

Are saltflats suitable supplementary nesting habitats for Malaysian Plovers *Charadrius peronii* threatened by beach habitat loss in Thailand?

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Summary

Resort development and coastal beach erosion have led to declines in beach breeding habitat for the near-threatened Malaysian Plover (*Charadrius peronii*) in the Gulf of Thailand. Semi-natural saltflats may provide supplementary nesting areas. We compared the environmental conditions, incubation behaviour and nesting success of plovers breeding on sandy beaches and saltflats in Thailand. In total we monitored 21 and nine nesting attempts in 2004 (beaches and saltflats, respectively) and 26 and 22 nesting attempts in 2005. Despite higher air temperatures in the saltflats ($P < 0.0001$), we detected no significant differences in nest attendance ($P = 0.542$ and $P = 0.885$ for 2004 and 2005, respectively), number of incubator changes between parents ($P = 0.776$ and $P = 0.823$) or number of parental nest departures ($P = 0.087$ and $P = 0.712$) during 120 incubation observations on 55 nests. There was also no difference in hatching success between beaches in 2004 (beach = 0.65, saltflat = 0.55; $P = 0.692$, $n = 26$) and 2005 (beach = 0.46, saltflat = 0.35; $P = 0.539$, $n = 41$). These results suggest that saltflats may provide nesting habitat for Malaysian Plovers and could help enhance overall hatching success rates by reducing nesting densities on beaches. Although there are few remaining intact saltflats in coastal Thailand, there are currently vast areas of abandoned tiger prawn aquaculture ponds that could be rehabilitated into saltflats at relatively low cost. Given the large area of disused aquaculture ponds throughout Thailand and South-East Asia and the substantial human pressure on coastal habitats, there could be considerable conservation benefits to the restoration of aquaculture ponds.

Introduction

Sandy tropical beaches are important breeding and foraging areas for waterbirds. However, these habitats are threatened by resort development, road construction, coastal erosion, sea-level rise and human disturbance (Burger *et al.* 1997, Brown and McLachlan 2002, Yasué and Dearden 2006b). The population impacts of such habitat changes depend on whether there are alternative areas waterbirds can use and attain similar levels of survivorship and fecundity (Elphick 2000, Smart and Gill 2003). Research relating the values of alternative habitats to wildlife, along with the socio-economic costs of protecting these areas, can help resource managers partition conservation efforts between different types of habitats efficiently (Bernstein *et al.* 1991).

Malaysian Plovers (*Charadrius peronii*) are a Red-listed species affected by habitat degradation in beach breeding habitats throughout their range in South-East Asia (Baillie *et al.* 2004, Yasué and Dearden 2006b). In Thailand, coastal development and beach erosion have reduced habitat availability in the main breeding habitats in Petchburi and Prachuap Khiri Khan

provinces on the east coast of Thailand (Natalaya 2006, Yasué and Dearden 2006b). At present there is little government support to conserve sandy beach habitat for wildlife because of the tremendous economic importance of beach tourism in Thailand. Consequently many more beach habitats will probably be lost to commercial development as the Thai economy continues to improve and domestic tourism expands.

A previous study of Malaysian Plovers suggested that pairs in areas of high conspecific nest density had lower hatching success (Yasué and Dearden 2006b). If Malaysian Plover populations are limited by breeding success and habitat availability, seasonal, semi-natural saltflats may provide supplementary nesting areas which could reduce beach nesting densities and buffer the population impacts of habitat loss. These saltflats are formed by natural tidal inundation as well as anthropogenic dyking or canalization for aquaculture, mangrove reforestation and the creation of salt evaporation ponds. They are sparsely vegetated with mangrove and halophyte vegetation and, because they are only inundated during high-level high tides that occur during the winter, they provide supratidal foraging habitat for a range of wintering waterbirds during low and mid-tides (Velasquez and Hockey 1992, Weber and Haig 1997) and also breeding habitats for species such as Malaysian Plovers, Black-winged Stilts *Himantopus himantopus*, Little Terns *Sterna albifrons* and Red-wattled Lapwings *Vanellus indicus* during the summer when maximum high tides are lower (P. Round, unpubl. data).

To date, apart from anecdotal or census information, few studies have examined the breeding ecology of the Malaysian Plover (Yasué and Dearden 2006a, 2006b, 2006c, 2007) and limited research has been conducted on the habitat use of tropical saltflats by waders in general (Gorman and Haig 2002). In Khao Sam Roi Yod National Park (KSRY), Malaysian Plovers nest either on coastal sandy beaches that are immediately adjacent to tidal mudflats, or on saltflats. Saltflats are beside the sandy beaches (i.e. beaches are located between saltflats and mudflats) and both habitats are available throughout the entire breeding season. Consequently KSRY provides an excellent opportunity to assess the relative habitat value of saltflats.

In this study we compared environmental factors that affect behaviour and breeding success in waders. These factors include thermal stress (Brown and Downs 2003, Amat and Masero 2004a), predation risk (Brook and Tanacredi 2002, Amat and Masero 2004b), flood risk (Round *et al.* 2004) and human disturbance or trampling (Weston 2000, Ruhlen *et al.* 2003). Although foraging quality is another factor influencing habitat selection in waders (Ens *et al.* 1992), this was not examined in our study because both beach and saltflat adults and chicks fed together on the mudflats in front of the beaches.

Thermal regulation of clutches is a key factor influencing avian breeding success (White and Kinney 1974). In tropical environments, waders must shade eggs to prevent overheating (Ward 1990). Air temperatures may be greater on saltflats than beaches because a 5–40 m wide vegetated border between the beaches and saltflats prevents cool oceanic breezes from reaching the saltflats. Adults in hot environments may spend more time attending nests because of the greater need to shade eggs (Carey 1980, Weathers and Sullivan 1981, Ward 1990). Also, birds may alternate incubation duties more frequently between mates during hot weather to reduce excessive heat stress on adults (Ward 1990). There may be higher attendance, higher rates of nest abandonment and lower hatching success on saltflats because unattended nests on saltflats may quickly reach lethal temperatures (Dunning and Bowers 1990, Conway and Martin 2000, Amat and Masero 2004b).

The vulnerability of nests to predators may also differ between the two habitats. The extent of vegetation cover and proximity to water can influence predator density and a nest's vulnerability to predators (Page *et al.* 1985, Burger 1987, Pampush and Anthony 1993, Wolff *et al.* 1999). There may be higher densities of marine predators (e.g. crabs) on beaches and higher densities of mangrove predators (e.g. snakes and mongooses) on saltflats. The dykes or *Acacia* and mangrove bushes that surround most saltflats may lower visibility and reduce an incubating adult's ability see approaching predators. Moreover, nests on saltflats may also be more vulnerable to predators because the vegetation between saltflats and beaches prevents adults that are feeding on the

mudflat from detecting predators approaching the nest. In contrast, due to the open structure of the beach, beach-breeding plovers can simultaneously feed and watch for predators. When predators are detected, *Charadrius* plovers conduct distraction displays or attack predators to reduce predation rates (Gochfeld 1984, Yasué and Dearden 2006a).

Nests located on narrow strips of sandy beach are vulnerable to tidal inundation during very high level tides or storm surges (Eyler *et al.* 1999, Round *et al.* 2004). Saltflat nests are less vulnerable to floods because of the slightly elevated vegetated area between beaches and saltflats. Although the saltflats occasionally flood at very high tides in the winter, during the breeding season they were never inundated by tides at KSRY (M. Yasué, unpubl. data).

Anthropogenic disturbance could also differ between habitats. Beaches are likely to be favoured transportation routes for people, dogs and cattle because they are more accessible, cooler and less vegetated. As a result, beach-nesting plovers may spend more time responding to anthropogenic disturbances and suffer greater clutch mortality due to direct trampling (Melvin *et al.* 1994, Ruhlen *et al.* 2003).

In this study we compared environmental conditions as well as the behaviour and breeding success of Malaysian Plovers on sandy beaches and saltflats to evaluate whether saltflats could provide suitable supplementary nesting habitats and help to reduce the population impacts of beach habitat loss.

Methods

Study area

All data were collected within a 5 km stretch of beaches in Khao Sam Roi Yod National Park ($99^{\circ}58'N$, $12^{\circ}06'E$) in Prachuap Khiri Khan province from 25 April to 25 July in 2004 and 2005. Both beach and saltflat plovers defended 100–300 m long linear territories that consisted of a mudflat (20–400 m exposed at low tide) as well as a 4–80 m wide beach section or saltflat nesting area. Both beach- and saltflat-nesting pairs fed on the mudflats and hid chicks in the vegetated area next to the beach or on saltflats when there were disturbances on the beach. The vegetated area between beaches and saltflats had short shrubby dune vegetation, mangroves, *Acacia* bushes or *Casuarina* trees. Vegetation covered 1–30% of the land surface on the saltmarsh and the size of individual saltflats (as demarcated by dykes and vegetation) ranged from 2,000 m² to 350,000 m². In contrast to the porous sandy beaches, the substrate of saltflats was hard, consolidated mud with a surface layer of evaporated salt.

Nest monitoring

We found nests by searching in areas where pairs were frequently observed or by watching birds return to nests. We also floated eggs in water and measured the diameter of eggs above the surface of water in order to detect embryo mortality, estimating laying date and hatching date based on a 30-day incubation period (Westerkov 1950, Powell 2001, Yasué and Dearden 2006c). We checked the nests every 3–5 days to determine nest survival or cause of failure. Checks were conducted more frequently close to hatching date because of the high mortality rates of very young chicks. If any clutches less than 25 days old disappeared between checks and there was no sign of inundation (destroyed nest structure, tidal debris at nest) or trampling (crushed nest structure and eggs, tracks of vehicles and footprints), we assumed that eggs had been depredated. This was a reasonable assumption because at our study area local people did not collect eggs for consumption. During nest checks we re-sighted adults to ensure that they were still present and to discriminate between desertion and predation as cause of failure (Yasué and Dearden 2006b). Detailed observations of adults and chicks helped us to determine whether nests had failed or succeeded. Adults with failed nests roosted or fed in pairs on the mudflat, whereas adults with young chicks conducted conspicuous distraction displays when we approached the nest-site. We

captured and individually colour-banded chicks within 2 weeks of hatching and returned to the nesting territories weekly to assess chick survival up to 30 days. Assessing fledgling success was not difficult because plovers did not move more than 300 m from their nest-sites. Family groups could be identified because at least one of the chicks or adults was individually colour-banded. The majority of adults were caught and banded either during the preceding winter, summer or on nests using noose mats or funnel traps (number of banded adults and chicks: 72 and 94, respectively; Mehl *et al.* 2003).

In total we monitored 21 and nine nesting attempts in 2004 (beaches and saltflats, respectively) and 26 and 22 nesting attempts in 2005.

Nest observations

We recorded shaded air temperature using a mercury thermometer at a height of 20 cm above the beaches and saltflats several times during the day throughout the course of the study.

We continuously watched incubating plovers using a 15–45 × spotting scope or 10 × 50 binoculars for 1–2 hours (mean length = [mean ± SE] = 81 ± 3.2 min) from either a hide or a seated position on the mudflat or elevated position within saltflats located more than 100 m from the plovers. One hundred and twenty incubation watches were conducted on 55 different nests between April and July in 2004 and 2005. No incubation watches were conducted on the same pair on the same day.

Malaysian Plovers are biparental incubators and the male and female alternate incubation duties throughout the day (Yasué and Dearden 2007b). During incubation watches we recorded the time when each of the parents arrived or left the nest. Attendance was the proportion of time the clutches were incubated by either bird. We also recorded the total number of times the sexes alternated incubation duties and the total number of times either adult left the nest during incubation watches. We standardized values to hourly values.

For nests in which we conducted replicate observations, we calculated mean values for the three incubation behavioural variables and used aggregated values in statistical analysis. However, we considered multiple nests of the same pair as independent. This is because incubation behaviour is influenced by several factors such as nest location and microclimate, weather and time of year that vary between different nesting attempts of the same pair (Carey 1980, Amat and Masero 2004b). The variability in incubation behaviour that results from these factors is likely to be more important than variability that occurs between individual pairs. However, as some pairs nested on both saltflats and beaches in a single year, this may have made our results less likely to detect differences between the habitats.

Vulnerability to predators and flooding

By crouching to the height of a Malaysian Plover, we visually estimated the percentage of the circumference around the nest where an incubating plover would be able to detect an approaching predator 20 m away. Percentage visibility from nests affects both clutch survival and the predation risk on adults incubating clutches (Wiebe and Martin 1998, Amat and Masero 2004b). Plovers rely largely on sight to watch for predators and early detection of predators allows adults to distract predators away from nests to increase hatching success (Amat and Masero 2004b). We also measured the distance from the nest to the nearest contiguous vegetated area (either the start of the vegetation line adjacent to the beach, or the closest vegetated boundary of the saltflats). This is because predators such as raptors can use vegetation cover to approach and ambush waders (Wolff *et al.* 1999, Dekker and Ydenberg 2004). We also measured the distance from the nest to the nearest high-tide line, based on the location of the strandline and the presence of tidal debris on the beach, in order to assess flood risk. For this analysis, if a single pair of plovers nested more than once on the beach or saltflat in a year, we used mean values of the different nesting attempts in each of the two habitats.

Disturbance responses

We quantified anthropogenic (people, dogs, cattle and vehicles) and natural (predators such as raptors, mammals and crabs, false alarms) disturbance responses by recording the type of disturbance stimuli and the length of time of the adults' response during incubation watches. Birds were categorized as disturbed if they were exhibiting anti-predatory behaviour such as neck-outstretched vigilance posture, flushing onto the mudflat, 'rat-running', chasing intruders, calling to distract predators, false brooding or crouching (Gochfeld 1984). The amount of time birds responded to disturbances was standardized to minutes per hour. Occasionally we were not able to detect the stimuli causing the disturbance response of birds. These disturbances were categorized as 'natural disturbances' because anthropogenic stimuli such as cars, people or dogs are unlikely to be missed, whereas natural disturbance stimuli such as cryptic predators or false alarms may be much harder to detect. Frequently birds responded to the rapid flights of other waders or to fish-eating raptors such as Osprey *Pandion haliaetus*.

The disturbance measure we used in this study was based on the response of the birds, rather than on the frequency of potential disturbance stimuli. Comparing disturbance stimuli was difficult for this study (e.g. the number of people or predators that approach the nest per hour) because the ability of plovers to detect predators probably varied between the two habitats. Moreover, we were able to see very few predators during our study and it is unlikely that we would be able to detect predators in a standardized way without relying on cues from the behaviour of the birds.

For nests in which we conducted replicate observations, we calculated mean values for the anthropogenic and natural disturbance rates and used aggregated values for statistical analysis. We did not pool data between different nesting attempts of the same pair because there is likely to be greater variability between nesting attempts due to seasonal changes in predators (DeCandido *et al.* 2004) or human disturbance rates and weather rather than between individual pairs.

Statistical analysis

We used a paired *t*-test to compare the temperature between the beach and salt ponds that were taken in the same hour and within 500 m. If multiple measurements were taken in each habitat during an hour we compared mean values.

For all comparisons of habitat characteristics, behaviours and disturbance rates between beach and saltflats we used a Mann–Whitney Test of Independent Samples because data could not be normalized using standard data transformations. We conducted analysis for the two years separately to reduce pseudoreplication because several pairs nested at our site in both years.

We calculated hatching success based on the daily exposure method (Mayfield 1961). A nest that hatched at least one chick was considered 'successful' in this study. If a single pair laid more than one clutch on a beach or saltflat site in the one year, we randomly sampled one of these nests for the Mayfield calculations. Consequently, although a total of 37 and 52 nests were monitored in the two years, our Mayfield nest probabilities were based on 26 and 41 nests. We used a two-sided Fisher's Exact Test to compare hatching success between the two habitats (Dow 1978, Johnson 1979) because this is more robust to low sample sizes than the chi-squared test.

All error estimates presented are standard errors.

Results

Although temperature was slightly higher on the saltflats (34.0 ± 0.3 °C) than on the beaches (32.2 ± 0.3 °C) (paired *t*-test: $t = -8.7$, $n = 71$, $P < 0.0001$), there was no significant difference in the number of parental changes in incubation duties, number of times an adult left the clutch during an incubation observation, or nest attendance (Table 1).

Table 1. Results of Mann–Whitney tests comparing incubation behaviour for beach and saltflat breeding habitats.

	Year	Z	P	Pooled mean
Nest attendance (proportion)	2004	-0.9	0.391	0.6 ± 0.1
	2005	-0.2	0.885	0.6 ± 0.1
Number of incubator changes (h^{-1})	2004	-0.3	0.776	0.8 ± 0.2
	2005	-0.2	0.823	0.9 ± 0.2
Number of adult clutch departures (h^{-1})	2004	-1.7	0.087	1.6 ± 0.3
	2005	-0.4	0.712	1.9 ± 0.2

Sample sizes for beaches and saltflats were $n_{\text{BE}} = 15$ and $n_{\text{SF}} = 8$ for 2004 and $n_{\text{BE}} = 27$ and $n_{\text{SF}} = 19$ for 2005

Saltflats were significantly further from the high-tide line and from contiguous vegetation than the beach nests. However, there was no significant difference in percentage visibility (Table 2).

Anthropogenic and natural disturbance rates were generally very low for both habitat types (pooled anthropogenic and natural disturbance rates 2004: beach, $3.6 \pm 0.8 \text{ min h}^{-1}$; saltflat, $2.2 \pm 0.3 \text{ min h}^{-1}$; 2005: beach $0.85 \pm 0.3 \text{ min h}^{-1}$; saltflat, $0.33 \pm 0.3 \text{ min h}^{-1}$). Anthropogenic disturbance rates were higher during incubation watches on beach nests in 2005 ($z = -2.4$, $P = 0.019$, $n_{\text{BE}} = 33$, $n_{\text{SF}} = 22$; beach, $0.7 \pm 0.3 \text{ min h}^{-1}$; saltflat, $0.3 \pm 0.3 \text{ min h}^{-1}$) but not in 2004 ($z = -0.35$, $P = 0.750$, $n_{\text{BE}} = 20$, $n_{\text{SF}} = 10$; pooled mean = $2.0 \pm 0.62 \text{ min h}^{-1}$). The main sources of anthropogenic disturbances were local fishermen, cattle or motor vehicles. We only detected two disturbance responses caused by natural predators on saltflats. Consequently, we did not conduct tests to compare natural disturbance rates between the two habitat types.

Plovers responded to humans, dogs and mongooses in the same way. Beach plovers would sneak away from the nest and run onto the mudflat or 20–30 m away from the nest along the beach. Then they would approach or circle the disturber, call, feign injury or false brood (Gochfeld 1984, Montgomerie and Weatherhead 1988). When the disturber began to walk away, plovers continued to follow the disturber for 30–100 m from the nest. Eventually the plovers would run back out to the mudflat directly in front of the nest, and then discreetly and quickly return directly to the nest. Saltflat birds responded to people in a similar way. If the people were on the beaches adjacent to their nesting territory, saltflat birds would frequently fly out onto the mudflat or beaches to conduct distraction displays. If people walked along the saltflat, then birds tended to display on the saltflat and try to lead the person onto the mudflat or beach. When approached by cattle or motor vehicles, plovers tended to remain either on the nest or stay on the nest until the disturber had approached within 5–10 m of the nest. Then beach plovers would run quickly onto the mudflat directly in front of the nest before returning to the nest. Saltflat plovers did not fly to the mudflats, but rather ran 30–50 m away from the nest and conducted

Table 2. Results of Mann–Whitney comparisons of conditions contributing to predation and flood risk for beach and saltflat breeding habitats.

	Beach	Saltflat	z	P
Visibility (%)	2004	52.8 ± 3.5	-1.0	0.312
	2005	50.3 ± 3.2	-0.6	0.588
Distance to vegetation (m)	2004	6.9 ± 1.1	13.3 ± 2.8	-2.0
	2005	9.8 ± 4.5	18.6 ± 7.2	-2.1
Distance to tide line (m)	2004	6.7 ± 0.9	32.2 ± 9.5	-2.6
	2005	10.2 ± 1.6	37.5 ± 3.8	< 0.001

$n_{\text{BE}} = 17$ and $n_{\text{SF}} = 9$ for 2004 and $n_{\text{BE}} = 23$ and $n_{\text{SF}} = 14$ for 2005.

Significant results are in bold.

distraction displays within the saltflat environment. When ghost crabs (*Ocypode* spp.) approached the nest on beaches, plovers would chase the crab, extend and bat their wings, or feign injury within 1 m of the crab. When responding to a peregrine falcon or a false alarm caused by another bird, plovers would remain on the nest, crouch and look up (Gochfeld 1984).

Breeding success and re-nesting behaviour

There was no significant difference in hatching success between the two habitats in 2004 (Fisher's Exact Test, $n = 26$, $P = 0.692$) or 2005 ($n = 41$, $P = 0.539$; Table 3). We could not use a Pearson's chi-squared test to assess whether the number of nests that failed due to flooding, desertion, or predation varied between the two habitats due to low cell counts in contingency tables (Dow 1978) and so we present a descriptive graph of the causes of nest failure in the two years.

Nine nests failed on the beaches and none on the saltflats due to tidal inundation (Figure 1). Tidal flood risk was higher on beaches than saltflats because, in our study area, beaches were

Table 3. Mayfield nest success calculated from nest daily survival rates.

	Total nests found	Total nests failed	Nests found	Nests failed	Mayfield nest-days	Nest success
2004						
Beach	26	9	17	5	357	0.65 ± 0.13
Saltflats	11	5	9	4	207	0.55 ± 0.17
2005						
Beach	31	14	24	10	407	0.46 ± 0.11
Saltflats	21	12	17	10	298	0.35 ± 0.12

Total nests found and failed include multiple nests from the same pair in the same habitat (columns 1 and 2 from left). Nest success was calculated based on nest survival by sampling one of the nests of the same pair in each habitat (columns 3 and 4). Nests succeeded if they hatched at least one chick.

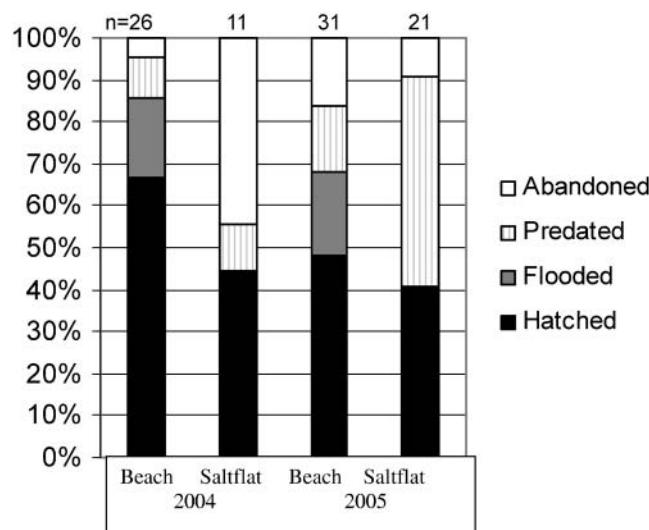


Figure 1. Cause of nest failure for beach and saltflat nests in 2004 (left bars) and 2005 (right bars). Sample sizes for each of the bars are denoted above each column.

between the saltflats and the tidal edge so any tide inundating the saltflat would also inundate the beach habitat. The one saltflat nest that did fail because of flooding did so during a period of intense rainfall in May of 2004 (90 mm in 2 days), the greatest rainfall in a 24 hour period between May and August since at least 1994 according to a national meteorological weather station in Hua Hin city, $99^{\circ}57'N\ 12^{\circ}36'E$). Water could not penetrate through the surface layer of the saltflat and pooled on it. This type of flooding is unlikely to be significant source or mortality in most years because of the rarity of such intense rainfall during the breeding season. No beach nests were flooded by rain and no other saltflat nests were flooded, despite moderate rain in 2004 and 2005 (15–20 mm in 1 day).

For most of the suspected depredated nests, entire clutches disappeared between checks and we were unable to identify the predator (Yasué and Dearden 2006b). We saw Small Indian Mongoose *Herpestes javanicus* on three occasions (twice on beaches, once on saltflats) in our study area and terns and Malaysian Plovers exhibited intense anti-predation responses. On six occasions we observed *Ocypode* ghost crabs apparently attempt to predate clutches on beaches. Adult plovers responded by attacking and chasing crabs. Corvids, gulls or other known diurnal avian *Charadrius* plover nest predators (Mayer and Ryan 1991, Lauro and Tanagredi 2002) were never observed searching for nests during the course of our study.

There were approximately 100 pairs of Little Terns *Sterna albifrons* sharing the saltflat with Malaysian Plovers in KSRY. In 2005 there were three nest checks in which entire clusters of five to 20 Little Tern and a few Malaysian Plover nests (within 1 km of each other) were found to be depredated on the saltflats. Predation rates appeared to be marginally higher on the saltflats in 2005 (Figure 1).

After very low success rates at the start of the 2005 breeding season, a significant proportion (58%) of the birds re-nested after failed breeding attempts. In 2005, seven of the 12 pairs that nested on saltflats, also nested at least once in the beach habitats. In 2004, three out of four of the pairs that re-nested, nested in both habitat types in the same year.

We could not compare fledging success rates (the proportion of hatched chicks that fledged) between the two habitats statistically in this study because of insufficient sample size. However, we believe that it was more important to focus on differences in nest success because *both* beach- and saltflat-nesting plovers reared chicks on mudflats, beaches and saltflats. In 2004, 81% ($n = 16$) and 80% ($n = 5$) of nests that hatched chicks, fledged chicks on the beach and saltflats, respectively, while in 2005 10% ($n = 21$) and 17% ($n = 6$) of the successful nests fledged chicks in the two habitats. It appeared that fledging success rates differed more between years rather than between nesting-habitats.

Discussion

Saltflats as supplementary breeding habitats

The results suggest that saltflats may provide suitable nesting habitat for Malaysian Plovers. Contrary to our predictions, there was no evidence indicating that thermal stress or predation risk was greater for birds breeding on saltflats. Environmental conditions on saltflats did not differ from beaches enough to affect Malaysian Plover breeding behaviour or hatching success.

In comparison with most other beaches in the Gulf of Thailand, disturbance rates were very low at KSRY and there was no evidence of direct trampling of eggs by people in our study area. We did find trampled nests in concurrent studies on other beaches in the Gulf of Thailand (Yasué and Dearden 2006b). Human disturbance on beaches is thought to limit the size of breeding populations of Malaysian Plovers (Baillie *et al.* 2004, Yasué and Dearden 2006b) and other related *Charadrius* plovers (Flemming *et al.* 1988, Ruhlen *et al.* 2003, Weston and Elgar 2005). Disturbance may be a more important difference between these two habitat types on beaches used more by tourists and the relative importance of saltflats to Malaysian Plover conservation may be greater in other coastal areas of Thailand.

Previous research on *Charadrius* plovers demonstrated substantial annual variability in breeding success due to changes in environmental or ecological conditions (Lauro and Tanagredi 2002, Wallander and Andersson 2003). Annual variability in maximum temperatures, beach morphology, maximum water levels and flood-risk, or the presence of a highly effective wide-ranging predator in one of the habitats, could influence relative nesting success on sandy beaches and saltflats (Burger 1987, Koenen *et al.* 1996). For these reasons, more studies over several years would be necessary to evaluate the generality of these results.

Based on site visits to beaches along both eastern and western coasts of Thailand, and interviews with local bird-watchers and Thai academics (M. Yasué, unpubl. data), KSRY National Park had one of the highest densities of Malaysian Plovers in Thailand. This park may be favoured by plovers because it is one of the few areas where semi-natural saltflats still exist next to beaches and have not been replaced by roads, housing or tourism development. At KSRY both beaches and saltflats are available and plovers can adjust habitat choice depending on current environmental conditions such as maximum water height or predation risk (Amat and Masero 2004b). The ability to select different habitat types within a breeding territory may be particularly important for Malaysian Plovers because adults appeared to return to the same territory between years (M. Yasué, unpubl. data).

At present even pairs that nested on saltflats tended to spend most of the chick-rearing period on beaches. This is probably related to the proximity of the beaches to high-quality feeding areas on the mudflats. Thus Malaysian Plover populations may still depend on the protection of beach habitats. However, chicks sometimes fed on saltflats and other *Charadrius* plovers are known to feed in similar saltflat habitat (Warriner *et al.* 1986, Koenen *et al.* 1996, Masero *et al.* 2000). Habitat management on saltflats and the removal of some of the dykes or erosion-prevention structures that have been created for aquaculture or salt-production ponds in the past, may improve chick-rearing habitat quality and could allow chicks to be reared on saltflats.

At our site, it appeared that density-dependent reduction in breeding success occurred during the nesting stage (Yasué and Dearden 2006b) and it is possible that adults moved chicks onto the beaches because they are more able to tolerate higher densities when rearing chicks. In addition, plover densities on beaches during chick-rearing may still be below carrying capacity even including chicks from both beaches and saltflats because so many breeding attempts fail at the nesting stage. Additional studies on how saltflats are used by chicks, and how breeding densities during chick-rearing stages affect success, are necessary to assess whether saltflats can help buffer the population impacts of beach habitat loss.

The potential to conserve saltflats and the restoration of aquaculture ponds

Although there are currently few remaining semi-natural saltflats in the Gulf of Thailand, there may be greater potential for conservation of saltflats than beach habitats for two reasons. First, compared with sandy beaches, there is much greater government support for saltflat and wetland conservation in Thailand (Thongchai 1998, Erftemeijer and Lewis 1999, Stevenson *et al.* 1999). The recent enhanced awareness of the economic and ecological value of mangrove forests has led to saltflat restoration or reforestation initiatives (Macintosh 1996, Balmford *et al.* 2002). Secondly there may be lower financial costs for governments to conserve saltflats because there are currently vast areas of abandoned and naturalizing shrimp (*Peneaus monodon*) ponds in the Gulf of Thailand (Office of Environmental Policy and Planning (OEPP) 1994, Potaros 1995, Flaherty and Vanderveest 1998) and throughout Asia (Sammut and Mohan 1996, Yap 1997) that could be naturalized into saltflats (Stevenson *et al.* 1999). In the 1980s, mangrove forests, natural saltflats and salt-evaporation ponds were rapidly converted into high-density industrial tiger prawn aquaculture ponds (Parr *et al.* 1993). However, water pollution, environmental degradation and disease lead to very high prawn mortality rates and proprietors generally abandoned ponds after 3–7 years of use to seek out new areas to construct ponds (Enright 1995).

The majority of the coast in KSRY is dominated by aquaculture ponds of which 70–80% are no longer in use (Parr *et al.* 1993, Enright 1995, Stevenson *et al.* 1999). With deep sloping banks preventing any tidal inundation and no vegetation, these disused aquaculture ponds provide none of the wildlife values of the former natural coastal habitats. Park managers or conservation organizations could rehabilitate these ponds into semi-natural saltflats to create habitat for plovers and other waterbirds to feed and rear chicks. Removing dykes and allowing partial tidal inundation would help increase invertebrate prey densities and promote natural regeneration of wetland vegetation (Elphick and Oring 1998). Restoration may have tremendous conservation value because KSRY is the only National Park in Thailand with a significant population of Malaysian Plovers. In addition to resident species, KSRY has one of the highest densities of migratory waders in the Gulf of Thailand and the saltflats at KSRY provide important supratidal foraging areas for these birds (M. Yasué, unpubl. data).

The ability of Malaysian Plovers to use abandoned shrimp ponds for both nesting and fledging habitat was demonstrated on one beach 15 km south of KSRY. In July 2004, after illegal aquaculture operations were closed, these ponds were partially drained and allowed to naturalize. In contrast to other aquaculture ponds in the region abandoned several years ago, these ponds still had permanent pools of water covering 5–15% of the total area and short shrubby vegetation. In 2005 two pairs of plovers nested and fledged chicks in these aquaculture ponds. Although adults still fed on the mudflats, chicks fed exclusively within the disused aquaculture ponds around the water pools.

Despite the potential for habitat rehabilitation of aquaculture ponds, the availability of these abandoned aquaculture ponds still depends precariously on the lack of alternative lucrative land uses. There were several new resorts built near aquaculture ponds in 2005 within Prachuap Khiri Khan and Petchburi provinces. Without effective protection and active habitat rehabilitation, it is likely that these disused aquaculture ponds will be quickly converted to houses, resorts or roads and lost as potential habitats for birds (Kontogeorgopoulos 2004). Furthermore, managers of protected area have become accustomed to viewing abandoned ponds purely as an environmental problem rather than as potential areas for biodiversity conservation. This research suggests that ponds also offer considerable potential to help augment breeding habitat for certain species if active management measures are taken to assist this process. Given the area covered by abandoned ponds in South-East Asia and other areas of the tropics, the cumulative effects of rehabilitation on conservation could be substantial.

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