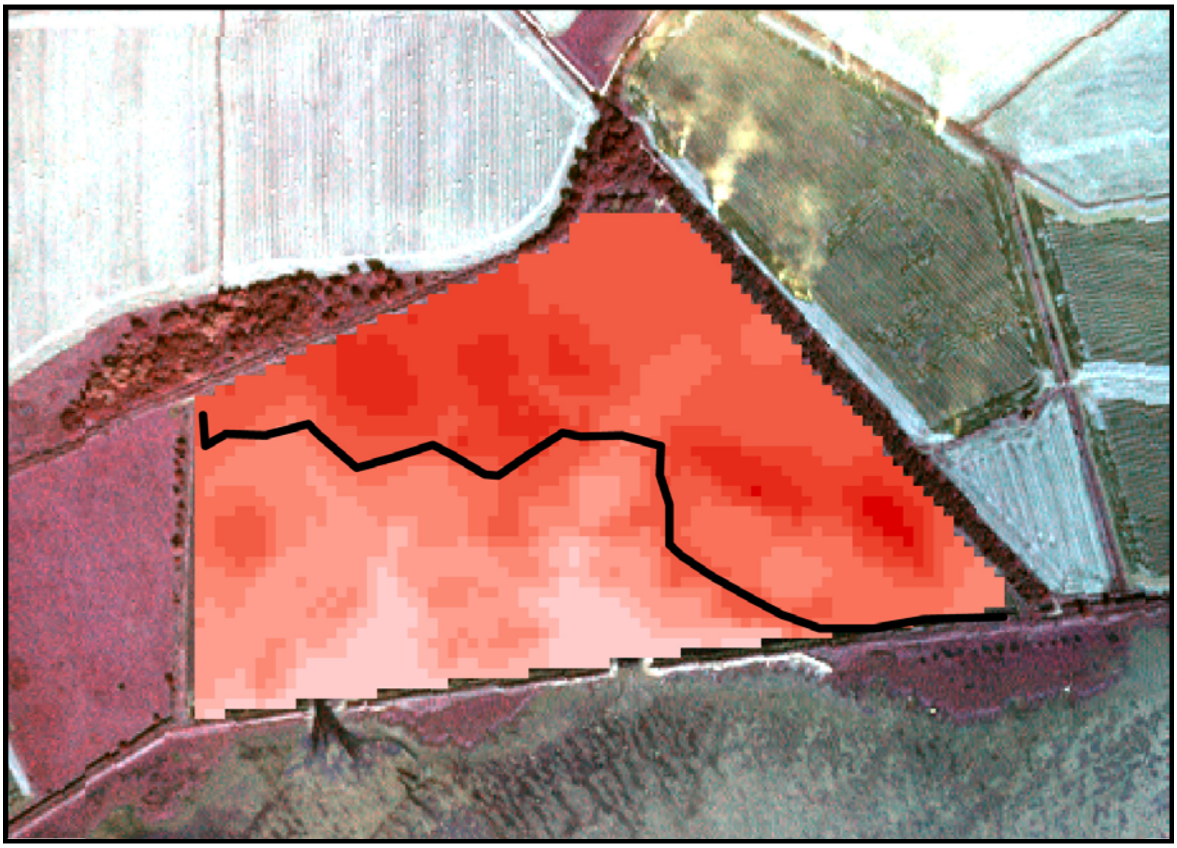


Figure 7.2: Elevation. Colours are graduated at 0.2 m intervals from 1.5 (light) – 3.1 (dark) m OD.

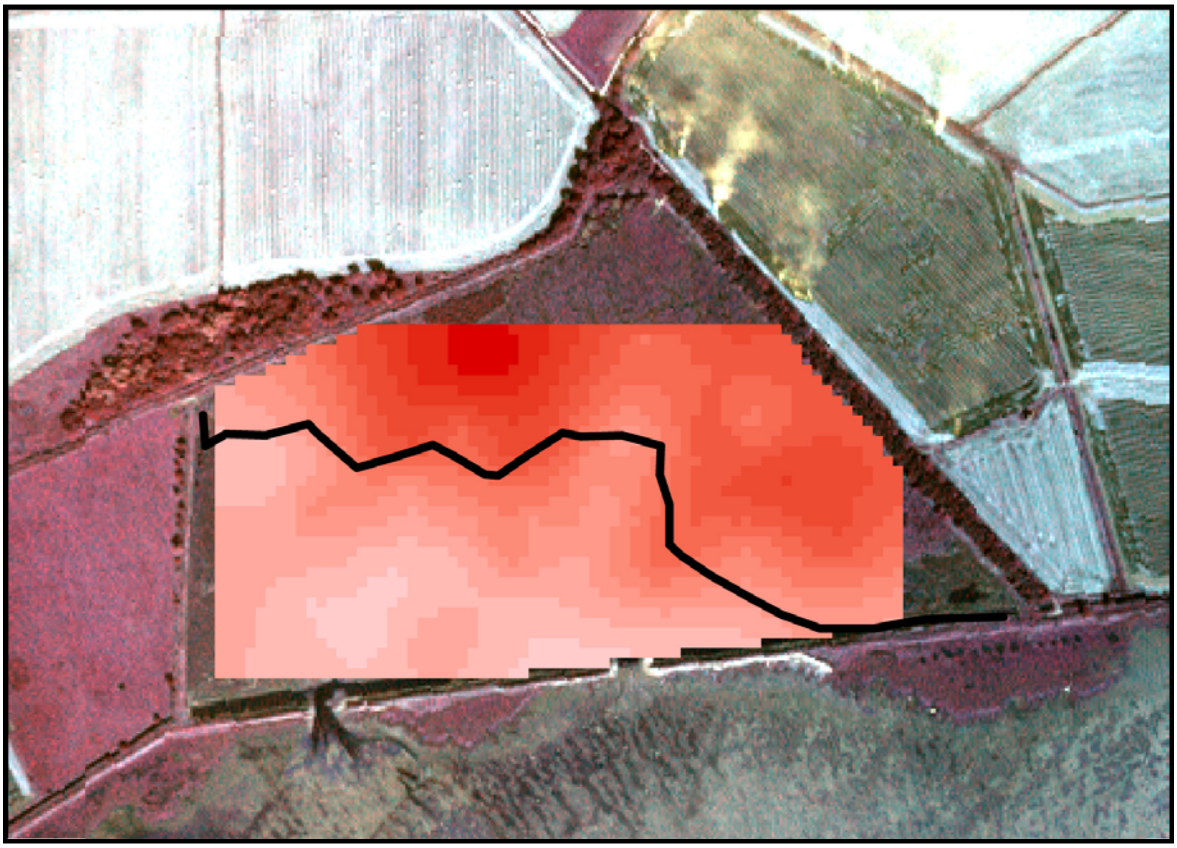


Figure 7.3: Total vegetation cover. Colours are graduated at 10% intervals from 0 (light) – 120 (dark) %.

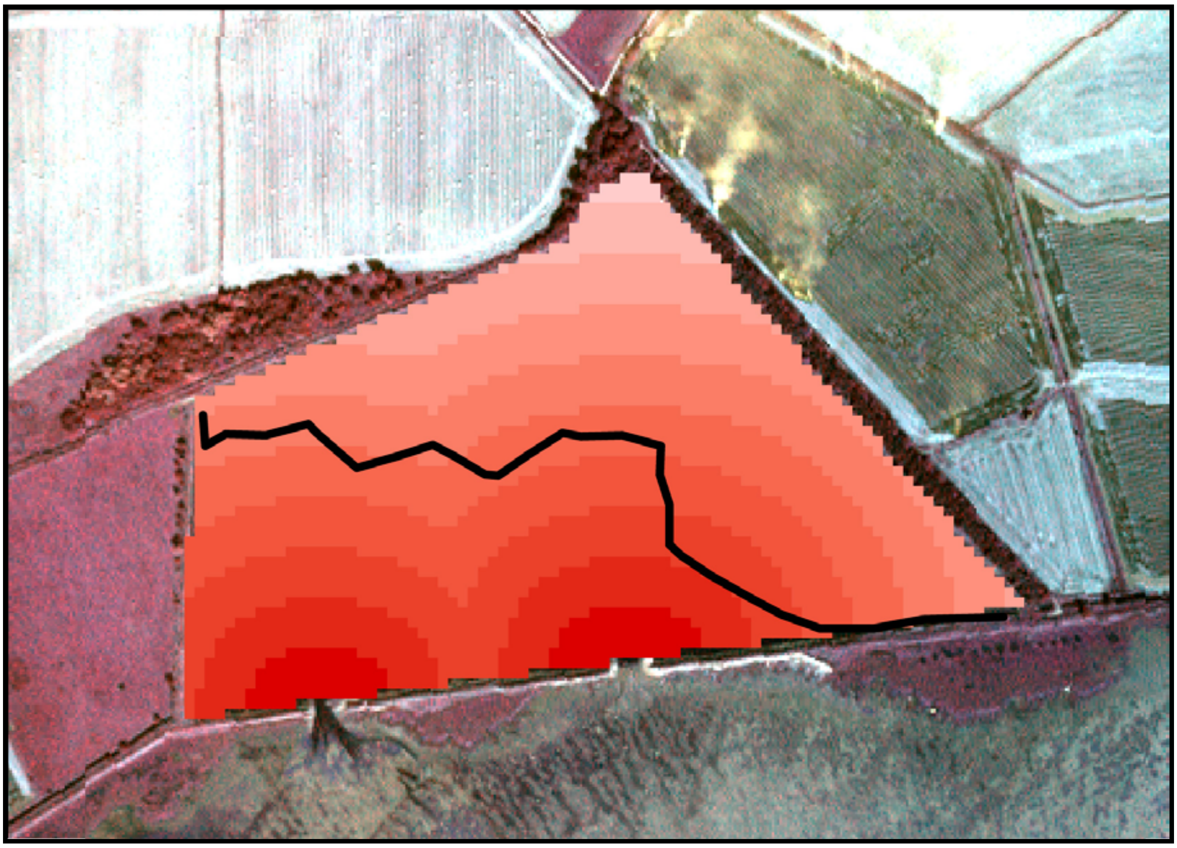


Figure 7.4: Distance from breaches. Colours are graduated at 50 m intervals from 0 (dark) – 500 (light) m.

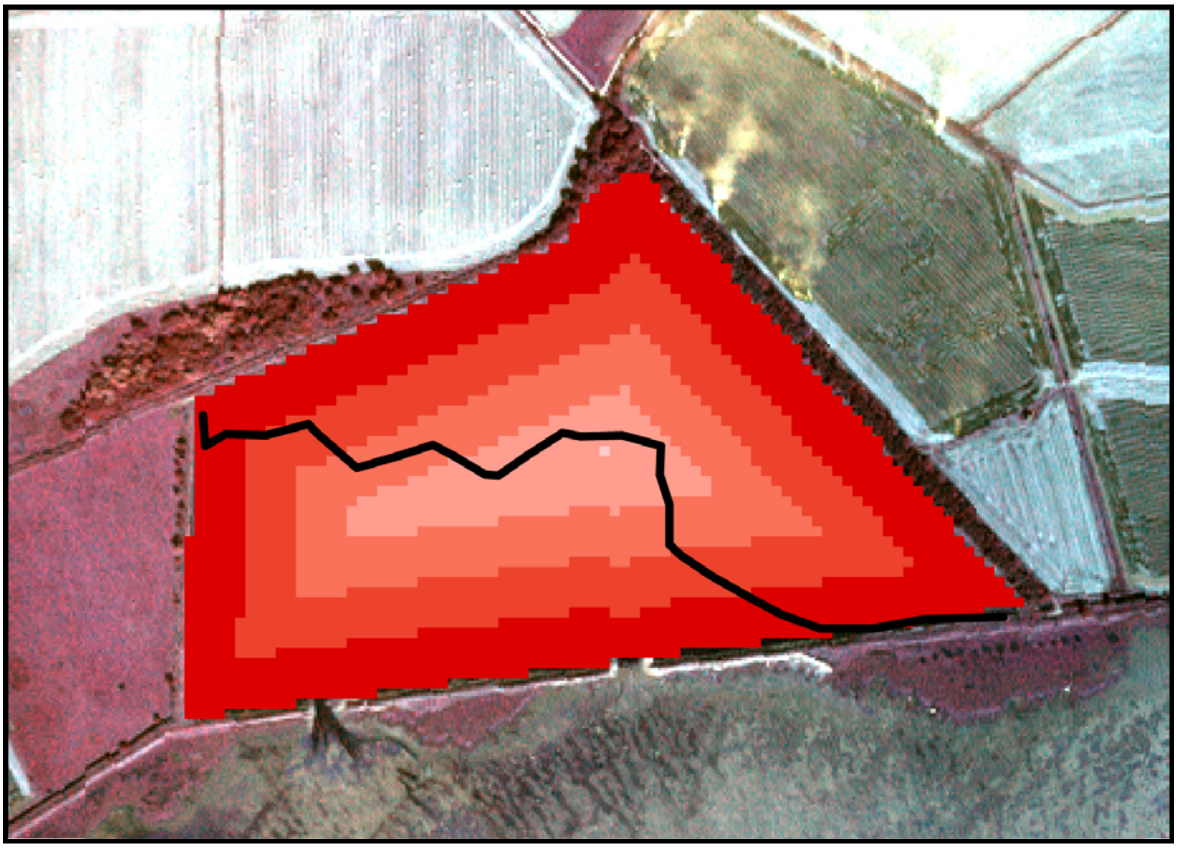


Figure 7.5: Distance from embankments. Colours are graduated at 50 m intervals from 0 (dark) – 200 (light) m.

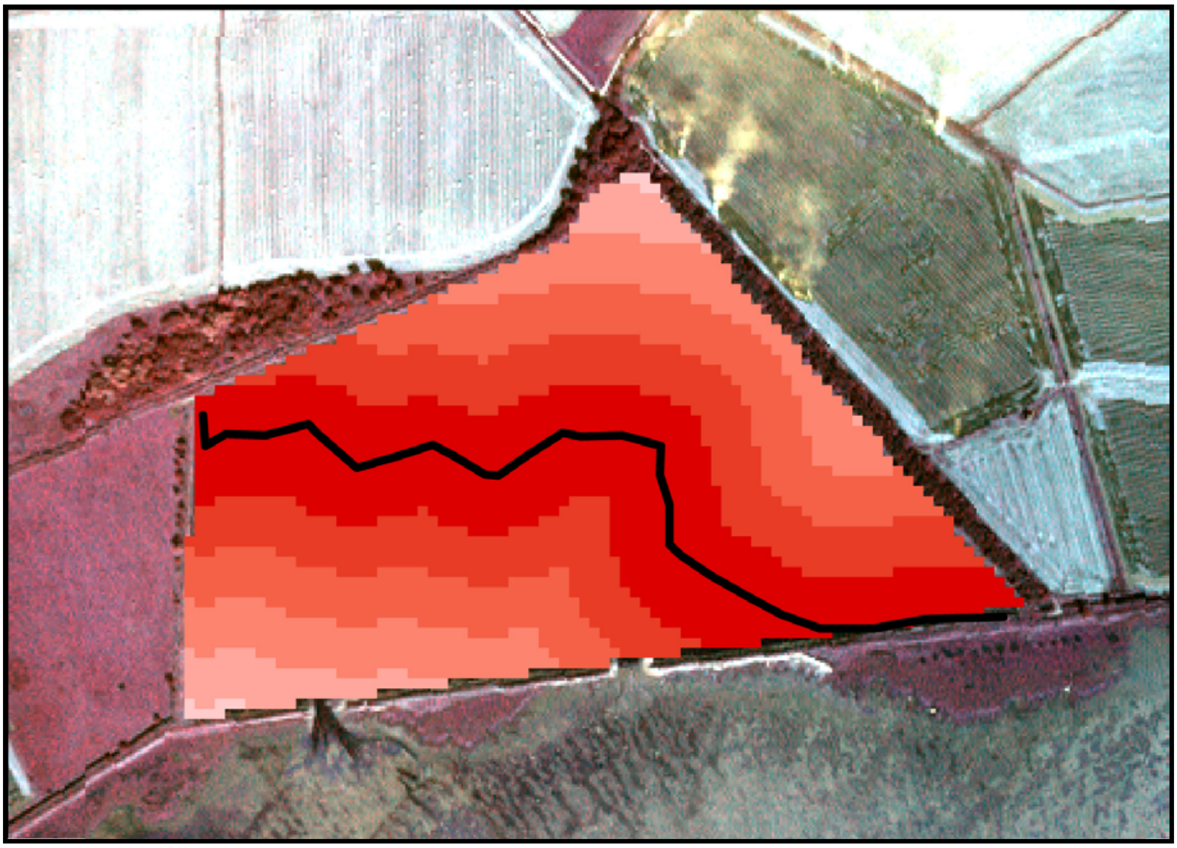


Figure 7.7: Distance from fence. Colours are graduated at 50 m intervals from 0 (dark) – 250 (light) m.

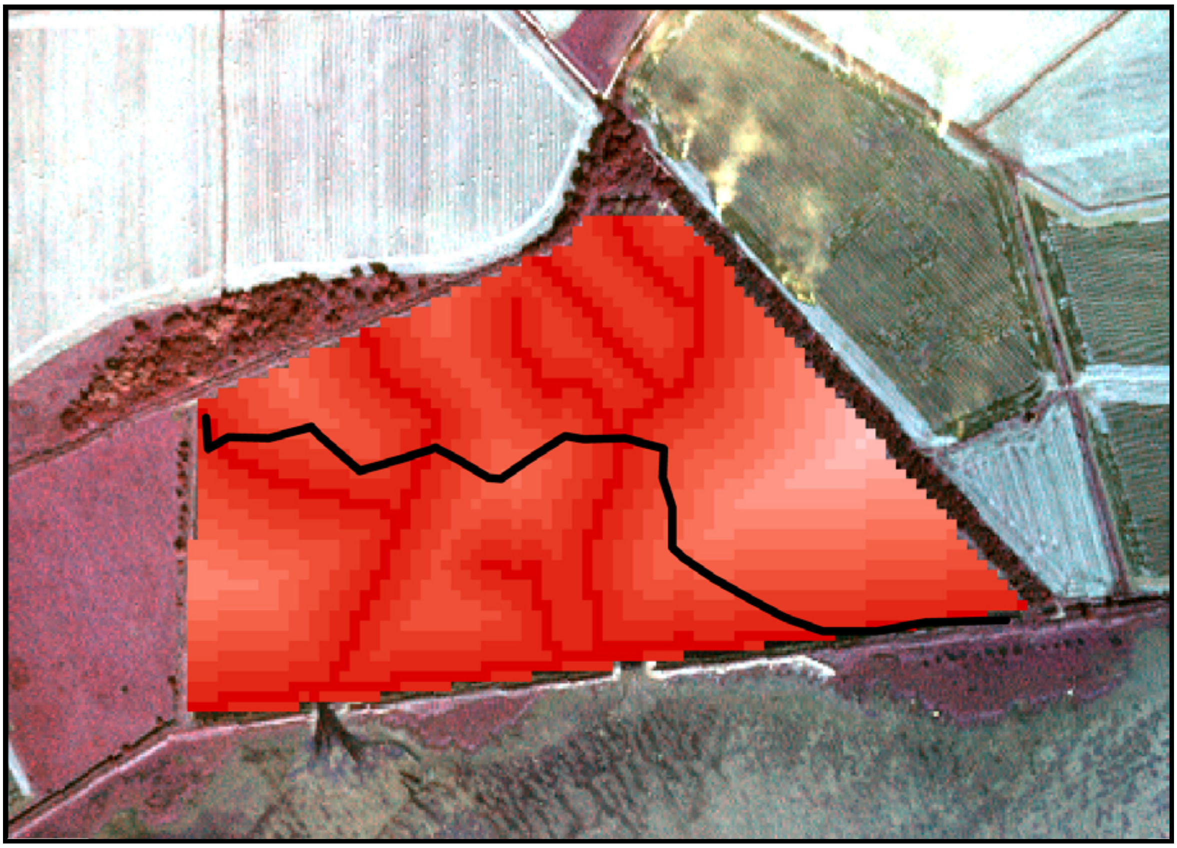


Figure 7.7: Distance from creeks. Colours are graduated at 20 m intervals from 0 (dark) – 180 (light) m.

Table 7.2: Results of Pearson Correlation between physical features in Nigg Bay Managed Realignment Site.

		Creeks	Fence	Elevation	Vegetation	Embankments
Breaches	*r*	**0.18****	**-0.66****	**0.69****	**0.54****	**0.53****
	N	304	305	295	273	305
Creeks	*r*		-0.04	**0.50****	**0.27****	0.10
	N		304	294	273	304
Fence	*r*			**-0.63****	**-0.73****	**-0.53****
	N			295	273	305
Elevation	*r*				**0.68****	**0.52****
	N				273	295
Vegetation	*r*					**0.68****
	N					273

** Correlation is significant at the 0.01 level (2-tailed).

Table 7.3: Principal Components Analysis of the physical features in Nigg Bay Managed Realignment Site. Weightings of each of the measured variables for each component (C1 and C2) are shown, together with the total variance explained by each component.

Features	**Units**	**Component**	
		C1	**C2**
Breaches	m	**0.83**	-0.17
Creeks	m	0.33	**0.92**
Elevation	m OD	**0.86**	0.29
Embankments	m	**0.81**	-0.13
Fence	m	**-0.81**	0.36
Vegetation	%	**0.87**	-0.01
Variance explained (%)		59.8	18.6

7.3.2 Overall wader distributions

The majority of areas used by waders were used for both foraging and resting (Figure 7.8). Waders used the areas behind both breaches, although hotspots (areas of highest density) of both foraging and resting birds only occurred in the area behind the west breach.

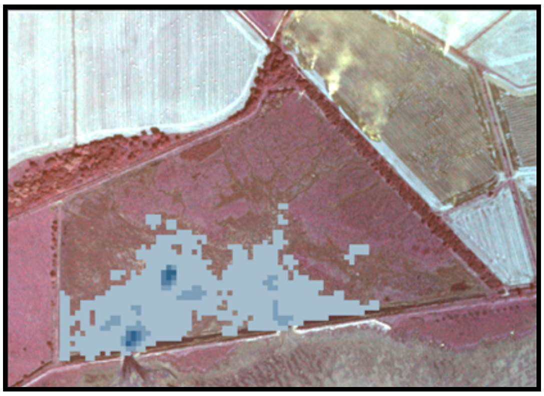
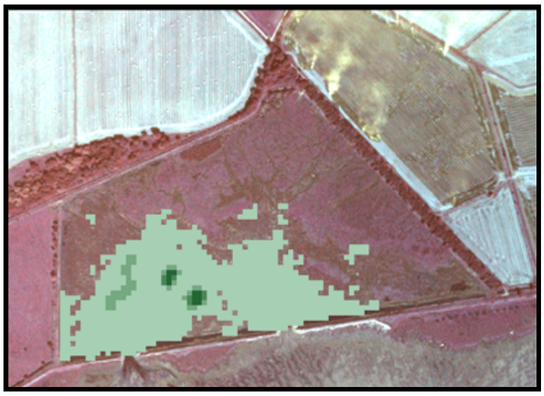
SP	FORAGING	RESTING
All		

Figure 7.8: Density distributions (birds ha^{-1}) of foraging (1-2 , 3-4 , 5-6 , 7-8) and resting (1-10 , 11-20 , 21-30 , 31-40) waders in Nigg Bay Managed Realignment Site in W3.

Each of the wader species investigated (except Red Knot) used the areas behind both breaches for foraging (Figure 7.9). However, Dunlin predominantly foraged in the area behind the west breach. Dunlin and Redshank were the only species which had high density foraging hotspots (at the ≥ 3 birds ha^{-1} level), both in the area behind the west breach. Eurasian Curlew and Common Redshank foraged over the widest areas, 5.76 and 5.67 ha of Nigg Bay MRS, respectively. The other species each foraged over less than 2.5 ha of Nigg Bay MRS.

Every wader species (except Eurasian Oystercatcher) predominantly rested in the area behind the west breach, with Bar-tailed Godwit, Dunlin and Red Knot using only this area (Figure 7.9). Eurasian Curlew reached higher resting densities (up to 16 birds ha^{-1}) than the other wader species, with three hotspots (at the ≥ 12 birds ha^{-1} level) in the area behind the west breach. Eurasian Curlew rested over the widest area of Nigg Bay MRS, 5.8 ha, while other species each rested over less than 2.4 ha of Nigg Bay MRS.

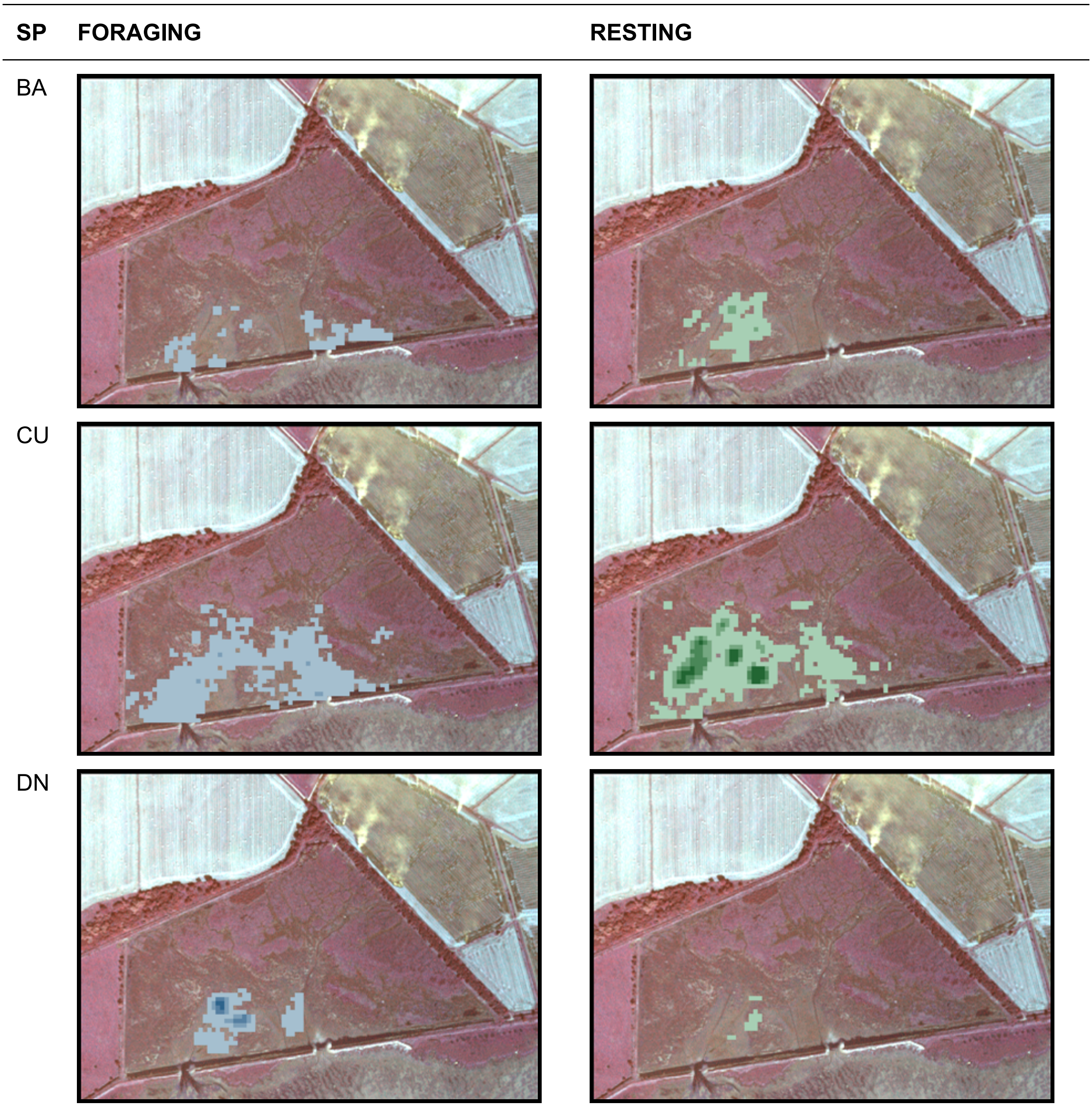


Figure 7.9: Density distributions (birds ha^{-1}) of foraging (1, 2, 3, 4) and resting (4, 8, 12, 16) waders in Nigg Bay Managed Realignment Site in W3. Continues overleaf.

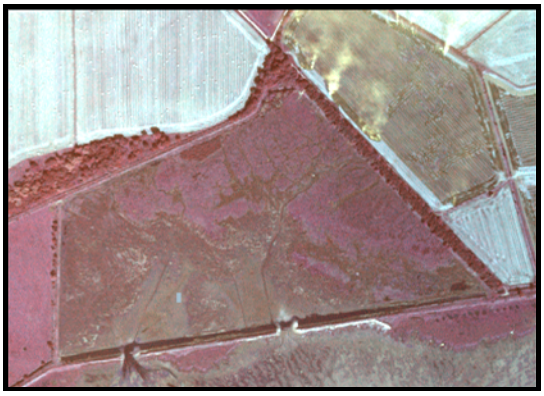
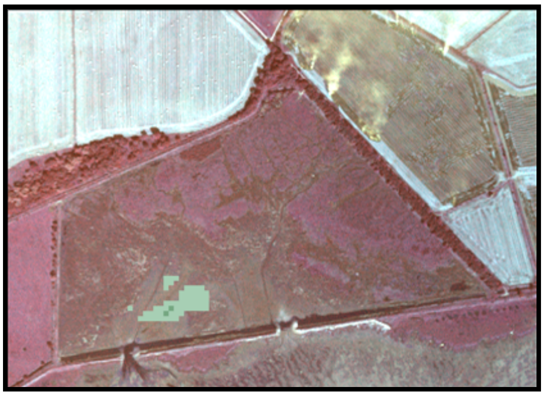
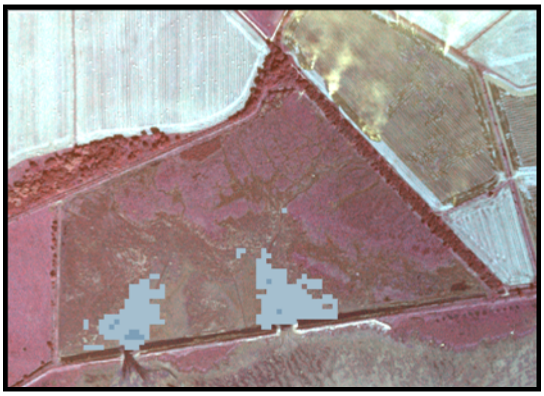
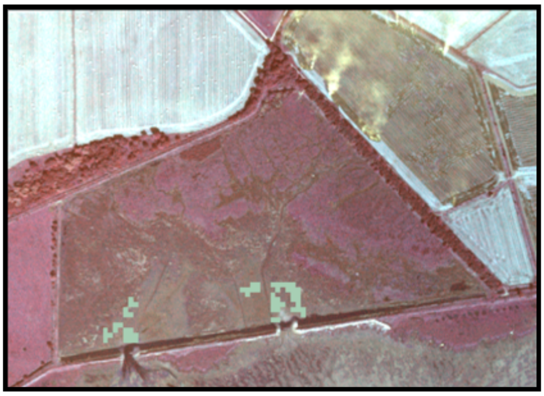
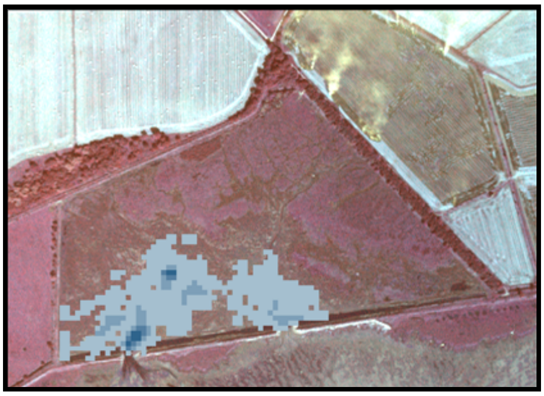
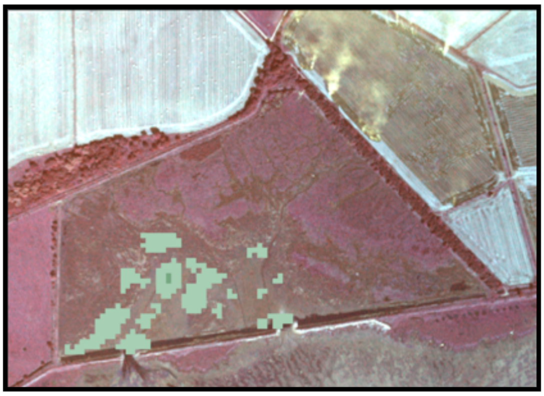
SP	FORAGING	RESTING
KN		
OC		
RK		

Figure 7.9 continued

7.3.3 Distributions of waders when the tide was absent

Bar-tailed Godwit predominantly foraged towards the south of Nigg Bay MRS, reaching highest density (1.5 birds ha^{-1}) near the west breach gap (Figure 7.10a). Eurasian Oystercatcher also had a foraging hotspot (at the ≥ 2.5 birds ha^{-1} level) near the west breach gap (Figure 7.11a), while Common Redshank had foraging hotspots near both breach gaps (Figure 7.12a). Foraging Eurasian Curlew (Figure 7.13a), Eurasian Oystercatcher (Figure 7.11a) and Common Redshank (Figure 7.12a) all exhibited linear patterns of higher density, one running perpendicular to the southern embankment from the east breach gap, and another running in a north easterly direction from the west breach gap.

Bar-tailed Godwit (7.10b), Eurasian Oystercatcher (7.11b) and Common Redshank (7.12b) all rested predominantly in areas towards the south of Nigg Bay MRS, near to the breach gaps. However, Eurasian Curlew rested throughout Nigg Bay MRS, with several hotspots in the area behind the west breach (Figure 7.13b).

The distributions of many of the wader species at TS0 were positively correlated (Table 7.4). No species distributions were significantly negatively correlated, which could have arisen if one species competitively displaced another. The areas used by every wader species for foraging and resting at TS0 had a significantly lower C1 score than areas with no birds (Table 7.5). The areas used by foraging Eurasian Curlew and both foraging and resting Common Redshank at TS0 had a significantly lower C2 score than areas with no birds (Table 7.5). The densities of foraging Common Redshank were significantly greater below 1.7 m OD and within 10 m of creeks (Table 7.5). There were no significant relationships between the presence of foraging wader species and presence of invertebrate prey once a Bonferroni correction was applied to allow for multiple testing.

a)

b)

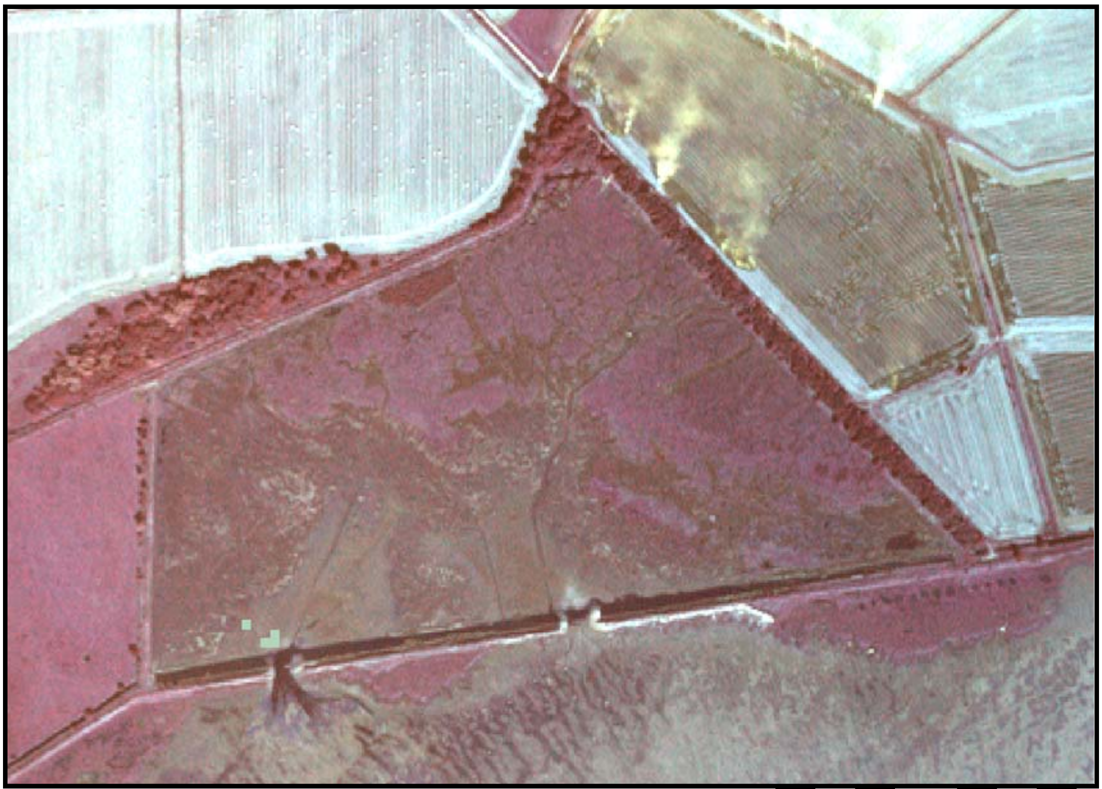


Figure 7.10: Density distributions (birds ha^{-1}) of (a) foraging (0.5 , 1 , 1.5 , 2 , 2.5) and (b) resting (0.5 , 1 , 1.5 , 2 , 2.5) Bar-tailed Godwit in Nigg Bay Managed Realignment Site at TS0 in W3.

a)

b)

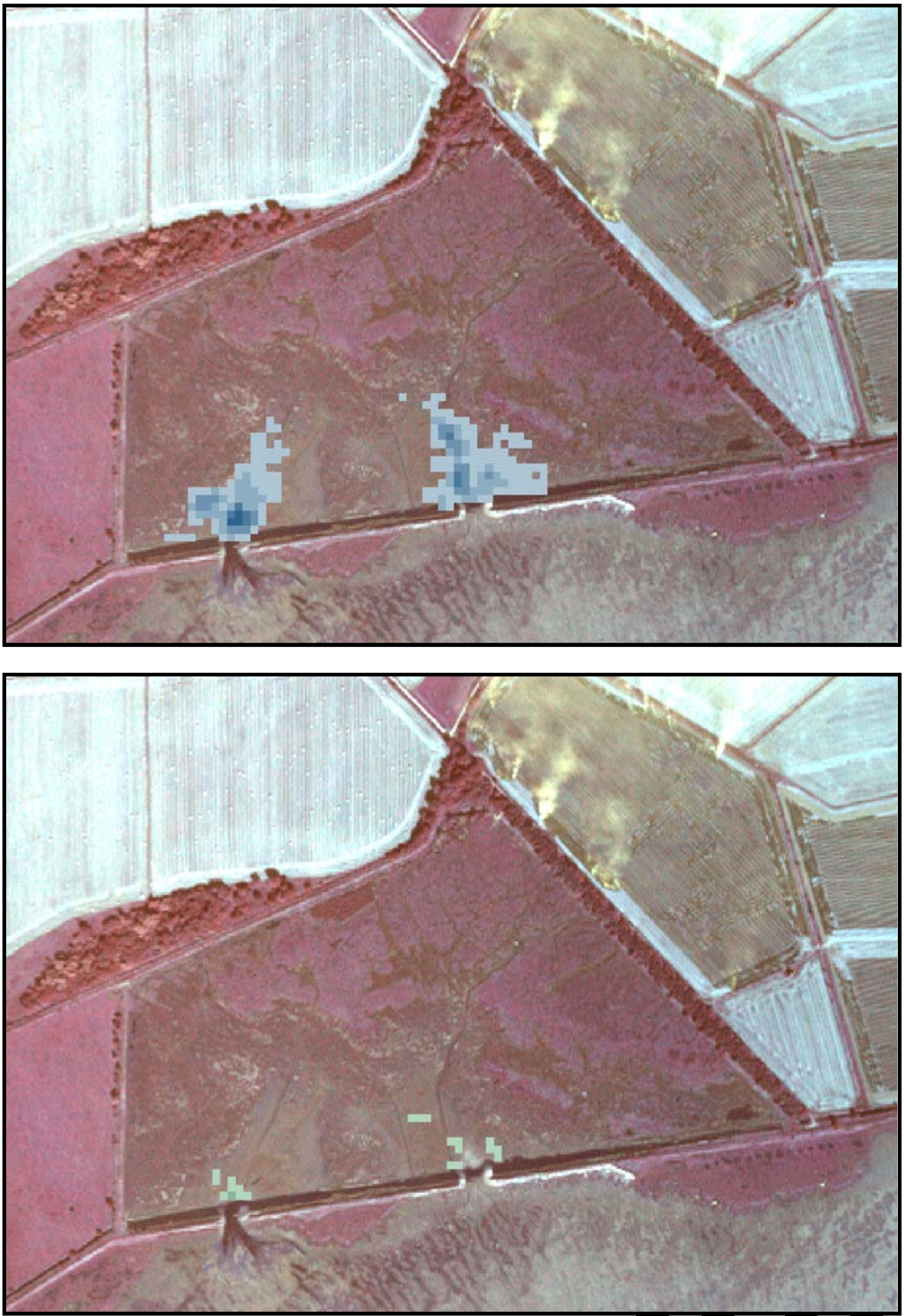


Figure 7.11: Density distributions (birds ha^{-1}) of (a) foraging (0.5 , 1 , 1.5 , 2 , 2.5) and (b) resting (0.5 , 1 , 1.5 , 2 , 2.5) Eurasian Oystercatcher in Nigg Bay Managed Realignment Site at TS0 in W3.

a)

b)

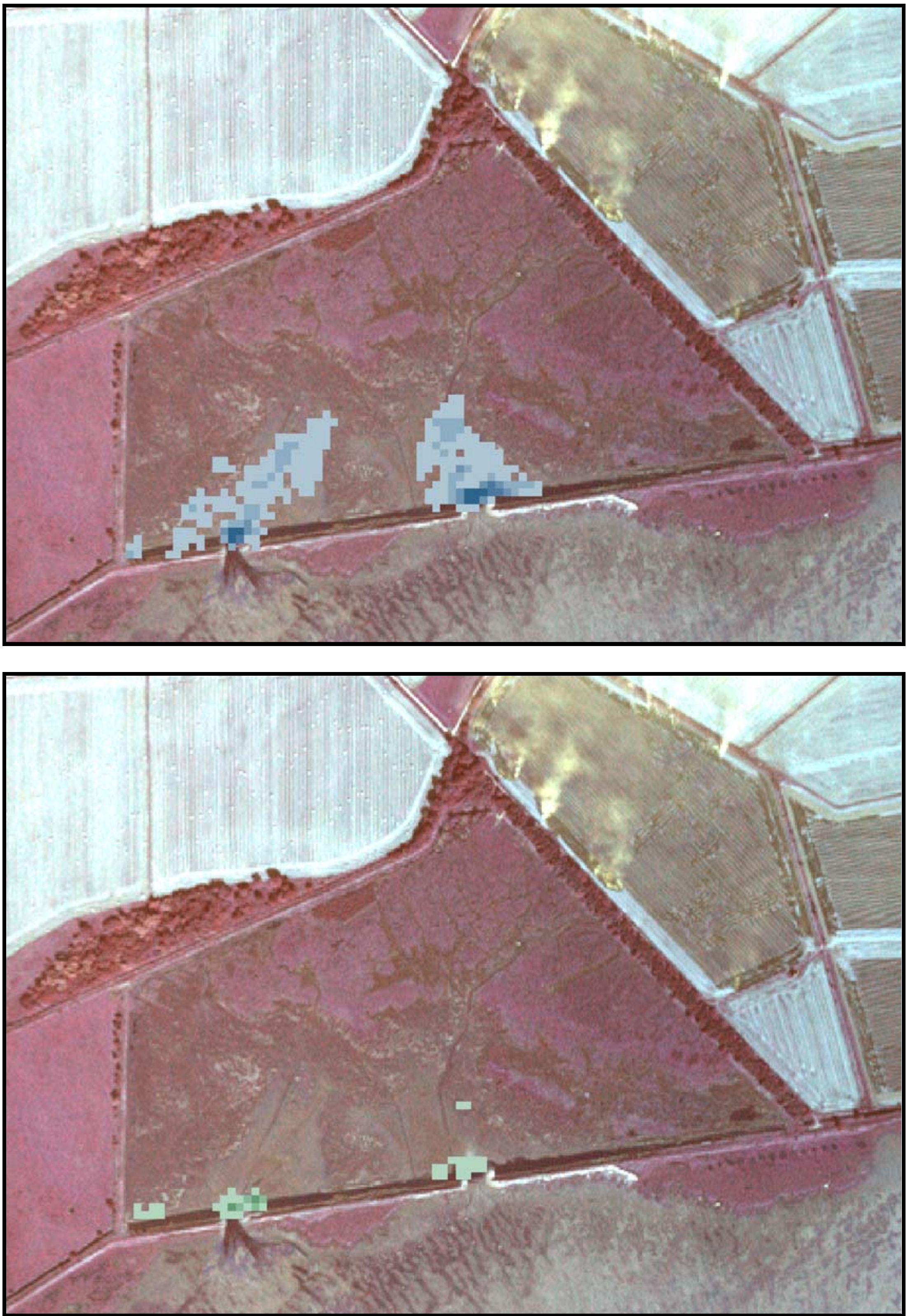


Figure 7.12: Density distributions (birds ha^{-1}) of (a) foraging (0.5 , 1 , 1.5 , 2 , 2.5) and (b) resting (0.5 , 1 , 1.5 , 2 , 2.5) Common Redshank in Nigg Bay Managed Realignment Site at TS0 in W3.

a)

b)

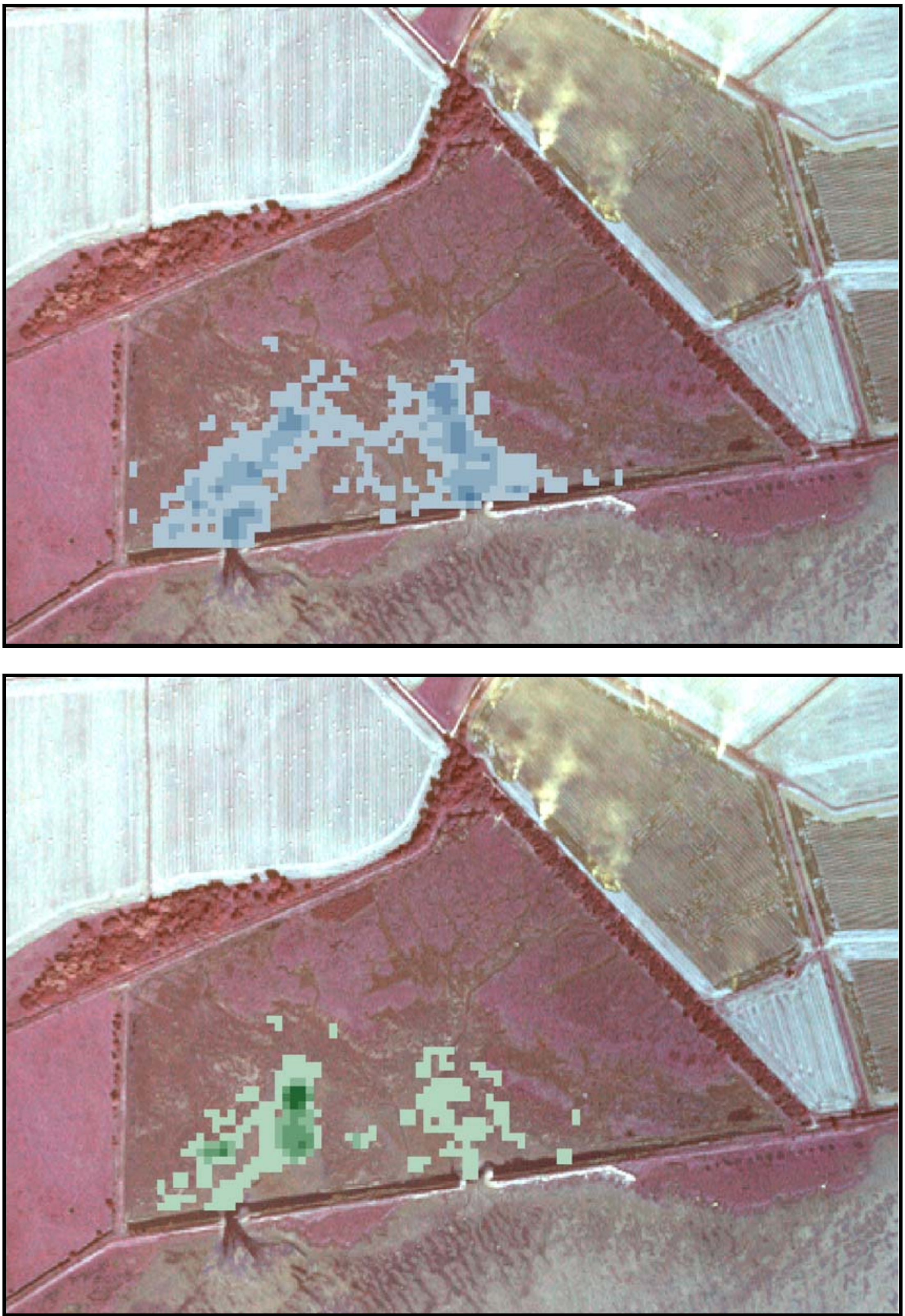
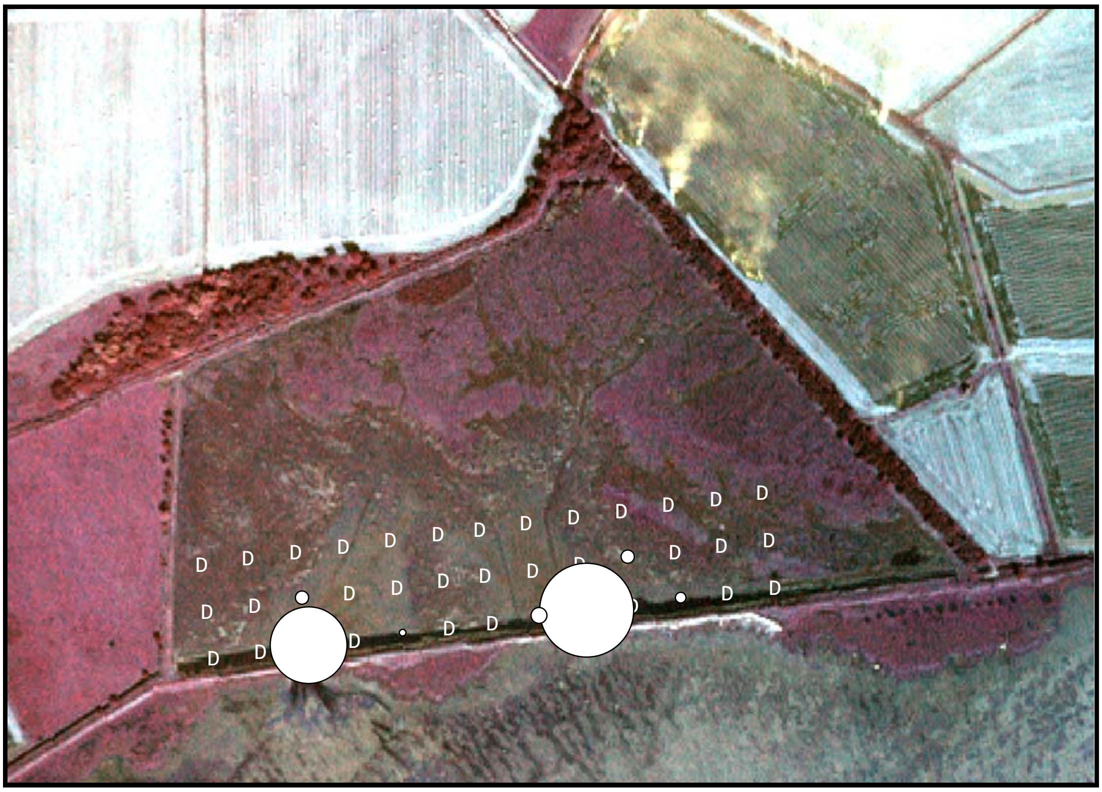


Figure 7.13: Density distributions (birds ha^{-1}) of (a) foraging (0.5 , 1 , 1.5 , 2 , 2.5) and (b) resting (0.5 , 1 , 1.5 , 2 , 2.5) Eurasian Curlew in Nigg Bay Managed Realignment Site at TS0 in W3.

a)



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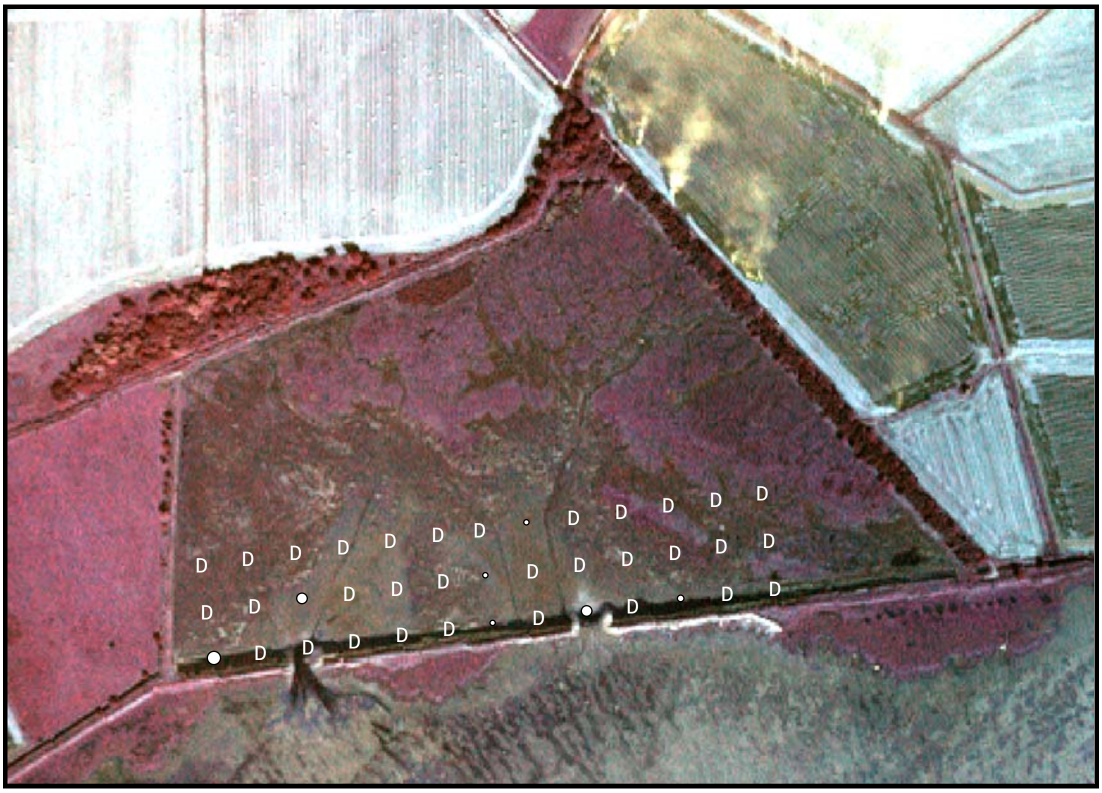
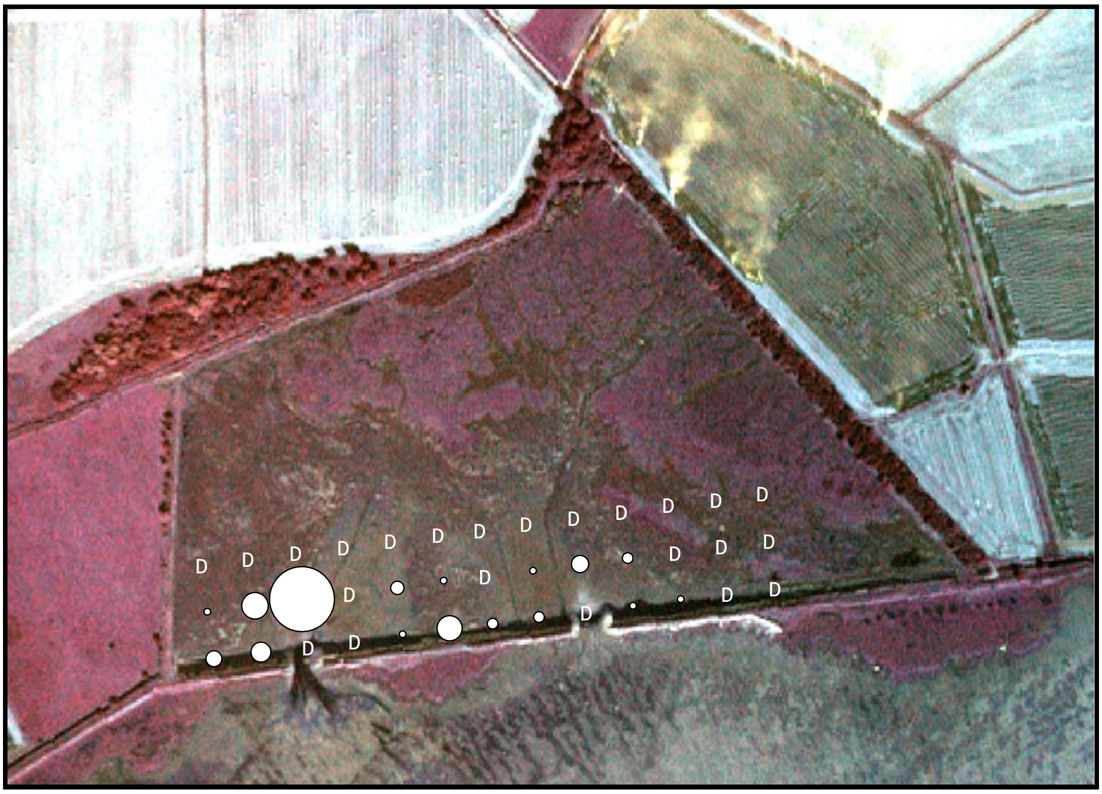


Figure 7.14: Density of (a) *Corophium volutator*, (b) *Hediste diversicolor*, (c) *Hydrobia ulvae* and (d) *Macoma balthica* in Nigg Bay Managed Realignment Site in W3. Largest circle = 6600 m^{-3}, X = 0 m^{-3}. Continues overleaf.

c)



d)

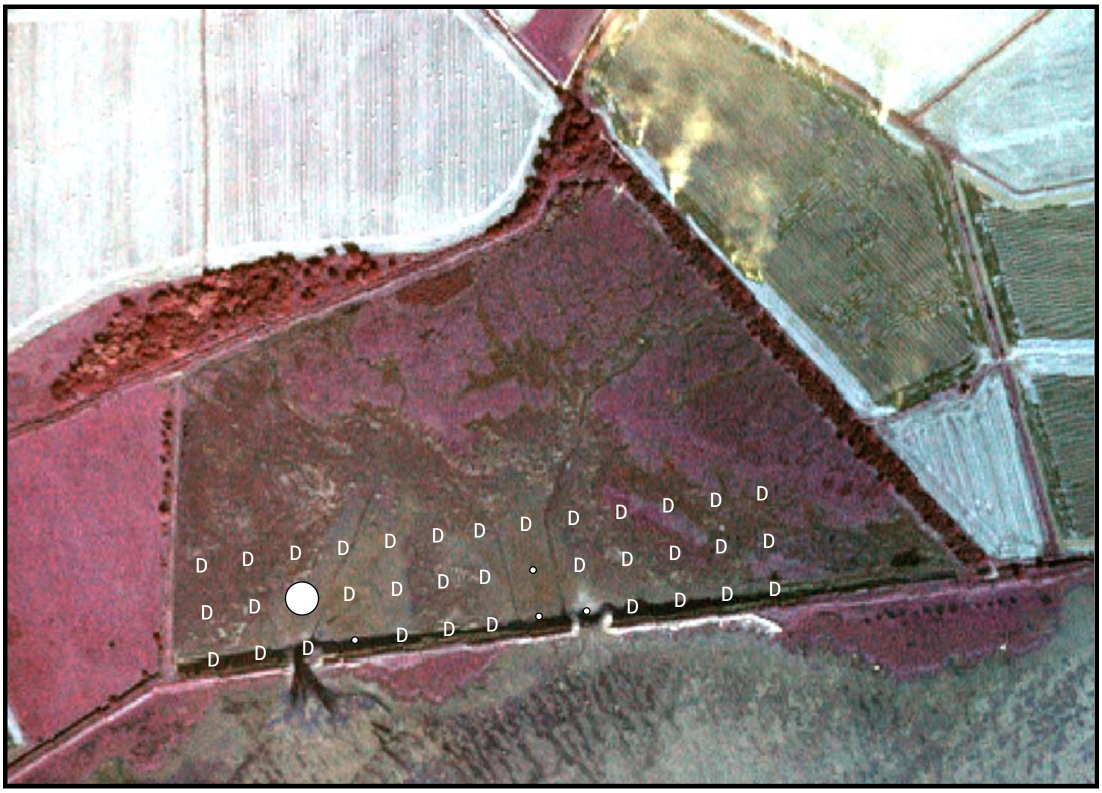


Figure 7.14 continued.

Table 7.4: Results of Pearson's Correlation between wader species distributions in Nigg Bay Managed Realignment Site.

			BA R	CU F	CU R	DN F	OC F	OC R	RK F	RK R
BA	**F**	*r*	**0.32****	**0.21****	-0.00	-0.05	**0.32****	**0.29****	**0.17****	**0.30****
		N	305	305	305	305	305	305	305	305
BA	**R**	*r*		0.11	0.04	-0.02	0.10	-0.01	0.00	0.08
		N		305	305	305	305	305	305	305
CU	**F**	*r*			**0.31****	0.04	**0.65****	**0.24****	**0.49****	**0.28****
		N			305	305	305	305	305	305
CU	**R**	*r*				**0.37****	0.04	0.04	0.08	-0.02
		N				305	305	305	305	305
DN	**F**	*r*					0.35	-0.03	**0.11***	-0.03
		N					305	305	305	305
OC	**F**	*r*						**0.35****	**0.52****	**0.18****
		N						305	305	305
OC	**R**	*r*							**0.21****	**0.25****
		N							305	305
RK	**F**	*r*								**0.37****
		N								305

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 7.5: Tests for significant differences in C1 and C2 in Nigg Bay Managed Realignment Site between 10 m cells with and without birds at TS0. All significant differences had higher factor scores for areas without birds than those with birds.

Species	Activity	N absent	N present	C1	C2
BA	F	251	21	**1434*****	2632
	R	271	2	**41***	177
CU	F	151	122	**6004*****	**7455****
	R	202	71	**4791*****	6602
DN	F	252	21	**1711****	2441
OC	F	215	58	**3719*****	5426
	R	267	6	**263****	736
RK	F	221	52	**2068*****	**4707***
	R	265	8	**205*****	783

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
*** Correlation is significant at the 0.001 level (2-tailed).

Table 7.6: Tests for significant differences in densities of waders between areas above and below 1.7m OD and within and beyond 10m of creeks at TS0. All significant differences had higher densities below 1.7 m OD and within 10 m of creeks.

Species	Activity	N >1.7 m OD	N <1.7 m OD	Elevation	N >10 m of creek	N <10 m of creek	Creeks
CU	F	23	99	960.5	53	69	1708
OC	F	16	37	213	23	30	246.5
RK	F	26	37	**277****	29	34	**337***

7.3.4 Changes in the distributions of waders through the tidal cycle

The average C1 score was significantly higher at TS2 and TS3 than at TS0 for resting Eurasian Curlew and significantly higher at TS3 than at TS0 and TS1 for foraging Common Redshank, indicating that at higher tidal states these species move away from the breach gaps and embankments, towards the fence and higher, more vegetated areas (Table 7.7, Figures 7.3 and 7.4). The average C2 score for foraging Common Redshank was significantly higher at TS3 than at TS2 indicating that at higher tidal states foraging Common Redshank move away from the creeks (Table 7.7, Figures 7.3 and 7.4).

Table 7.7: Tests for significant differences in distribution of Eurasian Curlew and Common Redshank between tide states in relation to C1 and C2. Statistically significant values are emboldened.

Species	Activity	C1				C2			
		Kruskal-Wallis test across TS0-3		Multiple comparison test		**Kruskal-Wallis test across TS0-3**		Multiple comparison test	
		$n^{\S}$	χ^2	*Q*	TS diff[†]	$n^{\S}$	χ^2	*Q*	TS diff[†]
CU	Resting	257	**38.7***	**5.4*** **5.3***	**TS2 > TS0** **TS3 > TS0**	257	**7.9***		
RK	Foraging	204	**33.0***	**5.1*** **4.8***	**TS3 > TS0** **TS3 > TS1**	204	**19.4***	**4.3***	**TS3 > TS2**

§ *n* is the number of 10x10 m squares with each species present.
† 'TS diff' indicates which tidal state has the highest component score.
* Asterisks indicate statistically significant differences (*P* < 0.05).

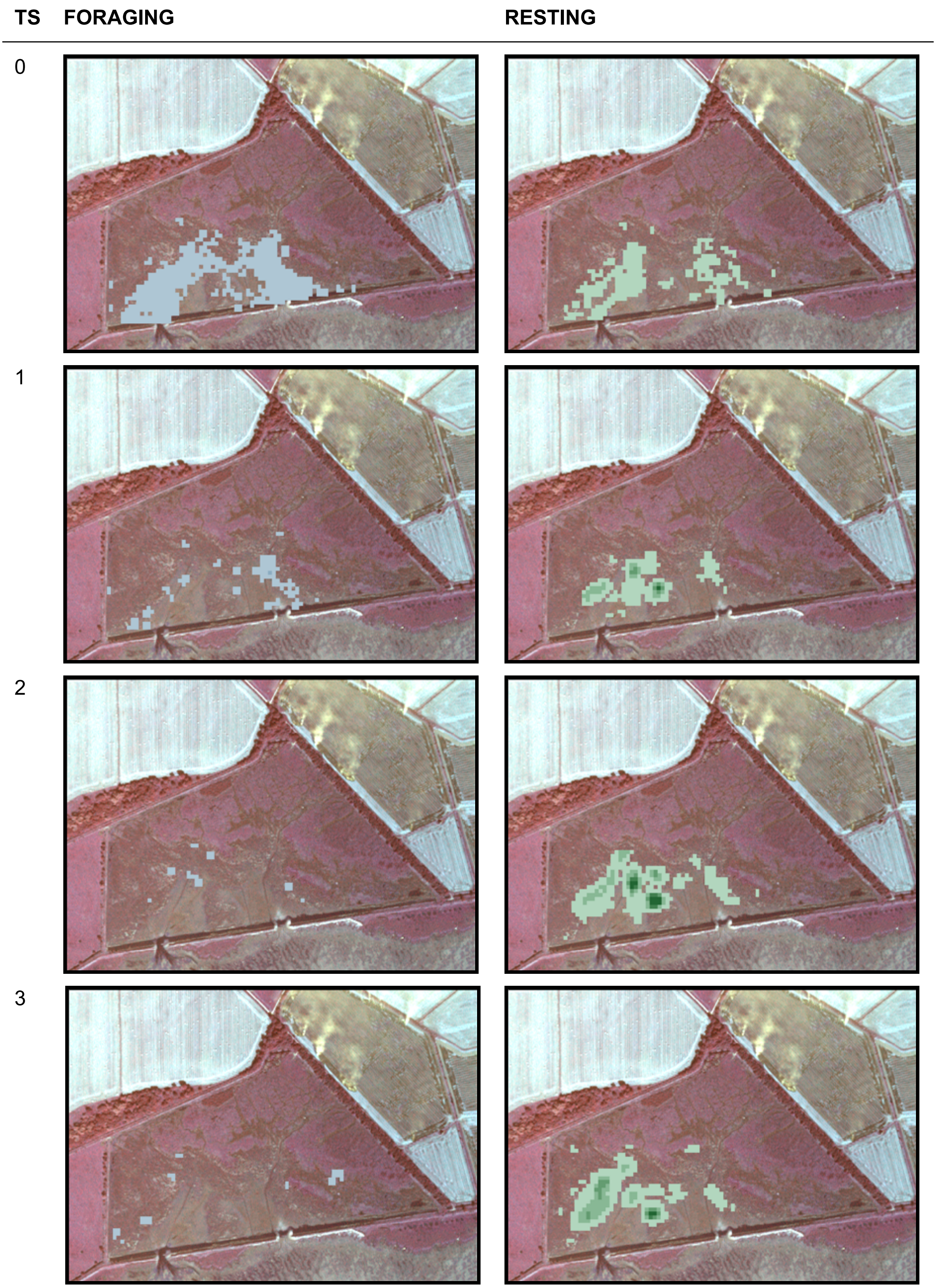


Figure 7.3: Density distributions (birds ha^{-1}) of foraging (1-5, 6-10, 11-15, 16-20, 21-25) and resting (1-20, 21-40, 41-60, 61-80, 81-100) Eurasian Curlew in Nigg Bay Managed Realignment Site in W3 at TS0-TS3.

TS	FORAGING	RESTING
0		
1		
2		
3		

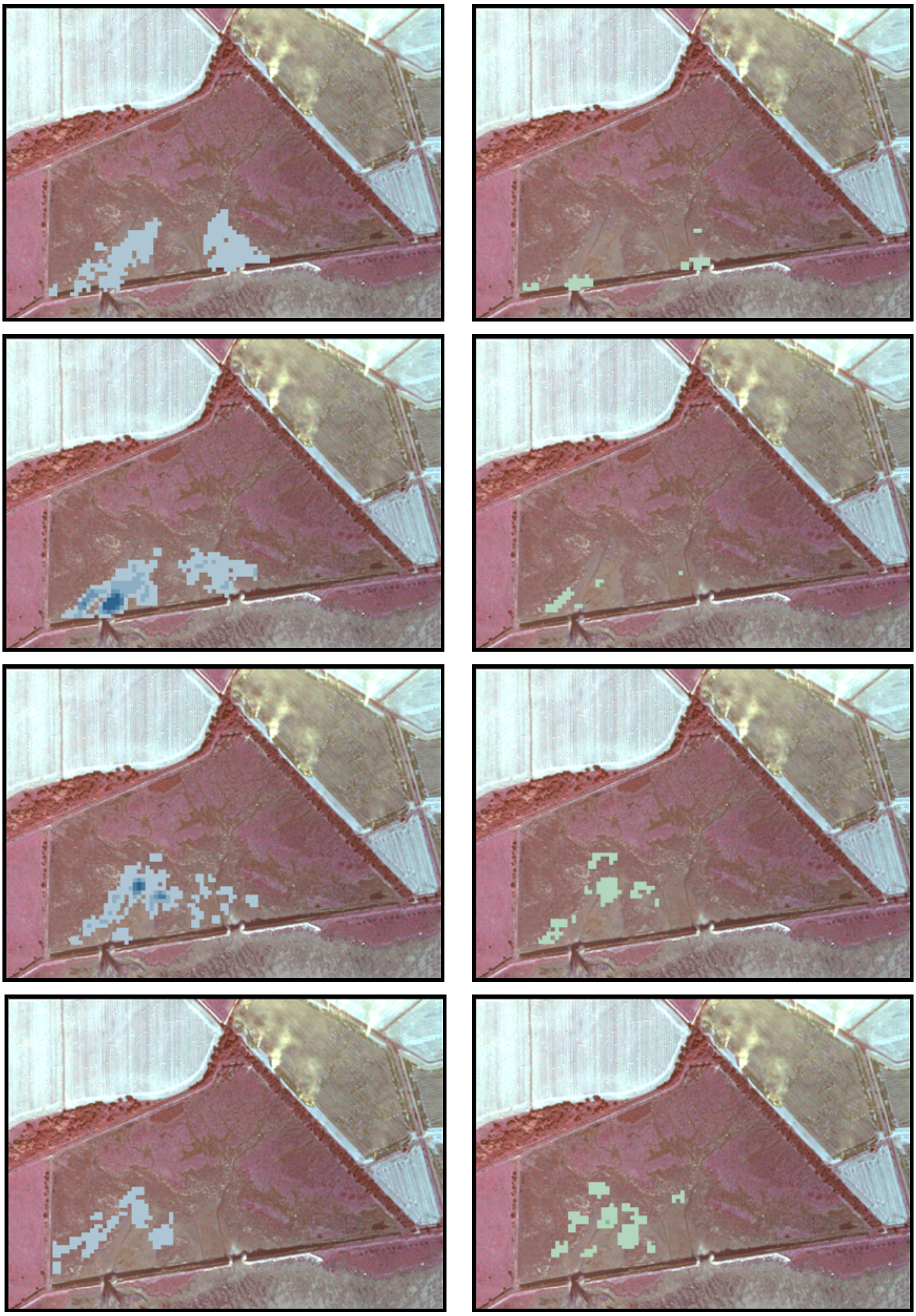


Figure 7.4: Density distributions (birds ha^{-1}) of foraging (1-5, 6-10, 11-15, 16-20, 21-25) and resting (1-20, 21-40, 41-60, 61-80, 81-100) Common Redshank in Nigg Bay Managed Realignment Site in W3 at TS0-TS3.

7.4 Discussion

As highlighted in Section 7.2.3.1, problems of spatial autocorrelation, pseudoreplication and scale can complicate spatial analysis. The following interpretation of the results assumes that the sub-sampling significantly reduced the problems of spatial autocorrelation and pseudoreplication and that the wader and invertebrate data were investigated at a sufficient range of scales to detect significant differences. If more time were available, the implications of these problems on the data could be investigated more thoroughly.

7.4.1 Physical features

The spatial distribution of waders in Nigg Bay MRS at TS0 was affected by physical features. However, as many of these were correlated, it is not possible to distinguish fully the effects of individual features. The design of Nigg Bay MRS resulted in the breach gaps aligning with relic drainage channels in the site and coinciding with the lower, muddier areas.

The spatial distribution of waders in Nigg Bay MRS reflects the topography of the site. Wader foraging hotspots coincided with areas of lower elevation on the intertidal flats while resting hotspots coincided with two areas of higher elevation on the developing saltmarsh (Figure 7.2). These areas of higher elevation may be attractive roost sites as they will become islands at higher tidal states, lowering the predation risk from land-based predators such as Red Fox *Vulpes vulpes*. At Freiston Shore Managed Realignment Site, the creation of a saline lagoon with islands within the site has increased the attractiveness to waterbirds (Badley & Allcorn 2006a, 2006b). The present study further demonstrates that providing islands in managed realignment sites can be beneficial to waterbirds.

Foraging Eurasian Curlew and foraging and resting Common Redshank were more likely to use areas closer to creeks and there were significantly higher densities of foraging Bar-tailed Godwit, Eurasian Curlew, Dunlin and Common Redshank within 10 m of creeks. Previous studies have demonstrated the importance of creeks and drainage channels to waterbirds. On the Tagus Estuary, Portugal, for example, 44% of birds fed less than 5 m from the edges of drainage channels (i.e. just 12% of the available area) where invertebrate prey were most abundant (Lourenço *et al*. 2005). At lower tidal states, the sediments nearest to creeks are likely to remain wetter for longer periods, increasing the availability of prey to waders. Dunlin, for example, selectively forage in wetter areas since these softer sediments are more easily penetrated by their bills (Kelsey & Hassall 1989). Freshwater flows can also provide waders with a resource for drinking (Ravenscroft & Beardall 2003). Deeper channels can provide shelter for waders (Ravenscroft & Beardall 2003), which can be particularly important in harsher weather conditions when cold temperatures and high wind speeds can rapidly deplete a birds energy reserves (Goss-Custard *et al*. 1977a). Although, it is not clear exactly which, if any, of these benefits the waders were deriving from the presence of creeks in Nigg Bay MRS, it demonstrates the importance of ensuring that sites considered for managed realignment to restore intertidal habitats for waterbirds have a creek network in place, or at least have a high probability of developing one.

Within Nigg Bay MRS, vegetation cover and embankments are likely to provide cover for avian predators such as Eurasian Sparrowhawk *Accipter nisus* and Merlin

Falco columbarius, while trees and fence posts are likely to provide perches from which avian predators can launch a surprise attack (Cresswell 1996). Peregrine Falcon, *Falco peregrinus* and Eurasian Sparrowhawk were both observed in Nigg Bay MRS during the course of the study (Appendix 7). In order to minimise risk of predation, waders might be expected to forage and rest where they have the greatest field of view, to give themselves the best chance of detecting an approaching predator. Although waders were more likely to use areas close to the embankments, it is likely that this was, in part, due to correlation with proximity to breach gaps. Near to the breach gaps, waders were likely to have had a greater field of view, and would have had a greater chance of seeing avian predators approaching from the adjacent intertidal area. Common Redshank, in particular, reached highest foraging densities near to the breach gaps and this was the only area of the site in which they rested when the tide was absent. Common Redshank are particularly vulnerable to attack by predators, as has been shown on other Scottish estuaries (Cresswell & Whitfield 1994). These findings highlight the requirement for managed realignment sites to be designed with consideration of the predation risk of birds. As the waders in Nigg Bay MRS appear to predominantly use the areas near to the breach gaps, this suggests that breached realignments are likely to be more attractive to waders than sites created through regulated tidal exchange. However, breached realignments are likely to be less attractive to waders than banked realignment, where the site forms a more natural extension of the estuary (Pontee *et al*. 2006) and visibility is maximised.

7.4.2 Invertebrate prey

The distribution and density of intertidal invertebrates is usually cited as one of the main factors governing the distributions of waders in intertidal areas (Goss-Custard *et* *al*. 1977b, 1977c; Bryant 1979; Rippe & Dierschke 1997; Dierschke *et al*. 1999; Arcas 2004; Ieno *et al*. 2004; Santos *et al*. 2005). In Nigg Bay MRS, hotspots of foraging Common Redshank coincide with the areas of highest *Corophium volutator* density (Figure 7.12a), their preferred prey (Goss-Custard 1977b, 1977d). No species had a significant relationship with the presence of invertebrate prey, at any of the scales investigated.

Invertebrates were not detected at many of the sampling locations in W3 (Figure 7.13), despite waders being observed foraging at these locations earlier in the winter. There are several possible explanations for this finding. It is possible that the invertebrates were patchily distributed on a fine scale and that the majority of invertebrate samples were taken from sites with relatively few invertebrates and are not representative. Perhaps a more likely explanation is that the waders depleted the invertebrates over the course of the winter, leaving very few to be sampled. Prey depletion by waders has been reported in a number of other studies at an estuarine scale (Goss-Custard 1969, 1977c; Prater 1972; Bengston *et al*. 1976; Horwood & Goss-Custard 1977; Schneider 1978; Evans *et al*. 1979; Schneider & Harrington 1981; Frank 1982; Sutherland 1982; Zwarts & Wanink 1984; Marsh 1986; Székely & Bamberger 1992), and is perhaps more likely in newly created sites. In light of this, it is not possible to rule out the importance of invertebrate distributions and densities in determining the spatial distributions of waders in managed realignment sites.

7.4.3 Tidal cycle

The spatial distribution of waders in Nigg Bay MRS was affected by the tidal cycle, supporting the temporal patterns established in Chapter 6. When the tide was absent, there was no restriction on where waders could forage or roost in the site, although many used the lowest areas nearest to the breach gaps. However, once the tide entered and advanced within Nigg Bay MRS, the waders were gradually forced away from the breach gaps and embankments towards more vegetated areas, higher in the tidal frame.

Common Redshank and Eurasian Curlew had different responses to the arrival of the tide in Nigg Bay MRS, which is likely to reflect the different ecology of these species. Common Redshank densities increased in the area nearest to the breach gaps. The increase in the density of foraging Common Redshank in the area near the west breach gap may be due to increased invertebrate activity in the shallow water. Previous studies have shown that *Corophium*, the preferred prey of Common Redshank (Goss-Custard 1977d), only come to the surface in wet sediments (Colwell & Landrum 1993). The west breach area may be more attractive than the east breach area, since this is where the tide first enters Nigg Bay MRS (pers. obs.). Eurasian Curlew abandoned the areas closest to the breach gaps, with the majority moving to roost sites within Nigg Bay MRS. By the time that the intertidal flats were no longer accessible, the density of birds at these roost sites had increased, although distributions were largely unchanged. The high average density at these sites may indicate that they are among a small number of roost sites within Nigg Bay which are regularly used (Colwell *et al*. 2003).

7.5 Conclusion

The spatial distribution of waders in Nigg Bay MRS was related to a number of physical features including elevation in the tidal frame, vegetation cover and proximity to breach gaps, embankments, fence and creeks. However, it was not possible to determine the relative importance of these factors due to correlations between the factors. When the tide was absent, waders favoured the lower-lying areas with no vegetation cover, which are closest to the breach gaps and the embankments. It is suggested that these areas were favoured because invertebrates are likely to have been more abundant and the predation risk is likely to have been lower, as the breach gaps would have allowed waders to see approaching predators. Densities of foraging Common Redshank were significantly greater within 10 m of creeks, although it was not possible to determine whether this was due to invertebrate prey being more accessible or some other factor. No significant relationships were found between distributions of each wader species and distributions of invertebrate prey. It is suggested that waders depleted the invertebrates over the course of the winter, leaving very few left to be sampled. The presence of the tide affected wader distributions in the site as they were forced higher in the tidal frame.

Chapter 8

Use of Nigg Bay Managed Realignment Site and Nigg Bay by individually marked birds

8.1 Introduction

On an estuarine scale, studies of individually marked birds have established that although populations may be distributed across the entire available habitat, individual home ranges may be considerably smaller. Specific demographic groups may only use certain areas, for example, adults may exclude juveniles from prime foraging sites (Van der Have *et al*. 1984; Goss-Custard & Durell 1984; Summers *et al*. 1990). Diurnal and nocturnal distributions of individual waders have also been shown to differ (Section 1.1.3.5).

Monitoring usage patterns by individuals will be particularly important in assessing the success of habitat creation and restoration schemes, including managed realignment, to restore intertidal habitat for waterbirds (Section 1.1.3.5). The ability to identify individuals will enable a managed realignment site to be linked temporally and spatially to specific areas of the adjacent estuary and therefore give an indication as to whether the site is functioning as a natural extension of the estuary. Knowledge of the number of different individuals and demographics of the birds using a site will provide an indication of the value of the site to the population as a whole and may allow inferences to be drawn about the quality of the created habitats.

This chapter presents the first study of the use of a managed realignment site by individually marked birds. This study uses colour-ringing and radio-tracking of Common Redshank to investigate the use of Nigg Bay MRS and the wider estuary and attempts to answer the following questions: Does Nigg Bay MRS have a regular and exclusive clientele? What is the age structure of the birds present? Which other areas of intertidal habitat are used by the individuals which use Nigg Bay MRS? Is Nigg Bay MRS used at night?

8.2 Methods

8.2.1 Choosing a technique to mark individual birds

Much of our detailed knowledge on use of intertidal habitats by non-breeding waterbirds comes from studies of individuals (Section 1.1.3.5). A wide range of techniques has been used to allow individual birds to be identified in the field. Conventional bird ringing involves attaching a metal ring with a unique number and return address to a bird's leg. This type of bird ringing relies on a ringed bird being re-caught or found dead and, as a result, only a small proportion of ringed birds are ever recovered. Colour marking removes the need for re-trapping and greatly increases the chances of multiple recordings of the same individual. Colour marking may include dye on a conspicuous area of plumage (Symonds & Langslow 1986), coloured plastic rings on the leg(s) (Gunnarsson *et al*. 2005), a numbered plastic leg ring (Ogilvie 1972), wing (patagial) tag (Evans *et al*. 1999) or collar (Frederiksen *et al*. 2004). In contrast to ringing techniques, radio-tagging (Reynolds 2004) allows birds to be located without the need for re-sighting and can therefore be used to locate individuals in conditions when it would otherwise be impossible to distinguish colour markings, such as during poor weather, at night or over large distances. Radio-tracking is most suitable for local studies and satellite telemetry for studies on a global scale (Weimerskirch *et al*. 1993).

Both colour-ringing and radio-tagging were selected as the most appropriate methods of marking individuals for this study. Common Redshank *Tringa totanus* were chosen for this study as they were the most common species in Nigg Bay MRS in the first winter following the re-establishment of tidal conditions (Chapter 5) and have been used successfully in colour-ringing and radio-tracking studies of non-breeding populations on other UK estuaries (Burton 2000; Burton & Armitage 2005; Burton *et al*. 2006, Symonds & Langslow 1984).

8.2.2 Trapping and colour-ringing birds

A total of 126 Common Redshank was colour-ringed by the Highland Ringing Group on 5 occasions during W2 and W3 (Tables 5.1 and 8.1). Common Redshank were trapped by (day-time) cannon- or (night-time) mist-netting at high tide roost sites in Nigg Bay and by (night-time) mist-netting across the breach gaps of the Nigg Bay MRS on a rising tide (Figure 8.1).

Each individual was classified as an adult or juvenile according to its plumage characteristics (Prater *et al*. 1977) but was not sexed. Biometric data, including body mass, were also recorded. A colour-ringing scheme was provided by the Wader Study Group Colour-marking Register. The scheme identifier was a single yellow Darvic ring on the right or left tarsus (below the knee). In the majority of cases this ring was fitted on the right leg, and only fitted on the left leg if the bird already had a metal British Trust for Ornithology (BTO) ring on the right. Each individual was given a unique combination of Darvic rings, two on each tibia (above the knee), using the colours: black (N), lime (L), pale blue (P), white (W), and yellow (Y). Details of all the individuals ringed during this study are presented in Appendix 8.

Table 8.1: Details of Common Redshank trapping events.

Date	Location	Method	Adults	Juveniles	Total
23/10/2004	Bayfield	Mist	1	7	8
23/10/2004	Meddat	Mist	3	5	8
28/11/2004	Bayfield	Cannon	29	2	31
11/12/2004	Nigg Bay MRS	Mist	4	0	4
24/09/2005	Balintraid	Cannon	41	28	69
10/12/2005	Nigg Bay MRS	Mist	6	0	6
		TOTAL:	78	42	126

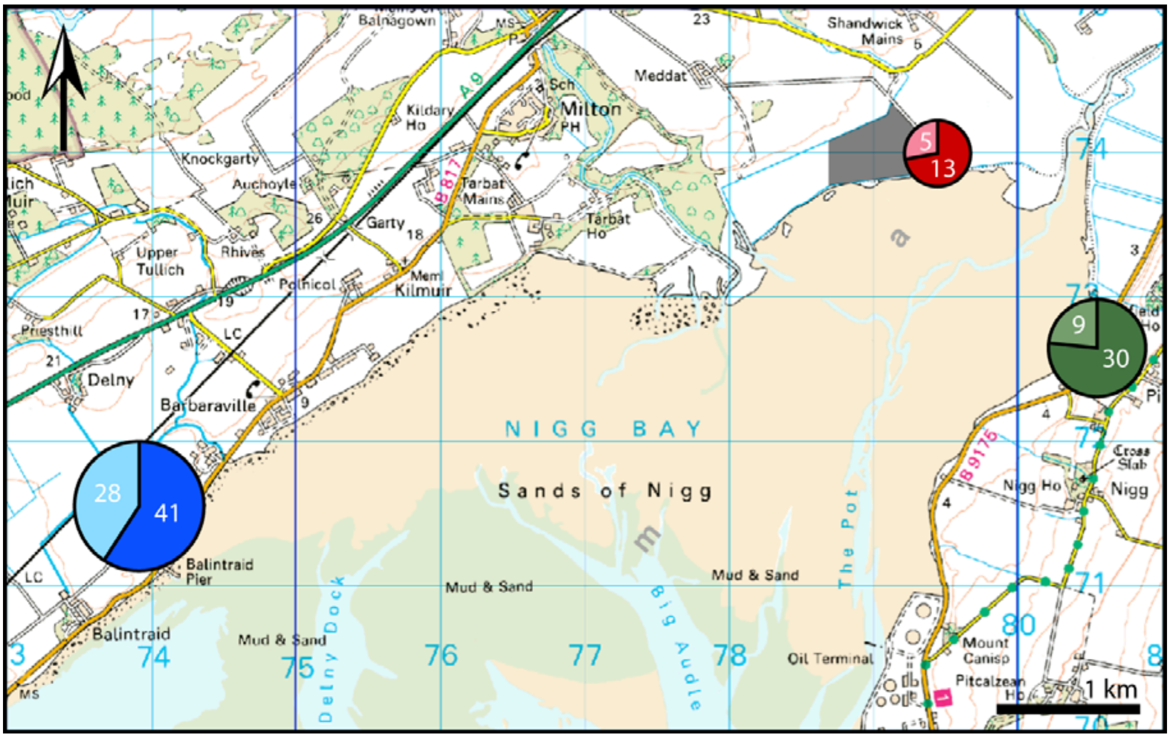


Figure 8.1: The locations of trapping sites at Balantraid (blue), Meddat (red) and Bayfield (green) in Nigg Bay. Pie charts indicate the trapping locations and the numbers in each pie chart are the numbers of adults (darker shading) and juveniles (lighter shading) ringed at each location.

8.2.3 Searching for colour-ringed birds

Nine areas of Nigg Bay were searched for ringed birds (Table 8.2 and Figure 8.2) throughout W2 and W3, between 1 and 515 days after the first individuals were ringed. Areas A and B were searched every 15 minutes throughout the tidal cycle on several days each month. The remaining seven areas were searched opportunistically. Areas D, E and I were usually searched at lower tidal states, while the remaining areas were searched at higher tidal states from vantage points on the shore. Royal Society for the Protection of Birds (RSPB) staff participated in a coordinated search for colour-ringed birds at locations throughout the Cromarty Firth once per month throughout W3 (Table 8.2 and Figure 8.3).

Table 8.2: Number of days each search area in Nigg Bay and the Cromarty Firth was visited in each winter. Area codes are as in Figures 8.2 and 8.3.

Area		W2	W3
Nigg Bay	A	29	24
	B	0	26
	C	0	9
	D	0	7
	E	0	3
	F	4	19
	G	0	11
	H	0	15
	I	0	9
Cromarty Firth	J	0	5
	K	0	4
	L	0	3
	M	0	4
	N	0	3
	O	0	2

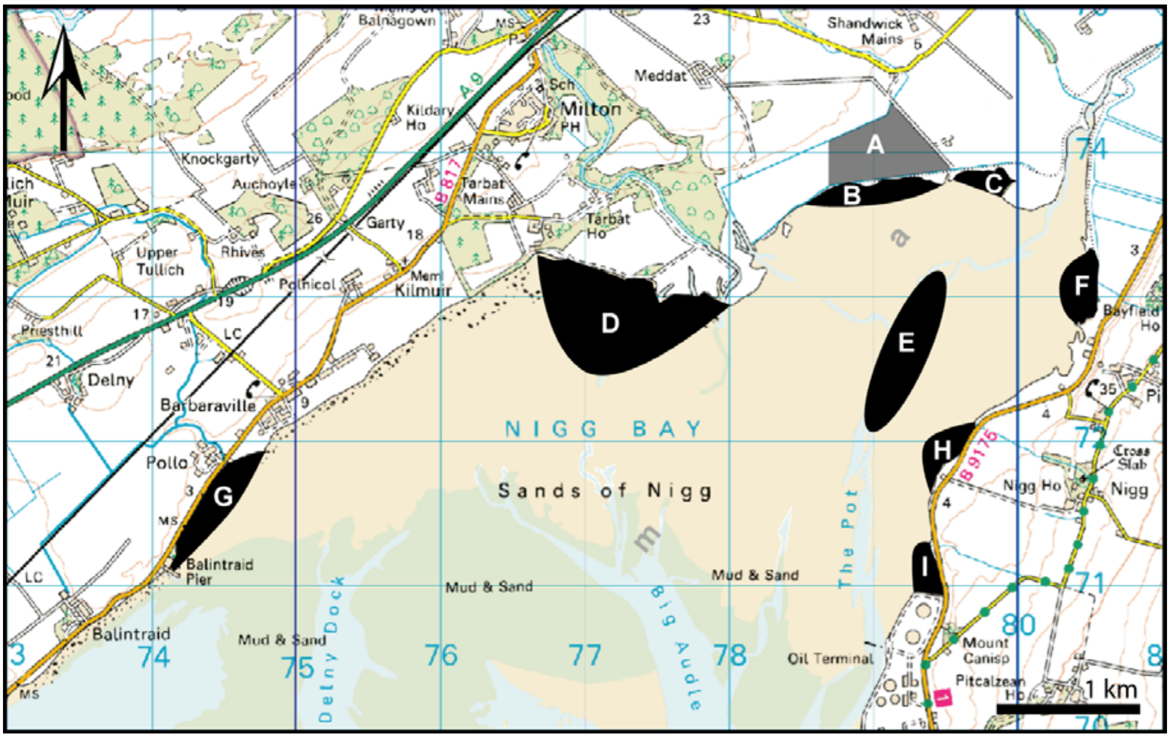


Figure 8.2: Approximate extents of the areas of Nigg Bay (labelled A-I) that were regularly searched for colour-ringed birds.

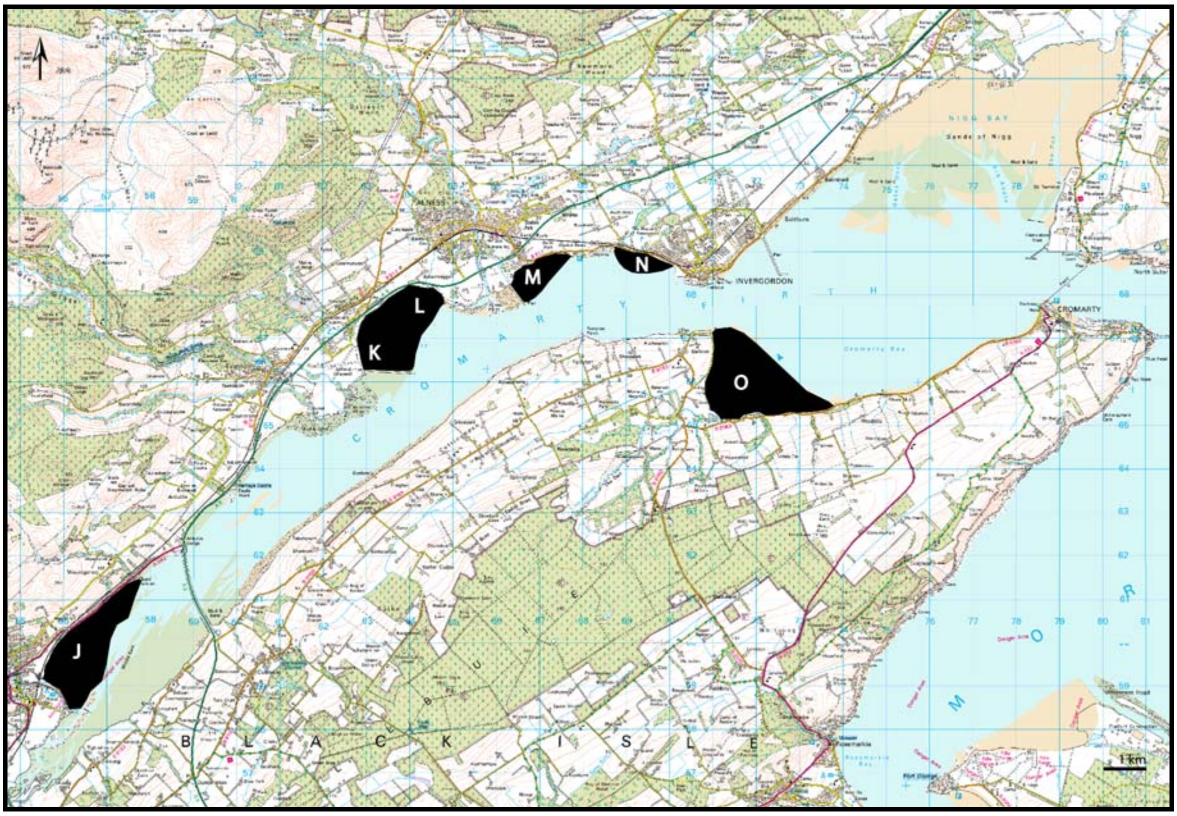


Figure 8.3: Areas of the Cromarty Firth (labelled J-O) regularly searched for colour-ringed birds in W3. Areas of Nigg Bay (labelled A-I) are shown in Figure 8.2.

8.2.4 Analysis of colour-ringed bird data

Trapping and sighting details were managed in an Access database. Sightings data are presented on maps (e.g. Figure 8.4). Within each search area in Nigg Bay a dot represents a different individual and the size of each dot is proportional to the number of days on which an individual was (re-)sighted within that search area. Movements of individuals between different search areas are represented by lines connecting the two areas (e.g. Figure 8.5). The weight of the line is proportional to the number of different individuals that were recorded in both of the search areas at the ends of each line.

8.2.5 Trapping and radio-tagging birds

Ten Common Redshank were radio-tagged by the Highland Ringing Group during W2 and W3, five in each winter (Table 8.3).

Table 8.3: Trapping details of birds radio-tagged for this study. Birds radio-tagged in W3 were each given a unique combination of colour-rings.

ID	Frequency (Hz)	BTO number	Colour-ring ID/combination	Date	Age*	Weight (g)
A	173.954	D005269	n/a	11/12/2004	J	161
B	173.494	D005270	n/a	11/12/2004	J	175
C	173.371	D005265	n/a	11/12/2004	A	179
D	173.894	D005266	n/a	11/12/2004	A	173
E	173.477	D005272	n/a	11/12/2004	A	180
F	173.194	D002072	87 W/N//M; N/W//Y	12/12/2005	A	179
G	173.346	D005271	88 W/N//M; W/W//Y	12/12/2005	A	163
H	173.413	D002075	89 W/N//M; W/N/Y	12/12/2005	A	170
I	173.438	D002073	90 W/N//M; W/Y//Y	12/12/2005	A	170
J	173.782	DD02070	99 W/W//M; Y/Y//Y	12/12/2005	A	187

* A = Adult, J = Juvenile

Common Redshank were trapped by (night-time) mist-netting across the breach gaps of Nigg Bay MRS. The 2.5 g transmitters (model TW-4, Biotrack Ltd., Wareham, Dorset, UK) were fitted with a small piece of gauze to aid attachment and had a battery life-expectancy of up to three months. The transmitters were glued with cyanoacrylite to a small area of clipped feathers on the lower back (Warnock & Warnock 1993). As the birds fitted with transmitters weighed between 161 g and 187 g the transmitters were between 1.3 and 1.6 % of their body mass, which is below the suggested maximum (5% of body weight) for small birds over 50 g (Brander & Cochran 1971; Cochran 1980). Each Common Redshank fitted with a transmitter in W3 was also given a unique combination of Darvic colour-rings (as described in Section 8.2.1).

8.2.6 Tracking radio-tagged birds

Movements of radio-tagged individuals were monitored using a three-element hand-held Yagi antenna and a Telonics TR-5 receiver (Telonics Inc., Mesa, Arizona, USA). Bearings were collected from locations around the periphery of Nigg Bay using a compass and the birds' positions were determined by triangulation. Since the birds could move large distances between fixes recorded at long intervals, fixes were only triangulated if they were obtained within a 30 minute period. Due to the scale of the intertidal habitat in Nigg Bay and restricted access to the shoreline, it was usually only possible to obtain two fixes per bird within this period. Most data were collected during the diurnal tidal cycle, however, nocturnal fixes were also obtained in W2. The position of the tide line on the shore was also noted at the time of each fix.

8.2.7 Analysis of radio-tagged bird data

Fix data were plotted in ArcGIS™ (ESRI). Any points that were inferred to be non-intertidal or were greater than 100 m below the observed tide line, possibly due to birds moving between fixes, were judged to be anomalous and were therefore excluded from subsequent analyses.

A diurnal low-tide home-range was calculated for each bird for which there were more than 5 fixes, the minimum number required to calculate core areas and home ranges. In order to allow comparison with the study of Common Redshank use of intertidal flats on the Severn Estuary (Burton & Armitage 2005) equivalent methods were adopted. Fixed kernel home ranges (Worton 1989) were calculated for the 50% and 95% volume contours (i.e. the lines within which there would be a 50% or 95% chance of finding the individual concerned, representing the core area and home range, respectively) using the Home Range Extension (Rodgers & Carr 1998). The data were re-scaled using the unit-variance method then the spread of the kernels was estimated by least-squares cross-validation.

8.3 Results

8.3.1 Colour-ringed birds

Details of all sightings of colour-ringed birds are presented in Appendix 9. Of the 126 birds that were colour ringed, all re-sightings (of 88 birds) over the three winters of study were within the Moray Firth. Of these birds, 85 were re-sighted in Nigg Bay.

8.3.1.1 The wider use of sites in the Cromarty and Moray Firths and beyond by individuals colour-ringed in Nigg Bay

Two colour-ringed birds were located outside Nigg Bay during the coordinated searches of the Cromarty Firth in W3, one (of 51 ringed prior to the date of the sighting) in Dingwall Bay (Area J) and one (of 126 ringed prior to the date of the sighting) at Udale Bay (Area O) (Table 8.4).

There were sightings of individuals at widespread locations in the Moray Firth including one (of 120 ringed prior to the date of the sighting) at Culbin Sands and one (of 126 ringed prior to the date of the sighting) at each of Dornoch Sands, Balintore and Lonnie (Table 8.5). Four individuals that were colour-ringed at Balantraid in September 2005 had previously been ringed by the Highland Ringing Group at other locations in the Moray Firth including Brora, Tain and Ardullie (Table 8.6). Only two individuals were recorded beyond the Moray Firth (Table 8.5). One adult bird (of 51 ringed prior to the date of the sighting) was sighted in the Montrose Basin, 144 km south east of Nigg Bay, 244 days after it had been colour-ringed. A second adult bird (of 126 ringed prior to the date of the sighting) was sighted in North West Iceland, 1340 km north west of Nigg Bay, 2 years and 217 days after it was colour-ringed. This same individual was sighted in Den Helder, Kooysluis, North Holland, 770 km south east of Nigg Bay, ten days later.

Table 8.4: Details of co-ordinated searches for colour-ringed Redshank in areas of the Cromarty Firth (as shown in Figure 8.3) showing the proportion of birds checked for coloured-rings and the number of colour-ringed birds sighted.

Date	Area											
	J		K		L		M		N		O	
	Checked	Ringed	Checked	Ringed	Checked	Ringed	Checked	Ringed	Checked	Ringed	Checked	Ringed
21/09/2005	410/410	0	52/52	0	-		140/155	0	-		?/?	1
19/10/ 2005	84/350	0	181/181	0	108/108	0	0/0	0	27/27	0	250/302	0
17/11/ 2005	20/270	0	70/150	0	7/1001	0	41/63	0	1/1	0	259/259	0
20/12/ 2005	400/425	1	-		-		-		-		-	
12/01/ 2006	-		-		-		-		-		-	
13/02/ 2006	200/300	0	107/107	0	36/36	0	145/145/0	0	6/6	0	-	

Table 8.5: Encounter histories of individuals that were colour-ringed in Nigg Bay and subsequently re-trapped or re-sighted elsewhere in the Moray Firth or beyond.

ID	Encounter	Age	Date	Location	Time since first trap	Distance and direction from first trap
40	Trap	J	23/10/2004	Area F		
	Sighting	J	26/11/2004	Area F		
	Sighting	J	14/12/2004	Area F		
	Retrap	**A**	**31/12/2005**	**Balintore, Moray Firth**	**0 y 34 d**	**6.7 km NE**
	Sighting	A	19/01/2006	Area C		
	Sighting	A	27/01/2006	Area B		
	Sighting	A	16/02/2006	Area F		
54	Trap	A	28/11/2004	Area F		
	Sighting	A	13/12/2005	Area F		
	Sighting	A	19/12/2005	Area C		
	Sighting	A	20/12/2005	Area C		
	Sighting	A	18/01/2006	Area C		
	Sighting	A	19/01/2006	Area C		
	Sighting	A	27/01/2006	Area B		
	Sighting	A	03/02/2006	Area F		
	Sighting	A	13/02/2006	Area B		
	Sighting	A	22/03/2006	Area H		
	Sighting	**A**	**07/07/2007**	**NW Iceland**	**2 y 277 d**	**1340 km NW**
	Sighting	**A**	**10/07/2007**	**Den Helder, Kooysluis, North Holland**	**2 y 227 d**	**770 km SE**
61	Trap	A	28/11/2004	Area F		
	Sighting	**A**	**30/07/2005**	**Montrose Basin, Angus, Scotland**	**244 d**	**144.0 km SE**
	Sighting	A	07/10/2005	Area F		
	Sighting	A	19/10/2005	Area F		
	Sighting	A	04/11/2005	Area F		
	Sighting	A	05/11/2005	Area F		
	Sighting	A	13/11/2005	Area F		
	Sighting	A	17/11/2005	Area F		
	Sighting	A	18/11/2005	Area F		
86	Trap	A	10/12/2005	Area A		
	Sighting	A	19/12/2005	Area A		
	Sighting	A	20/12/2005	Area B		
	Sighting	A	16/01/2006	Area B		
	Sighting	A	13/02/2006	Area A		

Table 8.5 continued.

ID	Encounter	Age	Date	Location	Time since first trap	Distance and direction from first trap
	Sighting	**A**	**14/08/2006**	**Lonnie, Alturlie, Moray Firth**	**274 d**	**25.0 km SSW**
98	Trap	A	24/09/2005	Balintraid		
	Sighting	**A**	**02/11/2005**	**Culbin Sands, Moray Firth**	**0 y 39 d**	**20.4 km SE**
100	Trap	J	24/09/2005	Balintraid		
	Sighting	**J**	**20/12/2005**	**Dingwall Bay, Cromarty Firth**	**87 d**	**21.7 km SW**
116	Trap	A	24/09/2005	Balintraid		
	Sighting	**A**	**25/11/2006**	**Dornoch Sands, Moray Firth**	**1 y 62 d**	**17.6 km NNE**

Table 8.6: Encounter histories of individuals that were colour-ringed in Nigg Bay but had previously been ringed elsewhere in the Moray Firth.

ID	Encounter	Age	Date	Location	Time since first trap	Distance and direction from first trap
113	**Trap**	**J**	**11/12/04**	**Tain, Ross-shire**		
	Retrap	A	24/09/05	Balintraid	287 d	12 km, SSW
116	**Trap**	**J**	**07/12/02**	**Tain, Ross-shire**		
	Retrap	A	24/09/05	Balintraid	2 y 291 d	12 km, SSW
	Sighting	A	25/11/2006	Dornoch Sands, Dornoch Firth		
122	**Trap**	**A**	**19/09/04**	**Brora, Sutherland**		
	Retrap	A	24/09/05	Balintraid	1 y 5 d	36 km, SSW
126	**Trap**	**J**	**17/08/03**	**Ardullie,Cromarty Bridge**		
	Retrap	A	24/09/05	Balintraid	2 y 38 d	18 km, ENE

8.3.1.2 The use of Nigg Bay by individual birds

Five individuals that were colour-ringed as part of this study had originally been ringed by the Highland Ringing Group in Nigg Bay up to 12 years previously (Table 8.7). A total of 49% of the birds ringed in Nigg Bay in W2 were re-sighted in Nigg Bay in W3 (Table 8.8).

Table 8.7: Encounter histories of individuals that were colour-ringed for this study and had previously been ringed in Nigg Bay.

ID	Encounter	Age	Date	Location	Time since first trap
75	**Trap**	**A**	**28/12/97**	**Bayfield**	
	Re-trap	A	28/11/04	Bayfield	6 y 336 d
	Sighting	A	07/10/05	Area F	
	Sighting	A	05/11/05	Area F	
76	**Trap**	**A**	**28/12/97**	**Bayfield**	
	Re-trap	A	28/11/04	Bayfield	6 y 336 d
	Sighting	A	11/11/05	Area C	
	Sighting	A	02/12/05	Area F	
	Sighting	A	06/12/05	Area C	
	Sighting	A	14/12/05	Area C	
	Sighting	A	18/12/05	Area C	
	Sighting	A	19/12/05	Area C	
	Sighting	A	19/01/06	Area C	
	Sighting	A	27/01/06	Area B	
74	**Trap**	**J**	**01/12/02**	**Oil terminal**	
	Re-trap	A	28/11/04	Bayfield	1 y 363 d
	Sighting	A	30/11/04	Area F	
	Sighting	A	04/11/05	Area F	
	Sighting	A	08/11/05	Area F	
	Sighting	A	15/12/05	Area F	
	Sighting	A	17/01/06	Area F	
	Sighting	A	25/01/06	Area H	
	Sighting	A	27/01/06	Area H	
	Sighting	A	03/02/06	Area E	
	Sighting	A	16/02/06	Area H	
	Sighting	A	22/03/06	Area I	
73	**Trap**	**J**	**01/12/02**	**Oil terminal**	
	Re-trap	A	28/11/04	Bayfield	1 y 363 d
	Sighting	A	10/12/04	Area F	
59	**Trap**	**A**	**07/11/92**	**Barbaraville**	
	Re-trap	A	28/11/04	Bayfield	12 y 21 d

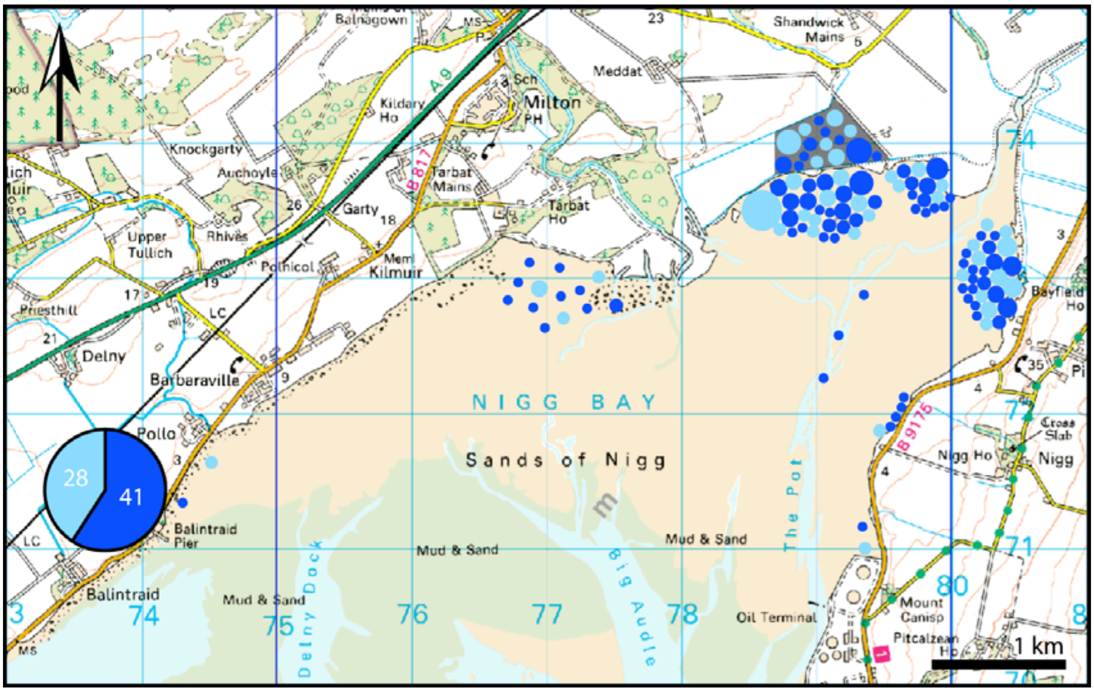
Table 8.8: Proportions of colour-ringed birds re-sighted within and between winters.

	Number ringed	Number re-sighted	
		W2	**W3**
W2	51	7 (14%)	25 (49%)
W3	75	-	66 (88%)

Adult and juvenile birds were sighted in all of the search areas in Nigg Bay apart from Area E (the Pot), where only adults were sighted (Figure 8.4). A total of 28 individuals were only sighted in areas to the west of the Pot (Figure 8.5), a further 21 individuals were only sighted in areas to the east of the Pot (Figure 8.6), while 35 individuals used areas on both sides of the Pot (Figure 8.7).

Data on the movements of individuals sighted more than once in a day (Figure 8.8) shows that there are movements of birds between different areas of Nigg Bay during the tidal cycle. This is supported by data on movements of individuals re-sighted within a seven day period (Figure 8.9) and also general observations of movements of all birds as the tide moves in Nigg Bay (pers. obs.).

a) **Balantraid**



b) **Bayfield**

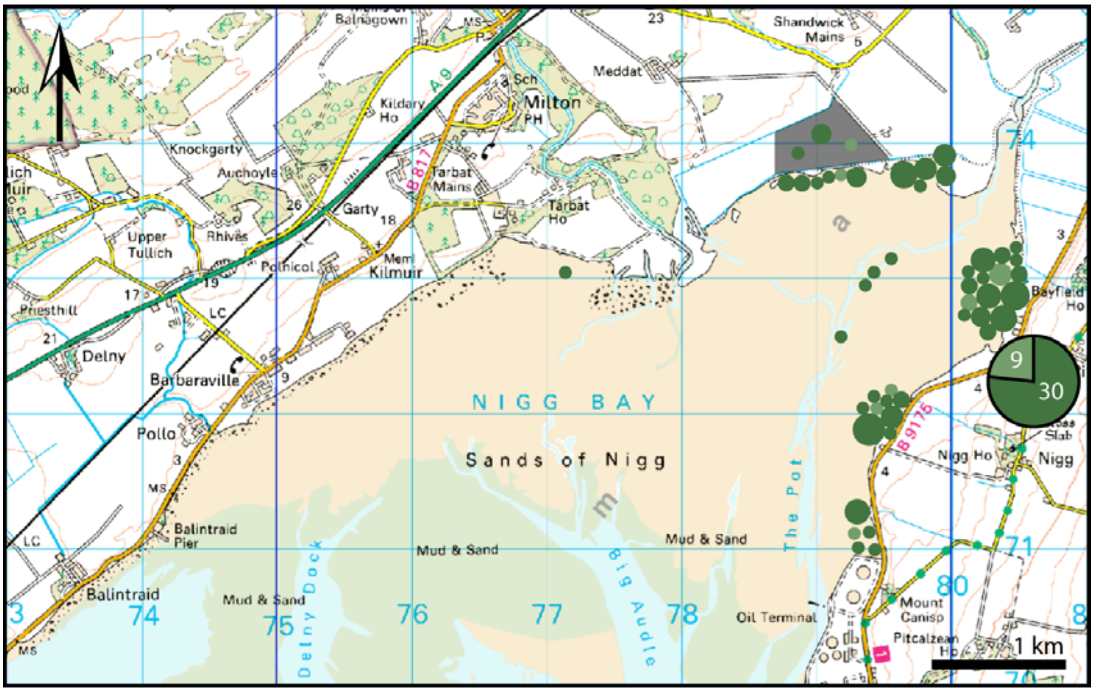


Figure 8.4: Sightings of individuals colour-ringed at (a) Balantraid, (b) Bayfield and (c) Meddat within search areas in Nigg Bay (as shown in Figure 8.2). Each dot within a search area represents an individual and the size of the dot represents the number of times that the individual was re-sighted in the area. Darker-shaded dots represent adults and lighter-shaded dots represent juveniles. Continues overleaf.

c) Meddat

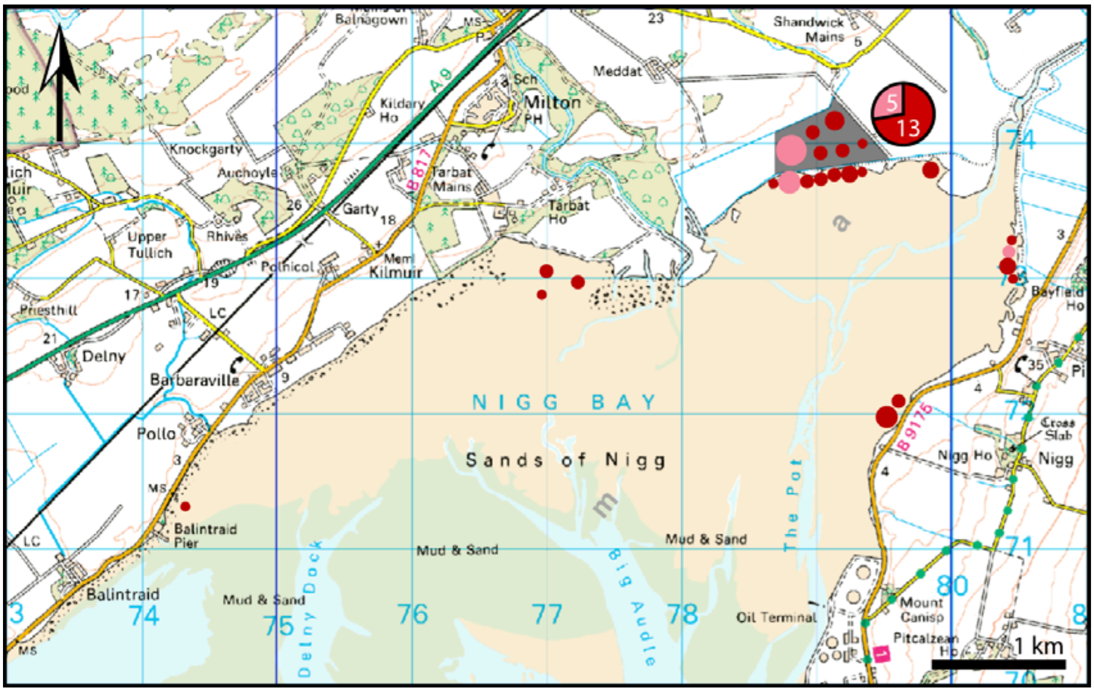


Figure 8.4 continued.

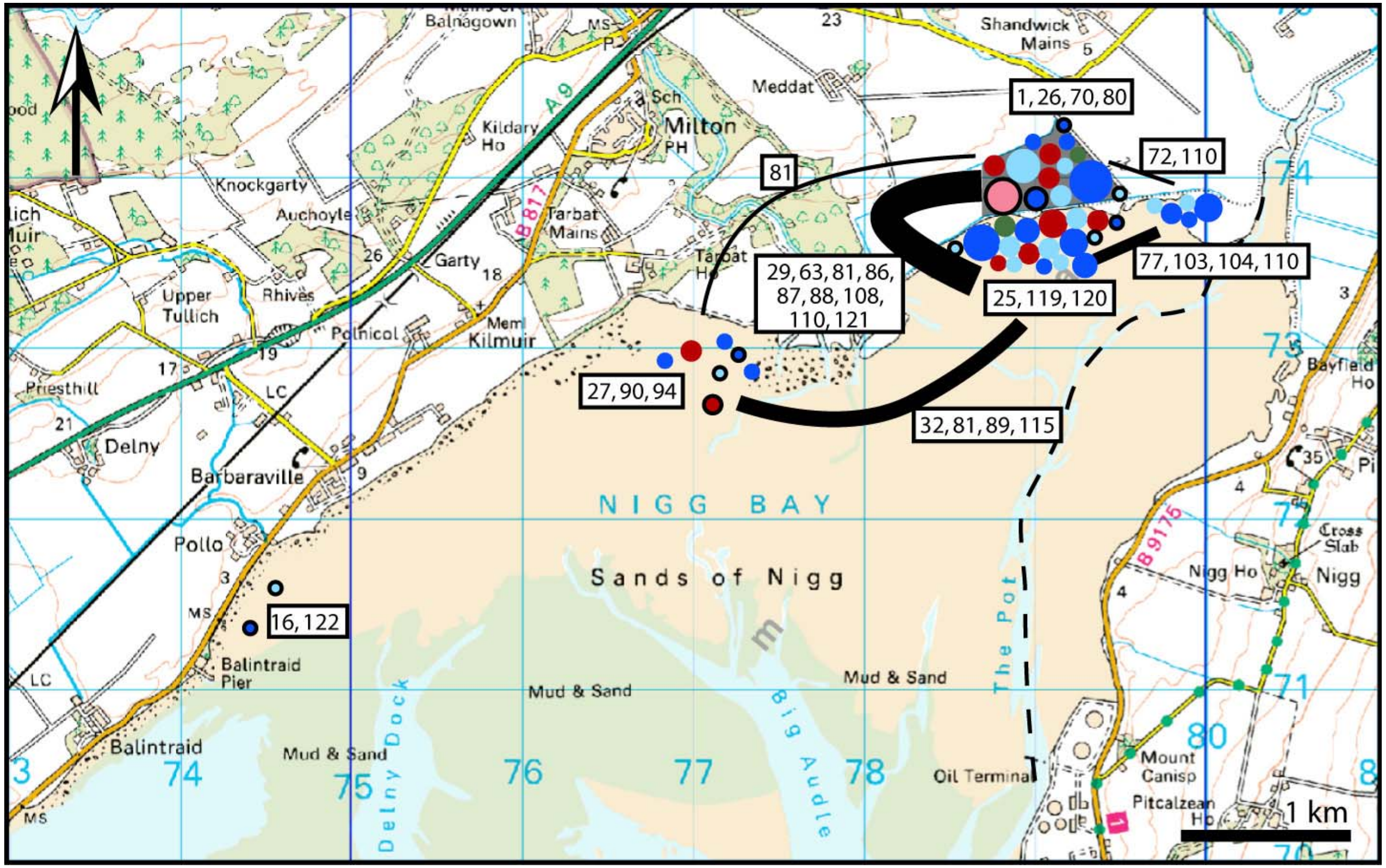


Figure 8.5: Sightings of individuals that were only recorded west of the Pot (indicated by the dashed line). Each dot within a search area represents an individual and the size of the dot represents the number of times that the individual was re-sighted in the area. Dot colours represent the trapping locations (as in Figure 8.1). Darker-shaded dots represent adults and lighter-shaded dots represent juveniles. Dots with black borders indicate birds that were only sighted in a single search area. Movements of individuals between different search areas are represented by lines connecting the two areas. The weight of the line is proportional to the number of different individuals that were recorded in both of the search areas at the ends of the line. Numbers associated with each line are the bird ID numbers (as in Appendix 8).

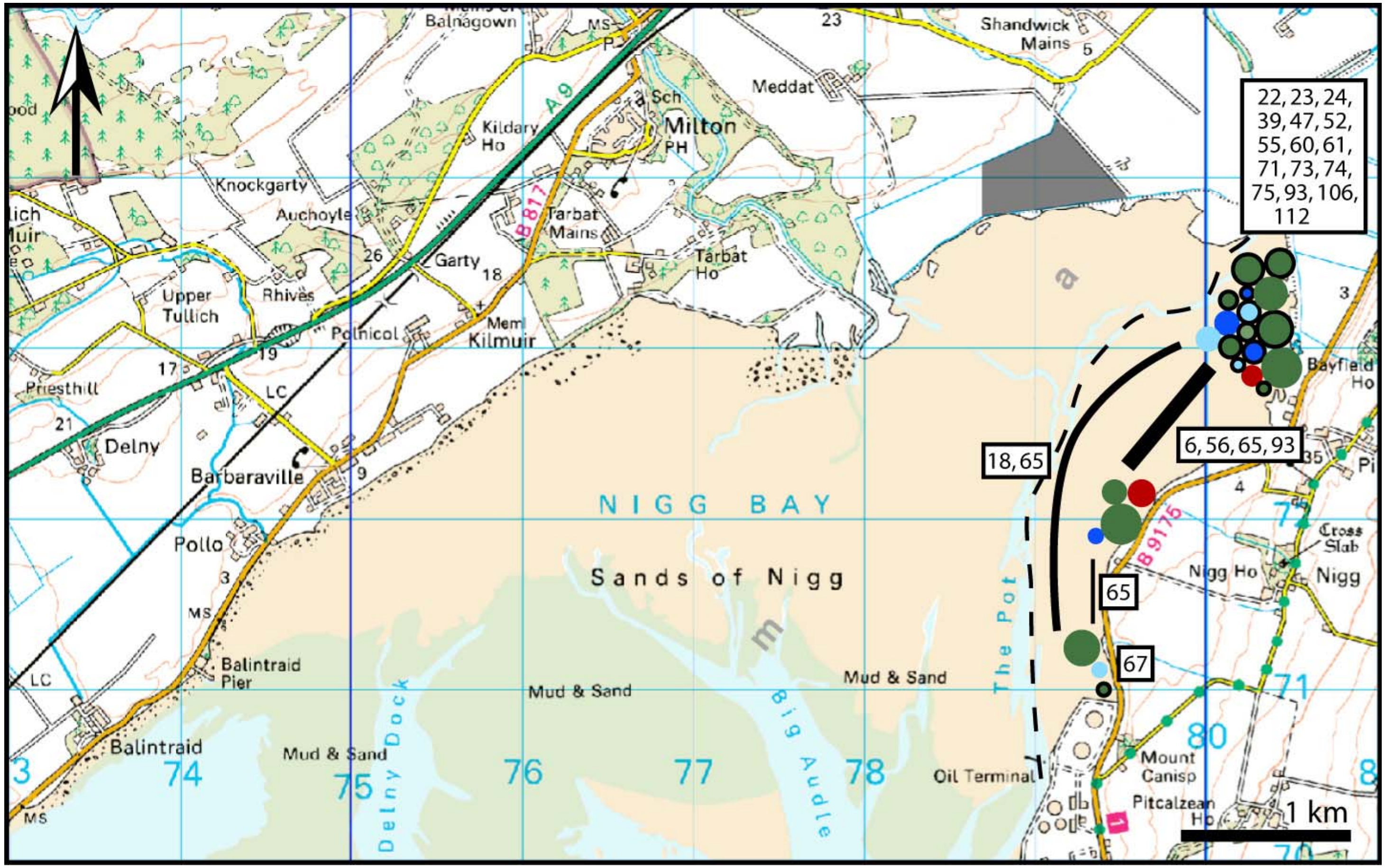


Figure 8.6: Sightings of individuals that were only recorded east of the Pot (indicated by the dashed line). Each dot within a search area represents an individual and the size of the dot represents the number of times that the individual was re-sighted in the area. Dot colours represent the trapping locations (as in Figure 8.1). Darker-shaded dots represent adults and lighter-shaded dots represent juveniles. Dots with black borders indicate birds that were only sighted in a single search area. Movements of individuals between different search areas are represented by lines connecting the two areas. The weight of the line is proportional to the number of different individuals that were recorded in both of the search areas at the ends of the line. Numbers associated with each line are the bird ID numbers (as in Appendix 8).

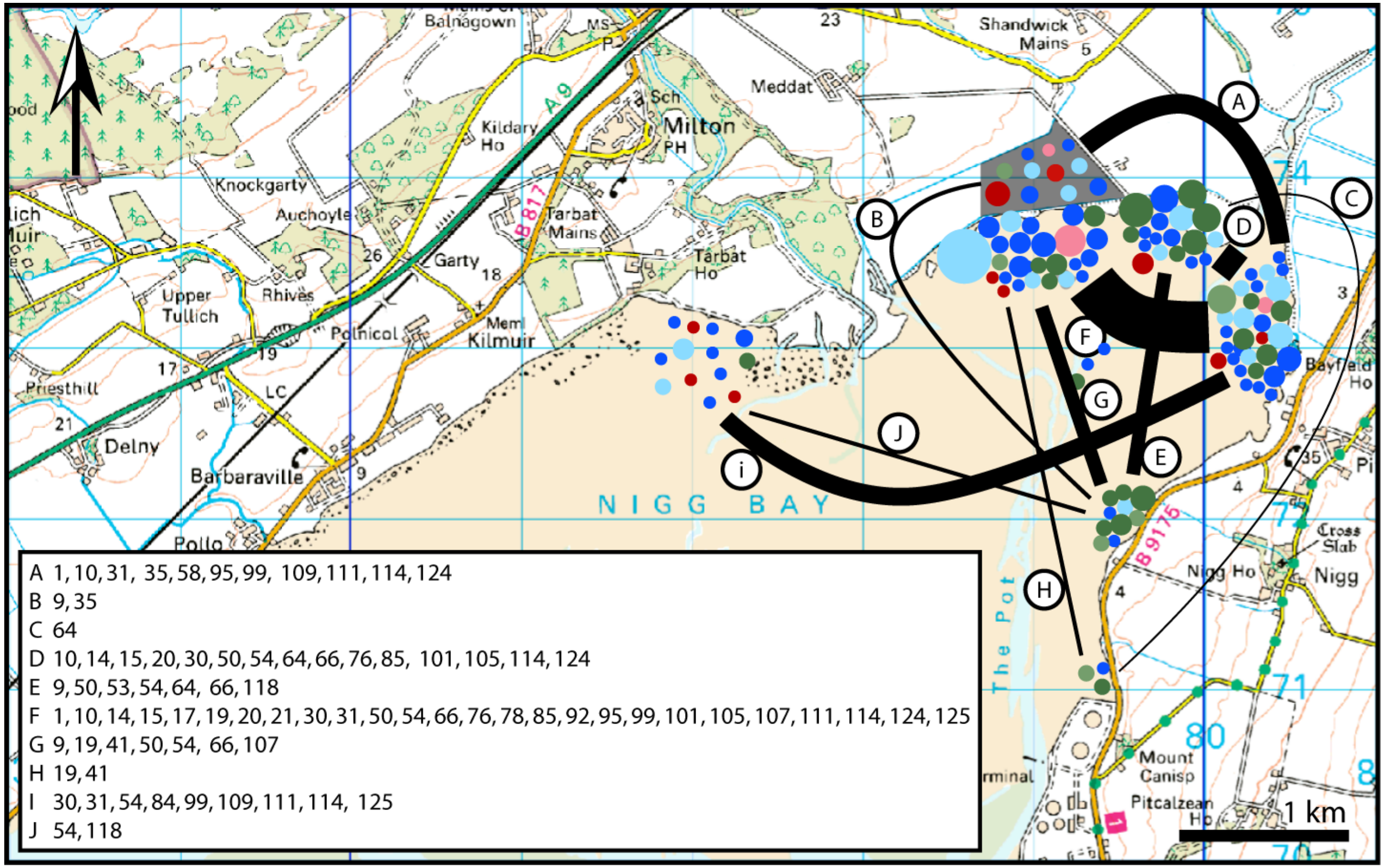


Figure 8.7: Sightings of individuals that were recorded on both sides of the Pot. Each dot within a search area represents an individual and the size of the dot represents the number of times that the individual was re-sighted in the area. Dot colours represent the trapping locations (as in Figure 8.1). Darker-shaded dots represent adults and lighter-shaded dots represent juveniles. Movements of individuals between different search areas are represented by lines connecting the two areas. The weight of the line is proportional to the number of different individuals that were recorded in both of the search areas at the ends of the line. Numbers associated with each line are the bird ID numbers (as in Appendix 8).

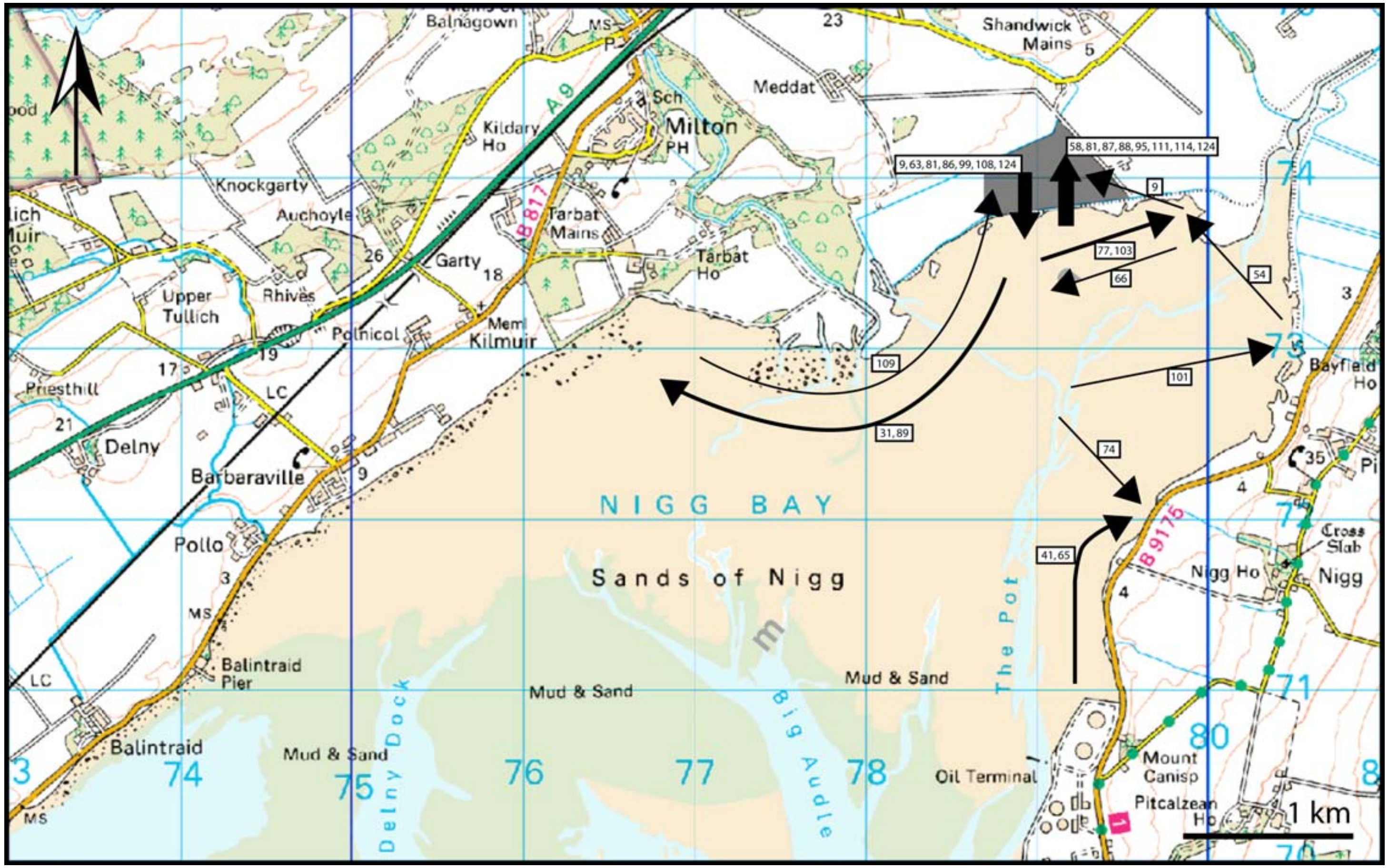


Figure 8.8: Movements of individuals re-sighted within the same day. Routes are based on the observed movements of birds within Nigg Bay. The weight of the line indicates the number of individuals recorded making the same movements. Numbers associated with each line are the bird ID numbers (as in Appendix 8).

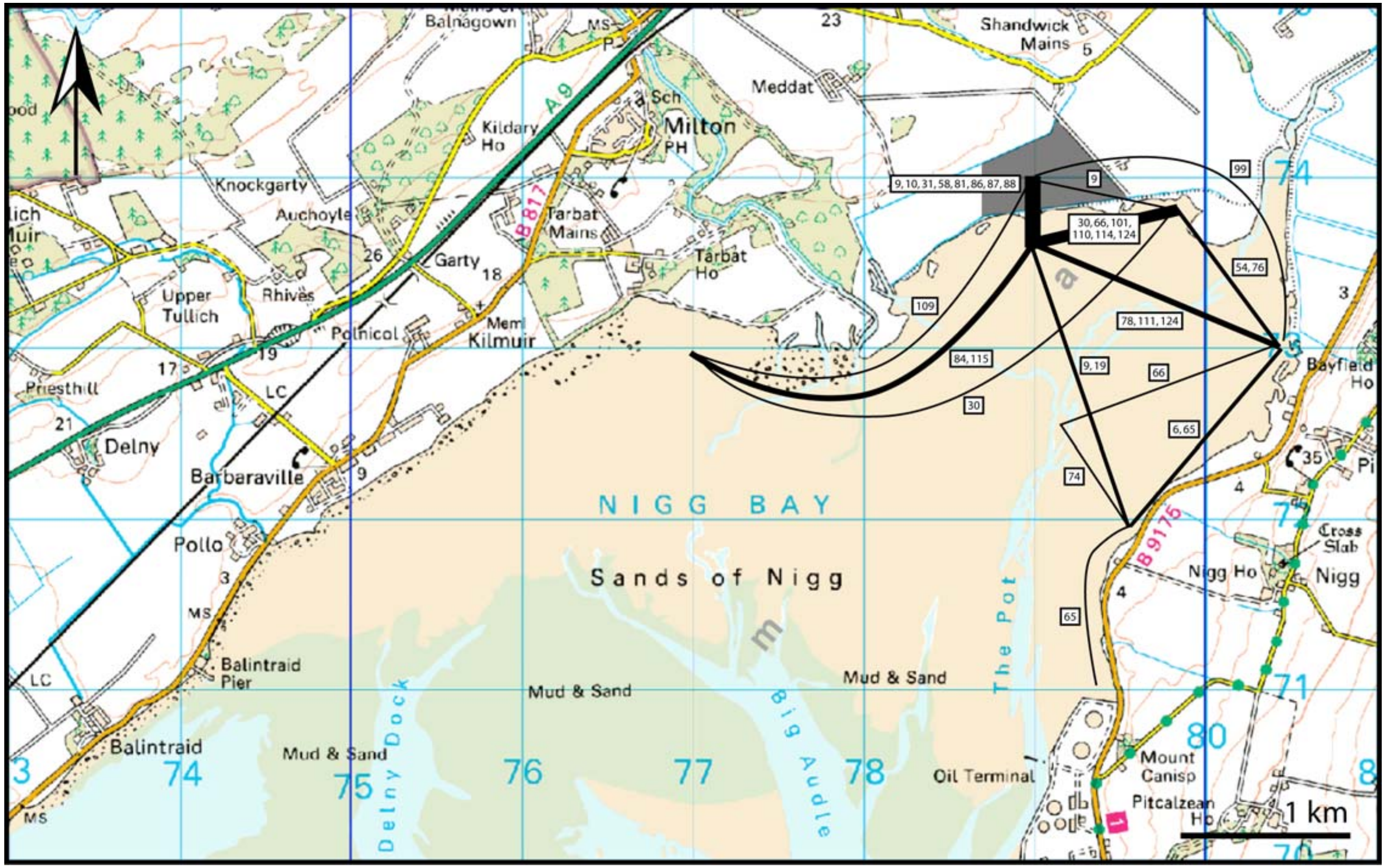


Figure 8.9: Movements of individuals re-sighted within seven days. The weight of the line indicates the number of individuals recorded making the same movements. Numbers associated with each line are the bird ID numbers (as in Appendix 8).

8.3.1.3 The use of Nigg Bay Managed Realignment Site by individual birds

Over the course of the study, 25 different individuals were recorded in Nigg Bay MRS. These birds included representatives from each of the three trapping locations (16 from Balantraid, 3 from Bayfield and 6 from Meddat). Taking into account the number of birds trapped at each location, there was no significant association between trapping locations and numbers seen in Nigg Bay MRS (G = 4.70, P < 0.05). Of the 25 individuals that were sighted in Nigg Bay MRS, 12 were only sighted on a single day, whereas the remaining 13 were recorded on multiple days. The most frequently recorded individual was recorded in the site on seven days between the 23rd November and 11th December 2004. The majority of sightings in Nigg Bay MRS were in December (across both W2 and W3), when 20 individuals were recorded using the site. Between one and seven individuals were recorded in Nigg Bay MRS in each of the other months. Individuals were recorded using the areas behind both breach gaps although the majority (17 individuals) only used the area behind the west breach gap. Two individuals only used the area behind the east breach gap and six individuals used the areas behind each breach gap. Nigg Bay MRS was used by 15 adults and 10 juveniles. This ratio of adults to juveniles is not significantly different to the ratio in which they were ringed (G = 0.21, P < 0.05).

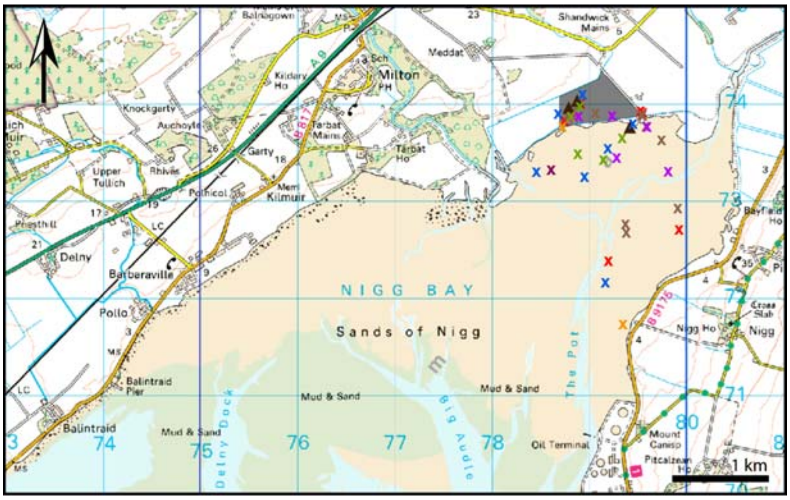
Of the 25 individuals recorded in Nigg Bay MRS, 21 were also sighted elsewhere in Nigg Bay. Re-sightings of birds in different areas of Nigg Bay within the same day suggest that there are movements of birds between Nigg Bay MRS (Area A) and Areas B, C, and D (Figure 8.8). These movements are supported by re-sightings of birds within a seven day period (Figure 8.9).

8.3.2 Radio-tagged birds

Patterns of movement through the tidal cycle are described below for a rising tide, these patterns were reversed on a falling tide. Figures 8.10-8.18 show patterns for each of the radio-tagged birds, except Bird A for which there was a lack of fix data.

a) High

b) Mid



c) Low

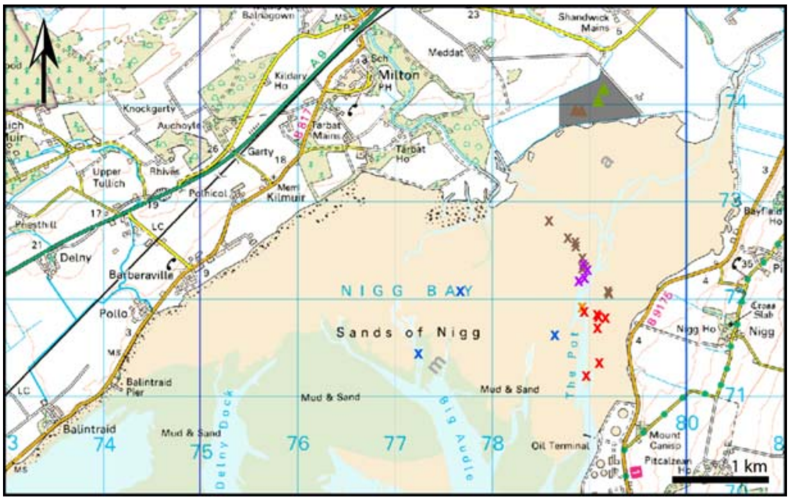
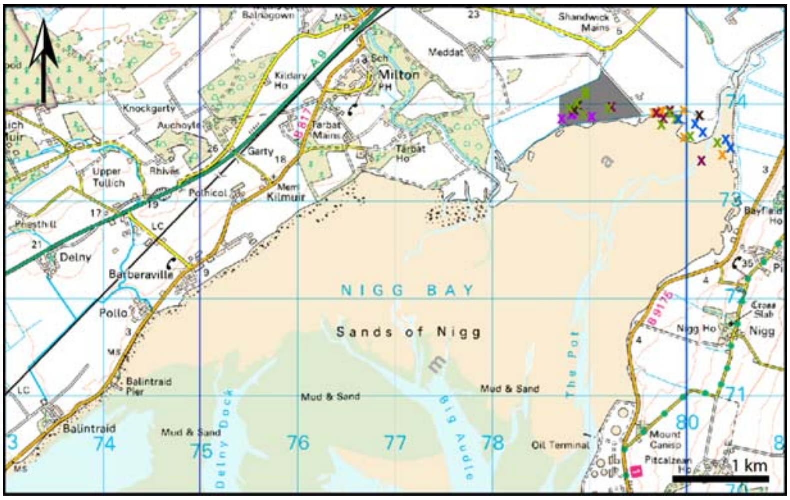
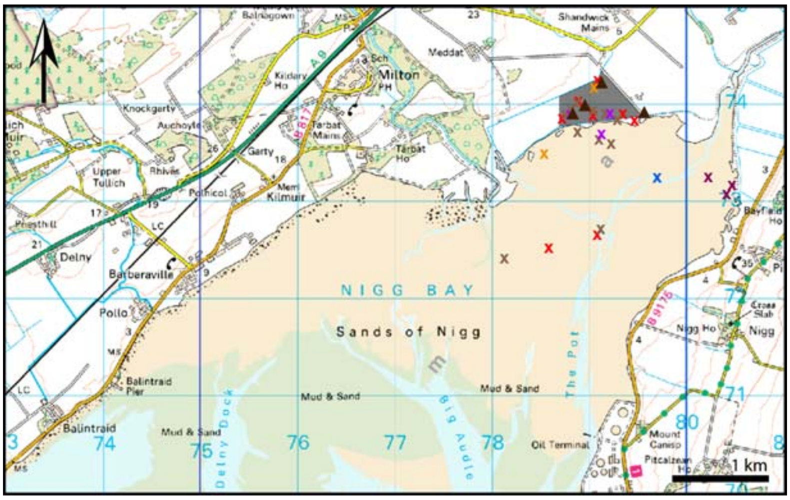


Figure 8.10: Fixes of Bird B at (a) high, (b) mid and (c) low tide on eight days in January 2005. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High



b) Mid



c) Low

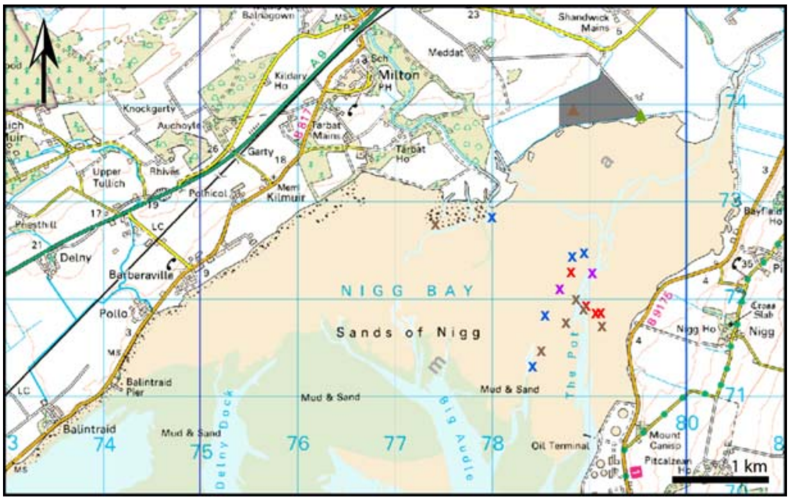
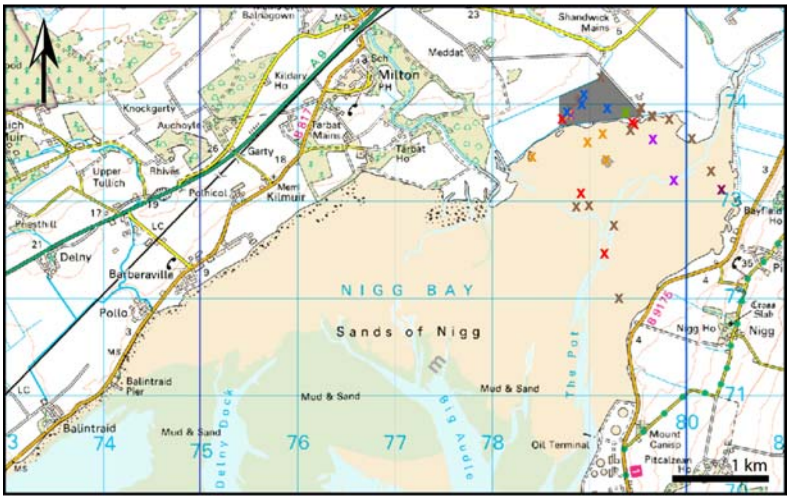


Figure 8.11: Fixes of Bird C at (a) high, (b) mid and (c) low tide on eight days in January 2005. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High

b) Mid



c) Low

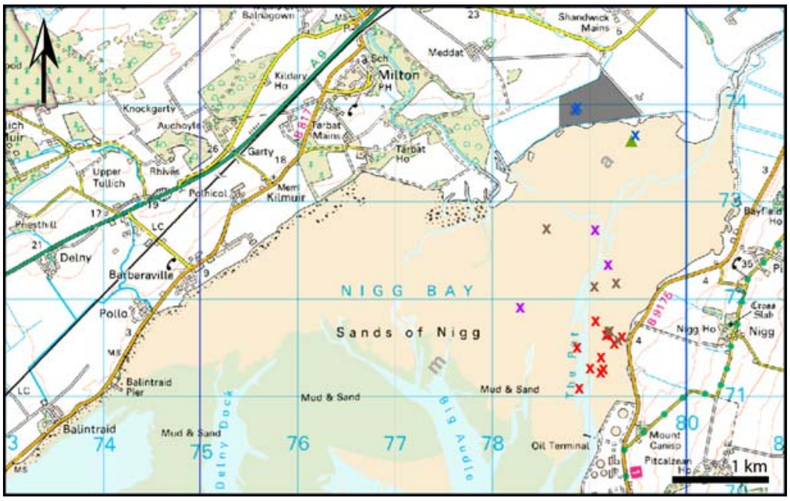
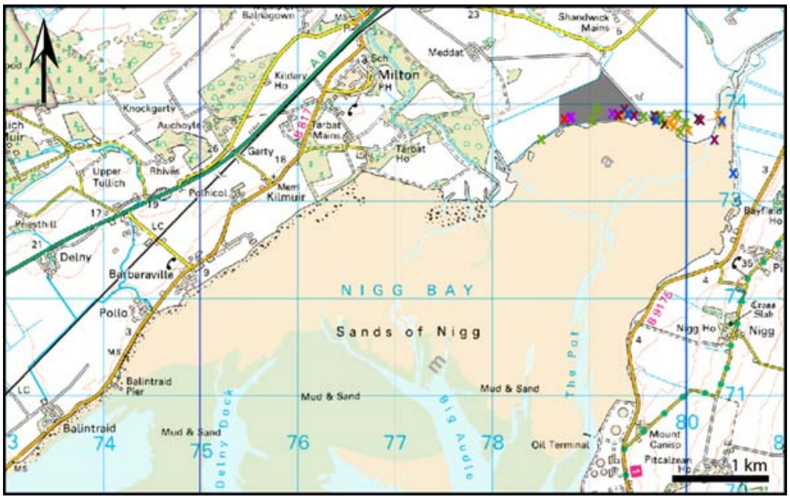


Figure 8.12: Fixes of Bird D at (a) high, (b) mid and (c) low tide on eight days in January 2005. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High



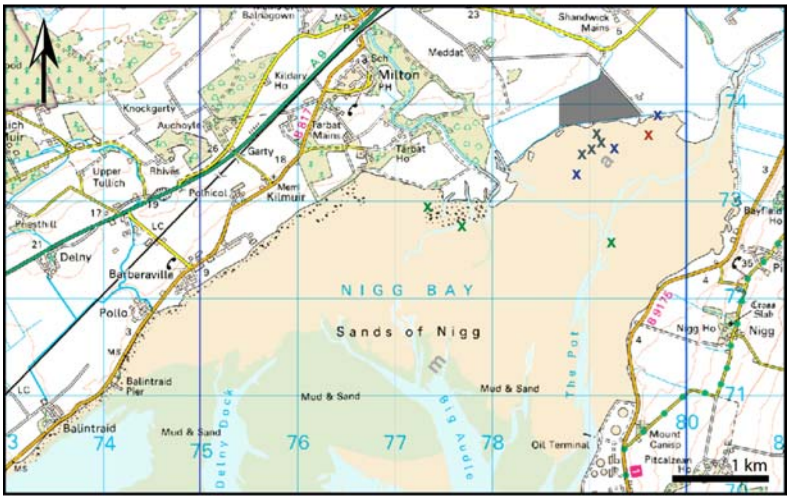
b) Mid

c) Low

Figure 8.13: Fixes of Bird E at (a) high, (b) mid and (c) low tide on eight days in January 2005. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High

b) Mid

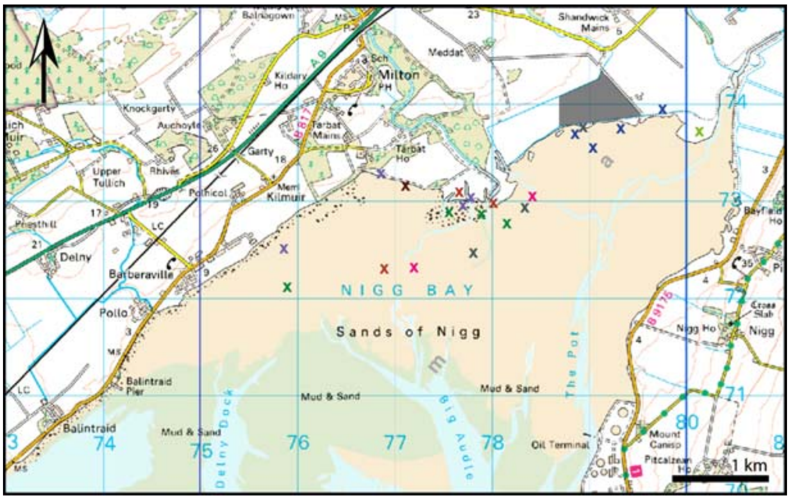


c) Low

Figure 8.14: Fixes of Bird F at (a) high, (b) mid and (c) low tide on eight days in W3. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High

b) Mid



c) Low

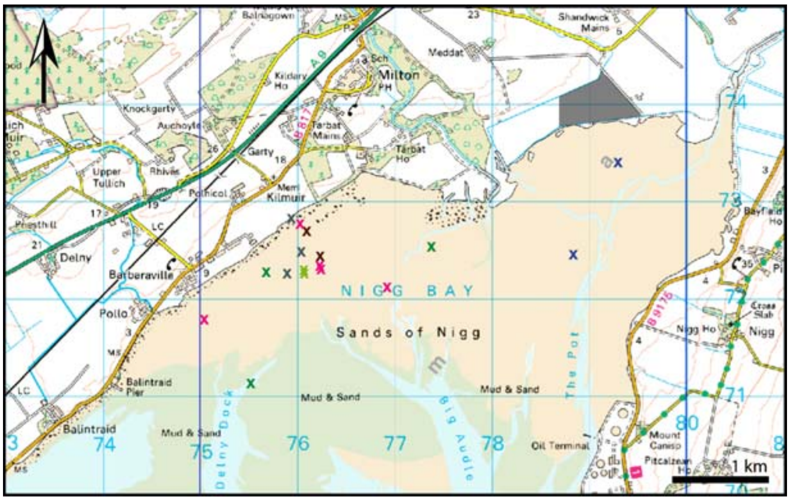


Figure 8.15: Fixes of Bird G at (a) high, (b) mid and (c) low tide on eight days in W3. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High

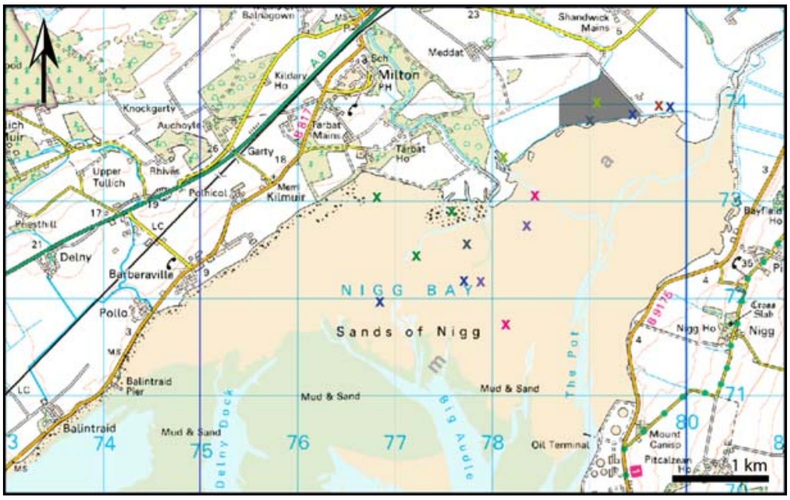
b) Mid

c) Low

Figure 8.16: Fixes of Bird H at (a) high, (b) mid and (c) low tide on eight days in W3. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High

b) Mid



c) Low

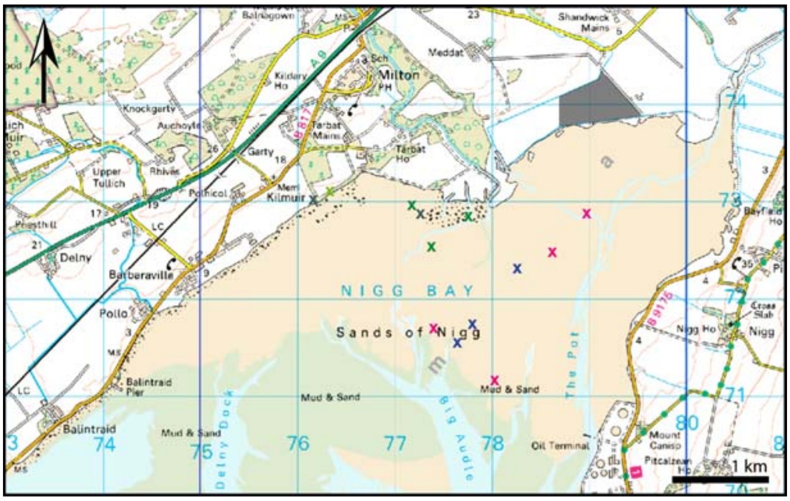
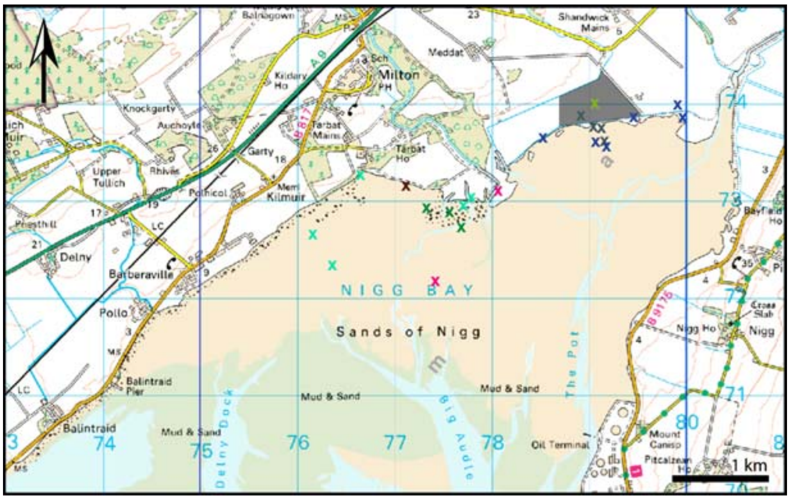


Figure 8.17: Fixes of Bird I at (a) high, (b) mid and (c) low tide on eight days in W3. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

a) High

b) Mid



c) Low

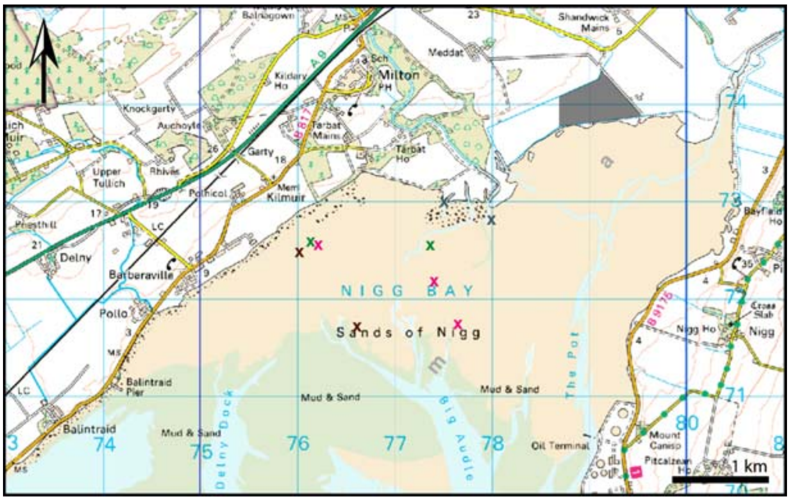


Figure 8.18: Fixes of Bird J at (a) high, (b) mid and (c) low tide on eight days in W3. Each day is represented by a different colour. Triangles indicate nocturnal fixes.

8.3.2.1 Low tide use of Nigg Bay

At lower tidal states, the radio-tagged birds were generally absent from the upper intertidal flats. Birds radio-tagged in W2, in particular Birds B, C and D, were regularly detected towards the south east of Nigg Bay on intertidal flats either side of the Pot. Birds radio-tagged in W3 were regularly detected towards the south west of Nigg Bay. However, at night time, four of the birds radio-tagged in W2 were recorded using both the upper intertidal flats and the managed realignment site.

The calculated low-tide core areas were between 13.6 and 287.4 ha while home ranges were between 69.6 and 1024.1 ha (Table 8.9). As the number of fixes per bird increased there was a reduction in the size of the calculated areas. As this relationship did not approach an asymptotic value, the sizes of the calculated areas are likely to have been overestimated, so comparisons with other studies must be treated with caution.

8.3.2.2 Mid tide use of Nigg Bay

At intermediate tidal states, the birds radio-tagged in W2 had generally moved into the head of Nigg Bay, including Nigg Bay MRS, while the birds radio-tagged in W3 continued to occupy the south east of Nigg Bay with some movement into the head of Nigg Bay to the west of the Pot, including Nigg Bay MRS.

8.3.2.3 High tide use of Nigg Bay

At high tidal states, when the intertidal flats were no longer accessible, each bird roosted in the head of Nigg Bay, either on the saltmarsh bordering Nigg Bay or within Nigg Bay MRS.

8.3.3 Night time use of Nigg Bay Managed Realignment Site by other species

Night-time mist-netting across the breach gaps to trap Common Redshank for the radio tracking study in December 2005 trapped one Eurasian Oystercatcher, one Dunlin and five Red Knot, in addition to the five Common Redshank fitted with transmitters.

8.4 Discussion

8.4.1 The use of sites in the wider Cromarty and Moray Firths and beyond by individuals

Birds that were colour-ringed at Balantraid in September 2005 were subsequently sighted in each of the search areas in Nigg Bay and individuals were also sighted at widespread locations in the Moray Firth. However, birds trapped later in the winter at both Meddat and Bayfield were never recorded outside Nigg Bay in winter. Since Balantraid is typically only used as a roost site in September (Bob Swann, pers comm.), it is likely that the individuals that were caught at Balantraid in September had recently arrived from their breeding grounds in Iceland (Summers 1988) and had yet to disperse to their final wintering grounds.

One of the individuals colour-ringed at Balantraid in 2005 had originally been ringed at Brora, 36 km NNE of Nigg Bay, 1 year and 5 days earlier. As this individual was not seen in Nigg Bay after it was coloured-ringed it is possible that it may have been using Nigg Bay as a stopover site on its way to an estuary further south.

An individual colour-ringed at Balantraid had originally been ringed at Tain (on the south shore of the Dornoch Firth) in December three winters earlier. In November 2006 it was re-located at Dornoch Sands (on the south shore of the Dornoch Firth). A further individual was sighted in the Montrose Basin at the end of July, three months before it returned to Nigg Bay to spend the winter. Long-term data for the Moray Firth suggests that Common Redshank often arrive at estuaries further south, before moving north later in the winter (Swann & Etheridge 1996), a pattern which is also observed for Red Knot arriving on the Wash. An individual sighted in July 2007 in North Holland was also likely to relocate to Nigg Bay later that winter as waders tend to show high site fidelity to the estuary that they settled on in their first winter (Clark 2006). This particular individual is likely to have been an unsuccessful breeder (Bob Swann, pers. comm.).

8.4.2 The use of Nigg Bay by individuals

Re-trap and re-sighting data for individual birds in this study suggest that many Common Redshank that over-winter in Nigg Bay return each winter. Of the birds that were colour-ringed in Nigg Bay in W2 and subsequently re-sighted in W3, 100% were re-sighted in Nigg Bay. These findings are compatible with the long-term data of the Highland Ringing Group which show that of the birds re-trapped on the Cromarty Firth between 1977 and 1995, 96% of adults and 93% of juveniles had originally been caught on the Cromarty Firth and within Nigg Bay 73% of adults and 39% of juveniles were re-trapped at the same site (Swann & Insley 1997).

Both adult and juvenile birds were sighted in most of the search areas in Nigg Bay indicating that there is no apparent segregation of Common Redshank according to age, as has been shown for Dunlin (Van der Have *et al*. 1984), Oystercatcher (Goss-Custard & Durell 1984) and Purple Sandpiper (Summers *et al*. 1990) elsewhere.

Just under half of the colour-ringed birds sighted in Nigg Bay spent time on both sides of the Pot, while more than half were faithful to sites on a particular side of the

Pot. Data on the movements of colour-ringed birds suggest that the Pot may act as a natural division between two populations of Common Redshank. To the west of the Pot one group spends time in Area D at lower tidal states and moves into the head of Nigg Bay as the tide rises, while to the east of the Pot a second group appears to move between Areas J, H and F. There is evidence to suggest that birds remain faithful to these groupings in the long-term as two individuals were re-trapped at Bayfield (Area F) seven winters after first being trapped there and a further two individuals were re-trapped at Bayfield two winters after being trapped at the oil terminal (Area I).

Radio-tracking data, however, showed that there were three general routes that birds took from the lower intertidal flats to the upper intertidal flats in the head of Nigg Bay: two separate routes to the west of the pot and a route to the east of the Pot. As the tide rises in Nigg Bay, water fills the Pot and then gradually overtops both banks from the seaward end. As the tide advances, birds that used the lower intertidal flats around the lower reaches of the Pot in the south east of Nigg Bay are forced to move and follow the tide line as it expands westwards, eastwards and northwards from the Pot. Ring identification was biased towards the nearer edges of the intertidal flats and only detected the individuals following the tide edge to the east of the Pot, missing those following the tide edge to the west of the Pot. Because of the way that the tide advances in Nigg Bay, the birds that spend time in the south east of Nigg Bay at lower tidal states are forced by the tide to move into the head of Nigg Bay much earlier than those which spend time in the south west of Nigg Bay.

Functional units have been described for Dunlin in a coastal lagoon, where a group of feeding areas and high-tide roosts are used by a group of birds during a period of time (Luis & Goss-Custard 2005). The different areas used by the separate groups of Common Redshank in Nigg Bay, could also be described as functional units. It is not possible to determine whether these groupings of Common Redshank reflect different demographics. Previous studies have shown that in some locations there is segregation between males and females in some species (Durell *et al*. 1993; Both *et al*. 2003; Durell & Atkinson 2004), however, as the Common Redshank in this study were not sexed it is not possible to determine if this was the case.

The diurnal low-tide core areas and home ranges of the Common Redshank in this study were larger than those recorded in Cardiff Bay and the Rhymney Estuary (Burton & Armitage 2005). Differences between the two studies may be, in part, due to methodological differences. Although home-range analysis was performed using equivalent methods, in this study radio-tags were only fitted to a relatively small number of birds and fewer fixes were obtained per bird. However, it is possible that the coarser sediments of Nigg Bay resulted in lower invertebrate densities (Chapter 4) compared to the two Welsh estuaries, which may have caused birds to forage over a wider area. Alternatively, differences in bird densities between studies may be explained by differences in competition (both intra- and interspecific), predation risk and weather conditions. The only juvenile Common Redshank for which a home range could be calculated in this study had a smaller core area and home range than any of the adults, in line with results for Cardiff Bay (Burton & Armitage 2005).

All the Common Redshank in Nigg Bay move into the head of the bay as the tide forces them into progressively smaller areas of the intertidal flats. When the intertidal flats become inundated and foraging on the intertidal flats is no longer possible, they move to nearby roost sites This supports the suggestion that Common Redshank in Nigg Bay are tide followers (Chapter 6) as on the Forth Estuary (Warnes *et al* 1980). As Nigg Bay MRS is situated at the head of Nigg Bay, and is located in an area to which the birds are naturally progressing, it demonstrates the value of creating managed realignment sites near intertidal habitat that is already used by birds. This reduces the travel time between feeding and roosting areas, reducing energy costs and possibly vulnerability to predation (Dias *et al*. 2006; Rogers *et al*. 2006).

Birds exclusively using the area to the east of the Pot, however, have not directly benefited from the presence Nigg Bay MRS. This highlights the importance of understanding the distribution and patterns of movement of birds in planning where to locate a managed realignment project, particularly where it is being created to mitigate for future losses of important bird habitat (Section 1.2.5).

8.4.3 The use of Nigg Bay Managed Realignment Site by individuals

About 20% of the birds colour-ringed as part of this study were sighted in Nigg Bay MRS on at least one occasion, suggesting that the creation of Nigg Bay MRS has been beneficial to a substantial proportion of the Common Redshank in Nigg Bay. Just over half of these birds were sighted in Nigg Bay MRS on multiple occasions, indicating that Nigg Bay MRS has a subset of regular users. Although a minority of Common Redshank hold territories (Goss-Custard 1970), there was no territorial behaviour, as would be indicated by frequent agonistic interactions on the feeding grounds, at Nigg Bay (pers. obs.).

The age structure of birds using a site is often believed to reflect the quality of the habitat, with adults expected to defend prime sites against juveniles (Cresswell

1994). Both adults and juveniles used Nigg Bay MRS, which could be taken to indicate that the habitat was of lower quality and therefore not worth defending. However, Common Redshank cannot economically defend areas of high prey density to which many birds are attracted (Myers *et al*. 1979). It was established that use of Nigg Bay MRS by Common Redshank was greatest at higher tidal states when other areas of intertidal flat in Nigg Bay were inaccessible, particularly during more severe weather conditions (Chapter 6). Common Redshank were therefore unlikely to be able to economically defend the Nigg Bay MRS at higher tidal states. The age structure of the birds using Nigg Bay MRS may therefore reflect the timing of peak use (relative to tide state and weather conditions), rather than habitat quality.

Mist-netting across the breach gaps revealed that at least four wader species use Nigg Bay MRS as a high tide roost at night. Two species (Common Redshank and Eurasian Oystercatcher) were frequently recorded in Nigg Bay MRS during daylight hours, however, Dunlin and Red Knot were recorded infrequently (Chapter 5). Radio-tracking data provide further evidence that Nigg Bay MRS is used by Common Redshank at night, even at lower tidal states, when during daylight most Common Redshank feed on the lower intertidal flats. In addition to providing further evidence that nocturnal ranges of Common Redshank differ from diurnal ranges (Burton & Armitage 2005), the fact that two species that were infrequently recorded in Nigg Bay MRS during daylight hours were recorded in Nigg Bay MRS at night on just two trapping attempts may suggest that Nigg Bay MRS supports a different species assemblage at night to that during daylight hours. There is some evidence that the created intertidal flats at Seal Sands are used more by some species at night raising the possibility that some species are reluctant to use Nigg Bay MRS during daylight because of the risk of predation by diurnal avian predators (Evans *et al*. 1998). This is also a possibility at Nigg Bay MRS where the embankments may restrict the waders' view of approaching raptors (Chapter 7). Differences between diurnal and nocturnal use of intertidal habitats has been found in a number of other estuaries (Rohweder & Baverstock 1996; McCurdy *et al*. 1997; Dodd & Colwell 1998; Sitters *et al*. 2001; Conklin & Colwell 2007). These findings highlight the importance of considering both diurnal and nocturnal distributions of birds when assessing the benefit of a managed realignment site to bird populations.

8.5 Conclusion

Nigg Bay MRS has a subset of regular users that comprise both adults and juveniles. During the winter, when these individuals are not in Nigg Bay MRS they spend time on the intertidal flats elsewhere in Nigg Bay. Nigg Bay MRS is used at night as well as during daylight hours. Within Nigg Bay the majority of Common Redshank spend time on the lower intertidal flats when they are accessible, but as the tide rises they follow one of several routes into the head of Nigg Bay where they either move into the Nigg Bay MRS or move directly to alternative high-tide roost sites on the saltmarsh.

Chapter 9

Restoration of intertidal habitats: Conservation management indicators from the Nigg Bay Managed Realignment Project

9.1 The success of breached managed realignment in restoring intertidal habitats in Nigg Bay

There is a growing body of literature showing that breached managed realignment can be used successfully to restore intertidal habitats (Dixon *et al*. 1998; Atkinson *et al*. 2004; Garbutt *et al*. 2006). Restored intertidal habitats often differ considerably from local reference sites (Zedler & Callaway 1999; Warren *et al*. 2002; Atkinson 2003), however, and Nigg Bay Managed Realignment Site (Nigg Bay MRS) is no exception. Although saltmarsh (Chapter 3) and intertidal flats (Chapter 4) were created within four years of the re-establishment of tidal conditions, these differed considerably from the saltmarsh and intertidal flats in Nigg Bay. Four summers after the re-establishment of tidal conditions, almost all of the saltmarsh species recorded on the nearby saltmarsh had colonised Nigg Bay MRS. However, recognisable NVC communities (Rodwell 2000) had yet to establish (Chapter 3). This is to be expected given the early stage of development, since saltmarsh can take up to 80 years to reach a relatively stable community of plant species (Smart 2005).

Three winters after the re-establishment of tidal conditions in Nigg Bay MRS, the sediments had a significantly smaller particle size and higher organic matter content compared to the fine sands of the reference intertidal flats (Chapter 4). The small particle size is likely to be due to the enclosed nature of Nigg Bay MRS and the reduced wave activity allowing finer particles to fall out of suspension, while the high levels of organic matter may, in part, be due to the presence of large amounts of decaying vegetation from the pre-breach communities (Chapter 3). Following the re-establishment of tidal conditions, the intertidal invertebrate community within Nigg Bay MRS also differed from the adjacent intertidal flats with a notable absence of the annelids (except *Hediste diversicolor*) which were abundant elsewhere in Nigg Bay (Rafaelli & Boyle 1986; Rendall & Hunter 1986; Chapter 4). These differences are likely to be due to one or more of several factors, including: (i) the time since breaching (Atkinson *et al*. 2001); (ii) the position of the site in the tidal frame (Raffaelli & Boyle 1986; McLusky 1989); and (iii) sediment characteristics including particle size (Meadows 1964; Newell 1965; Longbottom 1970; Anderson 1972), organic matter content (Bolam *et al*. 2004) and salinity (Anderson 1972).

Despite the reported differences between the reference and restored intertidal habitats, Nigg Bay MRS attracted large numbers of waterbirds, with at least 2319 individual waterbirds (calculated as the sum of winter peak numbers for each species) using the site by the third winter following the re-establishment of tidal conditions (Chapter 5). Nigg Bay MRS supported each of the most common wader and wildfowl species present in the wider estuary. While previous studies have investigated colonisation of managed realignment sites by waterbirds in numerical terms (Atkinson *et al*. 2004; Badley & Allcorn 2006b; APB 2007; Halcrow Group Ltd. 2007), this study was the first to provide a detailed ecological investigation of temporal and spatial use of a managed realignment site by waterbirds (Chapters 6 and Chapter 7).

Nigg Bay MRS performs a number of important functions for waterbirds by: (i) providing a foraging and resting habitat when the tide is absent and intertidal sediments in Nigg Bay are exposed; (ii) providing a foraging resource as the tide passes over the intertidal sediments within Nigg Bay MRS once the intertidal flats in Nigg Bay are inundated; and (iii) providing a high tide roosting site (Chapter 6). Nigg Bay MRS is once again acting as a natural extension of the estuary, since these are functions that are provided by upper intertidal flats and saltmarsh in estuaries.

The use of Nigg Bay MRS by some species (Common Shelduck, Eurasian Curlew and Common Redshank) is related to the prevailing weather conditions (Chapter 6). In harsher weather conditions the energy demands of waders increase, yet their invertebrate prey are usually less accessible (Pienkowski 1983; Selman & Goss-Custard 1988; McGowan *et al*. 2002; Beauchamp 2006). Waders on estuaries often struggle to meet their energy requirements (Goss-Custard *et al*. 1969; Davidson & Evans 1986) and in order to avoid starvation have to increase their rate of energy intake by eating more and/or reduce their energy expenditure by reducing their activity levels or exposure to the weather. On days with low temperatures and high wind speeds, more birds use Nigg Bay MRS, suggesting that it is likely to be providing sheltering benefits (Peters & Otis 2007). Smaller species, such as Common Redshank, are particularly vulnerable to starvation (Calder 1974; Goudie & Piatt 1991), with increased mortality being reported during severe winters on the Moray Firth (Swann & Etheridge 1989; Insley *et al*. 1997). Since more Common Redshank feed in Nigg Bay MRS in harsher weather, Nigg Bay MRS appears to provide top-up feeding. Further work should determine the feeding rates and diet choice of waterbirds inside and outside of Nigg Bay MRS, perhaps through telescopic video recording (Kuwae 2007). In this way it could be determined if Nigg Bay MRS provided benefits though extended feeding hours, through higher-yielding choice of prey, or via both routes. Equally, research on the shelter benefits provided by Nigg Bay MRS would be useful. A device, such as a heated taxidermic mount (Bakken *et al*. 1883, 1985; Wiersma & Piersma 1994; Brown 1996), could assay the thermal options within Nigg Bay MRS and compare these with those in Nigg Bay. It might be expected that smaller sites such as Nigg Bay MRS provide relatively large benefits through the shelter they offer, because the surrounding embankments interrupt wind flow, but fewer feeding benefits than larger sites, because the number of feeding birds is constrained by competition. If this is the case, managed realignment sites in more northerly or exposed climes could deliver greater benefits than managed realignment sites of the same size located in more benign climates. A second research priority, therefore, is to assess the energetic effects of managed realignment sites of different sizes and configurations to determine the relative balance of feeding and thermal costs and benefits. With this information it would be possible to generate priority ranking for managed realignment site creation in different regions.

The factors that often influence the spatial distributions of waders in estuaries appear to be operating within Nigg Bay MRS (Chapter 7). Wader densities appear to be greater on the intertidal flats when they are accessible than on the saltmarsh. Wader densities are also greatest close to creeks and drainage channels, possibly due to higher invertebrate densities (Lourenço *et al*. 2005), more accessible prey (Kelsey & Hassall 1989) or due to sheltering benefits (Ravenscroft & Beardall 2003).

This is the first study to provide an insight into the use of a managed realignment site by individual birds (Chapter 8). It has shown that Nigg Bay MRS has a subset of regular users including both adults and juveniles. On estuaries, adults are expected to defend prime sites against juveniles (Cresswell 1994), although only a minority of Common Redshank hold exclusive territories (Goss-Custard 1970). Nigg

Bay MRS does not appear to be held by its users as a set of territories since it was used by birds of all ages and agonistic interactions were not recorded during the course of the study.

Studies of waders on estuaries have suggested that diurnal and nocturnal distributions of waders may differ (Rohweder & Baverstock 1996; McCurdy *et al*. 1997; Dodd & Colwell 1998; Sitters *et al*. 2001; Conklin & Colwell 2007). This study suggests that the wader assemblage in Nigg Bay MRS at night may differ from the assemblage during the day, which may be related to the relative importance of perceived predation risk (Evans *et al*. 1998). Further work at Nigg Bay MRS should provide more detailed investigation into temporal and spatial nocturnal use of Nigg Bay MRS by waterbirds to determine whether it differs from diurnal use. More waders might be expected to forage in the site at night when weather conditions are harsher. This could be investigated by using radio transmitters fitted with mercury tilt switches (Whittingham 1996; Whittingham *et al*. 2000). Managed realignment sites which are often hunted by avian predators during daylight hours might be expected to be used more by waterbirds at night, when the risk of predation is lower. Equally, when the risk of predation is lower, waders might be expected to use otherwise more risky areas of Nigg Bay MRS, away from the breach gaps.

When they are not in Nigg Bay MRS, the colour-ringed Common Redshank spend time elsewhere within Nigg Bay. This can be seen as an extension of the behaviour of several wader species, including Common Redshank and Ruddy Turnstone, which remain largely faithful to a particular part of an estuary throughout the non-breeding period (Burton & Evans 1997; Burton 2000; Rehfisch *et al*. 2003; Leyrer *et al*. 2006).

9.2 Implications for future managed realignment projects

9.2.1 Site selection

It has been recognised that the most suitable sites for undertaking managed realignment projects are those that have a recent history of supporting intertidal habitats and that, since being reclaimed, have had minimal human interference (Burd 1995; Leggett *et al*. 2004; Nottage & Robbertson 2005). Such sites are considered most likely to have retained a suitable estuarine morphology, topography, gradient and creek network and are therefore more likely to revert to their former status with the re-establishment of tidal conditions. Such sites may also have a viable soil seed bank which may provide colonists for saltmarsh development once saline conditions are restored (Wolters & Garbutt 2006). A source of colonists (both saltmarsh vegetation and intertidal invertebrates) is essential if intertidal habitats are to be successfully restored, so it is also recognised that proximity to existing saltmarsh and intertidal flats is important (Brooke *et al*. 1999).

In estuaries, waders will minimise travel as part of their site choices (Dias *et al*. 2006; Rogers *et al*. 2006), suggesting that managed realignment projects should be sited in close proximity to existing intertidal habitats used by waterbirds. Nigg Bay MRS is located in the head of Nigg Bay, and therefore in the area towards which birds naturally advance on the incoming tide. At lower tidal states, Common Redshank spent time on the lower intertidal flats in Nigg Bay, but as the tide rose they gradually moved towards the upper intertidal flats in the head of Nigg Bay before moving to their nearby high-tide roosts (Chapter 8). It appears probable that a managed realignment site located outside of the head of Nigg Bay would have been less used, and furthermore through additional flight costs, would have contributed to greater maintenance costs for any waders using Nigg Bay MRS.

Different sub-groups of Common Redshank appear to follow different but consistent routes into the head of Nigg Bay as the tide rises (Chapter 8). Nigg Bay MRS is within the area used by the majority of birds but was outside the area used by one sub-group, which, therefore, were not recorded in Nigg Bay MRS. Differences in habitat use between different age and sex groups have been shown for some species in estuaries (Durell *et al*. 1993; Both *et al*. 2003; Durell & Atkinson 2004). This specific sub-group in Nigg Bay did not reflect a particular age group although it may have reflected a sex group, albeit unlikely, but this was not recorded. In the event of habitat being lost, this subgroup would be expected to adapt and might change its distribution to make use of Nigg Bay MRS. For example, previous studies have shown that in the short-term some wader species have adapted to habitat loss in estuaries (Lambeck *et al*. 1989; McLusky *et al*. 1992; Burton *et al*. 2006). However, competitive exclusion may prevent a displaced sub-group from settling in Nigg Bay MRS. It may therefore be important, especially if loss of estuarine habitat is ongoing, to locate managed realignment projects within areas used by birds from every sub-group, rather than within areas used exclusively by one sub-group or create multiple sites (Chapter 8).

9.2.2 Site design

When designing managed realignment sites, there are several issues that need to be taken into consideration (Pontee 2003) including: (i) which technique to adopt (breached, banked, RTE); (ii) the desired ratio of intertidal habitats; (iii) the size of the site; and (iv) what features (creeks, topography) to ensure are present in the site.

Several different methods exist for undertaking managed realignment (Section 1.1.6). Although breached realignment is the main method that has been adopted in UK projects (Pontee *et al*. 2006), breached realignments are expected to have less ecological connectivity with the wider estuary compared to banked realignments (Pontee *et al*. 2006). This thesis has contributed to this debate by showing that breached realignments can function as an integral part of the wider estuary, particularly in terms of their use by waterbirds. An investigation into the temporal use of the managed realignment site by waterbirds (Chapter 6) showed that it appears to be functioning as would be expected for an upper intertidal habitat. It is used by a small number of foraging and resting birds at lower tidal states but is used extensively once the adjacent intertidal flats are inundated. Colour-ringing of Common Redshank (Chapter 8) has also confirmed that some individuals congregate outside the managed realignment site before flying in through the breach gaps as the adjacent intertidal area becomes inundated.

The desired ratio of habitats in a managed realignment site will depend on the goal of a project. Where the goal is to create foraging habitat as well as roosting and breeding areas for waders and wildfowl, as was the case in Nigg Bay MRS, then encouraging the development of both saltmarsh and intertidal flat is probably the best course of action. Results from this study suggest that saltmarsh is likely to colonise lower in the tidal frame in managed realignment sites which are better drained (Chapter 2). As the creation of saltmarsh is likely to be at the expense of intertidal flat, it is possible that poorly-drained (i.e. breached realignment) sites will be more favourable when the goal of the scheme is to create intertidal flats while better-drained sites (i.e. banked realignment) will be more favourable when the goal of the scheme is to create saltmarsh, particularly in more sheltered sites which will be less affected by scour and wind effects.

This study has shown that in addition to being important in de-watering the sediments (Brooke *et al*. 1999) to promote saltmarsh establishment at lower elevations (Chapter 3), creeks are important features to include in managed realignment sites restoring intertidal habitats for waterbirds (Chapter 7). Although this study did not determine why the creeks were attractive to waders, it appears likely that sediments nearer to the creeks supported invertebrate prey at higher densities, as has been found on studies of drainage channels on an estuarine scale (Lourenço *et al*. 2005). As the areas nearest creeks remained wetter for longer once the tide had fallen, the prey in these areas were also more likely to be accessible (Kelsey & Hassall 1989).

This thesis has also demonstrated that complex topography in managed realignment sites can be beneficial (Chapter 7). The presence of areas of higher elevation in Nigg Bay MRS, which form islands at higher tidal states, were particularly attractive to roosting waders and could be incorporated in the design of future managed realignment sites. This might involve consolidating some higher points using shingle and cockle dredgings to raise them above MHWS (Weinstein & Weishar 2002). This would provide both a more secure roost site, offering greater security through greater visibility of approaching predators, while also offering a potential breeding site for Eurasian Oystercatcher, Ringed Plover or Terns.

9.2.3 Promoting colonisation

Previous studies have investigated how intertidal habitats can be restored with human intervention. There are several examples in the literature of saltmarsh plants being transplanted into sites (Reviewed in Brooke *et al*. 1999).

This thesis (Chapters 3 and 4) adds to the growing body of literature showing that with time new sites can be naturally colonised from nearby sites (e.g. Eertman *et al*. 2002). However, the findings of the present study also indicate that the rate of colonisation might be increased with limited human intervention prior to the re-establishment of tidal conditions. The presence of dead vegetation, particularly *Juncus effusus*, in the first year after the re-establishment of tidal conditions (Chapter 3) is likely to have contributed to the high levels of organic matter in the sediments (Chapter 4). Unlike fine particulate organic matter, which usually promotes invertebrate production on estuaries (Pearson & Rosenberg 1978; Yates *et al*. 1993), these non-decayed plant remains would initially have provided little enrichment, but smothered the mud, perhaps inhibiting colonisation by some intertidal invertebrates (Diaz & Rosenberg 1995; Bolam *et al*. 2004). The smothering effect of the dead vegetation may also have prevented plants emerging from the seed bank (Chapter 3). Equally, the dead vegetation may have helped stabilise the sediment and, in time, created a suitable substrate for seeds and propagules that had dispersed into Nigg Bay MRS (Chapter 3). Distinguishing between these hypotheses will require experimental cutting and vegetation removal prior to breaching in other sites to determine whether it promotes or retards saltmarsh establishment.

9.2.4 Site management

Disturbance by both humans and avian predators is a major problem to waders and wildfowl in some estuaries (Cresswell & Whitfield 1994; Madsen & Fox 1995; Fox & Madsen 1997). Disturbance can lead to birds spending less time foraging which may reduce fitness in harsher conditions (Goss-Custard *et al*. 2006b). Disturbance is more likely to be an issue in smaller managed realignment sites, such as Nigg Bay MRS, where birds will be more easily disturbed (Laursen *et al*. 2005).

Recreational disturbance occurs on the RSPB Reserves on the Moray Firth (Crowther & Elliott 2006). Recreational disturbance also appears to affect waterbirds within Nigg Bay MRS, with waders and wildfowl flying out of the site in response to people walking past the breach gaps and on the crest of the southern embankment. Wildfowlers have also been recorded shooting from within Nigg Bay MRS, compromising the conservation value of the site for waterbirds. There may be merit to liaising with wildfowlers to make Nigg Bay MRS and the southern embankment a voluntary ‘no-shoot’ zone, as exists in an area on the nearby Udale Bay RSPB reserve. More visible signage, explaining the importance of Nigg Bay MRS to wintering waterbirds, may help reduce disturbance by members of the public. Educational site visits, though important for community engagement to raise the profile of managed realignment sites (Myatt-Bell *et al*. 2002, 2003a, 2003b, 2003c; Midgley & McGlashan 2004; Ledoux *et al*. 2005; Jude *et al*. 2006), could be restricted to summer months to minimise disturbance to over-wintering waterbird populations. Alternatively, a hide or screen could be provided so that Nigg Bay MRS can be viewed without disturbing waterbirds.

Predation also occurs in Nigg Bay MRS, with five different raptor species recorded flying over or perching within the site during the course of the study. On several occasions, waders reacted to the presence of raptors by flying out of the site and on one occasion a Peregrine Falcon was observed perched within the site eating a Common Redshank. Removing potential perches and cover, such as trees, from the embankments may lower the risk of predation, particularly from Eurasian Sparrowhawk, making the site more attractive to waders and wildfowl.

9.3 The future of managed realignment in the UK

This thesis has added to the growing number of studies showing that breached managed realignment can be used to successfully restore intertidal habitats for wildlife (Atkinson *et al*. 2004 Badley & Allcorn 2006b; APB 2007; Halcrow Group Ltd. 2007), particularly focussing on habitat restoration for the nationally and internationally important populations of non-breeding waders and wildfowl.

The RSPB has calculated that the potential for intertidal habitat creation around the UK coast could exceed 33,000 ha (Pilcher *et al*. 2002). Managed realignment will increasingly be adopted to restore intertidal habitats, as compensation for Natura 2000 sites which are adversely affected by development and also to replace habitats lost through 'coastal squeeze' (Doody 2004) as sea levels continue to rise (IPCC 2001). For example, managed realignment has been identified as an essential tool for the sustainable management of the Humber Estuary (Andrew *et al*. 2006; Edwards & Winn 2006).

In the UK there has been a tradition of protecting the coastline with hard defences and there is reluctance among many people in relinquishing this control to natural processes. There is also lack of understanding about coastal defence and managed realignment issues at all levels of the community. Often there is a public distrust in the agencies and organisations and their motives when undertaking managed realignment projects. Probably the greatest challenge for bringing managed realignment forward will be convincing local communities that breaching embankments is a sustainable solution to the flood defence problem, in addition to providing a range of environmental and socio-economic benefits (Myatt-Bell *et al*. 2002, 2003a, 2003b, 2003c; Midgley & McGlashan 2004; Ledoux *et al*. 2005). This can be achieved through engaging with communities to raise the profile of managed realignment (Jude *et al*. 2006; Greene 2006).

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Appendix 1

Coordinates of the marker posts for the vegetation quadrats in Nigg Bay Managed Realignment Site. Quadrats were sampled 1 m from the marker post in the direction indicated. Quadrat numbers are as in Figure 3.1.

No.	Easting	Northing	Direction
1	279239	874152	NE
2	279146	874142	E
3	279068	874127	NE
4	279013	874118	NE
5	278989	874113	NE
6	278937	874104	NE
7	279255	874062	E
8	279209	874056	NE
9	279130	874047	NE
10	279112	874043	NE
11	279051	874033	NE
12	279010	874030	NE
13	279292	874007	NE
14	279269	874002	NE
15	279218	873992	NE
16	279102	873967	E
17	279072	873962	NE
18	279038	873960	NE
19	279341	873946	NE
20	279315	873944	NE
21	279249	873936	E
22	279165	873925	NE
23	279122	873921	NE
24	279079	873920	NE
25	279392	873876	NE
26	279294	873857	NE
27	279219	873843	NE
28	279187	873836	NE
29	279110	873822	NE
30	279036	873813	NE

No.	Easting	Northing	Direction
31	278764	873812	NE
32	278803	873819	NE
33	278863	873829	W
34	278886	873836	E
35	278939	873845	NE
36	279024	873859	NE
37	278733	873863	NE
38	278815	873874	NE
39	278868	873883	NE
40	278921	873892	NE
41	278996	873906	E
42	279036	873911	NE
43	278726	873898	NE
44	278777	873904	E
45	278798	873909	NE
46	278886	873918	NE
47	278959	873913	E
48	279014	873930	NE
49	278770	873967	NE
50	278788	873968	NE
51	278814	873974	NE
52	278860	873983	NE
53	278915	873990	NE
54	278951	874000	NE
55	278749	874010	NE
56	278782	874016	NE
57	278820	874024	NE
58	278883	874038	NE
59	278916	874044	NE
60	278964	874054	NE

Appendix 2

Coordinates of the vegetation quadrats on the reference saltmarsh adjacent to Nigg Bay Managed Realignment Site. Quadrat numbers are as in Figure 3.2.

No.	Easting	Northing	No.	Easting	Northing	No.	Easting	Northing
61	190950	800760	105	200400	800780	149	200520	800770
62	190950	800750	106	200400	800770	150	200520	800760
63	190950	800740	107	200400	800760	151	200520	800750
64	190950	800730	108	200400	800750	152	200520	800740
65	190980	800770	109	200400	800740	153	200520	800730
66	190980	800760	110	200400	800730	154	200550	800840
67	190980	800750	111	200430	800820	155	200550	800830
68	190980	800740	112	200430	800810	156	200550	800820
69	190980	800730	113	200430	800800	157	200550	800810
70	200010	800770	114	200430	800790	158	200550	800800
71	200010	800760	115	200430	800780	159	200550	800790
72	200010	800750	116	200430	800770	160	200550	800780
73	200310	800810	117	200430	800760	161	200550	800770
74	200310	800800	118	200430	800750	162	200550	800760
75	200310	800790	119	200430	800740	163	200550	800750
76	200310	800780	120	200430	800730	164	200550	800740
77	200310	800770	121	200460	800830	165	200550	800730
78	200310	800760	122	200460	800820	166	200580	800840
79	200310	800750	123	200460	800810	167	200580	800830
80	200310	800740	124	200460	800800	168	200580	800820
81	200310	800730	125	200460	800790	169	200580	800810
82	200340	800810	126	200460	800780	170	200580	800800
83	200340	800800	127	200460	800770	171	200580	800790
84	200340	800790	128	200460	800760	172	200580	800780
85	200340	800780	129	200460	800750	173	200580	800770
86	200340	800770	130	200460	800740	174	200580	800760
87	200340	800760	131	200460	800730	175	200580	800750
88	200340	800750	132	200490	800830	176	200580	800740
89	200340	800740	133	200490	800820	177	200580	800730
90	200340	800730	134	200490	800810	178	200610	800850
91	200370	800820	135	200490	800800	179	200610	800840
92	200370	800810	136	200490	800790	180	200610	800830
93	200370	800800	137	200490	800780	181	200610	800820
94	200370	800790	138	200490	800770	182	200610	800810
95	200370	800780	139	200490	800760	183	200610	800800
96	200370	800770	140	200490	800750	184	200610	800790
97	200370	800760	141	200490	800740	185	200610	800780
98	200370	800750	142	200490	800730	186	200610	800770
99	200370	800740	143	200520	800830	187	200610	800760
100	200370	800730	144	200520	800820	188	200610	800750
101	200400	800820	145	200520	800810	189	200610	800740
102	200400	800810	146	200520	800800	190	200610	800730
103	200400	800800	147	200520	800790			
104	200400	800790	148	200520	800780			

Appendix 3

Percentage cover of each species recorded in quadrats on the reference saltmarsh adjacent to Nigg Bay Managed Realignment Site. Quadrat numbers are as in Figure 3.2.

2006: Quadrats 61-120

Species	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Armeria maritima																														
Aster tripolium	2	5	25	3	4	20	8	10	2	3	1	25		1	25											1				
Atriplex prostrata	2							1			1		1										1							
Atriplex littoralis	20	5	2	1	3		2	2		15	2	2	3										5	5						
Cochlearia officinalis	15	10	10	4	3		10	10	4	2		3												10	1					
Elymus repens					90																	100	90	2						
Glaux maritima			1	20					60					2										30	3					
Honkenya peploides													10																	
Festuca rubra	60	80	35	60	1		40	75	30	80	70												5	50	70					
Plantago maritima			25	10				2	4						1										25					
Puccinellia maritima					1	80	40				25	70		95	70											15				
Salicornia sp.															1	2										3	1			
Spergularia media														3	2										1					
Suaeda maritima																														
Bare													85			98	100	100	100	100	100					80	99	100	100	100

Species	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
Armeria maritima				2																										
Aster tripolium					1	2							5	10	1	1						3	2		5	3	10			
Atriplex prostrata																														
Atriplex littoralis		45	80								1	3	20	45	1						20	2	35	10	20					
Cochlearia officinalis			10									1	40	40	3						2	2	10	40	15					
Elymus repens	100										99																			
Glaux maritima															25						20	45	5			40				
Honkenya peploides																														
Festuca rubra				30								95	30	2	45						60	45	25	40	60	40				
Plantago maritima				20	5								5	3	25	1								10		20	1			
Puccinellia maritima		55	10	30	12	65										45							25				10			
Salicornia sp.						3	3									1				1										
Spergularia media					2	3										2														
Suaeda maritima																1											2			
Bare				20	80	30	97	100	100	100						50	100	100	100	99							80	100	100	100

2006: Quadrats 121-180

Species	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
Armeria maritima														1					2										1	
Aster tripolium	3		5	25	10	5		2	5					15	10	20	40	5	3	3				1	3	15	1	5	3	
Atriplex prostrata																							3				2			
Atriplex littoralis	1		2	5	2	4	30	1						2	1	30	2	1					50			20	1	60		
Cochlearia officinalis				5	3	10	15	10							3	7	10	20							5	10		10	4	
Elymus repens																							45							
Glaux maritima		20	45					70				45			5		10		25					4	45				10	
Honkenya peploides																														
Festuca rubra	60	75	45	40		20	5	30	90			40			20	20	30		25					45	45	30		7	50	
Plantago maritima	30	5	3	25		60	40		5			3		60	60	20	5	75	25					50	5	5			5	
Puccinellia maritima					10		10							20						30						10	95	15		
Salicornia sp.										1										5							1			
Spergularia media	5													1	1	3														
Suaeda maritima					1		1		2					1						1						1		2		
Bare					75					99	100		100						20	60	100	100							30	100

Species	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
Armeria maritima																														
Aster tripolium						2	3	25	5	4	1						10	4	5	70	10	15							20	10
Atriplex prostrata																														
Atriplex littoralis								10	2							2					20	5						15	7	5
Cochlearia officinalis					2	5	2	50	5	1						3	5	3		8	30	15						10	2	5
Elymus repens				40																								15		
Glaux maritima				1	5	45	5			45						15		45		2										
Honkenya peploides																														
Festuca rubra				60	75	45	70		5	5						40	25	45				70						60		40
Plantago maritima					20	3	20	5	30	45	2					40	40	3				5								40
Puccinellia maritima								10	50		45						20		95	20	40								20	
Salicornia sp.											2																		1	
Spergularia media																														
Suaeda maritima									5																				50	
Bare	100	100	100								50	100	100	100	100								100	100	100	100	100			

2006: Quadrats 181-190

Species	181	182	183	184	185	186	187	188	189	190
Armeria maritima										
Aster tripolium	60									
Atriplex prostrata										
Atriplex littoralis										
Cochlearia officinalis	3									
Elymus repens										
Glaux maritima										
Honkenya peploides										
Festuca rubra										
Plantago maritima										
Puccinellia maritima	40									
Salicornia sp.		30	2	2						1
Spergularia media										
Suaeda maritima										
Bare		70	98	98	100	100	100	100	100	99

Appendix 4

Percentage cover of each species recorded in quadrats in Nigg Bay Managed Realignment Site. Quadrat numbers are as in Figure 3.1.

2002: Quadrats 1-30

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Salt marsh species																														
Armeria maritima																														
Aster tripolium																														
Atriplex prostrata																														
Atriplex littoralis																														
Cochlearia officinalis																														
Glaux maritima																														
Plantago maritima																														
Puccinellia maritima																														
Salicornia																														
Spergularia																														
Suaeda maritima																														
Flowering plants																														
Achillea millefolium														5																
Angelica sylvestris																														1
Cerastium fontanum													1												1	1			1	
Cirsium palustre		25																												5
Crepis capillaris	10		5	2	5																				1			1	5	
Epibolium palustre																		1												
Epibolium montanum		2					5									1		1												
Galium aparine																			1											
Hypochoeris sp.																														
Lotus uliginosus						2																								
Potentilla anserina		1																	10											
Prunella vulgaris																													1	
Ranunculus acris	10	1	5		10	5		5		5	30	5			5		5		2	2		1	1		15					2
Ranunculus repens							2			2		30	1	1					5	5	1		30		10	51			3	
Ranunculus sceleratus																1														
Rumex acetosa					5		10				5								10	3			15		10					5
Trifolium repens	5		10						5	2		5					1			2		3	2	5	2	1		2	3	
Stellaria alsine							5									1								1						
Valeriana officinalis																														
Grasses																														
Agropyron repens																			50	50			5			1				
Agrostis capillaris			10	5	5	2		40		60	10	25	5		5	5	10			20	20	10	15							
Agrostis stolonifera							1		50		10				5			10					30	25	15		25	30	40	10

2002: Quadrats 1-30 continued

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Anthoxanthum odoratum	2		5	5	5			10																		1		5	5	
Arrhenatherum elatius		10	15	10				5																						
Cynosurus criststus						10																							2	
Danthonia decumbens					1																									
Deschampsia cespitosa						5				2								5												
Elymus repens																														
Glyceria fluitans																1														
Holcus lanatus	50	5	40	30	25	70	10		10	20	70	15	2	15			80	10	20	20	60	80		40	40	90		20		30
Phleum bertolonii																														
Poa annua																														
Festuca rubra				25	10																							10		
Rushes																														
Juncus acutiflorus																								1				3		
Juncus effusus		25					50	1					30	15	40	90			5	20	10		15	30				2	5	40
Luzula multiflora					1																									
Sedges																														
Carex flacca			2										1	1															2	2
Carex nigra	10			5	2	5												10											5	
Eleocharis uniglumis									20																					
Bryophytes																														
Eurhynchium sp.	10	20																15	10											
Hylocomium splendens																													40	
Pleurozium schreberi					40																									
Polytrichum juniperinum													12	1														10		
Pseudoscleropodium purum	40					10																								
Rhytidelphus squarrosus	30	10	15		50	40		30				25		30											25			60	15	10
Other vegetation																														
Callitriche sp.							1																							
Peltigera sp.																												2		
Algae																														
Non vegetation																														
Dead vegetation																														
Mud																														
Cow pat																														
Bare																														

2002: Quadrats 31-60

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Salt marsh species																														
Armeria maritima																														
Aster tripolium																														
Atriplex prostrata																														
Atriplex littoralis																														
Cochlearia officinalis																														
Glaux maritima																														
Plantago maritima																														
Puccinellia maritima																														
Salicornia																														
Spergularia																														
Suaeda maritima																														
Flowering plants																														
Achillea millefolium																														
Angelica sylvestris																														
Cerastium fontanum			1													2														
Cirsium palustre																														
Crepis capillaris					1																									
Epibolium palustre																														
Epibolium montanum												2																		
Galium aparine																														
Hypochoeris sp.																														
Lotus uliginosus																														
Potentilla anserina																														
Prunella vulgaris																														
Ranunculus acris						2	1	2		2			1								2	1		1	1			5	1	1
Ranunculus repens					1							5		3								15							10	1
Ranunculus sceleratus																														
Rumex acetosa												10		2				20												1
Trifolium repens			1	3	1	1				1			1			5	1						5	1						1
Stellaria alsine																														
Valeriana officinalis																										1				
Grasses																														
Agropyron repens																														
Agrostis capillaris					30	30	40	1	20	30			50	10		10			65	15	20	30	15	30	15	5			10	20
Agrostis stolonifera	30		25	40					20		40	25	15	20	40		30		20		20		15	10		10	5			

2002: Quadrats 31-60 continued

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Anthoxanthum odoratum					10					5																		1		
Arrhenatherum elatius								5				10						5				2						15		1
Cynosurus criststus						1											1													
Danthonia decumbens																														
Deschampsia cespitosa																		5					5							
Elymus repens																														
Glyceria fluitans																														
Holcus lanatus	2	35			50	30	50	1	60	50	10		30	60	10	30	30	10	10	90	50	5	40	50	80	70	5	80	80	80
Phleum bertolonii			10																											
Poa annua		5																												
Festuca rubra																														
Rushes																														
Juncus acutiflorus			1	1																										
Juncus effusus	50	1	20	5	5		5	70			30	50			50	1	50	2			60	10	10		15	85				
Luzula multiflora																														
Sedges																														
Carex flacca																														
Carex nigra		25				40				10	10					50	40								5		5			
Eleocharis uniglumis																														
Bryophytes																														
Eurhynchium sp.				5		5			5							10	10					25					40			
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus		40		10	45									40		10	20						10							20
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae																														
Non vegetation																														
Dead vegetation																														
Mud																														
Cow pat																														
Bare																														

2003: Quadrats 1-30

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Salt marsh species																														
Armeria maritima																														
Aster tripolium																														
Atriplex prostrata																														
Atriplex littoralis																														
Cochlearia officinalis																														
Glaux maritima																					0.5									
Plantago maritima																														
Puccinellia maritima																														
Salicornia																														
Spergularia																														
Suaeda maritima																														
Flowering plants																														
Achillea millefolium														10																
Angelica sylvestris																														
Cerastium fontanum		0.5	1									0.5																		
Cirsium palustre	0.5																													
Crepis capillaris	5		0.5	2	2	1													2			1			0.5					
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.	0.5		0.5																											
Lotus uliginosus						10																								
Potentilla anserina	0.5																		10											
Prunella vulgaris																														
Ranunculus acris	3		1	2	5	2		10				1		10																
Ranunculus repens													15																	
Ranunculus sceleratus					0.5																									
Rumex acetosa				0.5	1	0.5		0.5					2																	
Trifolium repens	10	0.5	2	3	1	1		8			2	5		3					1	3		2			0.5					
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris	5	2	15	2	15	30		2			25	15	2	4					15	1		20								
Agrostis stolonifera							3				30				90							1								

2003: Quadrats 1-30 continued

Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Anthoxanthum odoratum	0.5			1										1																
Arrhenatherum elatius																														
Cynosurus criststus	0.5																													
Danthonia decumbens																														
Deschampsia cespitosa																														
Elymus repens																				1										
Glyceria fluitans																														
Holcus lanatus	2	0.5	5	15	30	40		1			5		10	3					5			5								
Phleum bertolonii																														
Poa annua																														
Festuca rubra	1	0.5	0.5	5	25				1				0.5							65	0.5	6								
Rushes																														
Juncus acutiflorus																														
Juncus effusus		2	5		2								50	60					60											
Luzula multiflora																														
Sedges																														
Carex flacca			10																											
Carex nigra	75			40	5	3		60			10	5	2	5					5	15		30								
Eleocharis uniglumis																														
Bryophytes	10		10	2	1			15				10	2																	
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae									0.5							5	0.5	40					15	15			25	2	20	2
Non vegetation																														
Dead vegetation	3	80	5	20	3	5	80		96	97	1	50	3	2	10	10	98	60		10	99	15	85	10	99	97	10	5		20
Mud							15									85								75		3	55	93	80	78
Cow pat				1	4	1			3	3	6	1	6				2		1	4	1	1								
Bare																														

2003: Quadrats 31-60

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Salt marsh species																														
Armeria maritima																														
Aster tripolium												1																		
Atriplex prostrata																														
Atriplex littoralis																														
Cochlearia officinalis																														
Glaux maritima																														
Plantago maritima												0.5																		
Puccinellia maritima																														
Salicornia																														
Spergularia																														
Suaeda maritima																														
Flowering plants																														
Achillea millefolium																														
Angelica sylvestris																														
Cerastium fontanum																													0.5	
Cirsium palustre																														
Crepis capillaris																												5		
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.																														
Lotus uliginosus																														
Potentilla anserina																														
Prunella vulgaris																														
Ranunculus acris																													5	
Ranunculus repens																														
Ranunculus sceleratus																														
Rumex acetosa																														
Trifolium repens																												4	8	3
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris																												10	60	45
Agrostis stolonifera																													3	2

2003: Quadrats 31-60 continued

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Anthoxanthum odoratum																														
Arrhenatherum elatius																														
Cynosurus criststus																														
Danthonia decumbens																														
Deschampsia cespitosa																														
Elymus repens																		0.5												
Glyceria fluitans																														
Holcus lanatus																												0.5	0.5	10
Phleum bertolonii																														
Poa annua																														
Festuca rubra													1						2					2				5		1
Rushes																														
Juncus acutiflorus																														
Juncus effusus																								3						
Luzula multiflora																														
Sedges																														
Carex flacca																														
Carex nigra																												15	2	10
Eleocharis uniglumis																														
Bryophytes																													2	5
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae		80	5	25	15	5	65	15	40	50	5	25	15	0.5	15	70	95		0.5	0.5	1	20	30	20		2	10			
Non vegetation																														
Dead vegetation	70		10	75	83	25	35	60	5	20	1	75	80	98	85	30	5	99	98	99	98	80	70	75	100	98	90	50	10	10
Mud	30	20	85		2	70		25	55	30	95		5	1																
Cow pat														1							1							0.5	0.5	
Bare																														

2004: Quadrats 1-30

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Salt marsh species																														
Armeria maritima																														
Aster tripolium																	0.5				1					5				
Atriplex prostrata																														
Atriplex littoralis																	2						1							
Cochlearia officinalis																														
Glaux maritima																														
Plantago maritima									1																					
Puccinellia maritima																	0.5								2	5				
Salicornia																	0.5									1				
Spergularia																										6				
Suaeda maritima																							0.5			2				
Flowering plants																														
Achillea millefolium														10																
Angelica sylvestris																														
Cerastium fontanum		1	1		1	1						1	1	0.5																
Cirsium palustre													1																	
Crepis capillaris		0.5		0.5																										
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.	8	0.5	0.5		3																									
Lotus uliginosus						30																								
Potentilla anserina	1	1																	10											
Prunella vulgaris																														
Ranunculus acris	7		2	2	10	1		2				1	3	25																
Ranunculus repens													2																	
Ranunculus sceleratus																														
Rumex acetosa				0.5	1			0.5					2																	
Trifolium repens	40	0.5	10	5	6	3		30			3	30		5								3								
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris	10	5	40	10	10	25		10			35	70	5	5						10		40								
Agrostis stolonifera							1				45				80				15	3		30								

2004: Quadrats 1-30 continued

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Anthoxanthum odoratum	1			10	3	1								0.5																
Arrhenatherum elatius																														
Cynosurus criststus	1					2								0.5																
Danthonia decumbens																														
Deschampsia cespitosa																														
Elymus repens																			10	3										
Glyceria fluitans																														
Holcus lanatus	10	1	15	10	25	20		2				1	25	2								10								
Phleum bertolonii											2																			
Poa annua																														
Festuca rubra	0.5	8	1	20	20						2		0.5		2				2	75		15								
Rushes																														
Juncus acutiflorus																														
Juncus effusus			10										50	50					60	2										
Luzula multiflora														1																
Sedges																														
Carex flacca			3																											
Carex nigra	40			20	5	5		40			5	10	3	2	1					3		5								
Eleocharis uniglumis																														
Bryophytes	5		5	3	10	2		30				0.5	7																	
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae																										50	75			
Non vegetation																														
Dead vegetation		80	5	20	5		40		5		5		1	1	20		20				3		30		98		2			
Mud		2					60		95	100						100	75	100			97		70	5		30	25	100	100	100
Cow pat					1	3		2				1																		
Bare																				1				95						

2004: Quadrats 31-60

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Salt marsh species																														
Armeria maritima																														
Aster tripolium												7																		
Atriplex prostrata												5		3																
Atriplex littoralis																														
Cochlearia officinalis												1												0.5						
Glaux maritima																														
Plantago maritima																														
Puccinellia maritima	1								0.5			5		1					2	0.5		5		4						
Salicornia												3							1					3						
Spergularia												1																		
Suaeda maritima												3												1						
Flowering plants																														
Achillea millefolium																														
Angelica sylvestris																														
Cerastium fontanum																													0.5	
Cirsium palustre																														
Crepis capillaris																														
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.																												1		
Lotus uliginosus																														
Potentilla anserina																														
Prunella vulgaris																														
Ranunculus acris																													3	
Ranunculus repens																														
Ranunculus sceleratus																														
Rumex acetosa																														
Trifolium repens																												2	50	5
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris																												20	50	30
Agrostis stolonifera																													3	10

2004: Quadrats 31-60 continued

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Anthoxanthum odoratum																														
Arrhenatherum elatius																														
Cynosurus criststus																														
Danthonia decumbens																														
Deschampsia cespitosa																														
Elymus repens																														
Glyceria fluitans																														
Holcus lanatus																												1	2	20
Phleum bertolonii																														
Poa annua																														
Festuca rubra																												5	0.5	2
Rushes																														
Juncus acutiflorus																														
Juncus effusus																														1
Luzula multiflora																														
Sedges																														
Carex flacca																														
Carex nigra																												25		5
Eleocharis uniglumis																														
Bryophytes																														
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae	75									25	4										80	40	50			97	80			
Non vegetation																														
Dead vegetation	25							15				4	25	96	2			75	15		10	40		10		3	20	50	2	20
Mud		100	100	100	100	100	100	85	100	75	96	70	75		98	100	100	30	82	100	10	15	50	80	100					
Cow pat																													0.5	
Bare																														

2005: Quadrats 1-30

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Salt marsh species																														
Armeria maritima							0.5																			0.5				
Aster tripolium																	5				1		1			1				
Atriplex prostrata																														
Atriplex littoralis		1							1	0.5					2		5			5	0.25	0.5	6		0.5					
Cochlearia officinalis																						2								
Glaux maritima																														
Plantago maritima							5										2													
Puccinellia maritima									1	3							30				8		40		6	25			2	
Salicornia										25						0.5	30	2			0.25		10	4	2	5	1			
Spergularia									3	3											10				4	2				
Suaeda maritima										1																				
Flowering plants																														
Achillea millefolium														10																
Angelica sylvestris																														
Cerastium fontanum												2	5	1								0.5								
Cirsium palustre													1																	
Crepis capillaris		1																												
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.	8	3	2	1	6	1																								
Lotus uliginosus						50																								
Potentilla anserina	0.5	1																	5											
Prunella vulgaris																														
Ranunculus acris	7		0.5	2	3	3						4	1	25																
Ranunculus repens												1																		
Ranunculus sceleratus																														
Rumex acetosa				0.5	0.5								5						2											
Trifolium repens	25	20	15	25	30	10		25			25	15		5	0.5							5								
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris		10	45	40	5	20		10			10	40	2	7					40											
Agrostis stolonifera											60				80					20		80								

2005: Quadrats 1-30 continued

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Anthoxanthum odoratum					10	5			1				1		0.5															
Arrhenatherum elatius																														
Cynosurus criststus	5			2	5	10						1		0.5																
Danthonia decumbens																														
Deschampsia cespitosa																														
Elymus repens																				5										
Glyceria fluitans																														
Holcus lanatus	5	1	2	10	20	10		5				1	3	7	1				2											
Phleum bertolonii											1									1										
Poa annua																														
Festuca rubra	5	10	15					3							10					50		15			3					
Rushes																														
Juncus acutiflorus																														
Juncus effusus			10										90	50					50											
Luzula multiflora					1																									
Sedges																														
Carex flacca			10		50																									
Carex nigra	40	10		20		10		60			5	30																		
Eleocharis uniglumis																														
Bryophytes	2			5	10			3																						
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae																														
Non vegetation																														
Dead vegetation		20					5								5															
Mud		20					90		95	70						99.5	30	98			80		45	96	85	65	99	100	98	**100**
Cow pat																														
Bare			1																											

2005: Quadrats 31-60

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Salt marsh species																														
Armeria maritima																														
Aster tripolium	1				10			1				5	3		0.5			3			2	4		4			0.5			
Atriplex prostrata																														
Atriplex littoralis												10	5	1	4			5	15		2			5						
Cochlearia officinalis																														
Glaux maritima																														
Plantago maritima					1							2																		
Puccinellia maritima	2						15					5	0.5	10	8			50	1	1	4	45	2	30	1		2			
Salicornia	15	25	1		50	0.5	2	1	1	4	8	10	25	5	10	5	2	35	5	5	70	4	3	25	15	2				
Spergularia												3	1					4	1											
Suaeda maritima																														
Flowering plants																														
Achillea millefolium																														
Angelica sylvestris																														
Cerastium fontanum																													2	
Cirsium palustre																														
Crepis capillaris																														
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.																												0.5		
Lotus uliginosus																														
Potentilla anserina																														
Prunella vulgaris																														
Ranunculus acris																													3	
Ranunculus repens																														3
Ranunculus sceleratus																														
Rumex acetosa																														
Trifolium repens																													5	
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris																												30	75	5
Agrostis stolonifera																														10
Anthoxanthum odoratum																														

2005: Quadrats 31-60 continued

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Arrhenatherum elatius																														
Cynosurus criststus																														
Danthonia decumbens																														
Deschampsia cespitosa																														
Elymus repens																														
Glyceria fluitans																														
Holcus lanatus																													20	1
Phleum bertolonii																														10
Poa annua																														
Festuca rubra													10															40		
Rushes																														
Juncus acutiflorus																														
Juncus effusus																														
Luzula multiflora																														
Sedges																														
Carex flacca																														
Carex nigra																												25		2
Eleocharis uniglumis																														
Bryophytes																														
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae							83	90					55	85	75			5	68	96	22	50	95	35	84	98	68			
Non vegetation																														
Dead vegetation								5											10								30			
Mud	82	75	99	100	40	100			99	96	92	65				95	98													
Cow pat																												4		
Bare																														70

2006: Quadrats 1-30

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Salt marsh species																														
Armeria maritima																														
Aster tripolium									0.5								5	0.5			15		2		0.5	6				
Atriplex prostrata																														
Atriplex littoralis	3	1	0.5				0.5			3					2		0.5			3			0.5		0.5	1				
Cochlearia officinalis																														
Glaux maritima																														
Plantago maritima																							1							
Puccinellia maritima							0.5	0.5	8						0.5						1		75		6	80			2	
Salicornia									4	50					0.5		20				4		2	3	3	1	1	1	1	0.5
Spergularia									2	2					0.5		15	2			2				25	2				
Suaeda maritima									0.5	1							2						1			2				
Flowering plants																														
Achillea millefolium	0.5													1																
Angelica sylvestris																														
Cerastium fontanum				0.5	1							0.5	0.5																	
Cirsium palustre																														
Crepis capillaris		0.5				0.5																								
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.	5	10	1	3	1	3						1																		
Lotus uliginosus																														
Potentilla anserina																			1											
Prunella vulgaris																														
Ranunculus acris	0.5			1	1							2		4																
Ranunculus repens																														
Ranunculus sceleratus																														
Rumex acetosa													0.5	1																
Trifolium repens	5	5		6	25	8		0.25			2	2		1																
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris		4	2		10			0.5			20	20	3	10								5								
Agrostis stolonifera						1					75				5					15		40								
Anthoxanthum odoratum				1																										

2006: Quadrats 1-30 continued

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Arrhenatherum elatius																														
Cynosurus criststus	0.5			1	2							3																		
Danthonia decumbens																														
Deschampsia cespitosa						15																								
Elymus repens																			5			2								
Glyceria fluitans																														
Holcus lanatus		1		2		1						3																		
Phleum bertolonii																														
Poa annua																														
Festuca rubra	25	30	20	10	10			20				30			3		55		15	70		15			5					
Rushes																														
Juncus acutiflorus																														
Juncus effusus			2										10	30					5											
Luzula multiflora														0.5																
Sedges																														
Carex flacca																														
Carex nigra	40	30	10	25	50	70		2			2	40		10																
Eleocharis uniglumis																														
Bryophytes	1	3		25	5							5																		
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae																														
Non vegetation																														
Dead vegetation	15	10	65	25	5			75					85	45	90				80			40								
Mud							99		85	40						100		98			80		20	97	60		99	99	97	99.5
Cow pat																														
Bare																	2			15						5				

2006: Quadrats 31-60

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Salt marsh species																														
Armeria maritima																														
Aster tripolium	0.5				10			1				7	6	3	2			5		3	3	1		10	1		1			
Atriplex prostrata																														
Atriplex littoralis													2	2				2		2	0.5	0.5	0.5			0.5	1	1	0.5	
Cochlearia officinalis																														
Glaux maritima																														
Plantago maritima												2																		
Puccinellia maritima	5						15	5				50	50	70	20			15	1	50	25	80	0.5	50	2	1	10			
Salicornia	5	3	1		20	3	15	4	1	1	1	10	20	20	20	1	1	65	20	15	30	2	10	30	40	25	2			
Spergularia												0.5	2	2				2												
Suaeda maritima								0.5				2			2			1	1	5						3	0.5			
Flowering plants																														
Achillea millefolium																														
Angelica sylvestris																														
Cerastium fontanum																														
Cirsium palustre																														
Crepis capillaris																														
Epibolium palustre																														
Epibolium montanum																														
Galium aparine																														
Hypochoeris sp.																														
Lotus uliginosus																														
Potentilla anserina																														
Prunella vulgaris																														
Ranunculus acris																														
Ranunculus repens																														
Ranunculus sceleratus																														
Rumex acetosa																													0.5	
Trifolium repens																													3	2
Stellaria alsine																														
Valeriana officinalis																														
Grasses																														
Agropyron repens																														
Agrostis capillaris																												20	20	
Agrostis stolonifera																												5		5
Anthoxanthum odoratum																														

2006: Quadrats 31-60 continued

Species	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Arrhenatherum elatius																														
Cynosurus criststus																														
Danthonia decumbens																														
Deschampsia cespitosa																														
Elymus repens																														
Glyceria fluitans																														
Holcus lanatus																														
Phleum bertolonii																														
Poa annua																														
Festuca rubra																												25	40	30
Rushes																														
Juncus acutiflorus																														
Juncus effusus																														
Luzula multiflora																														
Sedges																														
Carex flacca																														
Carex nigra																												25	5	5
Eleocharis uniglumis																														
Bryophytes																														
Eurhynchium sp.																														
Hylocomium splendens																														
Pleurozium schreberi																														
Polytrichum juniperinum																														
Pseudoscleropodium purum																														
Rhytidelphus squarrosus																														
Other vegetation																														
Callitriche sp.																														
Peltigera sp.																														
Algae																														
Non vegetation																														
Dead vegetation																					20							5	25	10
Mud	90	97	99	100	70	97	70	90	99	99	99	25	20	5	55	99	99	10	80	25	20	20			60	70	90			
Cow pat																														
Bare																								10				15		45

Appendix 5

Sediment and intertidal invertebrate sampling points in Nigg Bay Managed Realignment Site.

Transect	Description	Sampling point	Easting	Northing	Elevation (m OD)	2003-2004	2004-2005	2005-2006
1	Transect from second breach	1.01	278839	873792	1.529	✓	✓	✓
		1.02	278836	873817		✓		
		1.03	278832	873842	1.687	✓	✓	✓
		1.04	278829	873866		✓		
		1.05	278826	873891		✓		
		1.06	278823	873916		✓		
		1.07	278820	873941		✓		
		1.08	278816	873965		✓		
		1.09	278813	873990		✓		
		1.10	278810	874015		✓		
		1.11	278807	874040		✓		
		1.12	278804	874065		✓		
		1.13	278800	874089		✓		
2	Transect from first breach	2.01	279131	873829	1.621	✓	✓	✓
		2.02	279128	873854		✓		
		2.03	279124	873879	1.734	✓	✓	✓
		2.04	279121	873903		✓		
		2.05	279118	873928		✓		
		2.06	279115	873953		✓		
		2.07	279112	873978		✓		
		2.08	279108	874002		✓		
		2.09	279105	874027		✓		
		2.10	279102	874052		✓		
		2.11	279099	874077		✓		
		2.12	279096	874102		✓		
		2.13	279092	874126		✓		
3	Transect 110 m from front sea wall	3.01	278727	873878		✓		✓
		3.02	278776	873885		✓		✓
					1.745			
		3.03	278876	873897		✓	✓	✓
		3.04	278925	873904		✓		✓
		3.05	278975	873910		✓		✓
		3.06	279019	873915		✓		✓
		3.07	279068	873922	1.621	✓	✓	✓
		3.08	279168	873934		✓		✓
		3.09	279217	873941		✓		✓
		3.10	279267	873947		✓		✓
		3.11	279316	873954		✓		✓
4	Transect 60 m from front	4.01	278733	873829		✓		✓
		4.02	278783	873835		✓		✓

Transect	Description	Sampling point	Easting	Northing	Elevation (m OD)	2003-2004	2004-2005	2005-2006
	sea wall	4.03	278882	873848	1.614	✓	✓	✓
		4.04	278932	873854	1.731	✓	✓	✓
		4.05	278981	873861		✓		✓
		4.06	279025	873866	1.719	✓	✓	✓
		4.07	279075	873872	1.62	✓	✓	✓
		4.08	279174	873885		✓		✓
		4.09	279224	873891		✓		✓
		4.10	279273	873898		✓		✓
		4.11	279323	873904		✓		✓
5	Transect 10 m from front sea wall	5.01	278740	873779		✓		✓
		5.02	278789	873786	1.773	✓	✓	✓
		5.03	278888	873798	1.583	✓	✓	✓
		5.04	278938	873805	1.721	✓	✓	✓
		5.05	278987	873811		✓		✓
		5.06	279032	873816	1.713	✓	✓	✓
		5.07	279081	873823	1.603	✓	✓	✓
		5.08	279180	873835	1.603	✓	✓	✓
		5.09	279230	873842		✓		✓
		5.1	279279	873848		✓		✓
		5.11	279329	873854		✓		✓
						69	**16**	**37**
	Additional sampling points	1	278826	873778			✓	
		2	278806	873774			✓	
		3	278797	873782			✓	
		4	278770	873772			✓	
		5	278737	873782			✓	
		6	278800	873825			✓	
		8	278821	873814			✓	
		9	278809	873802			✓	
		10	279105	873821			✓	
		11	279060	873813			✓	
		12	279051	873846			✓	
		13	279114	873867			✓	

Appendix 6

Sediment and intertidal invertebrate sampling points on the reference intertidal flats adjacent to Nigg Bay Managed Realignment Site.

Sampling point	Easting	Northing	Elevation (m OD)	2003-2004	2004-2005	2005-2006
B	78800	73700	1.45	✓	✓	✓
C	79000	73700	1.34	✓	✓	✓
D	79200	73700	1.30	✓	✓	✓
E	79400	73700	1.30	✓	✓	✓
F	78600	73500		✓		✓
G	78800	73500	1.32	✓	✓	✓
H	79000	73500	1.17	✓	✓	✓
I	79200	73500	1.05	✓	✓	✓
J	79400	73500	1.06	✓	✓	✓
K	78600	73300		✓		✓
L	78800	73300	1.16	✓	✓	✓
M	79000	73300	0.98	✓	✓	✓
N	79200	73300	0.62	✓	✓	✓
O	79400	73300	0.61	✓	✓	✓
P	78600	73100		✓		✓
Q	78800	73100	0.59	✓	✓	✓
R	79000	73100	0.67	✓	✓	✓
S	79200	73100	0.39	✓	✓	✓
T	79400	73100	0.13	✓	✓	✓
			TOTAL	19	16	19

Appendix 7

Humans, raptors and aircraft were all identified as potential or actual sources of disturbance in Nigg Bay MRS. Human disturbance included walkers, the local farmer, wildfowlers and educational visits run by the RSPB. Humans crossing the breach gaps and walking on the crest of the southern embankment regularly resulted in waders redistributing within or leaving Nigg Bay MRS. On several occasions wildfowlers were observed shooting within Nigg Bay MRS. Five different raptor species were observed perching within or flying over Nigg Bay MRS. Buzzards and Kestrels were regularly observed perching in trees on the west embankment and on fence posts within Nigg Bay MRS. On several occasions raptors flying within Nigg Bay MRS caused visible disturbance to waders which resulted in them redistributing within or leaving Nigg Bay MRS altogether. On one occasion a Peregrine Falcon was observed eating a Common Redshank within Nigg Bay MRS. Low-flying jets and helicopters also caused disturbance.

Date	Time	Category*	Detail¶	Note
05/10/2004	09:35	P	B	disturbed some of the waders in the second breach area
	11:02	H	W	walking in Nigg Bay MRS near shelterbelt – did not appear to disturb birds
07/10/2004	14:23	H	E	walking along 1st section of southern embankment before east breach
	14:30	H	E	walking along 1st section of southern embankment before east breach – disturbed lots of waders from Nigg Bay MRS
	14:38	H	E	in east breach gap
	14:44	H	E	in west breach gap
	14:53	H	E	in west breach gap
	15:06	H	E	in east breach gap
08/10/2004	14:04	P	B	buzzard harassed by crows caused Eurasian Curlew to leave the east breach area
10/10/2004	08:53	H	F	checking cattle near tree line – did not appear to disturb birds
	10:08	P	K	perched in vegetation to the left of second breach gap
	12:38	P	K	
	12:53	P	K	
	13:08	P	K	
	14:08	P	K	
	14:38	P	K	perched in shelterbelt
	14:53	P	K	perched in shelterbelt
11/10/2004	08:00	H	W	in Nigg Bay – occasional shots being fired
	11:12	P	B	perched in tree on west embankment
	10:20	H	E	walking along 1st section of southern embankment before east breach
	10:27	H	E	walking along 1st section of southern embankment before east breach
	10:36	H	E	in east breach gap - scaring Common Redshank, some into west breach area
	12:40	H	H	parked car on embankment
	08:20	H	F	checking cattle – did not appear to disturb birds
	11:39	A	Jet	low flying jet – disturbed many of the waders (especially Northern Lapwing) from west breach area
12/10/2004	08:00	H	W	in Nigg Bay – occasional shots being fired
	16:04	P	S/P	disturbed Common Redshank in east breach area
	11:05	H	H	parked car on embankment
	09:09	H	W	stood on embankment
13/10/2004	11:16	H	W	in Nigg Bay – occasional shots being fired
15/10/2004	08:00	H	W	in Nigg Bay – occasional shots being fired

Date	Time	Category*	Detail[¶]	Note
16/10/2004	08:00	H	W	in Nigg Bay – occasional shots being fired
18/10/2004	13:11	P	S/P	in west breach area
22/10/2004	12:18	A	Helicopter	disturbed waders from west breach area
24/10/2004	14:27	H	W	in east breach gap – disturbed many of the waders
26/10/2004	08:00	H	W	in Nigg Bay
27/10/2004	08:00	H	H	in Nigg Bay
08/11/2004	15:16	P	P	eating a Common Redshank
	15:19	P	P	eating a Common Redshank
	15:34	P	P	eating a Common Redshank
09/11/2004	08:00	H	W	in Nigg Bay
	10:36	H	W	crossed west breach gap – disturbed waders
	10:44	H	W	crossed east breach gap – disturbed waders
	11:00	H	W	crossed east breach gap – disturbed waders
	11:07	H	W	crossed west breach gap – disturbed waders
10/11/2004	08:55	P	P	disturbed waders just outside west breach which had potential to enter Nigg Bay MRS
	09:00	H	W	crossed west breach gap – disturbed waders
	09:03	H	W	crossed east breach gap – disturbed waders, some flew into west breach area
23/11/2004	15:33	H	W	crossed east breach gap – disturbed waders
01/12/2004	12:31	P	S/P	in east breach area
	12:46	P	S/P	in east breach area
	13:01	P	S/P	in east breach area
	13:16	P	S/P	in east breach area
	13:31	P	S/P	in east breach area
14/01/2005	10:52	P	S/P	attacking Common Redshank in east breach area
29/01/2005	11:20	P	S/P	in west breach area
05/09/2005	15:07	P	P	flew over Nigg Bay MRS and landed on post
	15:02	P	Osprey	flew over Nigg Bay MRS
	16:04	A	Jet	Jet
07/09/2005	11:22	P	B	flew over west breach area
19/09/2005	15:30	A	Jet	Jet
28/09/2005	11:16	P	K	hovering over southern embankment

Date	Time	Category*	Detail¶	Note
05/10/2005	10:17	P	K	perched on fence post
	12:04	A	Jet	flew over Nigg Bay MRS
	14:37	P	K	perched on fence post
	15:22	H	W	in Nigg Bay – shots being fired – caused most birds to scatter
	15:37	A	Jet	flew over Nigg Bay MRS
	15:41	A	Jet	flew over Nigg Bay MRS
	15:44	H	W	in Nigg Bay – occasional shots being fired
	15:45	H	W	in Nigg Bay – occasional shots being fired
	15:49	H	W	in Nigg Bay – occasional shots being fired
	15:50	H	W	in Nigg Bay – occasional shots being fired
	15:53	H	W	in Nigg Bay – occasional shots being fired
	15:54	H	W	in Nigg Bay – occasional shots being fired
11/10/2005	11:41	P	S/P	flew over Nigg Bay MRS
17/10/2005	08:55	H	W	3 wildfowlers leaving
	09:34	A	Jet	flew over Nigg Bay MRS
	10:27	A	Jet	flew over Nigg Bay MRS
	14:19	H	W	on first stretch of southern embankment
	14:25	P	S	in filed
	14:50	P	K	hovering over southern embankment
	15:10	P	K	hovering over southern embankment
	15:25	P	K	hovering over southern embankment
	15:40	P	K	hovering over southern embankment
26/10/2005	09:00	H	W	on lump of saltmarsh E of MR - left at 09:15
	11:24	P	K	sat on post outside west breach
	11:39	P	K	sat on post outside west breach
	12:09	P	K	hovering over southern embankment
	12:19	A	Helicopter	flew over Nigg Bay MRS
	12:24	P	K	hovering over southern embankment
	12:54	P	K	hovering over southern embankment
	13:54	P	K	hovering over southern embankment
17/11/2005	11:30	H	W	walking on first stretch of southern embankment

Date	Time	Category*	Detail¶	Note
	12:30	A	Jet	flew over Nigg Bay MRS – disturbed wildfowl
	12:45	P	K	perched in tree on west southern embankment
	13:00	P	K	hovering over southern embankment
	14:00	P	K	perched in tree in east breach area
03/12/2005	11:22	P	K	perched on fence post
	11:37	P	K	perched on fence post
	11:52	P	K	perched in tree in east breach area
08/12/2005	08:45	H	W	in Nigg Bay
	09:02	P	B	perched in tree on west embankment
	09:06	H	W	in Nigg Bay – occasional shots being fired
	10:02	P	K	perched in tree on west embankment
	10:17	P	K	perched on washed up tree outside west breach
	10:17	P	B	perched on bail on southern embankment
	10:38	P	K	perched on stakes outside west breach
	11:03	P	K	perched on stakes outside west breach
	11:18	P	K	hovering over southern embankment
	11:18	P	B	perched in tree near car
	11:33	P	B	perched in tree near car
	12:03	P	B	perched in tree near car
	12:03	P	K	perched in tree in east breach area
	12:18	P	K	perched on post on southern embankment
	12:18	P	B	perched in tree near car then flew to stakes outside east breach
	12:33	P	K	perched on stake near southern embankment then hovered above saltmarsh
	12:48	P	K	hovering over southern embankment
	13:03	P	K	perched in tree in east breach area
	13:03	P	K	hovering over southern embankment
	13:18	P	K	perched on post near southern embankment
	13:48	P	B	2 perched in trees on west embankment
	11:50	P	K	flew over Nigg Bay MRS
18/12/2005	14:00	H	W	disturbed roosting birds on west side of Nigg Bay – lots flew into Nigg Bay MRS
20/12/2005	10:40	P	K	perched in tree on west embankment

Date	Time	Category*	Detail¶	Note
09/01/2006	08:45	H	W	1 wildfowler parked at bottom of track
	09:33	P	B	perched in tree on west embankment
16/01/2006	12:43	P	B	perched in tree on west embankment
	13:13	P	B	perched in tree on west embankment
	13:14	P	K	flew over Nigg Bay MRS – disturbed waders
	13:28	P	K	perched in tree on west embankment
	14:06	A	Jet	flew over Nigg Bay MRS – disturbed waders
18/01/2006	13:00	H	W	2 wildfowlers and 4 dogs shooting in the Nigg Bay MRS
24/01/2006	09:50	P	Fox	Appeared on southern embankment at SW corner then passed through west breach area

* A = Aircraft, H = Human, P = Predator
¶ B = Buzzard, E = Educational visit, F = Farmer, H = Human, K = Kestrel, P = Peregrine Falcon, S = Sparrowhawk, W = Wildfowler

Appendix 8

Trapping details of Common Redshank colour-ringed during this study.

ID	Colour ring combination	BTO number	Method	Date	Location	Adult/ Juvenile	Weight (g)
1	L/L//Y;L/L//M	DD05201	Mist	23/10/2004	Meddat	J	160
2	L/L//Y;L/N//M	DD05202	Mist	23/10/2004	Meddat	J	137
3	L/L//Y;L/P//M	DD05203	Mist	23/10/2004	Meddat	J	167
4	L/L//Y;L/W//M	DD05205	Mist	23/10/2004	Meddat	J	150
5	L/L//Y;L/Y//M	DD05204	Mist	23/10/2004	Meddat	A	140
6	L/L//Y;N/L//M	DD05206	Mist	23/10/2004	Meddat	A	157
7	L/L//Y;N/N//M	DD05207	Mist	23/10/2004	Meddat	A	165
8	L/L//Y;N/P//M	DD05208	Mist	23/10/2004	Meddat	J	138
9	L/L//X;N/W//M	DD05267	Mist	11/12/2004	Meddat	A	138
10	L/L//M;N/Y//Y	DD05484	Cannon	24/09/2005	Balintraid	A	148
11	L/L//Y;N/Y//M	DD05273	Mist	11/12/2004	Meddat	A	
12	L/L//Y;P/L//M	DD05268	Mist	11/12/2004	Meddat	A	163
13	L/L//Y;P/N//M	DD05271	Mist	11/12/2004	Meddat	A	158
14	L/L//M;Y/L//Y	DD05486	Cannon	24/09/2005	Balintraid	J	137
15	L/L//M;Y/N//Y	DD05485	Cannon	24/09/2005	Balintraid	A	145
16	L/L//M;Y/Y//Y	DD05487	Cannon	24/09/2005	Balintraid	J	137
17	L/N//M;L/L//Y	DD05488	Cannon	24/09/2005	Balintraid	A	145
18	L/N//M;L/N//Y	DD05489	Cannon	24/09/2005	Balintraid	J	136
19	L/N//M;L/Y//Y	DD05490	Cannon	24/09/2005	Balintraid	A	148
20	L/N//M;N/L//Y	DD05491	Cannon	24/09/2005	Balintraid	A	150
21	L/N//M;N/N//Y	DD05492	Cannon	24/09/2005	Balintraid	J	135
22	L/N//M;N/Y//Y	DD05493	Cannon	24/09/2005	Balintraid	A	139
23	L/N//M;Y/L//Y	DD05494	Cannon	24/09/2005	Balintraid	J	144
24	L/N//M;Y/N//Y	DD05495	Cannon	24/09/2005	Balintraid	J	151
25	L/N//M;Y/Y//Y	DD05496	Cannon	24/09/2005	Balintraid	A	148
26	L/Y//M;L/L//Y	DD05497	Cannon	24/09/2005	Balintraid	A	140
27	L/Y//M;L/N//Y	DD05498	Cannon	24/09/2005	Balintraid	J	148
28	L/Y//M;L/Y//Y	DD05500	Cannon	24/09/2005	Balintraid	A	161
29	L/Y//M;N/L//Y	DD05499	Cannon	24/09/2005	Balintraid	J	138
30	L/Y//M;N/N//Y	DD02001	Cannon	24/09/2005	Balintraid	A	156
31	L/Y//M;N/Y//Y	DD02002	Cannon	24/09/2005	Balintraid	A	141
32	L/Y//M;Y/L//Y	DD02003	Cannon	24/09/2005	Balintraid	A	154
33	L/Y//M;Y/N//Y	DD02004	Cannon	24/09/2005	Balintraid	J	142
34	L/Y//M;Y/Y//Y	DD49108	Cannon	24/09/2005	Balintraid	J	138
35	N/L//Y;L/L//M	DD05173	Mist	23/10/2004	Bayfield	J	132
36	N/L//Y;L/N//M	DD05174	Mist	23/10/2004	Bayfield	J	132
37	N/L//Y;L/P//M	DD05175	Mist	23/10/2004	Bayfield	J	140
38	N/L//Y;L/W//M	DD05177	Mist	23/10/2004	Bayfield	A	156
39	N/L//Y;L/Y//M	DD05176	Mist	23/10/2004	Bayfield	J	149
40	N/L//Y;N/L//M	DD05178	Mist	23/10/2004	Bayfield	J	144
41	N/L//Y;N/N//M	DD05179	Mist	23/10/2004	Bayfield	J	133
42	N/L//Y;N/P//M	DD05180	Mist	23/10/2004	Bayfield	J	159
43	N/L//Y;N/W//M	DD05182	Cannon	28/11/2004	Bayfield	J	203
44	N/L//Y;N/Y//M	DD05181	Cannon	28/11/2004	Bayfield	J	169

ID	Colour ring combination	BTO number	Method	Date	Location	Adult/ Juvenile	Weight (g)
45	N/L//Y;P/L//M	DD05183	Cannon	28/11/2004	Bayfield	A	158
46	N/L//Y;P/N//M	DD05184	Cannon	28/11/2004	Bayfield	A	173
47	N/L//Y;P/P//M	DD05185	Cannon	28/11/2004	Bayfield	A	156
48	N/L//Y;P/W//M	DD05187	Cannon	28/11/2004	Bayfield	A	178
49	N/L//Y;P/Y//M	DD05186	Cannon	28/11/2004	Bayfield	A	171
50	N/L//Y;W/L//M	DD05192	Cannon	28/11/2004	Bayfield	A	159
51	N/L//Y;W/N//M	DD05193	Cannon	28/11/2004	Bayfield	A	188
52	N/L//Y;W/P//M	DD05194	Cannon	28/11/2004	Bayfield	A	185
53	N/L//Y;W/W//M	DD05196	Cannon	28/11/2004	Bayfield	A	164
54	N/L//Y;W/Y//M	DD05195	Cannon	28/11/2004	Bayfield	A	185
55	N/L//Y;Y/L//M	DD05188	Cannon	28/11/2004	Bayfield	A	167
56	N/L//Y;Y/N//M	DD05189	Cannon	28/11/2004	Bayfield	A	170
57	N/L//Y;Y/P//M	DD05190	Cannon	28/11/2004	Bayfield	A	157
58	N/L//Y;Y/W//M	DD05191	Cannon	28/11/2004	Bayfield	A	160
59	N/L//Y;Y/Y//M	DK60101	Cannon	28/11/2004	Bayfield	A	159
60	N/N//Y;L/L//M	DD05197	Cannon	28/11/2004	Bayfield	A	168
61	N/N//Y;L/N//M	DD05198	Cannon	28/11/2004	Bayfield	A	179
62	N/N//Y;L/P//M	DD05199	Cannon	28/11/2004	Bayfield	A	175
63	N/N//Y;L/W//M	DD05209	Cannon	28/11/2004	Bayfield	A	177
64	N/N//Y;L/Y//M	DD05200	Cannon	28/11/2004	Bayfield	A	165
65	N/N//Y;N/L//M	DD05210	Cannon	28/11/2004	Bayfield	A	174
66	N/N//Y;N/N//M	DD05211	Cannon	28/11/2004	Bayfield	A	180
67	N/N//Y;N/P//M	DD05212	Cannon	28/11/2004	Bayfield	A	185
68	N/N//Y;N/W//M	DD05214	Cannon	28/11/2004	Bayfield	A	164
69	N/N//Y;N/Y//M	DD05213	Cannon	28/11/2004	Bayfield	A	175
70	N/N//M;Y/L//Y	DD02005	Cannon	24/09/2005	Balintraid	A	158
71	N/N//M;Y/N//Y	DD02007	Cannon	24/09/2005	Balintraid	A	151
72	N/N//M;Y/Y//Y	DD02006	Cannon	24/09/2005	Balintraid	A	149
73	N/W//M;W/N//Y	DB99551	Cannon	28/11/2004	Bayfield	A	192
74	N/W//M;W/P//Y	DB99540	Cannon	28/11/2004	Bayfield	A	168
75	N/W//M;W/W//Y	DB14296	Cannon	28/11/2004	Bayfield	A	167
76	N/W//M;W/Y//Y	DB14298	Cannon	28/11/2004	Bayfield	A	173
77	N/Y//M;L/L//Y	DD02008	Cannon	24/09/2005	Balintraid	A	158
78	N/Y//M;L/N//Y	DD02009	Cannon	24/09/2005	Balintraid	A	139
79	N/Y//M;L/Y//Y	DD02010	Cannon	24/09/2005	Balintraid	J	142
80	N/Y//M;N/L//Y	DD02011	Cannon	24/09/2005	Balintraid	J	141
81	N/Y//M;N/N//Y	DD02012	Cannon	24/09/2005	Balintraid	A	142
82	N/Y//M;N/Y//Y	DD02013	Cannon	24/09/2005	Balintraid	A	146
83	N/Y//M;Y/L//Y	DD02014	Cannon	24/09/2005	Balintraid	J	131
84	N/Y//M;Y/N//Y	DD02015	Cannon	24/09/2005	Balintraid	A	142
85	N/Y//M;Y/Y//Y	DD02016	Cannon	24/09/2005	Balintraid	A	151
86	W/N//M;N/N//Y	D02074	Mist	10/12/2005	Meddat	A	175
87	W/N//M;N/W//Y	D02072	Mist	10/12/2005	Meddat	A	179
88	W/N//M;W/N//Y	D02075	Mist	10/12/2005	Meddat	A	170
89	W/N//M;W/W//Y	D02071	Mist	10/12/2005	Meddat	A	163
90	W/N//M;W/Y//Y	D02073	Mist	10/12/2005	Meddat	A	170
91	W/W//M;N/N//Y	DD02043	Cannon	24/09/2005	Balintraid	A	142
92	W/W//M;N/W//Y	DD02042	Cannon	24/09/2005	Balintraid	A	141
93	W/W//M;N/Y//Y	DD02044	Cannon	24/09/2005	Balintraid	A	139

ID	Colour ring combination	BTO number	Method	Date	Location	Adult/ Juvenile	Weight (g)
94	W/W//M;W/N//Y	DD02040	Cannon	24/09/2005	Balintraid	A	131
95	W/W//M;W/W//Y	DD02039	Cannon	24/09/2005	Balintraid	J	120
96	W/W//M;W/Y//Y	DD02041	Cannon	24/09/2005	Balintraid	A	148
97	W/W//M;Y/N//Y	DD02046	Cannon	24/09/2005	Balintraid	J	136
98	W/W//M;Y/W//Y	DD02045	Cannon	24/09/2005	Balintraid	A	151
99	W/W//M;Y/Y//Y	D02070	Mist	10/12/2005	Meddat	A	187
100	Y/L//M;L/L//Y	DD02017	Cannon	24/09/2005	Balintraid	J	142
101	Y/L//M;L/N//Y	DD02018	Cannon	24/09/2005	Balintraid	A	145
102	Y/L//M;L/Y//Y	DD02019	Cannon	24/09/2005	Balintraid	J	129
103	Y/L//M;N/L//Y	DD02020	Cannon	24/09/2005	Balintraid	J	151
104	Y/L//M;N/N//Y	DD02021	Cannon	24/09/2005	Balintraid	J	129
105	Y/L//M;N/Y//Y	DD02022	Cannon	24/09/2005	Balintraid	J	139
106	Y/L//M;Y/L//Y	DD02023	Cannon	24/09/2005	Balintraid	J	155
107	Y/L//M;Y/N//Y	DD02024	Cannon	24/09/2005	Balintraid	J	142
108	Y/L//M;Y/Y//Y	DD02025	Cannon	24/09/2005	Balintraid	J	129
109	Y/N//M;L/L//Y	DD02026	Cannon	24/09/2005	Balintraid	J	170
110	Y/N//M;L/N//Y	DD02031	Cannon	24/09/2005	Balintraid	A	142
111	Y/N//M;L/Y//Y	DD02027	Cannon	24/09/2005	Balintraid	A	148
112	Y/N//M;N/L//Y	DD02028	Cannon	24/09/2005	Balintraid	A	120
113	Y/N//M;N/N//Y	DD05236	Cannon	24/09/2005	Balintraid	A	146
114	Y/N//M;N/Y//Y	DD02029	Cannon	24/09/2005	Balintraid	J	141
115	Y/N//M;Y/L//Y	DD02030	Cannon	24/09/2005	Balintraid	A	163
116	Y/N//M;Y/N//Y	DB99578	Cannon	24/09/2005	Balintraid	A	146
117	Y/N//M;Y/Y//Y	DD02032	Cannon	24/09/2005	Balintraid	A	139
118	Y/Y//M;L/L//Y	DD02033	Cannon	24/09/2005	Balintraid	A	132
119	Y/Y//M;L/N//Y	DD02034	Cannon	24/09/2005	Balintraid	J	143
120	Y/Y//M;L/Y//Y	DD02035	Cannon	24/09/2005	Balintraid	J	151
121	Y/Y//M;N/L//Y	DD02036	Cannon	24/09/2005	Balintraid	J	152
122	Y/Y//M;N/N//Y	DB99422	Cannon	24/09/2005	Balintraid	A	146
123	Y/Y//M;N/Y//Y	DD02050	Cannon	24/09/2005	Balintraid	A	169
124	Y/Y//M;Y/L//Y	DD02037	Cannon	24/09/2005	Balintraid	A	138
125	Y/Y//M;Y/N//Y	DD02038	Cannon	24/09/2005	Balintraid	A	134
126	Y/Y//M;Y/Y//Y	DB99878	Cannon	24/09/2005	Balintraid	A	152

Appendix 9

Details of sightings of colour-ringed Common Redshank. Area letters are as in Figures 8.2 and 8.3. For sightings in Nigg Bay Managed Realignment Site, letters in parentheses indicate the nearest breach gap: W = west breach gap, E = East breach gap.

ID	Date	Time	Area
1	23/11/2004	12:49	A (W)
		14:34	A (E)
	24/11/2004	14:18	A (E)
	25/11/2004	9:42	A (W)
		11:27	A (W)
		12:12	A (E)
	26/11/2004	13:01	A (W)
		14:16	A (E)
		14:31	A (E)
		14:46	A (E)
	01/12/2004	9:46	A (E)
		13:16	A (E)
	09/12/2004	9:53	A (W)
		10:08	A (W)
		10:53	A (E)
		11:23	A (E)
		12:08	A (W)
	11/12/2004	11:49	A (W)
	06/09/2005	13:00	F
	03/12/2005	10:11	B (W)
	16/12/2005	10:00	B (W)
	13/01/2006	12:58	A (W)
	16/01/2006	10:55	B (W)
		15:20	B (W)
	13/02/2006	14:11	B (W)
6	21/09/2005	12:20	H
	07/10/2005	12:00	H
	04/11/2005	11:00	F
	05/11/2005	11:57	F
	08/11/2005	12:15	H
	03/02/2006	12:51	H
	16/02/2006	11:22	F
	22/03/2006	15:23	H
	09/02/2007	14:30	H
9	07/10/2005	12:00	H
	19/12/2005	12:20	C
	20/12/2005	13:00	C
		13:30	C
		14:55	A (W)
	16/01/2006	14:28	A (E)
	27/01/2006	9:46	B (E)
		10:08	B (E)
	31/01/2006	15:09	A (E)
	03/02/2006	11:20	C
	13/02/2006	13:43	A (E)
		14:23	B (E)
	16/02/2006	11:01	H
10	08/10/2005	14:45	F
	21/09/2005	12:00	G
	16/12/2005	12:35	A (W)
	20/12/2005	12:53	B (W)
	19/01/2006	13:05	C
	13/02/2006	13:56	A (W)
	16/02/2006	11:33	F
14	04/11/2005	10:13	F
		11:00	F
	05/11/2005	11:32	F
	18/12/2005	15:05	C
	20/12/2005	13:00	C
		13:15	C
15	07/10/2005	12:55	F
	17/11/2005	10:40	B (E)
	20/12/2005	13:14	B
	18/01/2006	12:28	C
16	06/12/2005	12:33	G
17	06/12/2005	14:00	F
	16/01/2006	10:57	B (W)
		15:23	B
	13/02/2006	14:13	B (W)
18	13/11/2005	10:40	F
	17/01/2006	11:30	F
	03/02/2006	10:43	F
	22/03/2006	9:52	I
19	07/10/2005	12:00	H
	05/10/2005	15:52	B
	17/11/2005	11:45	F
	18/12/2005	11:30	B (W)
	20/12/2005	13:00	B
	22/03/2006	13:38	I
20	06/12/2005	13:34	C
	15/12/2005	12:17	F
	19/01/2006	13:11	C
21	12/01/2006	9:45	F
	13/02/2006	14:18	B (W)

ID	Date	Time	Area
22	01/11/2005	11:15	F
		12:52	F
	05/11/2005	11:57	F
23	31/10/2005	11:42	F
	01/11/2005	10:58	F
		11:50	F
24	12/01/2006	10:00	F
25	05/10/2005	15:52	B
26	03/12/2005	14:37	A (W)
27	27/01/2006	12:37	D
28	06/12/2005	11:00	E
29	03/12/2005	14:37	A (W)
	16/12/2005	14:02	B
30	06/09/2005	11:45	H
	13/11/2005	9:47	F
	06/12/2005	11:15	E
	16/01/2006	15:26	B
	19/01/2006	13:29	C
	30/01/2006	14:09	C
	03/02/2006	11:56	D
31	01/11/2005	11:20	F
	18/12/2005	12:10	A (W)
	20/12/2005	13:31	B (W)
	27/01/2006	10:05	B (E)
		13:15	D
	15/02/2006	10:50	B (W)
32	20/12/2005	13:24	B (W)
	27/01/2006	13:17	D
35	28/09/2005	16:01	A (W)
	04/11/2005	11:42	F
	08/11/2005	13:30	F
	13/12/2005	10:37	F
	03/02/2006	12:35	H
	16/02/2006	11:19	F
39	05/11/2005	11:43	F
	18/11/2005	11:54	F
40	26/11/2004	13:05	F
	14/12/2004	12:00	F
	31/12/2005	12:00	Balintore
	19/01/2006	13:03	C
	27/01/2006	10:23	B (E)
	16/02/2006	11:28	F
41	17/11/2005	10:30	B (W)
	22/03/2006	13:47	I
		15:21	H
47	27/10/2005	10:38	H
	13/11/2005	10:40	F
50	07/10/2005	12:00	H
	19/10/2005	12:00	F
	06/12/2005	13:30	C

ID	Date	Time	Area
	20/12/2005	13:15	C
	18/01/2006	12:25	C
	19/01/2006	12:58	C
	27/01/2006	9:46	B (E)
		10:09	B (E)
52	30/11/2004	14:00	F
	10/12/2004	10:02	F
	07/10/2005	12:55	F
53	20/12/2005	13:15	C
	30/01/2006	10:15	H
	22/03/2006	15:18	H
54	13/12/2005	10:42	F
	19/12/2005	12:20	C
	20/12/2005	13:30	C
		13:00	F
	18/01/2006	12:29	C
	19/01/2006	13:00	C
	27/01/2006	9:54	B (E)
	03/02/2006	11:43	D
	13/02/2006	14:16	B (E)
	22/03/2006	15:29	H
	09/02/2007	14:30	J
	07/07/2007		NW Iceland
	10/07/2007		Den Helder
55	07/10/2005	12:55	F
	19/10/2005	12:00	F
	13/11/2005	9:25	F
		10:23	F
	15/12/2005	13:05	F
	16/02/2006	11:30	F
56	13/12/2004	12:19	F
	07/10/2005	12:00	H
		12:00	H
	31/10/2005	10:05	F
	04/11/2005	11:00	F
	05/11/2005	11:37	F
	13/11/2005	9:58	F
	17/11/2005	11:45	F
	02/12/2005	9:55	F
	12/01/2006	9:50	F
	17/01/2006	11:34	F
	27/01/2006	11:35	H
58	07/09/2005	13:30	F
	06/12/2005	11:25	E
	16/12/2005	12:35	A (W)
	18/12/2005	12:10	A (W)
	20/12/2005	12:50	B (W)
		13:40	A (W)
		14:26	A (W)
	16/01/2006	15:10	B (E)

ID	Date	Time	Area
		15:29	B
60	18/10/2005	11:35	F
	04/11/2005	11:00	F
	13/11/2005	10:18	F
	17/01/2006	11:47	F
	16/02/2006	11:21	F
	09/02/2007	14:30	H
61	30/07/2005		Montrose Basin
	07/10/2005	12:55	F
	19/10/2005	12:00	F
	04/11/2005	11:00	F
		12:12	F
	05/11/2005	11:52	F
	13/11/2005	9:55	F
	17/11/2005	11:45	F
	18/11/2005	11:55	F
63	17/11/2005	10:41	B (W)
	03/12/2005	14:22	A (W)
		14:52	B (W)
64	07/10/2005	12:00	H
		12:00	H
	04/11/2005	12:52	F
	08/11/2005	13:33	F
	06/12/2005	11:20	E
	20/12/2005	13:30	C
	03/02/2006	13:05	H
	22/03/2006	13:51	I
65	30/11/2004	14:00	F
	06/09/2005	11:55	H
	21/09/2005	12:20	H
	07/10/2005	12:00	H
	19/10/2005	11:20	H
	18/10/2005	9:34	H
	27/10/2005	14:00	H
	31/10/2005	11:28	F
	01/11/2005	11:02	F
	04/11/2005	10:13	F
	05/11/2005	10:50	H
	10/11/2005	11:00	I
		12:40	I
	13/12/2005	10:40	F
	15/12/2005	12:45	F
	20/12/2005	11:00	I
	17/01/2006	9:47	I
		10:47	H
	03/02/2006	9:35	I
	22/03/2006	9:42	I
		13:56	I
		15:20	H
	09/02/2007	14:30	H

ID	Date	Time	Area
66	08/11/2005	12:12	H
	02/12/2005	9:55	F
	06/12/2005	11:50	E
	19/12/2005	12:51	C
	20/12/2005	13:30	C
		13:12	B
	19/01/2006	12:48	C
	16/02/2006	11:23	F
67	22/03/2006	9:56	I
70	17/11/2005	14:10	A (W)
	16/01/2006	15:02	A (W)
	13/02/2006	10:58	A (W)
71	30/10/2005	9:30	F
	31/10/2005	10:05	F
	01/11/2005	10:55	F
	08/11/2005	13:32	F
72	16/12/2005	13:04	A (W)
	18/01/2006	12:30	C
	19/01/2006	12:49	C
73	10/12/2004	10:08	F
74	30/11/2004	14:00	F
	04/11/2005	13:05	F
	08/11/2005	13:36	F
	15/12/2005	12:47	F
	17/01/2006	11:41	F
	25/01/2006	10:15	H
	27/01/2006	11:39	H
	03/02/2006	10:10	E
		12:40	H
	16/02/2006	10:58	H
	22/03/2006	13:45	I
75	07/10/2005	12:55	F
	05/11/2005	11:32	F
	09/02/2007	14:30	H
76	11/11/2005	8:30	C
	02/12/2005	10:02	F
	06/12/2005	13:30	C
	14/12/2005	10:06	C
	18/12/2005	11:44	C
	19/12/2005	12:26	C
	19/01/2006	12:52	C
	27/01/2006	9:31	B (E)
77	03/12/2005	10:09	B (W)
		10:32	B (W)
	20/12/2005	13:30	C
		13:00	B
	16/01/2006	15:23	B
78	15/12/2005	12:00	F
	18/12/2005	11:30	B (W)
	16/02/2006	11:20	F

ID	Date	Time	Area
80	26/10/2005	9:09	A (W)
81	17/11/2005	13:40	A (W)
	03/12/2005	10:33	B (W)
		10:37	A (W)
	16/12/2005	12:20	A (W)
	19/12/2005	12:40	A (W)
	20/12/2005	12:56	B (W)
		13:40	A (W)
		14:52	A (W)
	13/01/2006	9:22	B (W)
	16/01/2006	11:07	B (W)
		11:12	A (W)
		15:01	A (W)
		15:18	B (W)
	25/01/2006	13:40	D
	13/02/2006	10:02	B
		10:43	A (W)
		13:53	A (W)
	15/02/2006	10:48	B (W)
84	16/12/2005	13:59	B (E)
	20/12/2005	13:10	B
	25/01/2006	13:45	D
	27/01/2006	13:03	D
	31/01/2006	15:34	B (E)
	16/02/2006	11:18	F
85	15/12/2005	12:39	F
	19/01/2006	12:55	C
86	19/12/2005	12:40	A (W)
	20/12/2005	12:57	B (W)
	16/01/2006	11:10	B (W)
		15:21	B (W)
	13/02/2006	11:08	A (W)
		14:12	B (W)
	14/08/2006		Lonnie, Alturlie
87	16/12/2005	13:00	A (W)
	13/02/2006	10:13	B
		10:53	A (E)
	15/02/2006	10:49	B (W)
88	18/12/2005	14:20	A (W)
	20/12/2005	12:40	B
		13:35	A (W)
		14:56	A (E)
89	19/01/2006	12:00	D
	27/01/2006	9:53	B (E)
		13:00	D
90	19/01/2006	11:30	D
	27/01/2006	13:24	D
92	20/12/2005	13:00	F
	16/01/2006	15:28	B

ID	Date	Time	Area
	16/02/2006	11:19	F
93	27/10/2005	9:38	H
	01/11/2005	11:26	F
	04/11/2005	11:00	F
	05/11/2005	11:57	F
94	19/01/2006	12:00	D
95	31/10/2005	12:19	F
	01/11/2005	11:24	F
	11/11/2005	9:20	B (E)
	20/12/2005	13:22	B (W)
		14:10	A (E)
98	02/11/2005	10:00	Culbin Sands
99	13/12/2005	10:39	F
	16/12/2005	13:33	A (W)
	16/01/2006	14:29	A (W)
		15:04	A (E)
		15:11	B
	25/01/2006	13:50	D
100	20/12/2005	13:00	Dingwall Bay
101	18/10/2005	11:50	F
	31/10/2005	10:20	F
	06/12/2005	11:50	E
		13:58	F
	19/12/2005	12:19	C
	20/12/2005	13:00	B
	24/01/2006	11:05	B (E)
	27/01/2006	10:20	B (E)
103	11/11/2005	9:10	C
		9:25	B (E)
	17/11/2005	14:30	B (W)
104	11/11/2005	8:45	C
	17/11/2005	10:40	B (W)
105	11/11/2005	9:07	C
	16/02/2006	11:30	F
106	31/10/2005	10:23	F
107	07/10/2005	12:00	H
	17/11/2005	11:45	F
	16/12/2005	9:57	B (W)
108	05/10/2005	16:22	A (E)
	11/10/2005	12:43	A (W)
		12:45	B (W)
	26/10/2005	11:09	B (W)
		11:54	B (E)
109	19/10/2005	12:00	F
	31/10/2005	10:05	F
	01/11/2005	11:37	F
	06/12/2005	12:47	D
	19/12/2005	14:40	A (W)
	20/12/2005	13:40	A (W)
		14:52	A (W)

ID	Date	Time	Area
		13:00	D
110	17/11/2005	10:25	B
		10:46	B (W)
	16/12/2005	13:33	A (W)
	20/12/2005	13:30	C
	16/01/2006	11:00	B (W)
	18/01/2006	11:50	C
		12:31	C
	19/01/2006	12:55	C
111	02/12/2005	10:06	F
	03/12/2005	10:34	B (W)
	20/12/2005	12:57	B
		13:40	A (W)
	27/01/2006	12:39	D
112	18/10/2005	11:48	F
114	31/10/2005	10:33	F
	17/11/2005	14:30	B (W)
	03/12/2005	10:30	B
	08/12/2005	13:00	B
	16/12/2005	10:19	B (E)
	16/12/2005	14:00	B (E)
	18/12/2005	11:30	B (W)
	20/12/2005	12:38	B
		13:26	B (E)
		14:19	A (E)
	13/01/2006	13:09	B (E)
	16/01/2006	15:15	B
	19/01/2006	13:13	C
	24/01/2006	11:05	B (E)
	27/01/2006	9:40	B (E)
	31/01/2006	15:08	B (E)
	03/02/2006	11:55	D
	13/02/2006	10:22	B
		10:50	A (W)
		13:41	A (W)

ID	Date	Time	Area
		13:51	A (E)
115	20/12/2005	13:20	B (W)
	16/01/2006	10:55	B (W)
	19/01/2006	10:07	D
	13/02/2006	14:20	B (W)
116	25/11/2006	12:15	Dornoch Sands
118	18/12/2005	11:54	C
	19/01/2006	12:00	D
	16/02/2006	11:03	H
119	17/11/2005	10:43	B (W)
120	05/10/2005	15:52	B
121	03/12/2005	10:52	A (W)
		14:37	A (W)
	18/12/2005	13:50	A (W)
	19/12/2005	14:30	A (W)
	20/12/2005	14:51	A (W)
	16/01/2006	15:19	B (W)
	31/01/2006	14:25	A (W)
	13/02/2006	14:21	B (W)
122	07/10/2005	11:25	G
124	16/01/2006	15:27	B
	19/01/2006	12:58	C
	27/01/2006	9:47	B (E)
	13/02/2006	10:34	B (W)
		10:54	A (W)
		13:58	A (W)
		14:14	B (W)
	16/02/2006	11:26	F
125	19/10/2005	12:00	F
	01/11/2005	11:09	F
	04/11/2005	11:00	F
	13/11/2005	9:28	F
	03/12/2005	10:30	B
	16/01/2006	15:25	B
	27/01/2006	12:56	D