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Literature Review: Importance of Artificial Roosts for Migratory Shorebirds

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Front cover: Whimbrel roosting. Image: Micha V. Jackson

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Summary

Migratory shorebirds including Far Eastern Curlew, a regional endemic, have experienced severe declines in recent decades in the East Asian-Australasian Flyway. Significant numbers of many species spend their non-breeding season in Australia, where disturbance, particularly at high tide roosts, causes negative impacts. Lack of safe roosts may constrain the number of shorebirds that can be supported in a given region. Far Eastern Curlew, Australia's largest shorebird, is particularly vulnerable to disturbance given its long flight initiation distance and tendency to abandon roosts for the tide cycle or even altogether when disturbed.

Though they should not be considered a replacement for natural habitat, a number of studies have shown that supratidal artificial habitats, particularly those shielded from disturbance, can provide attractive roosts for migratory shorebirds. These may include habitats that have been created 'accidentally' as a byproduct of human activities or those constructed or reconstructed deliberately to provide or maintain resources for shorebirds. Management of these habitats potentially provides opportunities to help shorebirds maintain a positive energy balance (i.e. daily energy intake generally equals or exceeds energy expenditure) during the non-breeding season, particularly when putting on weight before migration.

This review was compiled to consider the factors most important in roost choice by migratory shorebirds, particularly during the non-breeding season, and their use of artificial roosts, including those constructed and/or actively maintained for shorebirds. Particular focus was paid to research addressing these questions specifically for Far Eastern Curlew.

Proximity to foraging grounds and avoidance of disturbance and predation risk are documented in the literature as the most important factors affecting roost choice by shorebirds, and these factors may also drive different roosting behaviour between day and night. Other factors that can be important are microclimate and landscape features of the roost. In general it appears that roost site fidelity by migratory shorebirds is fairly high but this is not uniformly the case across species or regions.

A number of different types of artificial habitats are used by shorebirds for roosting in Australia and these are generally associated with commercial salt works, ports, wastewater treatment and in some cases specifically constructed roosts. Far Eastern Curlews are among the species that use artificial habitats, though only in large numbers (> 100 individuals) at a few locations in Australia.

Reports detailing artificial roost construction and maintenance reinforce the importance of providing roosts close to foraging grounds and shielding them from disturbance and predation risk; they also document differences in roost use by different species.

Variability in shorebird behaviour strongly indicates that managers wanting to improve roosting conditions for shorebirds of a given species in a given locality require a detailed local knowledge of available foraging and roosting habitat as well as the seasonal behaviour of target species for management. Similarly, design or implementation of artificial roosts in any particular locality requires careful consideration of regional and site-specific details and extensive consultation with relevant experts in ecology, engineering, etc.

Glossary

Artificial habitat	Any habitat used by shorebirds that is anthropogenic, whether accidentally or deliberately made or maintained for shorebirds' use. Examples include commercial salt ponds, port reclamation areas, aquaculture ponds and constructed shorebird roosts.
Disturbance	At a high tide roost, any factor that causes avoidance behaviour (generally increased alertness, walking away or taking flight) in shorebirds; generally this will be from a perceived predation threat, whether or not the risk is 'real'. Examples of disturbance include walking people, running dogs, boats, and flying raptors.
East Asian-Australasian Flyway	One of several global flyways comprising the migration, breeding and non-breeding areas used by migratory waterbirds in the East Asian-Australasian region. The flyway constitutes boreal/arctic areas of Russia, Mongolia, northern China and Alaska; much of east and southeast Asia; Australia; New Zealand; and, some western Pacific islands.
Far Eastern Curlew	Australia's largest migratory shorebird species, listed as Critically Endangered under national legislation since 2015.
Flight initiation distance	The distance at which a shorebird will initiate a flight because of the approach of a perceived predator.
Foraging	Feeding by locating and capturing prey items.
Foraging area	An area primarily used by shorebirds for feeding.
High tide roost	Sites primarily visited by shorebirds when intertidal areas are submerged at high tide. Behaviour at high tide roosts may include sleeping, resting, displaying vigilance behaviour and in some cases, supplemental foraging.
Home range	The entire area that a shorebird uses during the non-breeding season.
Internationally significant	A shorebird count is considered to be internationally significant if it totals $\geq 1\%$ of the estimated population of that species/subspecies in the East Asian-Australasian Flyway. This is based on Criterion 6 for identifying wetlands of international importance under the Ramsar Convention on Wetlands of International Importance.
Intertidal habitat	The coastal zone comprised of sandy and muddy substrate that is generally exposed at low tide but covered at high tide. This is the primary foraging habitat for many shorebird species during migration and non-breeding periods.
Migratory shorebird	Species within the order Charadriiformes that make regular annual movements along a migration pathway between breeding grounds in the boreal/arctic and non-breeding grounds in the southern hemisphere. 37 migratory shorebird species regularly visit Australia.
Non-breeding season	The period of the year when migratory shorebirds generally remain relatively stationary (making only short distance movements) in areas of the southern hemisphere after migrating from breeding areas in the boreal/arctic. This is roughly from about September to March in most species in the EAAF. Australia supports large concentrations of many migratory shorebird species during their non-breeding season.
Positive energy budget	A condition in which a shorebird consistently retains more of the energy it consumes from food than it expends.
Roost site fidelity	The regularity with which a shorebird returns to the same high tide roost while it remains in the region.
Staging area	Areas where migratory birds stop for a period of time (which can vary from hours to months) to rest and feed during migration.
Supratidal habitat	Shorebird habitat that occurs above the high tide mark.
Tidal cycle	A period covering the full tidal range from low to high tide.

Introduction

Shorebirds (also referred to as waders) comprise a group of species that frequently occur on shoreline habitats throughout the world, including those of the ocean, lakes, rivers and wetlands. They share morphological characteristics suited to foraging in shallow waters, generally with long legs compared to their body size and a variety of bill lengths adapted to accessing different prey types below or on top of muddy substrates (Geering et al. 2007). Taxonomically the term 'shorebird' refers to a group of 14 families within the order Charadriiformes, of which 55 species occur in Australia as non-vagrants (Geering et al. 2007).

A subset of 37 species of shorebirds that occur in Australia constitute annual breeding migrants, and travel 12,000-14,000 km to reach boreal/arctic areas of Russia, Mongolia, northern China and Alaska where they breed during the northern hemisphere summer. These birds use for their migration an area commonly referred to as the East Asian-Australasian Flyway (EAAF). Millions of shorebirds make this journey annually, including those that hatch in the boreal/arctic and make their first southward migration to Australia when only a few months old.

Far Eastern Curlew *Numenius madagascariensis* is one such migratory species. It is endemic to the EAAF and most of its known non-breeding habitat occurs in Australia, where it has been estimated that nearly three quarters of the population spends the non-breeding season (most of the remainder of the population is thought to spend the non-breeding season in the Philippines, Indonesia and Papua New Guinea (Bamford et al. 2008), though non-breeding areas outside Australia require significantly more study).

Shorebird populations have experienced major declines globally, nowhere more so than in the EAAF. A recent analysis of an extensive dataset from BirdLife Australia's monitoring program (now called Shorebirds 2020) spanning 1973-2014 showed continental decreases in Australia in the abundance of 12 migratory shorebirds (Clemens et al. 2016). A separate study showed that those species experiencing the most rapid declines are the ones most reliant on a migration route through the Yellow and Bohai Sea region (which encompasses parts of the coastlines of China, The Democratic Peoples' Republic of Korea and the Republic of Korea) (Studds et al. in press). Reflecting the seriousness of the decline in Australia's migratory shorebirds, eight species or subspecies have been listed or have had their conservation status uplisted under the *Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 since 2015*.

Far Eastern Curlew has experienced one of the most acute declines of any Australian shorebird species. Migration studies have shown that to the best of our knowledge, the entire population of Far Eastern Curlew that spends the non-breeding season in Australia passes through the Yellow Sea region during both northward and southward migration every year (Driscoll and Ueta 2002; Minton et al. 2011; Conklin et al. 2014). Similar to other species heavily reliant on this area, it has experienced a 5.8 % annual rate of decline; if this trend persists, the global population will fall to 10 % of its 1993 abundance by 2035 (Studds et al. in press). Reflecting these trends, in 2015 the Far Eastern Curlew was upgraded to Endangered on the IUCN Red List (IUCN 2016) and listed as Critically Endangered under Australia's EPBC Act.

In both the non-breeding season and during migration, coastal migratory shorebirds including Far Eastern Curlew use a combination of intertidal mudflats (primarily for foraging but also some roosting) and supratidal wetlands (primarily for roosting but sometimes for foraging, particularly in some species). Both of these habitats are increasingly under threat. By applying IUCN criteria, the intertidal mudflat system of the Yellow Sea region was classified as Endangered based on a decline in tidal flats of more than 50 %, and additional degradation through such effects as widespread pollution, algal blooms and declines of invertebrate and vertebrate fauna (Murray et al. 2015).

Yet habitat loss is not the only contributor to the decline of migratory shorebirds and it can be compounded by other impacts. During the non-breeding season, the daily movement pattern of many coastal shorebird species is largely governed by tidal cycles. Though movements may be complicated by a number of other factors, there is a subset of migratory shorebird species, including Far Eastern Curlew, that will generally forage for invertebrate fauna on intertidal mudflat habitats at low tide, and move to high tide roosts as the mudflat is covered by the incoming tide (Rogers et al. 2006; Lilleyman et al. 2016). Behaviour at high tide roosts can vary but generally involves periods of sleeping, resting, displaying vigilance behaviour (i.e. scanning for predators) and in some cases, supplemental foraging, though detailed research on exact shorebird behaviour during roosting (especially at night-time) is somewhat limited (Rogers 2003).

A widespread threat to shorebirds in Australia in the non-breeding season is the negative impact associated with disturbance, generally at high tide roosts, resulting from human (and associated canine) recreational use, which occurs even inside protected areas (Stigner et al. 2016). Given the huge distances they fly during migration, the effects of disturbances that cause shorebirds to expend extra energy by increasing vigilance behaviour, walking/running or initiating flights they otherwise would not have taken is often underappreciated. A study at Moreton Bay, Queensland showed that recreational use of foreshores, particularly by dogs, resulted in a consistent negative effect on the occupancy and abundance of shorebirds within a protected area (Stigner et al. 2016). A study from Lee Point near Darwin, Northern Territory used energy budget models to examine the effects of disturbance on two migratory shorebird species and concluded that the increased energy associated with 10 alarm flights per day could have negative consequences to the point of reducing survival or reproductive success (Lilleyman et al. 2016).

Some species may be particularly affected by disturbance. Flight initiation distance (the distance at which a shorebird initiates a flight because of the approach of a perceived predator) differs between species (Blumstein et al. 2003). Far Eastern Curlew is particularly intolerant to disturbance, with a mean flight initiation distance of over 125 m (and a maximum of almost 200 m) recorded in Victoria (Glover et al. 2011). Safe roosts where human recreational activities do not occur are therefore of great importance to migratory shorebirds, including Far Eastern Curlew, that congregate at the coast.

Artificial supratidal habitats, particularly those shielded from disturbance, have been shown to provide attractive high tide roosts as well as foraging opportunities (for some species), including in Australia. For example, artificial ponds associated with a former commercial salt operation generally support the largest abundance of shorebirds (consistently over 15,000 at single non-breeding season counts over the last several decades) in the Gulf St. Vincent area, South Australia (Purnell et al. 2015). Supratidal ponds associated with the Western Treatment Plant, Victoria consistently hold internationally significant¹ numbers of shorebirds throughout the tidal cycle and provide roosting, supplemental foraging, and preferential foraging opportunities for different species (Rogers and Hulzebosch 2014). Settling ponds at East Arm Wharf, associated with the Darwin Port, Northern Territory, support consistently large numbers of roosting Far Eastern Curlews whose abundance at the site has steadily increased in recent years despite the species-wide decline (Lilleyman et al. 2016). A commonality across these sites is their relative inaccessibility to the public, particularly dogs.

Taking this background into consideration, this review draws on both peer reviewed and 'grey' literature from within the EAAF and elsewhere, and was compiled primarily to consider the following two questions:

1. What factors are most important in high tide roost choice by migratory shorebirds, particularly during the non-breeding season? Related to this, what distances do shorebirds travel in order to move between foraging areas and roosts?
2. What is known about the importance of artificial roosts for shorebirds, with particular focus on artificial habitat types that occur in Australia and those roosts constructed and/or actively maintained for migratory shorebirds?

Where possible, research addressing these questions specifically for Far Eastern Curlew is detailed.

It is important to recall that shorebird foraging and roosting areas can be quite distinct, though sites where roosting occurs may provide supplemental or even preferential foraging opportunities for some species in the right conditions. This review is primarily focused on the literature relating to high tide roosts, considered in this report to be those sites primarily visited by migratory shorebirds when intertidal areas are submerged at high tide. For a review of managing supratidal wetland habitats to provide optimal foraging conditions in Australia, readers should refer to a comprehensive literature review from Victoria (Rogers et al. 2015), which considers in detail the management regimes that maximise provision of edible benthic fauna and control vegetation encroachment in supratidal wetlands.

This review is not intended in any way to provide any advice on the design or implementation of artificial roosts in any particular locality. This would require careful consideration of regional and site-specific details and extensive consultation with relevant experts in ecology, engineering, etc.

¹ It is well-accepted practice in the shorebird literature, based on a standard in the Ramsar Convention on Wetlands (<http://www.ramsar.org/>), to refer to 'internationally significant' numbers of a shorebird species to mean a count that totals $\geq 1\%$ of the estimated population of that species in the flyway. This report adopts this convention when referring to the literature. The authors of the studies referred to may use slightly different population estimates to calculate the 1% threshold as flyway population estimates are revised and updated over time; which estimate was used is generally noted within the study.

Methods

The scientific literature was searched using the Thomson Reuters Web of Science bibliographic database Core Collection from 1990-2016.

The following advanced search parameters were used to obtain literature on shorebird roosting, with particular focus on artificial roosts and the roosting behaviour of Far Eastern Curlew:

TI=(artificial* AND roost*) AND TS=(shorebird* OR wader*)

TS=(artificial* AND roost*) AND (*shorebird* OR *wader*)

TI=("artificial roost")

TS=("artificial roost")

TI=(roost* AND shorebird*)

TS=(roost* AND shorebird*)

TI=(roost* AND wader*)

TS=(roost* AND wader*)

TI=("Eastern Curlew" AND roost*)

TI=("Eastern Curlew" AND high tide*)

Google Scholar was also used to search Stilt (the bulletin of the East Asian-Australasian Flyway produced by the Australasian Wader Studies Group), which is not included in the Web of Science database, because of its direct relevance to regional shorebird research and tendency to publish raw count data that would be of relevance to this report. Google Scholar was used to search Stilt for:

"constructed roost"

"artificial roost"

"Eastern Curlew roost"

Additional peer-reviewed articles were identified by:

- i. investigating related articles arising from the above Web of Science searches suggested by article providers when accessing articles (for example, when a user accesses an article through Science Direct, it automatically recommends other related articles linked by topic); and,
- ii. receiving useful suggestions of relevant literature from colleagues, including literature dating from before 1990.

Grey literature was compiled by:

- i. utilising personal networks to identify relevant reports not in the peer reviewed literature;
- ii. discussing and requesting relevant reports from colleagues or researchers known to have experience with shorebirds and artificial roosts; and,
- iii. identifying relevant grey literature through citations in the scientific literature.

Approximately 150 articles were identified and reviewed using the above outlined methods. Of these approximately 80 were thought sufficiently relevant to be comprehensively read and included in this review.



Bar-tailed Godwit roosting. Image: Micha V. Jackson

Results and Discussion

Factors influencing roost choice

Shorebirds are well known to form communal roosting flocks, which protect them from predation and may also have social functions such as information exchange (Prater 1981). There are a number of trade-offs involved in roost choice for shorebirds whether on natural or artificial roosts. Several authors have outlined the key factors influencing this choice (Luis et al. 2001; Rogers 2003; Spencer et al. 2009) and others have looked in detail at specific aspects. The following sections discuss these factors.

It is important to consider that what makes a good roost for one shorebird species may not make an ideal roost for another (for example see Burton et al. 1996) and there are marked behavioural differences between shorebird species, so studies specifically documenting roost choice behaviour of Far Eastern Curlew or similar species are discussed in more detail wherever possible.

Distance, Disturbance and Predation

It is intuitive that shorebirds will prefer to roost as close to their foraging areas as possible to minimise energy costs during non-foraging (or reduced foraging) periods around high tide, but there are trade-offs affecting roost choice that can result in larger movements away from foraging grounds than may be expected.

Across the literature, avoiding disturbance and vulnerability to predation are consistently listed as factors most likely to explain roost choice after accounting for proximity to foraging areas. Disturbance at a high tide roost comprises any factor causing birds to exhibit avoidance behaviour, which includes increased alertness (also referred to as 'vigilance behaviour', causing birds to stop current behaviour in order to visually monitor a perceived threat) walking/running away from a perceived threat, or taking flight (Weston et al. 2012; Lilleyman et al. 2016). High tide roost disturbance is often caused by human recreational activity (e.g. walking or running, dog walking, horse riding, vehicle traffic) and so may not represent a 'real' predation risk. There is also some research on behavioural response to acute noise suggesting that it can also cause disturbance to shorebirds (Wright et al. 2010). Excluding human hunting, shorebird predation risk at high tide roosts is generally from avian raptors, usually falcon species (e.g. Dekker and Ydenberg 2004; Newman and Lindsey 2009), and potentially from predatory mammals (e.g. Richardson 2016), though these probably more often predate shorebird nests. In extreme cases where disturbance or predation risk is very high, shorebirds have been documented to roost 'on the wing' (in other words flying in a flock without settling on the ground) for significant periods of time, presumably with very high energy costs (Prater 1981; Ydenberg et al. 2010).

Given that responding to disturbance and predation risk both exact a cost in terms of energy expenditure that can be significant, shorebirds may try to choose roosts that minimise both.

In Roebuck Bay, Western Australia a model for predicting roosting behaviour of Red Knots *Calidris canutus* and Great Knots *Calidris tenuirostris* was quite effective; essentially it showed that a good way to predict shorebird roost choice was to look for the closest roosting habitat to a given foraging area that satisfied 'acceptable' threshold levels of predation vulnerability and microclimate (discussed later) factors (Rogers et al. 2006). The predation vulnerability factors used in the model were:

1. tall cover [dunes, cliffs or vegetation taller than 1 m]: a measure of the distance from the roost to tall cover (5 categories ranging from > 200 m to < 1 m from tall cover; more tall cover provides more opportunities for aerial predators, therefore less tall cover makes a roost more optimal); and,
2. visibility: a measure of the background colour of the tall cover within 200 m of the roost (3 categories from light to dark; a lighter background makes predators easier to spot and therefore the roost more optimal) (Rogers et al. 2006).

The study also suggests that predator avoidance drove observed differences in roosting behaviour between day and night because birds travelled further to reach roosts with lower predation risk (lighter backgrounds further from tall cover) at night-time (Rogers et al. 2006). Similar results were found in Humboldt Bay, California, where nocturnal roost use by Dunlin *Calidris alpina* was positively correlated with increasing distance to cover at night-time (i.e. birds preferred roosts further from cover), but not significantly correlated during the day (Conklin et al. 2008).

A radio-telemetry study from the Hunter Estuary, New South Wales, found that diurnal roosting behaviour by Bar-tailed Godwit *Limosa lapponica* was predictable and occurred near to foraging areas including on man-made dykes, but nocturnal roosting behaviour was markedly different – birds roosted significantly further away from foraging grounds at night and their use of roosts was sporadic, with unpredictable roost site abandonment after different periods of time (Richardson 2016). Based on circumstantial observation the author hypothesised that predation risk from Red Foxes *Vulpes vulpes* explained this behaviour, as signs of foxes, which generally hunt at night, were discovered on daytime roosts including on the dykes (Richardson 2016). Another study from the Richmond River Estuary, New South Wales also found noticeable differences between diurnal and nocturnal roosting behaviour, and while the authors could not find a relationship between roosting behaviour and their expected nocturnal predation risk from Red Foxes, they did suggest that disturbance and diurnal raptor predation could help to explain observed differences (Rohweder 2001).

In Moreton Bay, Queensland models for roost choice and usage applied to 12 species of migratory shorebirds including Far Eastern Curlew, during the non-breeding season showed the strongest variable affecting roost choice was proximity to a large foraging area; this was a positive predictor of roost choice in 7 of the 11 modelled species (Zharikov and Milton 2009). Perceived safety from predation (determined by assigning a 'view-shed' value to each roost area indicating extent of visibility and assuming this was preferred to be at least as large as flight initiation distance) was also an important predictor across species (Zharikov and Milton 2009). Far Eastern Curlew was one of the most abundant shorebirds at the site, and the best-fit model for its roost choice, which had a high predictive ability, encompassed a combination of safety, distance to sizeable foraging area, and roost characteristics: the probability of Far Eastern Curlew occurring at a roost decreased if a roost was < 12 ha in size or > 1 km from the nearest sizeable foraging area (Zharikov and Milton 2009).

A study in the Wadden Sea also found distance travelled to roosts to be linked to avoidance of disturbance and predation. Red Knots foraging around Griend, an island maintained artificially through the use of breaks and dykes, travelled 7.5 km to a roost at Richel Island despite having roosting habitat available on Griend immediately next to their foraging area (Piersma et al. 1993). The authors hypothesised that the most likely reason for this behaviour was aerial predation avoidance; they noted that Griend (next to intertidal flats used for foraging) had dense vegetation and a high dyke that would provide good cover for an aerial attack by Peregrine Falcons *Falco peregrinus* and Merlins *F. columbarius*, while Richel (7.5 km away) provided a clear view of the horizon and no tall structures and therefore a low chance of aerial predation (Piersma et al. 1993). Energy investment in this predation avoidance was high; with an average of two tides a day, extra flying to roost at Richel amounted to ~30 km per day, estimated by the authors to account for 10 % of daily energy expenditure (Piersma et al. 1993).

In the Tagus Estuary, Portugal, shorebirds generally face a roost choice at high tide of either reduced mudflat areas that remain exposed or adjacent supratidal saltmarsh. To determine whether avoidance of predation or additional foraging opportunities were more important in determining roost choice, a study measured the number of raptors over roosts, alarm flights caused by raptors, total alarm flights, and displays of vigilance behaviour (i.e. searching for aerial predators) and showed that saltmarsh habitats had significantly higher predation pressure than mudflats exposed at high tide, while food availability was low at both types of sites (Rosa et al. 2006). Shorebirds clearly preferred mudflat roosts, generally switching to saltmarsh only at the highest tides if mudflats were totally inundated, suggesting that predator avoidance was a factor driving roost choice (Rosa et al. 2006). Reinforcing this result, a study on Dunlin predation by Peregrine Falcons in British Columbia, Canada (which was significant, with 94 Dunlin observed taken) showed that falcon hunts over vegetated shoreline had much higher success rates than those over tidal flats, and the predation rate was significantly higher at high tide (Dekker and Ydenberg 2004).

Disturbance not necessarily associated with actual predation risk can also have strong effects on roosting behaviour. An experiment from northern Spain applied a controlled recreational disturbance treatment to waterbird habitat at low, mid-level and high tides and found that a single person walking and stopping along the shoreline was enough to cause a significant proportion (1-5%) of the wintering populations of most species present at the site (which included shorebirds and ducks) to flush from their roost (Navedo and Herrera 2012). This demonstrates that even minimal anthropogenic disturbance significantly affects roosting birds and can cause them to change behaviour. Disturbance provoked a particularly strong response from Eurasian Curlew *Numenius arquata* which, in contrast with other species that only flushed for a short period of time, generally left the area entirely as a result of the disturbance treatment with 1.5% of the wintering population changing its roost location (Navedo and Herrera 2012).

Interestingly, an experiment on the strength of shorebirds' behavioural response to disturbance showed that stronger birds in better condition (in the experiment, Ruddy Turnstone *Arenaria interpres* that had been provided with additional nutritious food in their foraging area for several days) were significantly more responsive to disturbance, suggesting that birds more vulnerable to the negative effects of disturbance (i.e. birds in poorer condition with less fat stocks) may actually exhibit less response to it (Beale and Monaghan 2004), presumably because they cannot afford the extra energy expenditure.

Dramatic declines of roosting shorebirds in the Dee Estuary, Wales from 1975-1985 were attributed to increased human-related disturbance (including from dogs, horse riding, human walkers and military exercises), with a 99 % and 79 % observed decline in Bar-tailed Godwit and Red Knot respectively (Mitchell et al. 1988). Observed increases at the adjacent Alt estuary suggested that both species that had formerly roosted on the Dee estuary had switched to the Alt, resulting in increased flight distance between foraging areas and roosts totalling 14 % of daily energy expenditure for some Red Knots (Mitchell et al. 1988).

These results were echoed in a recent protected area management scenario at Sandfly Creek Environmental Reserve, Queensland where the construction of pedestrian and cycle paths along a bund wall in the reserve caused a large decrease in usage of two formerly important shorebird roosts, with mean waterbird diversity dropping from 16 to 4 species after construction of the paths (Milton and Harding 2011). Internationally significant numbers of Far Eastern Curlew had used the roost prior to path construction, but presence dropped from 96 % of visits pre-construction to 62% of visits post construction (Milton and Harding 2011), strongly suggesting abandonment resulting from disturbance.

A radio-telemetry study of Far Eastern Curlew in Moreton Bay also showed birds leaving roosts when they were disturbed by people (Driscoll 1995), and a study from Dunwich, Stradbroke Island (also in Moreton Bay) observed that Far Eastern Curlew was often the first species to depart when disturbance occurred (Kyne 2010).

A study from Lee Point, near Darwin, supports the conclusion that the effects of disturbance are different for different species and indeed under different conditions. It found that sand plover species had shorter flight initiation distances but longer resettling periods than knot species during high tide roosting, and that smaller flocks were more likely to exhibit a flight response to disturbance (Lilleyman et al. 2016).

The physical characteristics that make artificial supratidal roosts most attractive to shorebirds are also likely to be related to disturbance and predation. For example, He et al. (2016) examined the relationship between shorebird roosting and the following six physical characteristics of constructed banks associated with aquaculture that provide a number of high tide roosts for shorebirds in Yalu Jiang, China:

- flatness;
- vegetation cover;
- bank width;
- proportion of soil coverage on the surface of each bank;
- bank length; and,
- distance (m) between the mid-point of the bank and the coastal road.

Vegetation (negatively correlated with more vegetation) and bank length (positively correlated with longer banks) most strongly affected use of banks for roosting; the authors suggest the most likely reasons for these results were that vegetation encroachment caused increased risk of predation while longer banks were associated with lower disturbance because disturbance usually occurs at the two ends of a bank (He et al. 2016).

It is clear from the literature that avoidance of disturbance and predation risk are important drivers of roost choice. Nonetheless birds' ability to travel from foraging areas to optimal roosts is finite and will expire when the cost of travelling to a more distant roost regularly exceeds the energy intake from foraging. It has been noted by several authors that a lack of roosts within a suitable distance can constrain foraging options and even the carrying capacity for shorebirds of a given area of intertidal foraging habitat (Hale and Davies 1980; Prater 1981; Rogers 2003; Dias et al. 2006; Rogers et al. 2006; Newman 2015).

Therefore it is important to understand the distance that shorebirds will travel from foraging areas to a roost if an ideal roost is not available in close proximity to a foraging area. This distance needs to be understood in terms of both regular movements (i.e. a consistent movement between foraging areas and roosts across multiple tide cycles, presumably maintaining a positive energy budget) and in exceptional circumstances (for example on a very high tide that inundates a regular roost or when short-term high levels of disturbance occur at a regular roost, when a positive energy budget may not be maintained in the short term). This precise distance is likely to be species specific as larger birds may be able to travel further on a regular basis because this represents a lower proportion of their energy intake than it would to smaller birds. On the other hand, species that are able to forage consistently at supratidal sites may not even need to move between foraging areas and roosts during every tidal cycle, making single tide movements less critical but seasonal movements associated with food availability more relevant.

Realistic estimates of the distances travelled by individual shorebirds from foraging areas to a roost on a given tide (as opposed to seasonal movements, discussed below) are largely lacking but studies that include specific distance information that could be identified are summarised in Table 1.

The maximum distance reported across studies was 20 km for Red Knots in the Dee Estuary, England, which were apparently forced to change roosting areas as a result of human disturbance to their historical roosts (Mitchell et al. 1988). However, Bar-tailed Godwits in Taman Bay, New Zealand are known by observers to occasionally fly ~25km from a foraging area at Nelson Haven to roost at Motueka Sandspit on king tides when usual roosts are flooded (D Melville pers comm). Hale and Davies (1980) also reported one-way journeys by waders in Europe of “15 kilometres or more” equating to extra flying of 60 km during the course of two daily tide cycles. They further reported Bar-tailed godwits remaining at roost sites longer than other species in the face of disturbance in the Forth Estuary, UK because of a 15 km one way distance to their alternative roost site (while other species relocated to closer roosts) (Hale and Davies 1980).

The next largest distance documented was regular movements of 14 km for small numbers of Willet *Tringa semipalmata*, Long-billed Curlew *Numenius americanus* and Marbled Godwit *Limosa fedoa* fitted with radio tags in the Gulf of Mexico, USA (Gabbard et al. 2001). Red Knots in the Netherlands travelled 7.5 km to roosts when the mudflat was totally covered (Piersma et al. 1993), and Great and Red Knots in Roebuck Bay up to 10 km at night-time, though only 1-3 km during the day (Rogers et al. 2006). The majority of the feeding records in a three year mark recapture study of Grey-tailed Tattler *Heteroscelus brevipes* and Bar-tailed Godwit in Moreton Bay were within 4 km of roosting site for both species (Coleman and Milton 2012). In general smaller birds seemed to move smaller distances on a given tide cycle with large studies of Dunlin (Dias et al. 2006), Piping Plovers *Charadrius melodus* (Drake et al. 2001) and Western Sandpipers *Calidris mauri* (Warnock and Takekawa 1995) showing regular travel distances of < 5 km, 3.3 km and 2.2 km respectively. However, a report on the diminishing availability of roosts in Lauderdale, Tasmania, suggested that Red-necked stints *Calidris ruficollis* may have been forced to fly up to 9 km to an alternate roosting location in bad weather, though this was not definitively confirmed (Newman 2015).

Data on Far Eastern Curlew are limited but suggest a maximum travel distance from foraging areas to roosts of about 12 km but a preference for smaller distances. A radio-telemetry study from Moreton Bay found mean travel distances of 4.9 km, 5.2 km, 8.3 km and 2.4 km to four roosts used by tagged Far Eastern Curlew, with a maximum distance of 12.4 km (occurring at high tide when other roosts were unavailable) (Driscoll 1995). Another study from Moreton Bay of roosting and foraging areas along 150 km of coastline found very similar numbers of Far Eastern Curlew on adjacent foraging areas over the 30 roosts counted, indicating that a high proportion of Far Eastern Curlew using a given roost also feed in the vicinity (Finn et al. 2002). Based on the correlation between roost and count numbers, the authors suggested a typical operating distance of 5-10 km for Far Eastern Curlews in Moreton Bay, but a high ability and willingness to move between foraging areas and roosts at distances smaller than this (Finn et al. 2002). As noted above, a modelling study from the same area found a low probability of Far Eastern Curlew occurring at a roost more than 1 km from the nearest sizeable foraging area (Zharikov and Milton 2009). Correspondence with the author of a study on Far Eastern Curlew distribution in southwest Western Australia (Singor 2016) resulted in provision of a map of the Mandurah region showing known foraging areas and roosts; of these, four foraging areas were within 2 km of known roosts, one within 7 km, one within 8 km and the furthest within 10 km (M Singor unpublished data).

Table 1: Summary of studies detailing distance travelled from foraging areas to roosts by non-breeding migratory shorebirds.

Species (n individuals)	Location	One-way foraging to roost distances observed	Observation method	Study
Marbled Godwit (unknown)	San Francisco Bay, California, USA	From Gabbard et al. 2001 [original study could not be located]: "Luther (1968) reported that roost and feeding sites averaged 6.1 km apart for the Marbled Godwit."	Unknown	Luther 1968
Red Knot (flocks up to 28,000)	Dee and Aly estuaries, Wales, United Kingdom	20 km after roosts in the Dee estuary experienced an increase in disturbance	Counts at multiple foraging areas and roosts	Mitchell, Moser et al. 1988
Red Knot (flocks up to 100,000)	Griend Island, Wadden Sea, Netherlands	7.5 km when high tide covered all available mudflat at foraging area	Approximate observed flight trajectories pencilled on a map	Piersma, Hoekstra et al. 1993
Far Eastern Curlew (8)	Moreton Bay, Queensland, Australia	Mean distance travelled to 4 roosts: 4.9 km (sd 2.3); 5.2 km (sd 2.0); 8.3 km (sd 2.7); 2.4 km Median distance travelled to 4 roosts: 3.9 km; 4.5 km; 7.6 km; 2.4 km Maximum distance travelled to 4 roosts: 9.7 km; 9.4 km; 12.4 km; 4.1 km	Radio-telemetry	Driscoll 1995
Western Sandpiper (59)	San Francisco Bay, California, USA	Average distance travelled between foraging areas and roosts: 2.2 km \pm 0.1 km	Radio-telemetry	Warnock and Takekawa 1996
Grey Plover (2) Willet (10) Marbled Godwit (1) Long-billed Curlew (1)	Gulf of Mexico, Florida, USA	Pattern 1 (n=2 Grey Plover): 0.5 km Pattern 2 (n=4 Willet): 1-2 km Pattern 3 (n=4 Willet, 1 Long-billed Curlew): 14 km Pattern 4 (n=2 Willet; 1 Marbled Godwit): 14 km at beginning of season, range contracted later in season	Radio-telemetry	Gabbard, Sprandel et al. 2001
Piping Plover (48)	South Padre Island, Texas, USA	Mean linear distance moved per individual averaged across seasons: 3.3 km \pm 0.5 km Mean core area: 2.9 km \pm 0.8 km	Radio-telemetry	Drake, Thompson et al. 2001
Far Eastern Curlew	Moreton Bay, Queensland, Australia	Typical operating distance of 5-10 km	Counts at 30 roosts and adjacent foraging areas over 150km of coastline	Finn, Driscoll et al. 2002
Great Knot (25) Red Knot (23)	Roebuck Bay, Western Australia	Median daytime flight distance: 1-3 km Median night-time flight distance: 8-10 km	Radio-telemetry	Rogers 2003
Dunlin (570)	Tagus Estuary, Portugal	> 80 % of marked Dunlin observed feeding within 5 km from the roost where caught	Mark recapture using dye	Dias, Granadeiro et al. 2006
Grey-tailed Tattler (53) Bar-tailed Godwit (16)	Moreton Bay, Queensland	Majority of feeding records within 4 km of roosting site for both species	Mark recapture using flags	Coleman and Milton 2012
Far Eastern Curlew	Mandurah, Western Australia	4 foraging areas within 2 km of roost 1 foraging area within 7 km of roost 1 foraging area within 8 km of roost 1 foraging area within 10 km of roost	Identification of foraging areas and roosts on map (unpublished)	Unpublished supplement to Singor 2016

Home range and roost fidelity

The distance that an individual shorebird travels from a foraging area to a roost during a given tidal cycle is distinct from that individual's movement patterns over the course of the whole non-breeding season. The entire area that a shorebird uses during the non-breeding season is referred to as its 'home range'. A related concept is that of 'roost fidelity', which refers to how consistently a shorebird uses a given roost over the course of the non-breeding season. Home range size and roost fidelity are to a degree behavioural characteristics, but may also depend on a range of other factors including consistency of food supply, availability of other foraging and roosts in the region, and, potentially, amount of disturbance experienced. Interestingly, a study from the 1980s on Grey Plover *Pluvialis squatarola* suggested that: 1. whether or not an individual bird was territorial or non-territorial in its feeding habits, and 2. the timing of its seasonal movements to and from the non-breeding area studied (both of which affect home range size and roost fidelity), were both determined in the first autumn of its life and as a consequence of events during migration, and that these behavioural patterns persisted throughout that individual's lifetime (Townshend 1985).

Studies on migratory shorebird home range size and roost fidelity have somewhat mixed results. A global summary of studies on the home range sizes of non-breeding shorebirds can be found in Table 4 of Choi et al. (2013), and is reproduced with some modification as Table 2 below. Most studies use a polygon to express home range size as the area within which 95 % of recorded movements of tracked birds occurred.

Home range size over a seasonal period differs markedly even within species. As shown in Table 2, Dunlin home range size varied from estimates of 10.8–15.7 km² in China (Choi et al. 2013) to 19–53 km² in Canada (Shepherd and Lank 2004) to 120–565 km² in the USA (Sanzenbacher and Haig 2002). Red Knot home ranges were estimated at 2–16 km² in Mauritania (Leyrer et al. 2006) but up to 800 km² in the Netherlands (Piersma et al. 1993). Studies of Western Sandpiper (Warnock and Takekawa 1995), Piping Plover (Drake et al. 2001), Grey Plover, Willet, Marbled Godwit, and Long-billed Curlew (Gabbard et al. 2001), all in the USA, showed small home ranges across all of these species, with the largest (Western Sandpiper) at just under 25 km² and the smallest only 0.1 km² (Grey Plover, though only 2 individuals were tagged). Choi et al. (2013) suggests that differences in foraging conditions associated with different habitats in the different regions may explain this variation in home range size.

Yet despite this variation in studies on home range size, a number of studies have found evidence for high roost fidelity in the non-breeding season. A 30-year mark recapture dataset from England comprising Grey Plover (n=4,125 ringed), Red Knot (n=38,041 ringed), Common Redshank *Tringa totanus* (n=11,729 ringed), Dunlin (n=96,801 ringed) and Eurasian Oystercatcher *Haematopus ostralegus* (n=24,576 ringed) found that a high proportion of adult birds (approx. 96 %, 95 %, 94 %, 92 % and 83 % of each species, respectively) moved between different roosts only within an approx. 10 km section of the whole bay area, though movements between foraging areas or between foraging areas and roosts were not studied (Rehfishch et al. 1996). A study in Moray Basin, Scotland applying the same methods found similar results, with Eurasian Oystercatcher, Common Ringed Plover *Charadrius hiaticula*, Purple Sandpiper *Calidris maritima*, Dunlin, Eurasian Curlew, Common Redshank, and Ruddy Turnstone displaying particularly high roost fidelity (Rehfishch et al. 2003).

For four species in Gulf of Mexico radio-tagged from 1995–97, site fidelity was also high. For the Grey Plover (n=2), Willet (n=10), Marbled Godwit (n=1) and Long-billed Curlew (n=1) for which home ranges were estimated, tagged birds tended to use a single foraging and roosting site with only 7 % of recorded locations falling outside of these (Gabbard et al. 2001).

A combined mark recapture and radio-telemetry study of Common Redshank at Cardiff Bay, Wales over two seasons found the majority to have high site fidelity both during a single non-breeding season and between the two non-breeding seasons (Burton 2010). In the two autumn-to-spring periods surveyed, 7 % and 20 % of ringed individual observations, respectively, were made outside the bay (175 ha in size) at a neighbouring site 4 km away, and 63 % of individuals recovered dead or injured in both winters were within 4 km of the capture area, though some had relocated to alternative wintering areas > 20km away (Burton 2010). These results were corroborated by high return rates of an estimated 89 % and 83 % over the two seasons, and by radio-telemetry results that also suggested adults were largely faithful either to the bay or to the neighbouring site. Another mark recapture study of Dunlin from Portugal found that over 99 % of resightings of marked birds during high tide counts (n=710 sightings) across two roosts occurred at the roost in which the bird was caught (Dias et al. 2006), though the overall recapture rate in this study is not reported.

A three season mark recapture study in Moreton Bay, Queensland from two sites including an artificial roost showed high roost fidelity for the two primary species captured: 96 % and 74 % of Grey-tailed Tattler and Bar-tailed Godwit roost resightings respectively were from the site where they were captured, with resighting rates of 69 % and 57 % for Grey-tailed Tattlers and Bar-tailed Godwits respectively in the first season after banding, and 34 % and 69 % in the second season. (Coleman et al. 2012).

By contrast, a study from Humboldt Bay, a large estuary in California, showed quite variable roost use across 14 shorebird species (Colwell et al. 2003). This study took a different reporting approach, examining roost occupancy during 28 surveys 7-10 days each across 240 high tide roosts over 10 months. Over 60 % of the 240 roosts identified had shorebirds present on less than 20 % of surveys and only 4 % of roosts had shorebirds present on more than 80 % of surveys, suggesting that across seasons shorebirds occupied most roosts only infrequently and that individual shorebirds in this area must consistently use multiple roosts (Colwell et al. 2003). The authors list varying high tide levels, the availability of supplemental high tide foraging habitat, disturbance and movements related to migration all as probable causes for the substantial roost variation observed, and conclude that multiple synchronized surveys carried out over large areas may be necessary to understand regional shorebird roosting and address habitat needs (Colwell et al. 2003). A further study of Dunlin in Humboldt Bay similarly showed similarly high variability in roost use both by individual Dunlins and the overwintering population as a whole (Conklin et al. 2008). A study of Long-billed Curlew in Elk River Estuary, which empties into Humboldt Bay, showed highly variable patterns in territorial occupancy, and that territorial occupancy within this tidal estuary decreased dramatically in autumn and winter non-breeding periods when feeding opportunities in agricultural pastures increased (Colwell and Mathis 2001).

For Far Eastern Curlew, a radio-telemetry study in Moreton Bay showed that individuals generally followed the same pattern during each tidal cycle and remained largely within the study area over the non-breeding season; however half of the birds studied disappeared from the area for periods spanning 2 days to 2 weeks between March and May (Driscoll 1995). Observations from a small roost in Dunwich, Stradbroke Island (also in Moreton Bay) showed considerable variability in monthly Far Eastern Curlew abundance over the non-breeding season (Kyne 2010).

On the whole, this literature suggests that home range size and roost fidelity may vary significantly across regions and species, so local studies of these would likely be needed to determine patterns in a given locality.

Supratidal foraging

As noted previously, it is sometimes difficult if not impossible to discreetly separate foraging and roosting areas, particularly for species that are able to obtain significant foraging resources from supratidal habitats. There are many studies across different habitat types and species that document supratidal foraging, which is sometimes preferential to intertidal foraging for some species (Sripanomyom et al. 2011; Choi et al. 2013; Dias et al. 2013; Rogers and Hulzebosch 2014). A study from Thailand concluded that supratidal habitats, including artificial habitats like commercial salt ponds, generally provide more foraging opportunities for smaller shorebirds species that consume small prey but few opportunities for larger species that consume large prey (Yasue and Dearden 2009). However, other studies have documented larger shorebirds obtaining small prey from these habitats, for example Black-tailed Godwits *Limosa limosa* consuming very small chironomid larvae on artificial salt ponds in Europe (Estrella and Masero 2010). The availability of supratidal foraging opportunities will influence roost behaviour for shorebirds in a given locality.

No studies could be identified with detailed documentation of supratidal foraging by Far Eastern Curlews in non-breeding or staging areas. However, Far Eastern Curlew are known to roost in saltmarsh habitat (Loyn et al. 2001; Spencer et al. 2009), which is notoriously difficult to access for surveys. Spencer et al. (2009) report a flooded saltmarsh roost in the Hunter Estuary, New South Wales supporting hundreds of Far Eastern Curlew at night-time, and mention supplementary foraging by small numbers on night-time high tides. Hale and Davies (1980) also report roosting by Eurasian Curlew to be mainly on saltmarsh, including in high *Spartina* grass (Hale and Davies 1980; Prater 1981). Far Eastern Curlew, as well as Whimbrel, are thought to forage in saltmarsh habitat in Darwin Harbour during both low and high tides; a Far Eastern Curlew was observed foraging in saltmarsh habitat on 25/01/2017 at very low tide (A Lilleyman, pers comm). Given the preference of Far Eastern Curlew for large prey including crabs during the non-breeding season (Zharikov and Skilleter 2004), it seems possible that foraging opportunities could become available, particularly from saltmarsh areas that become inundated to some degree at higher tides.

Thus it seems plausible that the availability of saltmarsh habitat, particularly if presenting supplemental foraging opportunities, could affect the high tide roost choice of Far Eastern Curlew.

Table 2: Results of studies on home range size of non-breeding migratory shorebirds in coastal landscapes*. Largely derived from Table 4 of Choi et al. (2013) with some modification.
*home range estimate is stated as mean (km²) ± SE unless otherwise noted

Species	Location	Home range estimate (km ²)	Method	Source
Dunlin	Willamette Valley, Oregon, USA	147.1 ± 27.7 (n=23); 120.1 ± 14 (n=16); 564.7 ± 99.9 (n=18)	95 % minimum convex polygons	Sanzenbacher and Haig 2002
Dunlin	Fraser River Delta, British Columbia, Canada	19 ± 5.6 to 52.6 ± 4.6 (n=47)	Fixed kernel 95% utilization distributions	Shepherd and Lank 2004
Dunlin	Chongming Dongtan, China	12.9 ± 3.2 (n=9); 17.5 ± 3.6 (n=10); 15.6 ± 4.0 (n=14)	95 % minimum convex polygons	Piersma, Hoekstra et al. 1993
Red Knot	Wadden Sea, Netherlands	800 (n up to 100000)	Subjective deduction	Piersma et al. 1993
Red Knot	Banc d'Arguin, Mauritania	2–16 (n=17)	Subjective deduction	Leyrer et al. 2006
Western Sandpiper	San Francisco Bay estuary, California, USA	24.6 ± 2.3 (n=21); 19.3 ± 4.1 (n=20); 23.4 ± 1.2 (n=18);	Weighted (95%) bivariate elliptical home range	Warnock and Takekawa 1996
Piping Plover	South Texas, Texas, USA	12.6 ± 3.3 (n=48)	Fixed Kernel	Drake et al. 2001
Grey Plover	Gulf of Mexico, Florida, USA	0.1 (n=2)	95% convex polygon	Gabbard et al. 2001
Willet	Gulf of Mexico, Florida, USA	14.9 (n=10)	95% convex polygon	Gabbard et al. 2001
Marbled Godwit	Gulf of Mexico, Florida, USA	6.7 (n=1)	95% convex polygon	Gabbard et al. 2001
Long-billed Curlew	Gulf of Mexico, Florida, USA	24.4 (n=1)	95% convex polygon	Gabbard et al. 2001

Other factors affecting roost choice

A study from 1994 suggested that microclimate was a factor affecting local and seasonal shorebird movements, and calculated the energy needs for Red Knots associated with thermoregulation when ambient temperature is below their thermo-neutral zone (Wiersma and Piersma 1994). Thermoregulation would also cost roosting energy in hot temperatures. Recognising this, Rogers et al. (2006) included microclimate of roosts as a covariate in their roost choice model at Roebuck Bay, noting that dry sites displayed temperatures at or in excess of body temperature, exposing birds to the risk of heat stress. Unsurprisingly, they found that diurnal roost choice was associated with cool, wet substrates (Rogers et al. 2006).

It is likely that this factor would affect roosting behaviour of Far Eastern Curlew in tropical north Australia, where a study of Great Knots has shown that a significant number of birds exhibited heat reduction and avoidance behaviour (raising feather, gaping and panting) on days with high temperature and solar radiation levels (Battley et al. 2003). Being a larger shorebird, Far Eastern Curlew would have an even less favourable surface-area-to-volume ratio for dissipating body heat than Great Knot, and could therefore be expected to favour cool, damp substrates during high tide roosting.

Wind is another microclimate factor that may affect roost choice (Davies and Hale 1980); while exposed roosts may generally be preferred for their decreased vulnerability to predation, a very exposed roost experiencing high winds may become unsuitable for roosting (Newman 2015).

Landscape composition is an additional factor that could affect roost choice. One of the roost choice studies from Moreton Bay included landscape composition in its roost model, assessing 11 land-cover classes in 0.5 km-radius plots around roosts (Zharikov and Milton 2009). The authors found composition effects were mostly only relevant for species that forage during high tide (in their study Black-winged Stilt *Himantopus himantopus* and Sharp-tailed Sandpiper *Calidris acuminata*, which foraged on claypans inland from mangroves) or those that roost on more complex structures (in their study Grey-tailed Tattler and Whimbrel, which use mangroves and hard artificial structures including rock-walls to roost on) (Zharikov and Milton 2009). These factors should be considered where species targeted for management may be affected by such variables.

Availability of alternate roosts could also plausibly influence roost choice, though exactly how is difficult to determine. In general, roosts will not be disturbance-free, so for species like Far Eastern Curlew which tend to abandon roosts as a result of disturbance, the availability of alternate roosts would likely lower the energetic cost of disturbance compared with seeking a more distant roost.

It is also worth considering potential habituation of shorebirds to harmless disturbance on roosts. While this phenomenon is largely undocumented, there are well-known examples of shorebird habituation to human disturbance at certain sites. For example adjacent to the Cairns Esplanade, Queensland, a high volume of walkers, joggers, etc. passes in close proximity to roosting shorebirds regularly without causing a flight response, but shorebirds are almost universally wary at remote sites like Roebuck Bay, Western Australia (M Jackson; D Rogers pers comm).

Management Implications

The variability in shorebird behaviour across regional studies strongly indicates that managers looking to improve roosting conditions for shorebirds in a given locality require a very good working knowledge of available foraging and roosting habitat, as well as the seasonal behaviour of target species for management. Knowledge of food availability (to predict where birds will be foraging), likelihood of predation and disturbance, and knowledge of the microclimate (in particular when an area may be too hot or windy for comfortable roosting) would all be needed to make any reasonable prediction of roosting behaviour.

Reinforcing this, the development of a GIS modelling methodology to evaluate both the existing network of available roosts and the creation or loss of new local roosts (Dias et al. 2006) could be useful for managers; the study that developed the method applied it to the Tagus estuary in Portugal but it could potentially be used in any locality. However, use of this model requires, as a pre-requisite, a good geographical knowledge of foraging areas and roosts and the distance of species movements between high-tide roosts and their foraging areas (Dias et al. 2006), so detailed site and species specific knowledge, requiring study of local movements, would be required to apply this type of approach to a different locality.

It is also worth reinforcing that management for high tide roosting is likely to differ significantly for different species. For Far Eastern Curlew, as has been examined in previous sections:

- high sensitivity to disturbance due to a high level of wariness;
- comparatively high risk of heat-stress due to large body size;
- potential to forage in supratidal saltmarsh habitat; and,
- very long leg length (which significantly widens field of view, ability to see over vegetation and largely allows birds to remain on inundated intertidal flats when preferred)

are all factors specific to this species that are highly likely to affect roost choice.

Shorebird roosting on artificial habitats in the EAAF

There are many examples in Australia, the EAAF and throughout the world of roosts utilised by shorebirds that exist as a result of human activities. These may have been created as an accidental by-product of human activities, as deliberately constructed areas designed for use by shorebirds, or a combination of both. The following sections provide a brief overview of the most important types of artificial habitats used in the EAAF with emphasis on those found in Australia.

The literature relating to artificial habitat use by shorebirds does not suggest that artificial habitats should be considered a replacement of natural ones. The devastating effects of habitat loss including mortality in the immediate term are well documented (e.g. Burton et al. 1996; Moores et al. 2016). Several studies directly comparing artificial and natural habitats have concluded that natural habitats remain the more useful to shorebirds. For example, in the Wadden Sea attempts to provide new wetland habitat did not fully compensate losses from reclamation (Hotker 1994); in Chongming Island, China, shorebirds generally preferred natural tidelands to adjacent artificial ones (Ma et al. 2004); and, in Sri Lanka shorebird density was found to be 3-6 times higher on natural lagoons than artificial wetlands across 9 sites (Bellio et al. 2009).

Rather, the literature indicates that shorebirds can utilise artificial sites in a number of circumstances to a greater or lesser degree, and points out that a lack of suitable roosts can restrict the usefulness of remaining intact intertidal flats (e.g. Rogers et al. 2006). In the most fortuitous circumstances, the presence of sufficient supratidal habitats, including artificial ones created for such a purpose, can increase the carrying capacity for shorebirds in a given locality and reduce the detrimental effects caused by the loss of intertidal habitats (e.g. WWF 2006a; Sripanomyom et al. 2011).

Commercial salt ponds

One artificial habitat type particularly relevant to shorebirds in the EAAF is salt ponds. These include ponds of various sizes that have been created for the commercial production of salt products through the evaporation of seawater. The maintenance of artificial salt ponds has created extensive shorebird habitat throughout the EAAF and in other places worldwide, including for example in the USA (Warnock et al. 2002), Spain (Masero et al. 2000) and Portugal (Dias et al. 2013).

Depending on the species and circumstances, salt ponds may provide complementary high tide roosts in the proximity of intertidal foraging areas, supplemental foraging at higher tides when regular foraging areas are inundated, or even preferential foraging grounds when conditions are suitable and prey is abundant and easy to catch (Masero et al. 2000). For example, nearly 95,000 shorebirds of 20 species were counted foraging on a single pond within the Nanpu salt complex in Luannan, China in 2013 when foraging conditions were excellent (Hassell 2013). An extensive study from the Inner Gulf of Thailand, where rapid and extensive land use change has occurred in coastal areas adjacent to tidal flats, assessed the importance of artificial salt ponds and semi-traditional aquaculture for shorebirds. It concluded that both types of habitat provide roosting and foraging opportunities for certain species, suggesting they provide a buffer against the adverse impacts of altered intertidal foraging habitats for at least some species (Green et al. 2015).

In Australia, artificial salt ponds provide important habitat for migratory shorebirds in a number of locations. For example, in the Gulf St. Vincent area around Adelaide, South Australia, ponds associated with the Dry Creek Saltfields and Price Saltfields, constructed in the 1930s, provide a significant amount of the supratidal area useful to shorebirds and are a major factor in the area's listing as an Important Bird Area by BirdLife International (Purnell et al. 2015); in the 2014-15 annual coordinated regional counts the salt ponds held over 10,000 shorebirds for 3 of the 5 counts, with shorebird diversity ranging from 7-14 species, (Purnell et al. 2015). A review of shorebird counts undertaken annually since 1981 (twice/year from 1981-2000; 4-6 times per year from 2000-2016) at salt ponds in the Avalon Saltfields, Victoria had an average count total of over 3,000 shorebirds across the whole period, with a peak count of over 15,000 shorebirds (including almost 12,500 migratory shorebirds) in the mid-1980s (Rogers et al. 2016).

Former Cheetham Salt operations at Moolap and Cook Point near Melbourne, Victoria; still-operating Dampier Salt operations at Port Headland and Dampier, Western Australia (Hassell 2006); and, the Cheetham Saltfield and Port Alma Saltfield in the Fitzroy River region, Queensland (Houston et al. 2012) are also well-known to support both roosting and foraging resources for significant numbers of shorebirds.

However, economic conditions have meant that many salt production sites have ceased or are scheduled to cease commercial operations, representing a potential loss of habitat for shorebirds. Generally, if former salt ponds do not have active operations involving, for example, frequent changes in water levels, their suitability as shorebird habitat decreases, and this has been documented in Australia. For example, declines in habitat quality have been documented since the closure of commercial operations at the Avalon Saltfields in 2000, with shorebird numbers declining more rapidly at Avalon than at other nearby sites between 2000 and 2016 (Rogers et al. 2016). The Dry Creek Saltfields, Western Australia, were decommissioned in 2012, with the habitat effects resulting from associated hydrological regime changes still uncertain (Purnell et al. 2015). Cheetham Salt has also ceased commercial operations at Moolap, Victoria and the area is scheduled for redevelopment; various land use scenarios are currently being considered, some of which would retain artificial salt pond habitat, others of which would not (State of Victoria 2016). To meet the ecological needs of shorebirds, artificial salt pond habitats must be deliberately maintained if commercial salt production is not occurring.

Wastewater treatment

Another artificial habitat that has resulted in the production of good shorebird habitat is the wetland habitat created for the purposes of human wastewater treatment. Even at small sites, the creation of open water ponds with sloping banks, long bunds (sometimes occasionally covered in shallow water), pond edges of shallow water, and islands all create suitable habitat for shorebirds and other waterbird species. The general inaccessibility of wastewater treatment sites to the public also limits recreational disturbance, though works within sites may frequently change or disrupt habitat conditions.

Probably the most well-known of these sites in Australia is the Western Treatment Plant in Victoria. Managed by Melbourne Water, it is 10,500 ha in size, treats half the sewage from Melbourne, and forms part of a Ramsar site². The site is quite unusual given its size and the connectivity of natural and artificial freshwater wetlands, intertidal mudflat, coastal saltmarsh areas, lagoons associated with sewage treatment and decommissioned treatment ponds now managed specifically for conservation. Counts from 2000-2012 showed that migratory shorebirds comprise the bulk of shorebird species found at the Western Treatment Plant, with Red-necked Stint, Sharp-tailed Sandpiper and Curlew Sandpiper *Calidris ferruginea* making up the majority of numbers in most years (Loyn et al. 2014). An examination of trends found that the Western Treatment Plant's capacity to support shorebirds remained relatively stable over the period, with seasonal patterns and climactic variables, as well as the overall declines experienced by populations in the EAAF, being the main drivers in observed changes in shorebird numbers over the period (rather than issues to do with management or site conditions) (Loyn et al. 2014).

In the Hunter Region, New South Wales, the maturation pond system associated with the original filter works plant of the Morpeth Wastewater Treatment Works, decommissioned in 2000, created sludge ponds and several ephemeral wetlands that formed suitable wetland habitat used by shorebirds; as a requirement of decommissioning, the ponds are now managed as wetlands for native species (Newman and Lindsey 2011). A ten year monitoring study from 2001-2010 showed that the site was used by 16 species of shorebirds (9 migratory), including by Sharp-tailed Sandpiper in internationally significant numbers. However patterns of occurrence suggest that the site is only used regularly by a few species and primarily as a foraging area, including as a drought refuge for Sharp-tailed Sandpipers when inland habitats are unsuitable; this suggests that the site forms part of a local mosaic of freshwater wetlands utilised by shorebirds (Newman and Lindsey 2011).

Wastewater treatment works in many other places, for example Leanyer (near Darwin, Northern Territory), Alice Springs (Northern Territory), Palmerston (Northern Territory), Broome (Western Australia), Wagin (Western Australia) and many others are well known for their value to shorebirds (including regular visits from vagrant species) and are often visited and counted by volunteers, though structured reports on overall shorebird abundance and trends from these sites is limited in the literature.

² A site recognised as an internationally important wetland using criteria established under the Ramsar Convention on Wetlands (<http://www.ramsar.org/>).

Ports

Shorebird roosts have also emerged as a by-product of port activities in several places in Australia. Ports are often associated with dredging and reclamation activities that can create large flat areas with varying water levels: useful roosting conditions for many species. Because these areas are adjacent to the marine environment and also largely inaccessible to the public (including dogs), they can create low-disturbance roosts close to foraging grounds, though these sites may often be temporary without intervention.

The Port of Brisbane, located on Fisherman Island (an artificial island reclaimed from the Fishermen Islands group) at the mouth of the Brisbane River since the late 1970s, has supported large numbers of shorebirds for at least two decades, particularly on a long term land reclamation project of 230 ha that places dredge material in constructed bunds on the northern end of the island. The Queensland Wader Study Group (QWSG) conducts standardised monthly counts of waterbirds at the Port of Brisbane on Fisherman Island and has recorded an annual average count across 10-12 monthly counts per year (2003-2015) of about 5,100 birds with the highest average count to date recorded in 2015 of 7,150 birds (1,737-14,299) (Cross 2016). Five species of migratory shorebirds occurred in internationally significant numbers in 2015 (Lesser Sand Plover, Grey-tailed Tattler, Red-necked Stint, Sharp-tailed Sandpiper and Curlew Sandpiper).

Far Eastern Curlew was present at all monthly counts at the Port of Brisbane in 2015 with an average count of 68 individuals, a high count of 137 (January) and a low count of 3 (June); over 100 curlew were present in January, February, October and December (Cross 2016).

Shorebird habitat has also resulted from the creation of dredge ponds at East Arm Wharf (part of the Darwin Port) and these are used for roosting at high tide when mudflat habitats are inundated. A monitoring project showed that 27 species of migratory shorebird used the site from 2010-2015, with overall usage increasing over that time (Lilleyman et al. 2015).

Use of East Arm Wharf by Far Eastern Curlews has been studied and roosting numbers found to be higher there than at Lee Point, the largest natural roost for other shorebird species in the area (Lilleyman et al. 2016). The authors suggest that the most likely attributes making the East Arm Wharf ponds attractive for Far Eastern Curlew are its availability at all tide heights, the lack of human disturbance (contrasting the Lee Point roost which experiences high levels of recreational use), and its close proximity to suitable foraging habitat on intertidal mudflats (which suggest it may be a low energy-cost site to access) (Lilleyman et al. 2016). Interestingly, an increase in Far Eastern Curlew of 17 % per year at East Arm Wharf was documented from 2009-2015 despite the observed species-wide population decline over the same period, with the site apparently becoming relatively more attractive over time (Lilleyman et al. 2016).

In New South Wales, creation of the Penrhyn Estuary resulted from construction of Port Botany in the 1970s, and the associated ecosystem that developed has become locally important for shorebirds, particularly as other developments have reduced other available habitat in the region. As part of the approval for the expansion of Port Botany, a plan to enhance the estuary was undertaken from 2012-17 with stated aims that include expansion of foraging areas and roosts for migratory shorebirds; this included creation of almost 14 ha of intertidal habitat and over 2 ha of saltmarsh (O'Donnell 2016).

Other ports in Australia that have interactions with shorebirds include Gladstone Port, Queensland; Port of Newcastle, New South Wales; and, Broome Port, Western Australia.

Aquaculture & Agriculture

There is substantial global literature on the use of agricultural areas by waterfowl and some on shorebirds (e.g. Czech and Parsons 2002; Huner et al. 2002; Sanzenbacher and Haig 2002; Shepherd and Lank 2004). Amano et al. (2010) characterise Far Eastern Curlew as occasionally using rice paddies in Japan, and Navedo et al. (2013) document substantive supratidal foraging in coastal pastures by Eurasian Curlew in Europe. These habitats will not be reviewed here as this type of habitat is largely not relevant for migratory shorebirds on Australian non-breeding grounds, though a few species of shorebirds have been recorded feeding in rice fields in the Murray-Darling Basin region (Taylor and Schultz 2010).

In China and Southeast Asia shorebirds also utilise coastal ponds associated with aquacultural activities adjacent to areas of intertidal mudflat (e.g. see Choi et al. 2013; Green et al. 2015; He et al. 2016; Melville et al. 2016). These also will not be specifically reviewed as this type of habitat is not generally found in Australia.

However, instructive research results from both of these habitat types are noted in other sections of this report as relevant.

Constructed roosts

In some cases in the EAAF and globally, managers have deliberately constructed or reconstructed areas specifically to support shorebird roosting, though there is relatively little available material in the peer reviewed literature. The following section summarises some useful examples of artificial roost construction. Straw (2013) also provides a very useful summary of lessons and examples from rehabilitation and reconstruction projects for shorebirds in Australia.

Moreton Bay, Queensland, Australia

A number of artificial roosts have been constructed in Moreton Bay, Queensland, one of the most important non-breeding shorebird areas in Australia.

When construction of a canal estate at Raby Bay caused one of Moreton Bay's most important shorebird roosts to be disrupted, a report on artificial roost construction was produced as part of a project led by the QWSG and supported by the Department of Lands attempting to compensate for some of the lost roosting habitat. The report's introductory remarks reinforce that shorebirds require roosts to be near to foraging grounds and on open undisturbed areas, and that remaining natural roosts need to be managed to maintain these properties and artificial roosts constructed as a last resort (Lawler 1995).

Before going into design concept and specific details of the site at Empire Point, Lawler (1995) presents the general factors that should be considered for any artificial roost as:

- openness
- substrate
- slope
- [proximity to open] water
- disturbance
- size [of the roost] and,
- proximity to foraging areas

and makes recommendations as to the optimal design for each. These features emphasise proximity to foraging areas and limitation of disturbance and predation risk as being the key factors in shorebird roost choice.

The roost at Empire Point was constructed in 1998 after most of the Raby Bay development had occurred (and displaced the previous roost). Early results from the first few months after artificial roost construction showed a gradual increase in use, with a maximum count in the following year of 81 (of Grey-tailed Tattler) (Harding et al. 1999).

In Hartlepool on the Tees Estuary, England, a historical pier consisting of a series of stone and wooden structures that became islands at high tide was an important high tide roost for shorebirds during the 1980s, but was scheduled for redevelopment in the late 1980s including creation of a marina and new sea defences (Burton et al. 1996). To offset this loss of roosting habitat for shorebirds, construction of a new artificial island (which was kidney shaped, steep-sided and faced with stone blocks) and pier, as well as monitoring of their use, was undertaken (Burton et al. 1996). While the island went on to become the main roost for all species still using the harbour, the success of its design was very species specific; among the birds roosting in the area in significant numbers, the new island was well utilised by Purple Sandpiper (which prefer rocky roosts), but numbers of Ruddy Turnstone, Eurasian Oystercatcher and Red Knot (which prefer open roosts with good visibility) declined in the harbour after construction (Burton et al. 1996). The authors suggested the increased disturbance associated with the marina was probably the primary cause for this decline, but also noted that the rock-based design of the island was probably not well suited to species like oystercatcher and knots which prefer open roosts (Burton et al. 1996).

Another constructed roost in the Moreton Bay region is the 11 ha artificial roost associated with the Port of Brisbane that was created in 2005 on the artificial Fisherman Island and consists of wet areas and a number of islands. Some key design features of the roost noted in the Port of Brisbane Shorebird Management Plan (Port of Brisbane 2016) are:

- It is connected to the marine environment by a weir and culvert system that allow intake of water at high tide and discharge of water at low tide;
- Saltwater inundation of the islands occurs at the highest high tide to limit vegetation growth, though manual vegetation removal is also carried out;
- The culvert system can be used to deliberately flood the roost for the purposes of vegetation control, which is done annually in the winter; and,
- A fence around the roost, controlled access and two bird hides for visitors, intended to minimise roost disturbance.

In 2012, monitoring by the QWSG suggested that shorebird numbers were dropping because the height (above water) of two of the islands was encouraging excessive vegetation growth that limited shorebirds' field of view to observe potential predators; in 2013 excavation works lowered these islands with apparently positive results by 2015 (Port of Brisbane 2016).

In 2015, the roost supported several hundred shorebirds, with 17 species using it throughout the year, though total numbers of shorebirds on the larger, active reclamation areas of Fisherman Island (not specifically managed for shorebirds) are significantly higher (Cross 2016).

An additional constructed artificial roost in the Moreton Bay area is at the Manly Boat Harbour, and one of the catching sites in the mark recapture study on Grey-tailed Tattler and Bar-tailed Godwit roost site fidelity (Coleman and Milton 2012). Moreton Bay contains a number of other constructed roosts, generally associated with developments.

Mai Po, Hong Kong

There is a long history of shorebird roost maintenance at Mai Po Inner Deep Bay Ramsar Site, Hong Kong, a major shorebird stopover and non-breeding area supporting 20-30,000 migratory shorebirds every year. Within the Mai Po Nature Reserve, WWF Hong Kong has managed two high tide shorebird roosts since 1986 in *gei wai*, traditional shrimp ponds, the larger of which covers about 18 ha of shallow, open water with twenty-eight islands (WWF 2006a). In 2005, following a review, a number of improvements were undertaken at the site that are highly instructive.

Several works were undertaken to increase the carrying capacity of the *gei wai* ponds for roosting birds, including a reprofiling of the largest island to increase foraging edge length, and the creation of three new islands. Several measures to reduce disturbance and predation risk were undertaken including:

- construction of 570 m embankment and grass barrier between the roost and a nearby Education Centre access track in order to reduce disturbance from vehicles;
- a reduction in the height (above water) of the largest constructed island; and,
- excavation of a deep ditch along a roost boundary to prevent vegetation encroachment (WWF 2006a).

These works all aimed to increase the attractiveness of the roost based on factors discussed earlier including ensuring good visibility, maintaining openness and reducing disturbance; specifics of construction undertaken are included in the report (WWF 2006a).

Waterbird monitoring in 2006 following the improvement works showed immediate positive results, with waterbird numbers increasing on the improved roost by over 13 % and the number of species with counts averaging above 5 individuals increasing by almost 30 % (WWF 2006b). The report notes that the 'Curlews and Whimbrels' group showed a noticeable spatial redistribution and zone preference shift following the reconstruction; in particular the large island that was reprofiled attracted new species from this group not recorded there the previous year (WWF 2006b).

Port Botany, New South Wales, Australia

The construction of three roost islands from sand for shorebirds was included in the Port Botany Expansion Penrhyn Estuary Habitat Enhancement Plan (implemented from 2012-17), with bare sand tops and sides planted with saltmarsh and small rocks around the largest island (construction and concept details are included in Sydney Ports (2012)). Six shorebird species were chosen for post construction monitoring over the whole estuary enhancement area to indicate project success and in 2015, one species met the target and another increased, but Bar-tailed Godwit and Red-necked Stint declined and there were no sightings of Red Knot or Curlew Sandpiper; the relationship between local changes and other regional factors affecting shorebird numbers is not yet clear (O'Donnell 2016).

Port Stephens, New South Wales, Australia

While not purposely built as a wader roost, a site in Port Stephens, New South Wales, provides an example of how a very simple manmade structure can provide good shorebird roosting habitat. Here, a nearshore shed associated with oyster processing was torn down but a cement pad that had supported the shed was left, providing a raised, flat surface extending from the shore out over shallow marine water; this created a roost with excellent visibility for spotting predators and little human disturbance (Wooding 2016). Annual counts showed an immediate increase in both Pied Oystercatcher *Haematopus longirostris* and Sooty Oystercatcher *Haematopus fuliginosus* (small numbers of which had roosted on the breakwater near the shed prior to its removal) with a sustained increase of 6 to 57 and 3 to 28 individuals respectively from 2011 to 2015 (Wooding 2016).

Recreation of saltmarsh and intertidal mudflat

While they will not be examined in detail here, it is interesting to note that there has been research into and implementation of projects aimed at restoring and/or creating new saltmarsh and intertidal mudflat habitat for shorebirds. For example, the above-mentioned Port Botany Expansion includes creation of 2.4 ha of saltmarsh and 10.4 ha of intertidal flat (Sydney Ports 2012), and at the Wild Bird Park in Osaka Port, Japan, restoration of a pond within a reclamation area to create about 2.5 ha of tidal flat resulted in about a fivefold increase in the average number of shorebirds present (from ~200 to ~1,000) (Natuhara et al. 2005).

A 2003 review of saltmarsh and mudflat creation, which has occurred largely in the USA, Europe and Japan, suggested that global efforts to recreate saltmarsh have had mixed results but that mudflat creation has been relatively successful with recolonisation by shorebirds and their benthic prey within a relatively short time; however, it cautions that that population level impacts of new habitat creation need to be better understood (Atkinson 2003).

Counts of Far Eastern Curlew on artificial habitats

As noted, Far Eastern Curlew use a number of the artificial roosts in Australia described in previous sections. Lawler (1995) characterises Far Eastern Curlew as having 'generalist' roost preferences, requiring open areas that are either bare or having only low vegetation; he further notes that Far Eastern Curlew roosts may be separated from the shoreline (for example by mangrove fringes) and reinforces their high sensitivity to disturbance.

Table 3 provides a summary of Far Eastern Curlew counts on artificial habitats in Australia for which reports including count data could be identified. The two highest counts were both from port sites (Brisbane and Darwin), and the other count with over 100 individuals was from the Cheetham Saltfield. Five sites are associated with salt production, three with ports, and one with a constructed roost.



Far Eastern Curlew. Image: Micha V. Jackson

Table 3: Counts of Far Eastern Curlew at artificial habitat sites in Australia

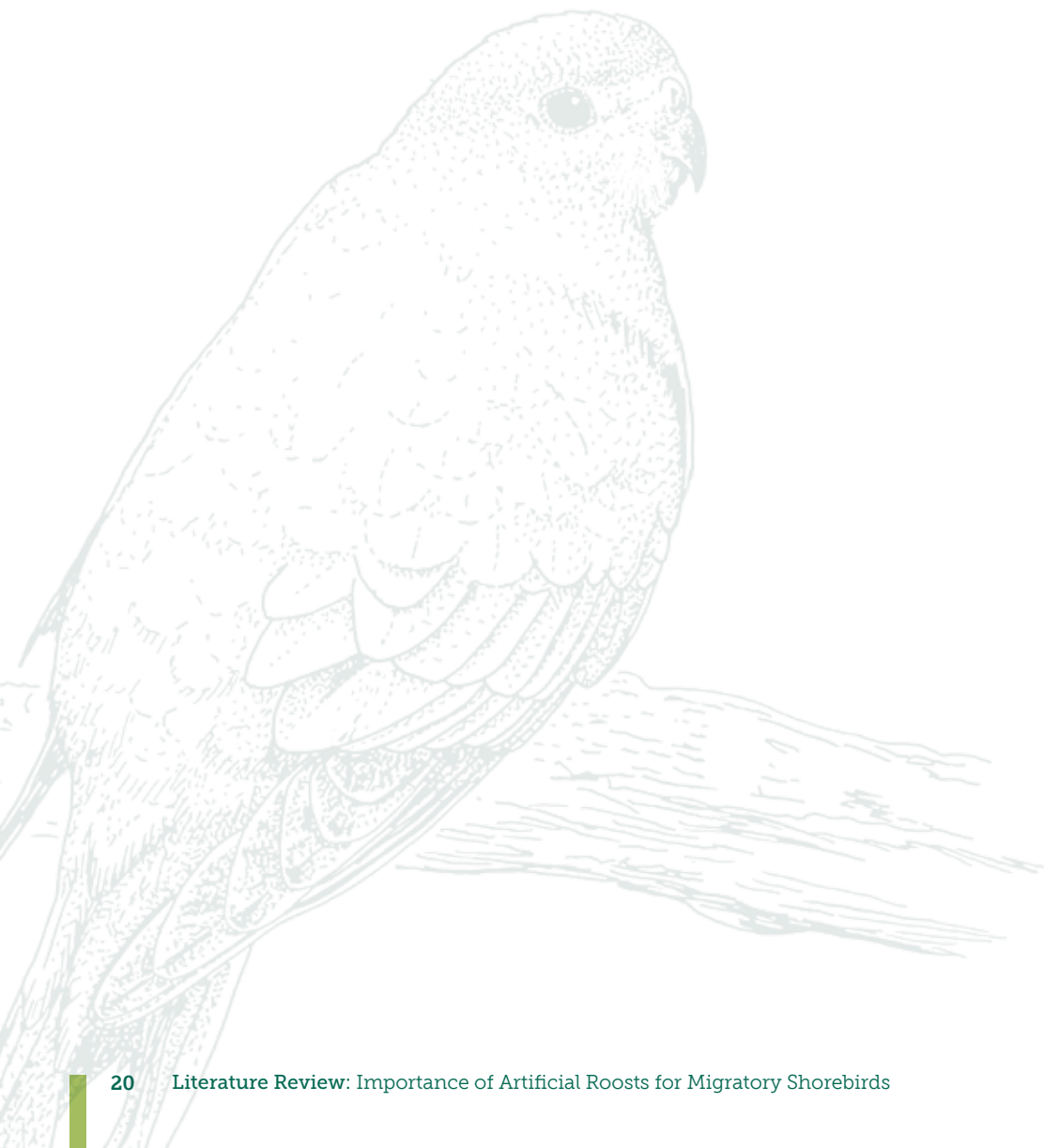
Roost	Background	Far Eastern Curlew Counts	Source
Empire Point, Moreton Bay, Qld	Artificial roost constructed to offset loss of some roosting habitat associated with a marina development	29/10/98: 12 13/02/99: 11 22/03/99: 3	Harding et al. 1999
Dampier Salt, Port Hedland, WA	Commercial salt works (Dampier Salt) surveyed once annually during southward migration (Oct-Nov)	Annual surveys 2002-2006 [n=5]* Mean count: 21 High count: 39 *includes adjacent mudflats	Hassell 2006
Dampier Salt, Dampier, WA	Commercial salt works (Dampier Salt) surveyed once annually during southward migration (Oct-Nov)	Annual surveys 2002-2006 [n=5]* Mean count: 5 High count: 10 *includes adjacent mudflats	Hassell 2006
Cheetham Saltfield, Qld	Operational commercial salt works surveyed over 3 years	Counts between July 2008 & March 2011 [n=29 surveys] High count: 100	Houston et al. 2012
Port Alma Saltfield, Qld	Operational commercial salt works surveyed over 3 years	Counts between July 2008 & March 2011 [n=29 surveys]: High count: 32	Houston et al. 2012
Western Basin Reclamation Area, Gladstone, Qld	A preliminary survey of this site, associated with the Gladstone Port, was undertaken to determine if shorebirds were using it as a roost, though the high levels of disturbance on the day may have reduced count numbers	07/02/2015: 3	Wildlife Unlimited 2015
Port of Brisbane, Qld	Reclamation areas of the Port of Brisbane (includes constructed roost)	Monthly surveys conducted for 2015 [n=12 surveys] Average count: 68 High count: 137	Cross 2016
East Arm Wharf, Darwin, NT	Artificial ponds at East Arm Wharf, used to store dredge spoil from Darwin Harbour	Regular surveys 2009-2015 [n=101 surveys] High count 01/2015: 237 >38 individuals counted 39 of 101 surveys	Lilleyman et al. 2016
Avalon Saltfield, VIC	Former salt works surveyed over 35+ years	Regular surveys 1981-2016 Annual mean: 3	Rogers et al. 2016

Concluding remarks

Shorebirds' use of artificial habitats (including constructed habitats) for roosting clearly reflects research results indicating that proximity to foraging areas and limited disturbance and predation risk are key factors required for viable roosts. Nonetheless other factors, including local microclimate (particularly in hot regions including tropical north Australia), alternate proximate roosts and landscape characteristics are also likely to be important. The usefulness of particular roosts is often species specific, with some species more tolerant to disturbance and others with different substrate requirements (for example some preferring sheltered rocky areas, others open sandy ones).

An interesting question sometimes posed about the use of artificial habitats by shorebirds (e.g. Cardoso and Zeppelini 2013) is whether they are using the site because it has advantageous properties, such as low disturbance, proximity to foraging habitat, or good visibility from which to observe predators, or because they are being 'forced' onto artificial habitat as a result of a lack of suitable remaining natural habitat. This is an important question when considering perceived benefits to shorebird from using of artificial habitats.

Nonetheless, the literature suggests that maintenance or improvement in the condition (particularly limiting disturbance and improving physical attributes that limit vulnerability to aerial predation) of existing roosts, and the development of additional roosts where roosting habitat has been lost, could be effective in assisting shorebirds to maintain a positive energy budget during the non-breeding season. However, a solid baseline knowledge and conscientious monitoring of local shorebird numbers and movements is critical in their development and evaluation of their effectiveness.



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Further information:

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