Shorebird disturbance on the beaches of Roebuck Bay, 2005-2006: Conservation implications and recommendations.

A report by Broome Bird Observatory for the WA Department of Conservation and Land Management, NHT and the Shorebird Conservation Project / WWF-Australia.

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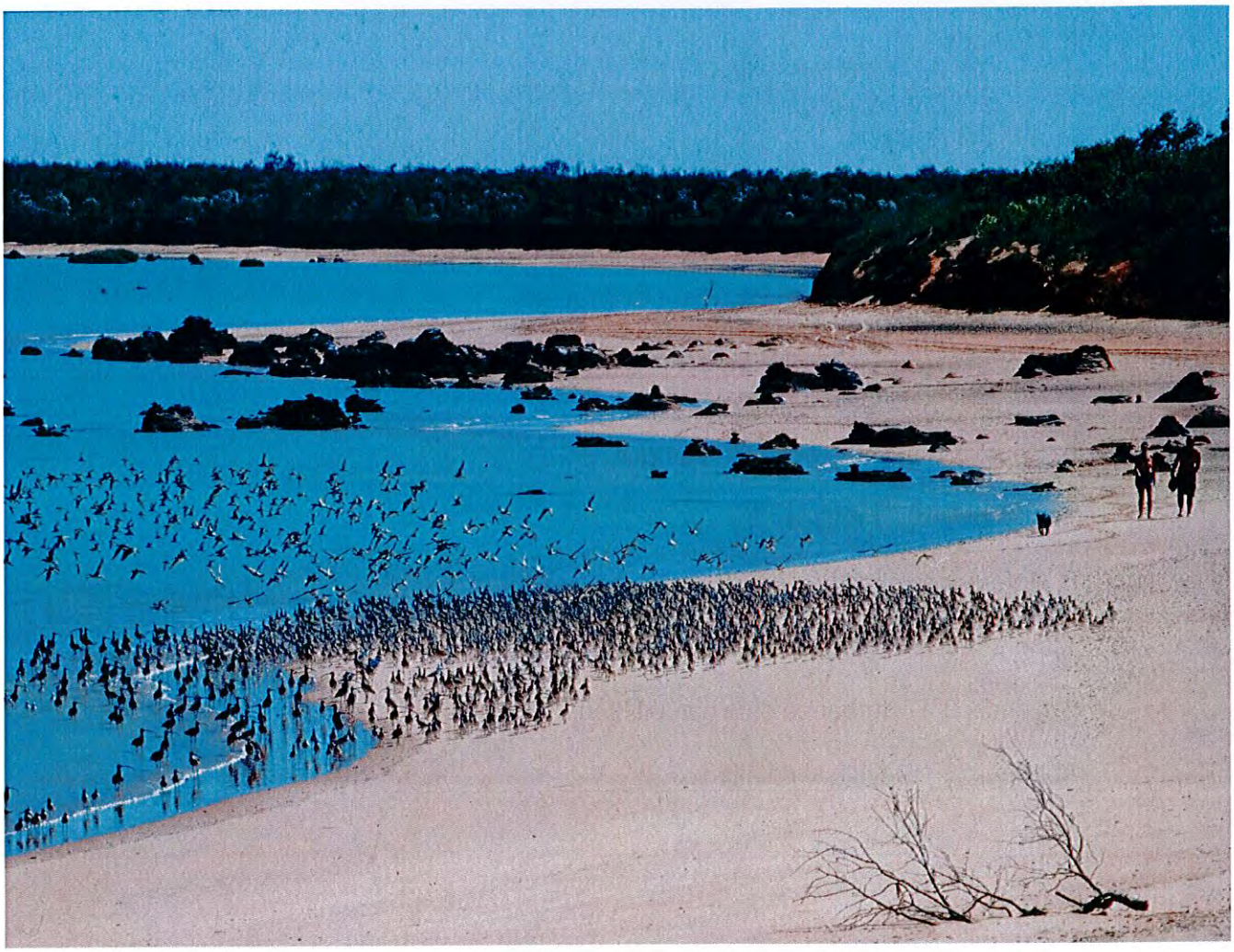

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1. Summary

Roebuck Bay, on the shores of North-western Australia, is an internationally important area for a number of migratory shorebird species. These small to medium-sized birds (sandpipers, plovers and allies) nest in the northern hemisphere and migrate annually to non-breeding sites such as Roebuck Bay. Australia has ratified a number of international shorebird conservation treaties and has a legal obligation to protect migratory shorebirds and their habitats.

The shorebirds of Roebuck Bay are specialised to feed on intertidal mudflats at low tide. At high tide rising waters force the birds from their feeding grounds to sites known as roosts. The beaches along the northern shores of Roebuck Bay are particularly important roost sites, and previous studies have shown that they are the only daylight roosting option available for shorebirds in the north of the bay when weather conditions are dry and tides are between 6 and 8.2 m high (i.e. on about half of the daytime high tides in the bay).

Shorebirds on the northern beaches of Roebuck Bay experience high levels of disturbance. This is potentially of conservation concern, because of the lack of alternative roost sites, and because migratory shorebirds face tight energy budgets; if too much energy is used up at roost sites it may become impossible to shorebirds to build up the stores required for migration. Modelling of the energetic costs of shorebirds in Roebuck Bay indicates that excessive roost disturbance could easily cause population declines.

Broome Bird Observatory carried out a study of disturbance on the northern beaches or Roebuck Bay from May 2005 to April 2006, co-ordinating a team of volunteers who twice a month recorded disturbance levels systematically at five beaches. Causes of disturbance were identified, and human use of the northern beaches was also investigated.

The study confirmed that disturbance levels are high. Controlling for a number of factors that influence disturbance levels, a multivariate analysis showed that disturbance levels are highest in the dry season from about May to August. Disturbance levels have increased slightly since a previous study carried out from 1997 to 2000. The main cause of disturbance was birds of prey, but people were also a major cause of disturbance.

A large proportion of the beach-users at Roebuck Bay were local residents; they and tourists visited the bay for a variety of reasons, with fishing predominating. Bird-watching, cultural activities (over half of the Broome residents visiting the bay identified themselves as Aboriginal) and sight-seeing were also important activities. Beach-walkers caused a disproportionate amount of shorebird disturbance, but beyond that, no one activity could be identified as more intrusive than any other. However, all activities caused some disturbance. Most of this disturbance was unintentional. In general beach-users were not well informed about the importance of the northern beaches as roost for shorebirds, and were thus unaware of the damage that can be caused by disturbance.

We consider the disturbance levels on the northern beaches to be worrying, but not yet critical because disturbance levels are only dangerously high from May to August, a time of year at which shorebird populations are naturally low. We make a number of recommendations to limit shorebird disturbance on the northern beaches. In the short term we propose that Crab Creek road shuld remain unsealed; working with Yawuru traditional owners to limit vehicle access onto beaches away from recognised boat ramps; continued monitoring of disturbance levels and also of birds of prey; and more public education about conservation of shorebird roosts. If these measures do not reduce shorebird disturbance levels over the next three years, more intrusive measures to control shorebird disturbance may be required, notably engineering works or re-routing of roads to restrict human access. Such actions would carry the risk of causing public resentment, and would require extensive consultation.

2. Introduction

Roebuck Bay is world-renowned as an important non-breeding site for migratory shorebirds (van de Kam et al. 2003). These small to medium sized birds (sandpipers, plovers and allies) nest at high latitudes in the northern hemisphere, and migrate annually to non-breeding grounds thousands of kilometres away. Many shorebird species are specialised to feed on intertidal flats at low tide during their non-breeding period, and thus have restricted non-breeding ranges. Roebuck Bay is one of the premier non-breeding sites for shorebirds in Australia. Only two sites in Australia hold larger numbers of shorebirds, and none have such a high diversity of shorebirds occurring in internationally important numbers. By ratifying a number of international conservation agreements designed to (e.g. Ramsar, JAMBA, CAMBA), Australia has accepted an obligation to protect migratory shorebirds and their habitats, notably through compliance with the *Environment Protection and Biodiversity Conservation Act 1999*.

This report focuses on the conservation of shorebird roosts on the northern beaches of Roebuck Bay. Roost studies in Roebuck Bay over the last few years have demonstrated that these beaches are of considerable conservation importance. They hold large numbers of shorebirds, and on tides of intermediate height (about 6.0 to 8.2 m) they are the only potential roost site that can be used by shorebirds in the north of Roebuck Bay.

The northern beaches of Roebuck Bay are well known to people in the Broome region, and they are often visited by birdwatchers, anglers and other people. The town of Broome, on the north-west shores of Roebuck Bay, is growing rapidly, and this likely to increase levels of human visitation to Roebuck Bay. Humans on the beaches of Roebuck Bay can cause disturbance to shorebirds, and previous studies of disturbance on the beaches of Northern Roebuck Bay (made between 1997 and 2000; Rogers et al. 2006b and D Rogers unpubl.) have indicated that disturbance levels are high.

High disturbance levels to migratory shorebirds are of conservation concern. Migratory shorebirds face tight schedules in the course of their annual cycle, and have to live within tight energy budgets. Increase energy expenditure at roost sites on the non-breeding grounds could prevent shorebirds from building up the enormous fuel stores required for successful migration. Modelling of the energetic costs of roosting in Roebuck Bay (Rogers et al. 2006b) has shown that disturbance costs could become high enough to force shorebirds to abandon the north of Roebuck Bay.

In view of the concern that shorebird disturbance lvels in Roebuck Bay may be dangerously high, and increasing, Broome Bird Observatory initiated a disturbance study in Roebuck Bay. The catalyst for the project was a grant of $10,000 from the Western Australian Department of CALM, subsequently "topped up" by an additional National Heritage Trust grant obtained through the shorebird conservation project of WWFAustralia.

The study was carried out in 2005-2006, and the results are presented in this report. We assess how much disturbance occurs on the northern beaches of Roebuck Bay,

and how this level varies with time of year and site; we assess the causes of disturbance, and we assess whether disturbance levels have increased in the last few years. In addition we studied human beach-users on the northern beaches of Roebuck Bay, in an attempt to find out how many people actually use the beaches, and what their reasons for visiting are.

On the basis of these data, we put forward recommendations for future management of the northern beaches of Roebuck Bay. We stress that these recommendations are specifically focussed on disturbance at high tide roosts. In seeking feedback on this project, we were frequently asked what the effects of the Broome Hovercraft were on shorebird disturbance. This is a low tide issue, and we did not collect any information about it in the course of this project.

3. Methods

3.1 Project organisation

The project was designed, and the data analysed, by Danny Rogers. An initial workshop was jointly organised and conducted by Chris Hassell, Danny Rogers, Neil McKenzie and Jan Lewis to introduce volunteers to the study and train them in data collection techniques. Chris Hassell co-ordinated the fieldwork, assembling teams of volunteers, ensuring data were collected in a consistent manner and entering data. Chris Hassell and Neil McKenzie (cultural advisor) conducted a series of interviews of beach users on each survey. Jan Lewis was involved throughout, especially in preparation of the project and completion of the final report.

3.2 Data collection

Surveys were conducted twice every month from May 2005 to April 2006. Surveys began two hours before the peak of high tide, and were concluded two hours after the peak of high tide. In each month, one of these surveys was carried out on a weekday, the other on a weekend. On a few surveys data could not be collected at all sites because of a shortage of volunteers. Volunteer availability was most limited in the wet season, when disturbance happened to be low anyway.

Surveys were carried out on five beaches (Fig. 1), selected because (1) These were all known to be sites where shorebirds roost regularly, thus allowing adequate samples to be built up; (2) they were considered representative of the range of variability in disturbance levels that occur on the Northern Beaches. In this report we have used the site names generally used by birdwatchers. Traditional names are also given (in parentheses) below, but in some cases the names refer to broader areas than the specific beaches that shorebird observations were focussed on.

From East to west, the sites where we collected data were:

1. Crab Creek Beach (Murragingun). A broad sandy beach, backed by low vegetated dunes, 0-1 km west of the Crab Creek Mangroves; according to the position of roosting shorebirds observations were made from sites known to birdwatchers as "Sandy Blowout", "Stilt Viewing" and "The Boiler". During the wet season this beach often holds more roosting shorebirds than any other site on the northern shores of Roebuck Bay, but it varies and sometimes holds no shorebirds at all, especially during the dry season. It is easilu accessed from crab Creek Road, which runs only a few metres behind the beaches, and is a popular fishing area, especially when threadfin salmon are running during the dry season.
2. Wader Beach (Gurlbinwula). A reasonably narrow beach, rocky in places, backed by 5-10m high red laterite cliffs. Once often used as a boat-launching area, but vehicle access to the beach was closed by Broome Shire council (in consultation with Broome Bird Observatory and the Rubibi) in the late 1990's. Crab Creek runs reasonably close to this beach, but human access to the beach involves a short walk over broken ground. The beach is used fairly consistently as a roost by moderate numbers of shorebirds (often in the low

thousands), but tends to be avoided on higher tides when it becomes very narrow.

3. Campsite Beach (Gurdidi Ngurnu). A moderately broad sandy beach, backed by red laterite cliffs about 10 m high. It is a relatively secluded roost; Crab Creek Road is some 50m behind the cliffs; there are some minor tracks allowing vehicles to approach the cliff edge if they take a detour, but access onto the beach is only possible for people on foot who are prepared to scramble down the cliff. Numbers of shorebirds using this roost vary, but at times (especially during the dry season) it can hold large numbers, up to 10,000 shorebirds. It tends to be avoided on higher tides when roosting shorebirds are forced into narrow areas between the waterline and the cliffs.
4. Quarry Beach (Bingaja). A broad sandy beach, partly backed by low vegetated dunes and partly backed by low red cliffs. The beach is often visited by people, some associated with a house at the junction of the All-weather Road with Crab Creek. It is a reasonably popular fishing area, and also receives casual visitors, as the east end of the beach is the first point of access to Roebuck Bay for people driving to the bay via the all-weather Road to Crab Creek Road. Formerly used as a boat launching site, the traditional point of vehicle access to this beach (at the eastern end) has now been closed off. Nevertheless, some vehicles do still reach this beach, accessing the beach from an access track about 2 km to the west and then driving along shore to Quarry Beach itself. Vehicles using this route thus travel through the western end of the beach, which would otherwise only be easily access by people if they were prepared to walk a reasonably long way. Quarry Beach is consistently used by roosting shorebirds, and is considered of particular importance on higher tides, when it is one of the few northern beaches that remains broad enough to be a suitable roost.
5. Simpson's Beach (apparently no traditional name exists). This broad sandy beach, backed by high sand dunes, lies between Broome Port and Town Beach. Although this beach is in Broome, and reasonably close to all-weather bitumen roads, the only ready access points to the beach are from the southern end (at the commercial Hovercraft launching site) and from the north (at Town Beach). A moderate number of visitors nevertheless walk along Simpson's Beach from these access points. The beach also has unusual numbers of birds of prey in the dry season, when as many as 250 Black and Whistling Kites have been seen there. In the wet season Simpson's Beach often holds good numbers of roosting shorebirds (counts of 3,000 shorebirds are typical), but in the dry season shorebird counts there are very low.

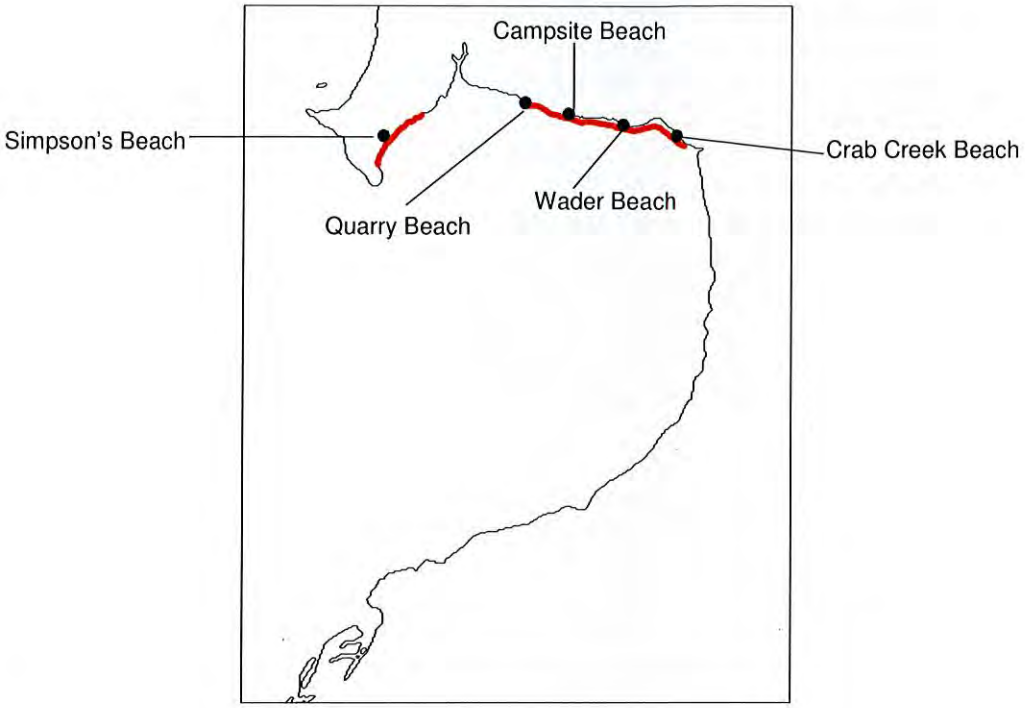


Fig. 1. Roebuck Bay; the red lines depict the northern beaches of the bay, and sites where disturbance observations were made are indicated.

Data were collected by volunteers (see Acknowledgements). Whenever possible we positioned two volunteers at each site. Volunteer availability was low in the wet season, but by this stage of the study most volunteers were experienced in the data collection procedures, and a single observer at each site could collect adequate data.

Observations were made from vantage points at which most or all of a shorebird roosts could be scanned without causing disturbance to the shorebirds under observation. It was not always easy to avoid causing disturbance, because shorebirds sometimes moved during the course of the observation period, settling at points closer to the observers than was desirable.

Two kinds of data sheet were filled in by all observers (Appendix 1). The core activity was systematic recording of shorebird disturbance. Every 10 minutes observers carried out a scan, recording the number of shorebirds present, and the percentage of these birds in flight. These regular scans were used to calculate the amount of time that shorebirds spent in disturbance flights at high tide. In addition observers recorded any disturbances or flights noted at any time, allowing us to calculate the number of alarm flights per hour. Not all flights were caused by disturbance (some were natural movements caused by the tide). Flights were classified as alarm flights if birds towered or gave alarm calls when they flew, or if there were other reasons to

believe they had taken off due to disturbance. The perceived cause of alarm flights was recorded whenever it could be identified.

Observers also recorded all people that they saw on their site during the observation period. The number of people observed, their times of arrival and departure, and their apparent activity were recorded. Brief descriptions of the people seen were made to avoid double counting, and so we could tell whether or not these people had been interviewed.

Beach users were interviewed whenever possible. Some interviews were carried out by the observers recording disturbance, especially at Simpson's Beach. Whenever possible though, interviews were conducted by a mobile team consisting of Chris Hassell and (when available), Neil McKenzie. This mobile team also dropped in regularly on the volunteer observers to ensure that data were being collected in a consistent manner between teams. The questionnaire used during the interviews was designed to find out how often, and why, people visited the beaches of Roebuck Bay; to find out how familiar they were with shorebirds and the problems posed by disturbance; and to find effective methods of public education about shorebird conservation. An equally important, though less formal objective of the interviews was to educate beach-users about disturbance of shorebird roosts.

3.3 Data analysis

The data collected were used to construct two indices of disturbance levels. The index most often used in this report was the number of alarm flights per hour. We also calculated the amount of time spent in alarm flights by an individual per hour. In doing this we restricted analysis to data collected in the regular scans made at ten-minute intervals; it was assumed that this gave us a satisfactory representation of the percentage of time that an individual spent airborne per high tide. The amount of time spent in alarm flights is a fairly direct measure of the energetic costs of a roost. However, there was potentially some error in this calculation, as it was based on counts that had to be made quickly.

Both of the above indices tended to underestimate the amount of disturbance caused, especially by people. Disturbance indices could only be calculated at sites where shorebirds were present, so our dataset was skewed against sites that were so heavily disturbed that they had been abandoned by shorebirds. This level of disturbance may have been caused by birds of prey on some occasions (especially at Simpson's Beach) but was more likely to be caused by people. Birds of prey tended to visit a site briefly, moving to another if few shorebirds were present. People made longer visits, often remaining on the beach for hours; simply by being there they prevented shorebirds from settling nearby.

Disturbance levels were influenced by a number of factors – day of the week, time of year, numbers of shorebirds present at a roost, and tide height. In order to unscramble these different effects we constructed a multivariate disturbance model (Appendix 2) using linear regression. GLM models made using Systat 10 generated identical results.

4. Results

We expressed the amount of disturbance as "number of alarm flights per hour" and as "amount of time spent in flight". The amount of disturbance observed in the course of the study is presented in full in Appendix 2.

The amount of disturbance could potentially be influenced by several different variables. We discuss these singly below. However, many of these variables interact with one another, so a full assessment of their effects requires multivariate analysis. The multivariate regression approach we used to do this is described in full in Appendix 3. In short, the models we constructed predicted disturbance rates reasonably effectively, and demonstrated that while some variables (especially time of year) had a large effect on observed disturbance levels, others were of relatively little importance.

4.1 Variables affecting disturbance levels.

Weekend/weekday: If people engaged in recreational activities contribute substantially to disturbance of shorebirds on the beaches of Roebuck Bay, we would expect disturbance levels to be higher on weekends. More people can get away from work at these times, and our past experience is that even those without weekday empolyment are more likely to visit the bay at weekends. Initial exploration of the data collected in 2005/06 suggested that a weekend effect existed. Whenever possible, disturbance levels at each site were measured twice every month, once on a weekend and once a weekday. Disturbance levels (indicated by number of alarm flights per hour) on weekends exceeded those on weekdays in 70.6 % of the 92 paired comparisons we could make within a site and within a particular month.

Tide state: Previous analysis of Roebuck Bay data has shown disturbance levels increase with tide height (Rogers et al. 2006b). On higher tides, shorebirds are compressed into smaller areas on the northern beaches, and have to roost closer to cover that may conceal predators. They may therefore become more wary, as they will have more difficulty escaping if a predator attacks. Data collected in the present study were consistent with this theory (Fig. 2). Our past experience has been that disturbance levels on the beaches of Roebuck Bay are higher on rising tides than they are on ebbing tides. Rather to our surprise, this trend was not strongly marked in the data collected in the 2005-06 study (Fig. 2). Disturbance levels were higher on rising tides in only 53.1% of the 81 paired comparisons possible where data were available within a site for both ebbing and receding tides on the same day.

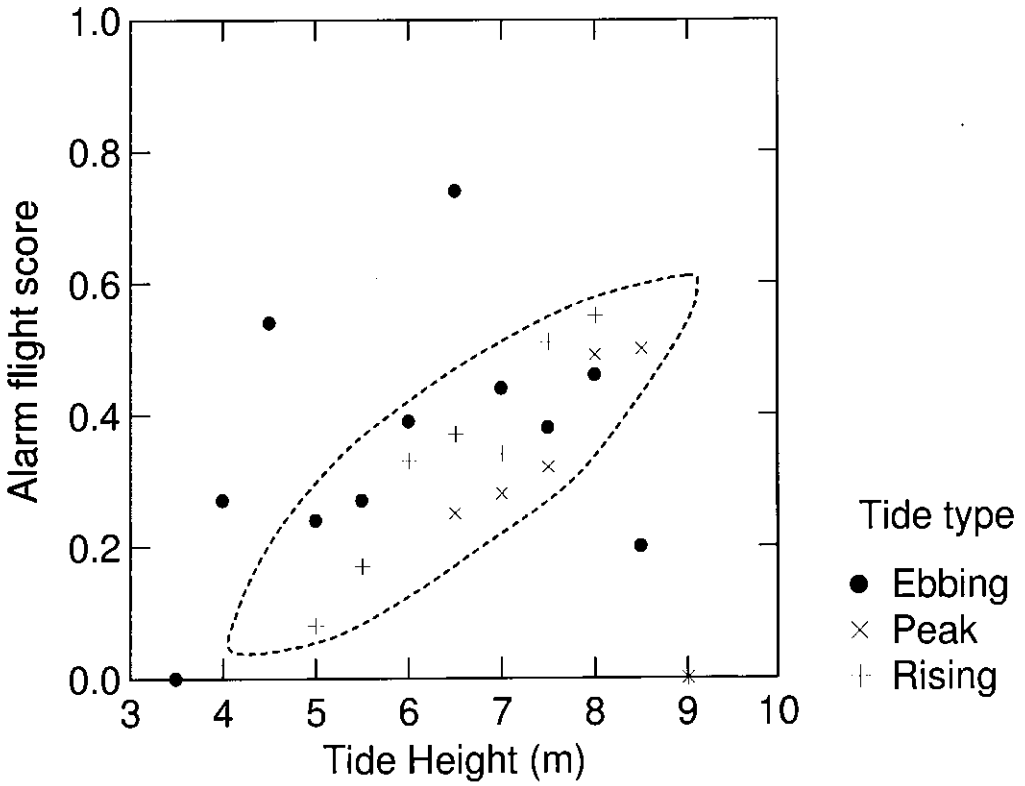


Figure 2. Number of alarm flights per site (corrected for the amount of observation carried out) plotted against the height of tide at which alarm flights were made. Tide heights are clustered into 0.5 m intervals. Data points outside the dashed line were based on short observation periods of two hours or less; data points inside the dashed line were based on longer observation periods of 3.5 to 33 hours.

Bird numbers present: Large shorebird flocks tend to be more readily disturbed than shorebirds occurring singly or in small groups (pers. obs.). This is very probably

because if a shorebird takes off in alarm, adjacent flockmates will take off as well, even if they have not seen the potential source of danger. Large flocks tend to be more vigilant than small flocks because there are more birds present looking out for potential sources of danger. Figure 3 indicates that this effect occurred during our study. The relationship between flock size did not appear to be linear; rather, disturbance levels climbed abruptly if birds numbers exceeded 50-100. For this reason, it was most convenient to analyse the effect of bird numbers present on disturbance levels by converting the bird numbers present to a logarithmic scale (Fig. 3).

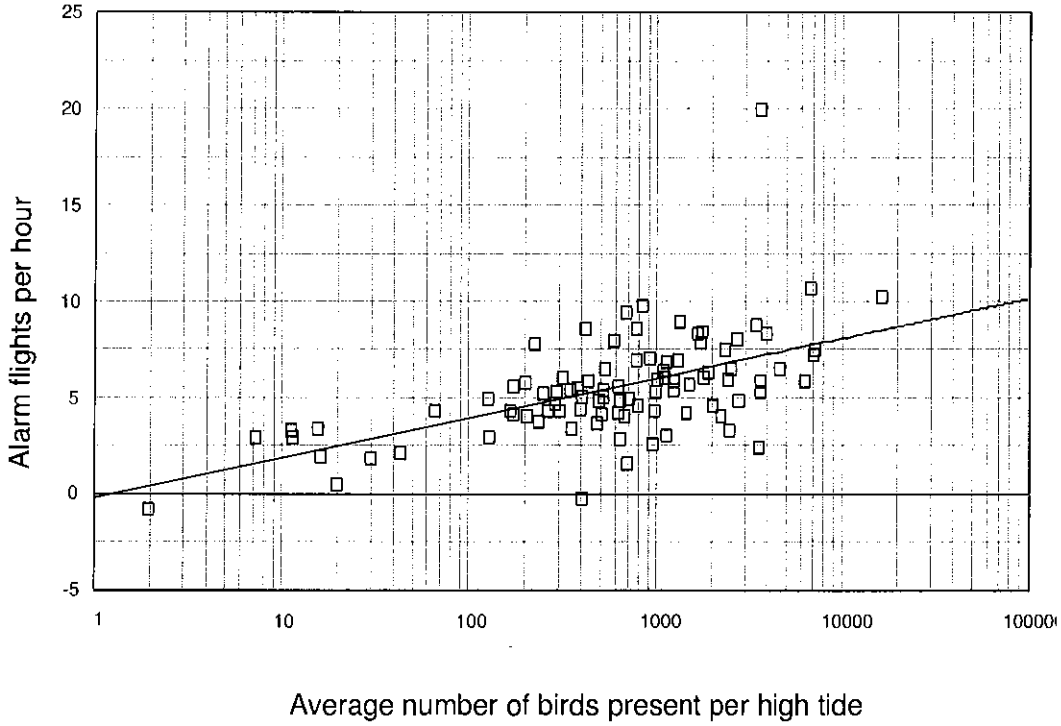


Figure 3. Alarm flights per hour (corrected for the effects of constant, month and tide height identified by multiple regression), plotted against the average number of shorebirds present at a site through a high tide observation period. Note that the scale on the X axis is logarithmic.

Site: The sites at which shorebird disturbance levels were measured in this study were not identical. Some beaches were broader than others; some were backed by low cliffs and pindan vegetation (offering potential cover for predators) while others were backed by sparsely vegetated sand-dunes offering little cover for predators; some were easily accessed and often visited by people, while others were less accessible and less regularly visited. Plots of disturbance levels at the different sites suggested differences were rather small (Fig. 4). However, this picture might be biassed if shorebirds completely abandon particular beaches in the face of high disturbance, as we could only measure disturbance levels if birds were present at the site being investigated.

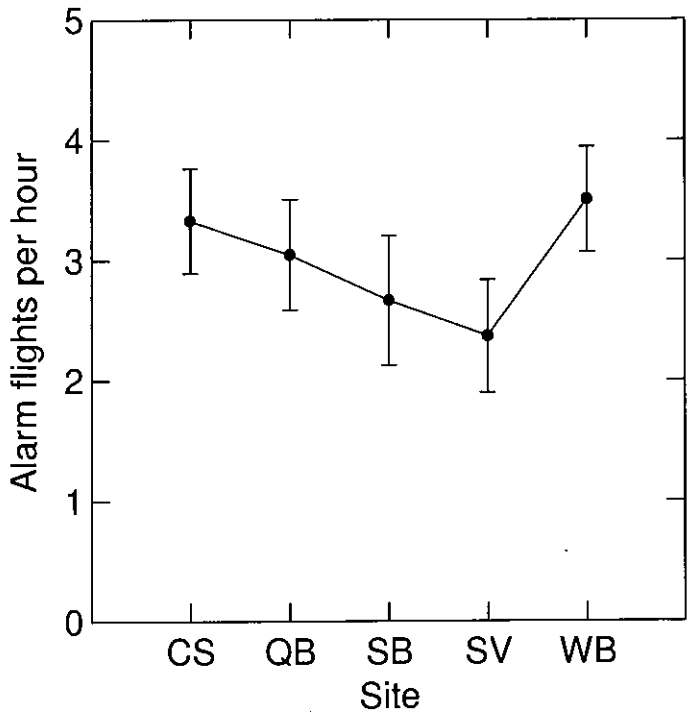


Figure 4. Alarm flights per hour (± standard error), plotted by site. CS = Campsite Beach, QB = Quarry Beach, SB = Simpson's Beach (between Town Beach and Broome Port), SV = Stilt Viewing (the layby from which roosting flocks just west of Crab Creek were usually observed) and WB = Wader Beach.

Month: There were substantial differences in disturbance levels in different months. These differences were clear both on unmodified data, and when adjustments were made to correct for potentially confounding interactions with other variables (Fig. 5). Disturbance levels were high from May to July, and rose to a high peak in August. We had expected this to be the case, as there are influxes of both birds of prey and tourists to Roebuck Bay during the dry season. In August adult shorebirds begin returning to Roebuck Bay from their northern breeding grounds, and the increase in the number of birds present might also influence disturbance levels.

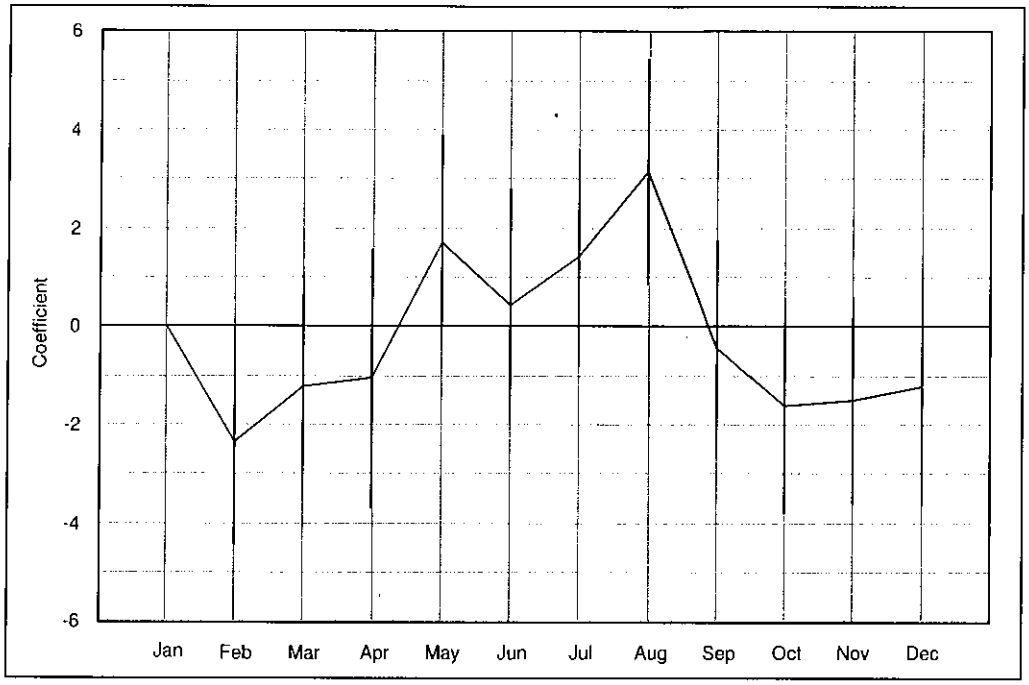


Figure 5. Regression co-efficient for number of Alarm flights per hour (with disturbance at January set at 0), adjusted for effects of tide height and number of birds present, ± 95% confidence limits, plotted by month.

4.2 Causes of disturbance

Overall, 918 alarm flights were observed at roosts in the course of the study. Flights were classified as "alarm flights" if birds gave alarm calls and towered, or if there were other reasons to believe they took off because they had been frightened by something. The total does not include a further 446 flights which were thought to be "commuting" flights made between pre-roosts and roosts, or which observers were unable to classify.

The causes of alarm flights are summarised in Table 1. It was not possible to identify the cause of 365 (39.8%) of the 918 alarm flights observed, and these are not included in Table 1.

Table 1. Causes of alarm flights from the Northern Beaches of Roebuck Bay

	Birds of prey	False Alarm	Observers	Aircraft	Other people
Number of alarm flights	311	82	31	24	114
% of alarm flights of identified cause	55.3%	14.6%	5.5%	4.3%	20.3%

Birds of prey were the main cause of disturbance. In 79 cases the raptor species causing disturbance was identified: most flights were caused by White-bellied Sea-Eagles (30.4%), Brahminy Kites (25.3%), Black Kites (15.2%) and Whistling Kites (15.2%). Small numbers of disturbances were also caused by Brown Goshawks, Collared Sparrowhawks, Swamp Harriers, Australasian Hobby, Brown Falcon, Lesser Frigatebird (not strictly speaking a bird of prey, but sometimes attacks gulls and terns in shorebird roosts) and Osprey (possibly false alarms, as we have never seen Osprey hunting shorebirds).

Many of the alarm flights (14.8%) observed were false alarms. Most commonly these were caused by the sudden appearance of flying birds that were presumably mistaken for predators, though they were in fact species that were not a real source of danger. These included Silver Gulls, several species of tern and heron, Whimbrel, Pied Oystercatcher, and once, a Rainbow Bee-eater. Other unusual causes of disturbance observed included splashing waves, a passing Willy-Willy and wind-blown litter. The high number of false alarms is indicative of the wariness of the shorebirds of Roebuck Bay while roosting.

Remaining disturbances were caused by people. A small proportion were caused by the observers recording disturbance (often because shorebirds settled or walked close to the observers and then suddenly noticed their presence). Some disturbances were caused by aircraft. Helicopters flew over the study site four times during the observation period, twice causing substantial disturbance (our previous field experience at of helicopters at Roebuck Bay is that shorebirds are almost always alarmed if helicopters pass by). Nineteen disturbances were caused by low-

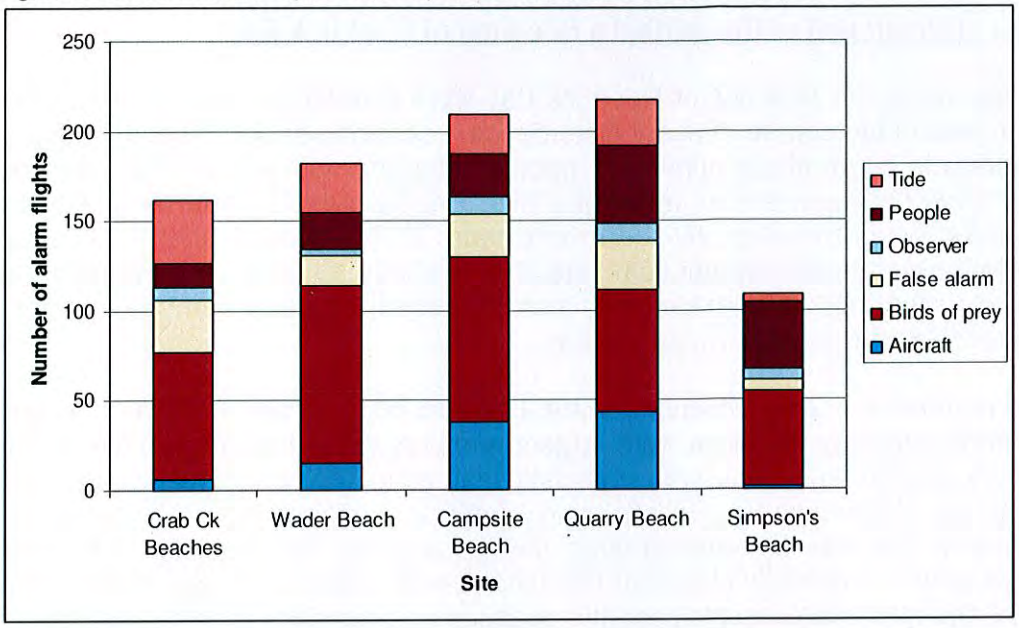
flying airplanes (usually approaching or taking off from Broome International Airport), but on least 80 occasions shorebirds did not react when airplanes flew low overhead.

About 20% of observed disturbances were caused by people. This is likely to be an underestimate of the amount of disturbance caused by people, as disturbance observations could only be made if shorebirds were present and they tended to avoid roosts if people were already on the beaches. In 66 cases the activities of the people who disturbed shorebirds were identified. Of these, 30.2% of disturbances were caused by vehicles (either on the beaches, or making loud sudden noises on sections of Crab Creek road that are very close to shorebird roosts). 18.2% of disturbances were caused by birdwatchers, 10.6% by people known to be fishing, and 9.1% by people walking dogs. The remaining 30.3% of disturbances were caused by people walking on the beaches, but not obviously fishing or birdwatching.

Sites did not differ greatly in the overall amount of disturbance that they received. However, there appeared to be differences in the causes of disturbance at different sites (Fig. 6). Birds of prey caused most disturbance at Wader Beach and Campsite Beach; both these roosts are backed by low cliffs which can be used as cover by hunting raptors, and it is possible that forces birds here to be more wary of raptors than they are in sights where raptor approaches can be seen from long distance. The apparently low levels of raptor disturbance at Simpson's Beach may be an artefact of data collection, as our field impression is that birds of prey (especially Black and Whistling Kites) are more common at this site than at any of the other roosts considered in this study. In the dry season as many as 250 kites were sometimes seen at this site. However very few shorebirds roosted at Simpson's Beach in the dry season, resulting in us calculating low levels of raptor disturbance for the site when in fact, the high numbers of kites present may have actually been the cause of the apparently low shorebird numbers.

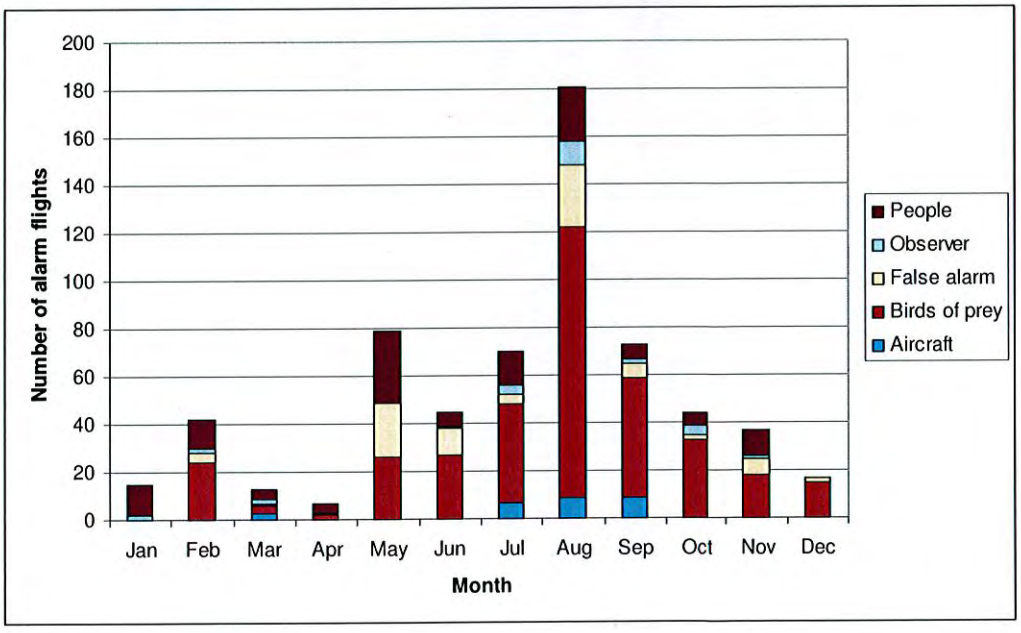
People caused most disturbance at the two most westerly of the roosts considered, Quarry Beach and Town Beach. These sites are relatively close to Broome and easily accessed by beach-walkers. Disturbance caused by aircraft increased on an east-west gradient along the northern shores of Roebuck Bay. This shoreline is a regularly used flight path for aircraft taking off and (especially) landing at Broome International Airport, and aircraft using this flight path are at lower altitude near Broome (e.g. at Quarry Beach) than at the eastern end of the shoreline (Crab Creek).

Figure 6. Number of alarm flights caused by different sources of disturbance, by site.



Shorebird disturbance levels fluctuated greatly by month. The relative disturbance contributions of birds of prey, people, false alarms and aircraft did not vary by month in a very predictable manner, but all of these variables tended to be highest in the winter months or in early spring (Fig. 7).

Fig. 7. Number of alarm flights caused by different causes of disturbance, by month



4.3 Human use of the northern Beaches of Roebuck Bay

People using the beaches of Roebuck Bay were counted by the volunteer teams at their sites in the course of every disturbance-recording session. These totals are not a complete count of the number of people using the northern bay, as other people may have been present on other beaches. People present on other beaches were recorded when observed by the mobile team (Chris Hassell and Nial McKenzie). While these counts were not complete, it is considered that a large proportion of the people using the Northern Beaches were recorded, and also that search effort was reasonably consistent between months.

The number of people observed on the beaches is presented in Table 2. There was a strong seasonal influence, with largest numbers occurring on the beaches during the dry season. This effect was especially marked on the beaches along the northern shoreline of Roebuck Bay, where almost nobody was seen between December and February; this was probably in large part because of the condition of Crab Creek Road, which is officially closed at this time of year and was deeply flooded in parts. Within months, more people used the beaches on weekends than on weekdays.

Table 2. Number of people observed on the Northern Beaches of Roebuck Bay in the course of the disturbance study.

Month	Northern Beaches		Simpson's Beach		All roosts	
	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday
Jan	0	0	11		11	
Feb	0	3	17	30	17	33
Mar	43	1			43	1
Apr	18	3	3		21	3
May	52	13	4		56	13
Jun	39	10	27	3	66	13
Jul	80	17	37	0	117	17
Aug	35	13	13	4	48	17
Sep	31	21	6	2	37	23
Oct	13	22			13	22
Nov	10	1	8		18	1
Dec	0	1				1

Activities of people occurring on the beaches could often be assessed by simply looking at them in the course of data-recording sessions. A summary of the activities identified is given in Table 3. Usually people occurred in groups, with the largest groups involving parties that were fishing, boat launching or engaged in general recreation; birdwatchers and walkers were more solitary. Most (60.6%) of the beach-visitors observed were fishing, with rods, throw-nets or spear. People walking along the beach, and bird-watchers, were also present in reasonable numbers. There were smaller numbers involved in stationary recreation (e.g. sight-seeing, picnicking or swimming; when a group of people was involved in both stationary recreation and fishing, we classified them as fishing), carrying out post-graduate bird research, or launching boats from Sabu Rocks or Crab Creek at high tide.

The number of people counted on different beaches of Roebuck Bay during the study, and their activities, are summarised in Table 3. Although counts of people at "other sites" are not comprehensive, it is considered that a large proportion of the people using the beaches of Roebuck Bay on the study days were counted. Almost half of the beach-users observed were found on the beaches immediately west of Crab Creek, a popular fishing area. Simpson's Beach was also heavily used, as was Quarry Beach, a site where walkers were disproportionately common.

Table 3. Number of people observed at different sites on the northern beaches of Roebuck Bay in the course of disturbance fieldwork.

Activity	Crab Creek Beach	Campsite Beach	Quarry Beach	Simpson's Beach	Wader Beach	Other sites	Total
Birding	28	15	6		24	5	78
Boat launch	29		3	2		9	43
Fishing	190	17	33	154	8	27	429
Recreation	26	13	5	8	4	7	63
Research	1				3	0	4
Unknown	12	6				0	18
Walking	15	4	23	33	2	0	77
Total	301	55	70	197	41	48	712

Volunteers classified the amount of disturbance that each category of human activity caused to shorebirds on a three-point scale (Table 4). It was often impossible to make an assessment of the amount of disturbance caused, usually because there were no shorebirds present anywhere near the beach-users observed. The data collected indicated that the most intrusive activity undertaken on the beaches was simply walking along them. Most people fishing, and most people birdwatching caused no disturbance, but some caused a little disturbance and some caused a lot. Although the relative proportions of disturbance caused by fishing and birdwatching were similar, the reasons behind this were probably quite different. People who were fishing did not often cause substantial disturbance as they were usually based in a single place. Birdwatchers travelled more widely but usually made an effort not to disturb birds.

Table 4 – Activities of beach-users on the Northern Beaches, and the amount of shorebird disturbance caused by each activity.

Activity	Number of beach-users (average group size)	As % of total beach-users	Nunber of groups for which bird disturbance assessed.	Amount of bird disturbance caused None	Little	Lots
Birding	78 (2.7)	10.8%	24	70.8%	12.5%	16.7%
Boat launching	43 (3.3)	6.0%	0			
Fishing	436 (3.4)	60.6%	67	70.1%	11.9%	17.9%
Recreation	63 (3.5)	8.8%	10	80.0%	20.0%	0.0%
Research	4 (1.3)	0.6%	3	100.0%	0.0%	0.0%
Unknown	18 (2.6)	2.5%	5	80.0%	0.0%	20.0%
Walking	77 (1.7)	10.7%	34	44.1%	8.8%	47.1%
Grand Total	719 (3.1)	100.0%	143	65.7%	11.2%	23.1%

Beach users were interviewed whenever practical to find more about who visits the beach, why they do so, and how well informed they are about the shorebirds of Roebuck Bay. The great majority of the interviews were conducted by DHJ and NM, who did not visit Simpson's Beach in the course of their mobile surveys (the site was too distant from the remaining roosts); beyond this bias, we consider the sample to be representative of the people present on the beaches. A questionnaire was used to ensure systematic data collection (Appendix 1). Fifty-five interviews were conducted. Usually people were in groups, and when this was the case, only one person from the group was interviewed; overall there were 159 people in the groups sampled (average group size 2.89, standard deviation 1.931). Nobody was interviewed more than once.

All interviews conducted were cordial, and they usually resulted in lengthy conversations about shorebirds and Roebuck Bay. We suspect that interactions of this kind may be a more effective way of informing the public about disturbance problems in Roebuck Bay than more conventional methods such as signposting or brochures. As many of the beach-users on the northern shores turned out to be people who visit the beaches regularly (especially local residents), it is feasible for an interviewing team to make direct contact with a fairly large proportion of the beach users at Roebuck Bay in only a few days.

Only two of the people interviewed had reached the beaches of Roebuck Bay without a vehicle (a beachcomber at Simpson's Beach who had walked to the site from his accommodation in Broome, and a bird-watcher staying at Broome Bird Observatory). Fifty of those interviewed had driven to the bay, the great majority (84%) using four-wheel drive vehicles. Some had arrived by two-wheel drive vehicles (10%), in a chartered bus (4%) or on a hired scooter (2%). Human visitation to the bay thus appears to be restricted by road conditions.

The origins of people interviewed are summarised in Table 5. Over half of the interviewees came from the Broome area or were visiting from elsewhere in the Kimberley, and individuals from these region visited the Northern Beaches far more times a year than did visitors from further away. Over half of the Broome residents and Kimberley visitors interviewed identified themselves as Aboriginal or Torres Strait Islander, an indication of the cultural importance of Roebuck Bay to Aboriginal people. The majority of visitors from further away lived in south-western Australia or interstate; in addition to being more numerous than visitors from overseas, Australian visitors stayed in the Broome area for longer and made more frequent visits to Roebuck Bay.

Table 5. Origins of visitors to Roebuck Bay.

Origin of beach user	Groups	People	Length of stay in Broome (days)	Average visits to Roebuck Bay pa	Aboriginal Groups	Aboriginal People
Broome	22	73		91	11	41
Kimberley	1	9	180	72	1	9
SWA	10	21	54.3	5.8	1	2
Interstate	20	53	32.2	26	1	6
Overseas	2	3	14	2.5	0	0

The reasons interviewees gave for their visits to Roebuck Bay are summarised in Table 6. Often they had more than one reason for visiting (e.g. cultural and fishing visits were often interlinked) but we only present the main reason here. Recreational bird-watching and bird research are combined below, and the site-seeing category is rather broad, including beach-combing and walking. All visitors from Broome and the Kimberley region who were interviewed were fishing or involved in cultural activities (there was something of a bias against Broome-based birdwatchers in this survey, as the volunteers conducting the survey were not interviewed, and they comprised a fair proportion of the Broome bird-watching community). Visitors from further away included people fishing and site-seeing, but bird-watchers predominated.

Table 6. Activities of visitors to Roebuck Bay

	Cultural	Fishing	Birding	Site-seeing

Origin of beach user	Groups	People	Groups	People	Groups	People	Groups	People
Broome	4	16	17	56				
Kimberley	1	9						
SWA			5	9	2	4	3	8
Interstate			7	17	10	28	3	8
Overseas					2	3		
Total	5	25	29	83	14	35	6	16

The questionnaire included some questions intended to provide guidance on how much visitors know about the shorebirds of Roebuck Bay. On the whole visitors were not very well informed. Most bird-watchers, a few anglers and one tourist were aware that the shorebirds nest in the northern hemisphere, but most interviewees got the question wrong (Table 7). We also asked interviewees "Why do you think shorebirds use these beaches?" Only two bird-watchers and five anglers correctly answered that the beaches were used as a roost. Some of the many incorrect answers received might have resulted from misinterpretation of the question (most people interviewed thought the beaches played some role in feeding or migration), but in general it was clear that the public, and even visiting birdwatchers, did not have a good understanding of the importance of the beaches to shorebirds.

Table 7. Interviewee answers to the question "Where do you think these shorebirds nest?" R = right answer, W = wrong answer.

Origin of interviewee	Broome		Kimberley		SWA		Interstate		Overseas	
Activity	R	W	R	W	R	W	R	W	R	W
Birding		1			1		6		1	1
Cultural		4	1	1						
Fishing	2	13			4	1	2			
Site seeing	1	3				3				

To get an idea of how to provide information to beach users in Roebuck Bay, we asked interviewees were asked how they first found out about the bay (Table 8). Most visitors had first heard about the site by word of mouth, usually from friends or family; a number of bird-watchers had become aware of the site through birding magazines or other literature. Interestingly, considering the amount of fishing that goes on in Roebuck Bay, nobody interviewed had first found the bay as a result of fishing magazines or other literature. Forty-two of 53 interviewees had never noticed signs or other information about disturbance of shorebirds of Roebuck Bay. The remaining 9 had heard something about the problem though a visit to Broome Bird Observatory (n = 3), a book (n=1), brochures (n=2), the bird platform outside BBO (n=1), a signpost at Quarry Beach (n=1), or television or radio (n=2).

Table 8. Number of people that first found out about Roebuck Bay through different sources of information (separate columns for people from different regions).

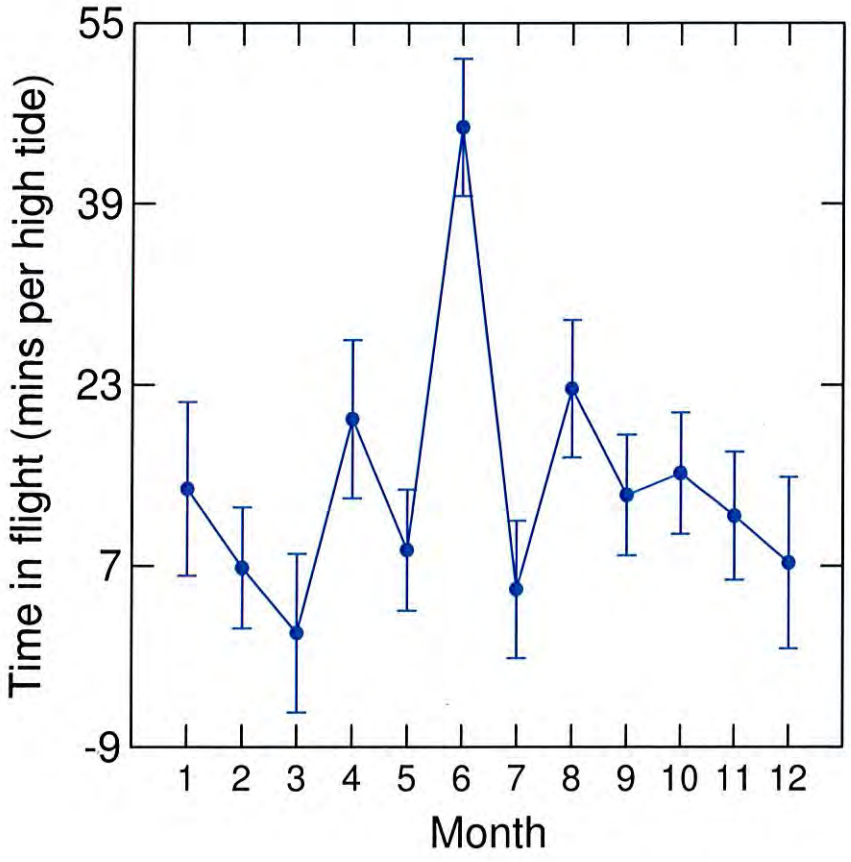
Information source	Broome	Kimberley	SWA	Interstate	Overseas
Word of mouth	16	1	6	9	
Birding				8	

Angling				
Unknown	2	2		1
Broome Tourist office		1	1	
Other tourist literature			1	
Internet				1
Self-exploration	4	1		

4.4 Costs of disturbance, and are levels increasing?

Although the relationship was not very neat, the amount of time that birds spent in flight at high tide was significantly correlated with the number of alarm flights per hour (r^2 = 0.065, df = 94, P = 0.012). The average amount of disturbance with sites and months pooled was 14.3 minutes per high tide, but this value varied considerably (standard deviation 19.381, range 0 -111.5, n =95). Multivariate regressions (not presented in full here) indicated that the amount of time spent airborme varied significantly by month (figure 8). The highest levels of disturbance were seen in June and August, the lowest levels in March. Much variation occurred, especially if different sites were examined separately; the amount of time spent in flight could be strongly influenced by unpredictable events such as the presence of a persistent hunting bird of prey. It could also have been influenced by observer error, as recording this variable required observers to make rapid counts of both the numbers of birds present, and the number of these birds in flight. The amount of time spent in flight is not as easily or repeatably recorded as the number of alarm flights per hour. It is however a more direct measure of the energetic costs of disturbance.

Fig. 8. Amount of time spent in flight per high tide per month ± s.e.



Statistical models have been developed that allow calculation of the energetic costs of flight (Nudds and Bryant 2000; Kvist et al. 2001), provided the amount of time spent in flight is known. Flight is a costly activity for birds. For example, 2.77 KJ of energy (about the amount of energy that can be obtained from consuming a large bivalve) is sufficient for a lean Great Knot to sleep for 6 hours; or to forage for 159 minutes; or to fly at a steady pace for 26 minutes. Alarm flights involve take-off, climbing and flight velocities that are uneconomical, making them considerably more expensive than steady flight; the energy obtained from the hypothetical large bivalve above would only fuel 7.5 minutes of short-range flight.

The flight costs of roosting shorebirds from the northern Beaches of Roebuck Bay have been explored by Rogers et al. (2006). It was calculated that if Great Knots on the northern beaches need to fly for 15 minutes or more per high tide as a result of disturbance, on tides of intermediate height (6-8.2 m), they would consume more energy than would be required to fly to Bush Point. Bush Point (at the southern end of Roebuck Bay) is the only alternative roost site available in such tide conditions.

It would appear from figure 8 that disturbance levels at Roebuck Bay do indeed rise so high that shorebirds are forced to fly for 15 minutes or more per high tide, especially during the winter months. Furthermore, it is possible that this influences shorebird numbers on the northern shores of Roebuck Bay during the austral winter. Table 9 compares shorebird counts from three major north-western Australian sites in the austral summer of 2004 and the following austral winter (July 2005). A 50 km stretch of Eighty-mile Beach was counted on both surveys, and the proportion of birds remaining at this pristine and undisturbed site in the austral winter was about 15% that of birds observed in the preceding austral summer. The winter-summer ratio recorded in northern Roebuck Bay was lower. In contrast, the winter-summer ratio recorded at Bush Point was considerably higher, a trend that has been noticed on several other counts in the region in recent years (C. J. Hassell, D.I. Rogers, pers. obs.). It is possible that the costs of disturbance on the northern shores of Roebuck Bay are so high in the winter months that many shorebirds relocate to Bush Point during the austral winter. This idea has not yet been proved, but it is the most plausible explanation for the discrepancy between Bush Point and Roebuck Bay count ratios that we have been able to find.

Table 9. Comparison of winter counts and summer counts at Eighty-mile Beach, Bush Point and on the northern shores of Roebuck Bay.

Site	Nov. 2004	July 2005	% of birds remaining
Eighty-mile Beach	276765	41797	15.1%
Bush Point	55677	38552	69.2%
N. Roebuck Bay	41364	4261	10.3%

The human population of Broome is growing, and this could lead to increases in the amount of shorebird disturbance on the Northern Beaches of Roebuck Bay. Some data on disturbance levels in Roebuck Bay were collected by DR in the course of roost choice studies between October 1997 and February 2000. The regression models developed from the 2005-06 data in this report allow us to predict how much disturbance would have happened in the previous survey period for particular

heights of tide, according to the number of birds present. Figure 9 compares these predictions with the amount of disturbance actually observed in the 1997-2000 study period. In general the correspondence is reasonably good, suggesting that there have not been large changes in disturbance levels over the past decade. There may have been a subtle increase through, given that the amount of disturbance predicted by the 2005/06 models exceeded that observed on 11 of the 15 surveys conducted between 1997 and 2000.

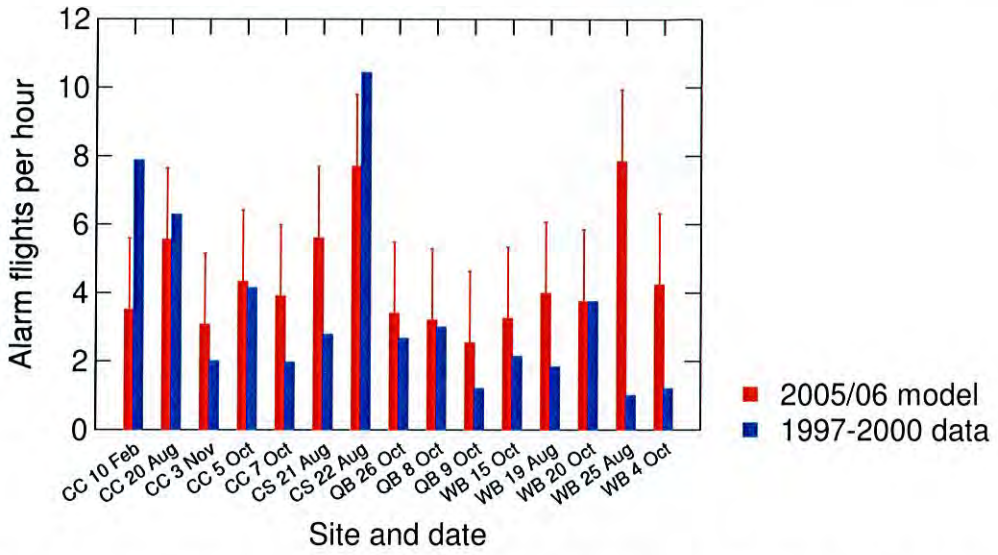


Fig. 9. Alarm flights per hour observed at Crab Creek (CC), Campsite (CS), Quarry Beach (QB) and Wader Beach (WB) between October 1997 and February 2000, compared with the number of alarm flights predicted at these sites (given tide conditions and number of birds present) by regression models calibrated on 2005-06 data.

If disturbance levels on the northern shores of Roebuck Bay are increasing and forcing some birds to move to Bush Point during the dry, we would expect to see a decline in the number of shorebirds using the northern beaches during the annual "winter count". This count has been carried out in repeatable fashion along the northern beaches of Roebuck Bay since 1993. A plot of data from these counts (Fig. 10) suggests that winter counts in the bay have indeed been declining, though the data series is not long enough to assess whether this trend is statistically significant.

There are some other data suggesting a decline in shorebird populations during the dry season along the northern shores of Roebuck Bay. In two of the past three years shorebirds from the northern Roebuck Bay have roosted on salt scolds on Roebuck Plains (in preference to the Northern Beaches) when these areas were damp, despite the fact that this required a substantial increase in the distance they commuted at high tide. Although these birds returned to the northern beaches after the salt scolds had dried out, we believe the change in roosting habitat indicates that shorebirds try to avoid the high disturbance levels found on the northern beaches during the austral winter. Finally, surveys of shorebird densities on the northern mudflats of Roebuck Bay carried out in the dry season (in 1998, 2003 and 2006) revealed proportionately low densities were present in the Dampier Creek area relative to densities of shorebirds in the east of Roebuck Bay. In wet season surveys

carried out in the same way (in 1997, 1998 and 2000), shorebird densities in the Dampier Creek area were proportionately much higher (D. Rogers unpubl. data). This difference is unlikely to have been caused by foraging considerations, as benthos sampling indicated that there was ample food available on the flats. It may be that these areas had become relatively unsuitable for shorebirds because the nearest roost sites, Quarry Beach and Town Beach, both happen to be heavily disturbed areas.

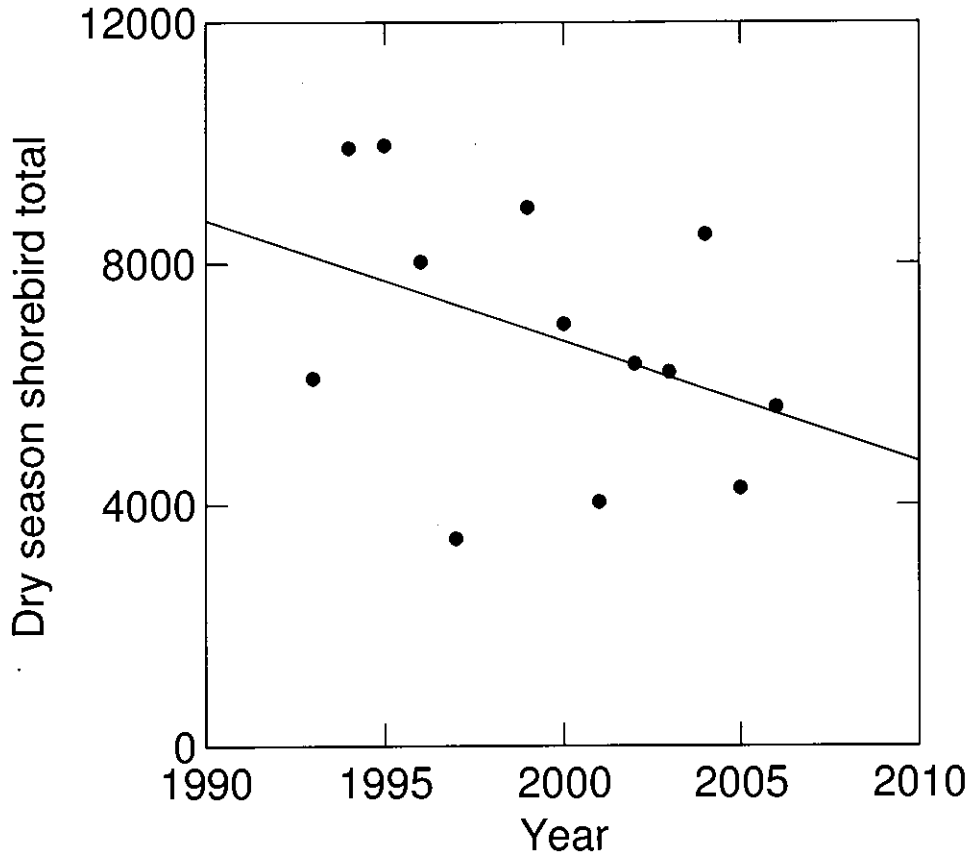


Fig. 10. Dry season counts (June-July) from the northern shores of Roebuck Bay. Data from the 1998 count were excluded as it was carried out in August, after adult shorebirds had begun to return from the breeding grounds. The trend line has a negative gradient, but the relationship between year and counts was not statistically significant ($r2 = 0.16$, $n=13$, $P = 0.175$).

5. Discussion

This study has confirmed that shorebirds roosting on the northern beaches of Roebuck Bay experience high levels of disturbance. In the winter months disturbance causes increases in energy expenditure that could make birds abandon these roosts. The nearest alternative roost in dry conditions, on tides of intermediate height, is at Bush Point, *c.* 25 km away. Radio-telemetry (Rogers et al. 2006a) and physiological modelling (Rogers et al. 2006b) indicate that the energetic costs of roosting at Bush Point, and commuting to feed on the rich intertidal mudflats in the north of Roebuck Bay, are too high to be sustained. Accordingly a loss of the roosting areas on the northern beaches would also effectively result in a loss of feeding areas to many shorebirds, and would in the long run lead to population decline (Rogers et al. 2006b), as well as the loss of a spectacle (shorebirds roosting on the northern beaches) that attracts many visitors to Broome.

The good news is that shorebird disturbance levels in Roebuck Bay only reach disturbingly high levels for part of the year, and this time of year happens to coincide with the period in which numbers of migratory shorebirds are naturally low. Roebuck Bay is used as a non-breeding area by migratory shorebirds. Adult migratory shorebird species are usually found in the northern hemisphere during the winter months from May to August, as they migrate to breeding grounds from the Chinese and Mongolian steppes to the high arctic. Most return to northern Australia between August and November.

In most species of coastal shorebird in Roebuck Bay, immatures do not migrate north, instead remaining on the Australian non-breeding grounds until they are two, three or four years old (this age varies according to species). Accordingly, for most of the austral winter, only immature migratory shorebirds remain in Australia. As Australian shorebird populations are low at this time (usually 10% to 20% of those found in the Australian summer), there is probably little competition for food on the mudflats, allowing shorebirds to shift to less intensively disturbed feeding and roosting areas. Count data collected in Roebuck Bay over the last decade or so suggest that this may be happening, as the number of shorebirds found on the northern beaches has been declining since 1992. The relatively high numbers of shorebirds found at Bush Point during the winter months may also indicate that some shorebirds are being forced from the Northern Beaches of Roebuck Bay by heavy disturbance.

There are brief periods of overlap between the period of high disturbance rates and the presence of adults. In most species this is likely to happen in August and perhaps early September. High disturbance levels in May may also influence a few late-migrating species such as Red Knot.

Most roost disturbance in Roebuck Bay was caused by birds of prey and by people. Disturbance by birds of prey is natural, and the northern shores of Roebuck Bay would be experience high disturbance levels even if the site was completely pristine. Numbers of birds of prey in Roebuck Bay have never been counted systematically, though on the basis of general birdwatching experience we have little doubt that there is an influx of raptors (especially Black Kites and Whistling Kites) to the coastline of Roebuck Bay during the winter months. In the absence of quantitative

data it is difficult to tell whether raptor numbers in the area have been changing. We suspect that numbers of Black and Whistling Kites may have increased, and this would not be unexpected, both being species that often feed on carrion around human settlements, garbage tips and roads.

People also caused a good deal of disturbance on the shores of Roebuck Bay, and were responsible for 20-30% of the alarm flights observed. Our survey methods might have resulted in an underestimate of the costs of human disturbance, because we could only collect data if shorebirds were present, yet the presence of humans on a beach could discourage shorebirds from settling there, and make them join other shorebird flocks. Roost disturbance levels increased with flock size, so compressing shorebirds into small roosting areas will increase disturbance levels.

People from many places were attracted to the beaches of Roebuck Bay, and they used them in a variety of ways. People who live in the Broome area were the most common visitors to the beaches, and the most common activity was fishing. Bird-watching (especially by visitors from interstate or overseas) was also a common activity, and a reasonable number of tourists dropped in on the bay for general sight seeing or beach-walking. However, the number of tourists visiting the beaches was probably lower than might have been expected given the proportion of tourists to residents present in Broome during the dry season. Access to the bay may have been an important part of this phenomenon. The majority of visitors to the bay reached the area in four-wheel drive vehicles, and many tourists flying into Broome probably do not have access to such vehicles.

The activity seen causing most disturbance to shorebirds on their roosts was simple beach-walking. Fishing and bird-watching caused proportionately less disturbance; anglers did not usually cause disturbance as they were usually fairly sedentary, and bird-watchers did not intentionally cause disturbance as this would have prevented them seeing birds well. In this study some shorebird disturbance was caused by the volunteers recording the data, although they were taking pains not to frighten birds. We suspect that the presence of people on the beach will inevitably cause some shorebird disturbance, no matter how non-intrusive their behaviour is.

Most beach-users did not know a great deal about the role that the northern beaches of Roebuck Bay plays in the economy of shorebirds, and were thus unaware of why disturbance could be harmful. All interviews conducted were cordial. Our general impression was that most visitors to the northern beaches were well intentioned, and would try to avoid causing disturbance if they knew more about the problem.

6. Conclusions and recommendations

We consider disturbance levels of shorebirds on the northern beaches of Roebuck Bay to be too high. At present we regard the situation as worrying rather than critical, because disturbance levels happen to be highest at a time when shorebird numbers in the bay are naturally low. We therefore do not advocate drastic measures such as road closure to control levels of shorebird disturbance; such actions could cause community resentment that would in the long run be detrimental to the shorebirds of Roebuck Bay. However, we do recommend:

1. No further development along Crab Creek Road, as this will inevitably increase the number of people visiting the northern beaches.
2. In conjunction with Yawuru traditional owners, identify and implement measures to ensure that there is no vehicle access onto the beaches apart from the boat launching ramp beside Sabu Rocks, and at Crab Creek. Signposting or a barrier required to ensure that vehicles at the boat launching area at Crab Creek do not drive westwards onto traditional shorebird roosts.
3. No creation of additional access points onto Simpson's Beach. Development on or beside the shore between Broome Port and Dampier Creek should be only be permitted if their potential effects on disturbance of shorebird roosts have been assessed and found to be negligible.
4. Initiating discussions with Broome International Airport and other relevant authorities to: (a) prevent helicopters flying near the shoreline, especially to the west of Dampier Creek; (b) investigate whether flight paths of commercial aircraft approaching Broome International Airport can be slightly realigned so they do not pass so close to shorebird roosts on the northern shores of Roebuck Bay, especially at Quarry Beach.
5. Allocation of funding to enable the continued careful monitoring of disturbance levels. This could be done with the methodology used in this study. Annual surveys would be desirable, but surveys every two years would be adequate. Surveying need only be done from April or May to September, as disturbance levels are low from October to March.
6. Initiating a monitoring program for birds of prey in the Broome area to establish seasonal patterns in abundance, and to establish a baseline so we can tell if numbers are increasing. It may be possible to tie this in with other survey work (e.g. Silver Gulls, direct counts of people on the beaches).
7. Further public education: (a) A signposting project has been in progress for some time, and should be completed. This study suggests strategic sites for signage about disturbance include Crab Creek, both the northern and southern ends of Simpson's Beach, and the access roads to Quarry Beach and Wader Beach. (b) Continue the program of interviewing beach-users. (c) Brochures about shorebird disturbance to be distributed from Broome Bird Observatory, the Broome Visitors Centre and other outlets in Broome. A suitable brochure, prepared by Rubibi as part of the Shorebird Conservation Project, already exists. (d) Local publicity about the disturbance problem every August, targeting Broome residents through (e.g.) radio interviews, local newspaper (including the fishing page) articles and possibly Goolari. In conjuction with KLC and the Yawuru traditional owners, develop an education strategy aimed at Aboriginal people.

If these publicity measures do not result in detectable decrease in the amount of disturbance within three years, or if winter counts of shorebirds continue to decline, more intrusive measures to control shorebird disturbance may be needed. Possibilities include:

1. Engineering works to restrict human access to key wader roosts. This may be of particular importance at Quarry Beach, often visited by beach-walkers.
2. Re-routing of Crab Creek road, or parts of it, so that vehicles do not pass so close to roosts easily disturbed from the road (e.g. Tattler Rocks, Wader Beach, some of Crab Creek Beach). Such measures should not be undertaken unless steps have been taken to minmise disturbance that might result from increased human visitation.
3. Imposing dog restrictions (e.g. designating selected beaches as dogs-on-leads sites or as dog-free).

7. Acknowledgements

This study was funded jointly by the Western Australian Department of Conservation and Land Management (CALM) and through National Heritage Trust funding obtained through the Shorebird Conservation Project of WWF-Australia. Thanks to both funding bodies for allowing variations to the project timelines to enable the project to proceed. Important early support for the project (which helped secure funding) was provided by the Roebuck Bay Working Group.

The study was carried out by Broome Bird Observatory, who also provided a base for the fieldwork and introductory workshop; the wardens and their teams (Ricki Coughlan, Chris Sanderson and Belinda Forbes; then Pete Collins and Holly Sitters) were helpful throughout the study. Neil McKenzie, representing Rubibi, was a very important part of this project. The assistance of the Rubibi, traditional owners group and Kimberley Land Council both in supporting the project concept, its establishment and in ensuring that the interviews went smoothly, is greatly appreciated.

Finally, the volunteers who collected the data on which this study is based were (in decreasing order of days spent in the field on our behalf): Liz Rozenberg (18 surveys, including one which she co-ordinated herself while the usual co-ordinators were overseas), Andrea Spencer, Clare Morton, David Trudgeon, Wendy Trudgeon, Alison Brown, Roni Starr, Grant Morton, Graeme MacAuslane, Maurice O'Connor, Adrian Boyle, Belinda Forbes, Chris Sanderson, Greer Keenan, John Keenan, Stewart Young, Mavis Russell, John Vines, Margaret Vines, Helen Macarthur, Jan van de Kam, Zhang Keija, Loyd Berry and an anonymous Broome Bird Observatory guest. Thank you all, for carrying a very worthwhile job very well indeed.

8. References

Kvist, A., Lindström, Å. Green, M., Piersma, T., Visser, G.H., 2001. Carrying large fuel loads during sustained bird flight is cheaper than expected. *Nature* 413: 730-732.

Nudds, R.L., Bryant, D.M., 2000. The energetic costs of short flights in birds. *Journal of Experimental Biology* 203: 1561-1572.

Rogers, D.I., P.F. Battley, T. Piersma, J. van Gils and K.G. Rogers. 2006a. High-tide habitat choice: modelling the roost selection of shorebirds around a tropical bay. *Animal Behaviour.* In press.

Rogers, D.I., T. Piersma and C.J. Hassell. 2006b. Roost Availability May Constrain Shorebird Distribution: Exploring the Energetic Costs of Roosting and Disturbance Around a Tropical Bay. *Biological Conservation.* In press.

Van de Kam, J., D.I. Rogers, T. Piersma, M. Lavaleye, G.B. Pearson and P. de Goiej. 2003. *Life along land's edge: wildlife on the shores of Roebuck Bay.* WA Department of Conservation and Land Management, Perth.

Appendix 1: **DISTURBANCE FORM**

SITE: DATE: OBSERVERS:

Time	Scan (R/I)	Total No. of shorebirds	Shorebirds flying		Alarm flight? (Y/N)	Cause of flight	Notes
			%	No.			

Scan: Use R for the scans done at Regular 10-minute intervals. Use I for irregular scans made at all other times (when any disturbance seen).

Total No of shorebirds: The number (species combined) in view from your position. **Don't include gulls and terns**. Counts of each species are useful if you have time; please put these on the separate count sheet.

Shorebirds flying: Record as % of shorebirds in view, or as a count – whatever is easiest. You only need to fill in one of the two columns.

Alarm flight: Yes or no. Alarm flights are flights obviously caused by disturbance; they are often characterised by sudden and steep take-off, alarm calls and fast manoeuvering.

Cause of flight: People; BOPs (birds of prey); false alarm (e.g. if the birds get spooked by a tern flying overhead); unknown. If you are able to give more detail (e.g. the species of bird of prey) please do this in the notes column.

Appendix 1 (cont.): **BEACH-USERS FORM**

DATE: OBSERVERS:

Site	Obs. period		Description of visitor/s (Give first name or nickname if known)	Time of Beach-users visit		Vehicle		No. of people	Activity	No. of dogs	Bird Disturbance	Interviewed
	Start	End		Came	Went	Where	No.					

Appendix 1 (cont.; reverse side of beach-users form)

HINTS ON FILLING IN THE FORM (also, feel free to add extra notes):

1. Obs. Period = The time at which observations began, and when they finished.
2. Description of visitor/s. This column is there so we can identify cases where the same people are seen on different beaches, or are recorded by both stationary and mobile teams. Name or vehicle description, if known, would be good; otherwise, pick out any attributes that will work for the day.
3. Time of Beach-users visit – record arrival and departure time if possible so we can figure out how long they were on the beach.
4. Vehicles – number of vehicles (will usually be 1) and whether it parked by the road or came onto the beach.
5. Activity: Birdwatching, Rod-fishing, Net-fishing, Walking, Site-seeing, Other (please specify).
6. Bird disturbance – caused by these particular people. Classify as none, a little, or a lot – and feel free to add notes.
7. Interviewed? – No, don't know, or yes. If yes, say whether the interview was done by the stationary or mobile team.

Example of a completed form:

Site	Obs. period		Description of visitor/s (Give first name or nickname if known)	Time of Beach-users visit		Vehicle		No. of people	Activity	No. of dogs	Bird Disturbance	Interviewed
	Start	End		Came	Went	Where	n					
Quarry B	9:00	13:00	Young asian couple with blue car	before us	9:45	Road	1	2	Walking	0	Little	By Us
Quarry B	9:00	13:00	Tall bald man with red t-shirt	9:40	11:30	Road	1	0	Rod-fishing	0	None	By Chris
Quarry B	9:00	13:00	Kimberley Birding tour (George)	10:30	10:45	Road	1	4	Birding	0	None	Dunno[1]
Quarry B	9:00	13:00	Family party including 4 kids	11:30	After us	Beach	2	8	BBQ and paddling	2	Lots [2]	By Chris

[1] Left before interviewed, but went towards Crab Creek and might have met other teams.

[2] Most disturbance caused by dogs, all waders moved to east of beach.

Appendix 1 (cont.): Interview form

Shorebirds on Roebuck Bay Beaches: Questionnaire

Observers:	Site:
Date:	Time of interview:

First name or nickname of interviewee (*so we don't double count their data*):

Other notes on interviewee (assess without asking them):

Age ± 10 years: _____ Sex: _____ State on vehicle number plate: _____

Car type (4WD, 2WD, Bus, Motorbike, Pushbike): No of people in group:

Brief description:

---

1. Have we interviewed you already today?

YES ☐ *Thanks & good-bye*
NO ☐ *Go to next question*

2. Have we interviewed you in previous surveys? *(If yes, ask if we can quickly do it again in case any answers have changed)*

YES ☐ NO ☐

3. Where are you visiting from?

A. Broome local ☐
B. Kimberley visitor ☐
C. WA visitor ☐
D. Interstate ☐
E. Overseas ☐

Any extra detail?: _____

4. If a visitor, how long are you staying in the Broome area?

Approx. no. of days: _____
Approx. no. of weeks: _____
Approx. no. of months: _____

5. (When in Broome area), how often do you visit these beaches of Roebuck Bay?

Approx no. of visits a week: _____
Approx no. of visits a month: _____
Approx no. of visits a year: _____

6. Do you identify with any of the following groups?

A. Aboriginal or Torres Strait Islander ☐
B. Birdwatcher ☐
C. Recreational fisher ☐
D. Tourism operator ☐
E. Tourist ☐

7. What is your main reason for visiting Roebuck Bay?

A. Cultural activities ☐
B. Birdwatching ☐
C. Fishing ☐
D. General sight-seeing ☐
E. Research ☐
F. Other ☐

Any extra detail?: _____

8. How did you find out about Roebuck Bay?

A. Friend, family or word of mouth ☐
B. From birders or birding mags ☐
C. From anglers or angling mags ☐
D. Don't remember ☐
E. Broome tourist info. ☐
F. Other tourist literature ☐
G. Internet ☐
H. Other ☐

Any extra detail?: _____

9. Why do you think the shorebirds use these beaches?

_____

10. Where do you think these shorebirds nest?

_____

11. Have you seen any signage or other publicity about disturbance of shorebirds at Roebuck Bay?

Appendix 2. Number of Alarm flights per hour on the Northern Beaches of Roebuck Bay during 2005-2006.

Month	Weekend	CS ebb	CS rise	CS total	QB ebb	QB rise	QB total	SB ebb	SB rise	SB total	SV ebb	SV rise	SV total	WB ebb	WB rise	WB total	Total
1	Weekday							5.22	4.50	4.86							4.86
2	Weekday	2.18	2.38	2.28				0.60				5.45		0.55	1.09	0.82	1.92
3	Weekday	4.50	2.96	3.73	1.64	0.55	1.09										2.41
4	Weekday	0.55	2.00	1.27	0.60			0.55	0.47	0.51							0.85
5	Weekday				4.16	7.85	6.00	2.80	0.39	1.60	2.40	5.05	3.73	7.80	9.23	8.52	4.96
6	Weekday	3.05	1.80	2.43	3.62	3.50	3.56				4.82	7.64	6.23		2.67		3.93
7	Weekday	2.11	3.00	2.55	6.34	5.33	5.84				2.73	2.33	2.53	0.50	2.29	1.39	3.08
8	Weekday	9.15	5.00	7.08	3.08	3.00	3.04				9.92	5.00	7.46	20.54	12.00	16.27	8.46
9	Weekday	6.00	4.42	5.21	2.65	1.89	2.27	0.55	1.50	1.02	3.27	2.50	2.89	1.19	7.09	4.14	3.11
10	Weekday	1.09	1.50	1.30	1.03	2.00	1.52	1.09	1.00	1.05	1.00			4.17	4.00	4.09	1.91
11	Weekday	0.55	0.50	0.52				0.50	0.50	0.50	2.63	0.60	1.62	3.56	2.00	2.78	1.36
12	Weekday		1.50		0.55	2.50	1.52	1.09			6.45	3.65	5.05	1.00	0.60	0.80	2.25
1	Weekend		2.40					1.50	13.04	7.27	0.92	4.00	2.46	3.41	2.40	2.91	4.03
2	Weekend	1.00	1.09	1.05	0.50			3.00	1.64	2.32	0.50	2.50	1.50	1.50	1.46	1.48	1.50
3	Weekend	2.00			2.00	2.09	2.04				1.09			1.09	1.09	1.09	1.56
4	Weekend					8.00						0.55					4.27
5	Weekend	2.02	5.71	3.87	2.73	1.68	2.20	0.55	1.38	0.97	3.13	1.80	2.47	8.35	5.00	6.67	3.23
6	Weekend	2.14	3.50	2.82	5.14	2.00	3.57				2.18				0.55		2.74
7	Weekend	2.00	8.87	5.43	7.64	8.08	7.86				1.64			0.55	1.50	1.02	4.46
8	Weekend	2.33	14.73	8.53		1.00					0.51	3.50	2.00	3.16	4.00	3.58	4.33
9	Weekend	0.60	5.08	2.84	1.80	2.77	2.28	1.20	2.77	1.98	1.09	2.00	1.55	2.88	2.50	2.69	2.27
10	Weekend	0.51	0.55	0.53	1.64	2.00	1.82	1.64	2.73	2.18	2.88	0.55	1.71	1.54	3.00	2.27	1.70
11	Weekend	3.53	1.50	2.51		2.50		2.73	3.50	3.11	6.00	0.50	3.25	2.07	3.50	2.78	2.88
Average		2.52	3.60	3.17	2.82	3.34	3.19	1.64	2.79	2.28	2.95	2.98	3.17	3.76	3.47	3.72	3.13

Appendix 2. (cont.). Amount of time spent in flight (minutes per high tide) on the Northern Beaches of Roebuck Bay during 2005-2006.

Month	Weekend	CS ebb	CS rise	CS total	QB ebb	QB rise	QB total	SB ebb	SB rise	SB total	SV ebb	SV rise	SV total	WB ebb	WB rise	WB total	Total
1	Weekday							17.1	0.0	17.1							17.1
1	Weekend	0.0	7.1	7.1				0.0	40.0	40.0	9.6	0.0	9.6	0.0	0.0	0.0	14.2
2	Weekday	0.0	1.1	1.1	0.0	0.0	0.0	1.1	0.0	1.1	0.0	29.8	29.8	0.0	0.0	0.0	6.4
2	Weekend	36.0	0.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2
3	Weekday	0.0	0.0	0.0	0.0	0.0	0.0										0.0
3	Weekend	5.3	1.1	6.4	0.0	0.0	0.0				0.0		0.0	0.0	0.0	0.0	1.6
4	Weekday	20.0	13.6	33.6	0.0		0.0	13.0	0.0	13.0							15.5
4	Weekend	19.7	26.3	46.0		26.7	26.7				0.0	0.0	0.0				24.2
5	Weekday	0.0	3.2	3.2	0.0	0.0	0.0	0.0	0.0	0.0	19.0	0.0	19.0	0.0	25.1	25.1	9.5
5	Weekend	0.0	0.0	0.0	15.6	0.0	15.6	7.4	0.0	7.4	0.0	13.5	13.5	0.0	0.0	0.0	7.3
6	Weekday	5.6	105.9	111.4	27.4	30.3	57.7				20.8	39.5	60.3		56.0	56.0	71.4
6	Weekend	6.1	36.1	42.2	18.7	1.2	19.8				9.6	7.7	17.2		0.0	0.0	19.8
7	Weekday	0.0	5.3	5.3	0.2	10.6	10.8				3.8	0.0	3.8	0.8	0.0	0.8	5.1
7	Weekend	0.0	0.0	0.0	0.0	2.0	2.0				1.3		1.3	12.0	2.2	14.2	4.4
8	Weekday	0.0	16.2	16.2	7.5	4.2	11.7				6.6	0.0	6.6	28.9	17.7	46.6	20.3
8	Weekend	5.3	54.8	60.1	0.0	0.0	0.0				0.0	8.8	8.8	10.0	19.7	29.7	24.7
9	Weekday	0.0	8.1	8.1	0.0	0.0	0.0	0.0	26.2	26.2	10.2	11.6	21.9	0.0	1.7	1.7	11.6
9	Weekend	0.0	11.6	11.6	17.9	3.5	21.3	0.0	25.7	25.7	0.0	2.4	2.4	1.4	12.1	13.5	14.9
10	Weekday	0.0	0.0	0.0	0.0	1.1	1.1	28.9	9.3	38.3	0.0	0.0	0.0	18.9	8.7	27.6	13.4
10	Weekend	21.6	3.1	24.7	0.0	31.7	31.7	0.0	2.6	2.6	18.1	4.0	22.1	0.0	3.5	3.5	16.9
11	Weekday	10.4	0.0	10.4			0.0	1.1	0.9	2.0	2.2	0.0	2.2	14.2	0.0	14.2	5.8
11	Weekend	0.0	0.0	0.0	0.0	2.4	2.4	0.0	0.0	0.0	9.0	0.0	9.0	9.4	57.3	66.7	15.6
12	Weekday	0.0	9.9	9.9	6.0	0.0	6.0	0.0	0.0	0.0	11.4	8.1	19.5	0.9	0.0	0.9	7.3
12	Weekend																
Average		5.4	12.6	18.1	3.9	4.7	8.6	2.9	4.4	7.2	5.1	5.2	10.3	4.0	8.5	12.5	14.5

Appendix 3: Statistical details.

We modelled levels of disturbance using linear regression. We calculated two indices of the level of disturbance for each day of fieldwork at each site (giving us a sample of 95 cases for analysis). The indices were:

Alarm flights per hour (given by the number of alarm flights observed, divided by the duration of observation in minutes, multiplied by 6).

Time in flight (calculated using the "R" scans carried out every ten minutes). On each of these scans, the total number of shorebirds present, and the number of those shorebirds in flight was counted. Dividing the total number seen flying by the total number seen in all, we calculated the percentage of birds in flight during the R scans. We assumed that this percentage was representative of the percentage of birds in flight during the high tide period from two hours before, to two hours after, the peak of high tide.

Except where stated, we used the former index in our modelling. "Time in flight" is a closer approximation to the energetic costs that birds experience on the roosts. However, the indices were strongly correlated with one another, and there was less error involved in the calculation of "alarm flights per hour", as it was based on larger samples (many alarm flights occurred between "R" scans).

"Alarm flights per hour" was treated as the dependent variable in our linear regression models. Independent variables investigated were:

Month - categorical
Weekend - "0" if sampling was carried out on weekend; "1" if it was not)
Site - categorical
Tide state - categorical: "rising", "peak" or "ebbing"
Tide height - peak height of tide on the day of sampling (m), obtained from tide timetables
Maximum shorebirds – The maximum number of shorebirds present at each site during each period of observation
Average shorebirds – The mean number of shorebirds at each site during each full period of observation

In initial models we treated rising and falling tides as separate data points (thus starting with a file of 188 cases). We could not find any significant effect of tide state using models based on this data set; any effect that might have existed was concealed by much greater variation in other independent variables. Accordingly we simplified the models by combining data from ebbing and rising tides on each day (thus working from a smaller data set with 95 cases). In addition to being simpler, subsequent models had an equivalent or superior predictive power to those obtained when rising and ebbing tides were separated.

"Maximum shorebirds" and "average shorebirds" were strongly correlated to one another, and including both in models did not improve their predictive power. Models using "average shorebirds" performed slightly better.

"Month" had a significant effect on the models. We found the models could be considerably simplified, with little effect on their predictive power, if we combined some months together. This was done in the final model for comparison with disturbance levels observed in a previous study between 1997 and 2000. Output for this model is summarised below.

Dep Var: AFPH N: 95 Multiple R: 0.618590 Squared multiple R: 0.382653

Adjusted squared multiple R: 0.355216 Standard error of estimate: 2.091730

Effect	Co-efficient	Std Error	Std Coef	Tolerance	t	P (2 Tail)
Constant	-8.772939	3.187575	0.000000	-	-2.75223	0.00716
Tide height	0.819942	0.359804	0.208089	0.822668	2.27886	0.02504
Month May-July	2.096134	0.795669	0.24646	0.943322	2.63443	0.00992
Month August	3.732294	0.790545	0.399997	0.955591	4.72116	0.00001
Log av no. of shorebirds	0.702006	0.133156	0.471128	0.858956	5.27207	0.00000

Effect	Coefficient	Lower 95%	Upper 95%
Constant	-8.772939	-15.105613	-2.440265
Tide height	0.819942	0.105129	1.534754
Month May-July	2.096134	0.515398	3.676870
Month August	3.732294	2.161738	5.302850
Log av no. of shorebirds	0.702006	0.437469	0.966543

Analysis of Variance

Source	Sum-of-squares	df	Mean-Square	F-ratio	P
Regression	244.078816	4	61.019704	13.946299	0.000000
REsdiual	393.779980	90	4.375333		

*** WARNING ***
Case 36 has large leverage (Leverage = 0.239768)
Case 87 is an outlier (Studentized Residual = 5.349157)

Durbin-Watson D Statistic 2.012753
First Order Autocorrelation -0.012811