MSc-Project: The effects of satellite tags on Red Knots (*Calidris canutus*) in Roebuck Bay, Australia.

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Summary

In order to find possible safe havens and alternative stopover sites for Red Knots migrating along the East Asian-Australasian Flyway, 30 Red Knots were caught and outfitted with satellite tags.

The focus of this research was: the spatial distribution of the Red knots on the northern shores of Roebuck Bay and measuring the possible effects which the satellite tags could impose on the birds.

A control group of 24 colour banded Red Knots was used to see whether there were behavioural differences between the birds carrying a satellite tag and the birds outfitted with colour bands.

A lager group of previously colour banded Red Knots gave insights in the preferences of certain beaches over time.

Both the colour banded control group as the satellite tagged birds were followed over a period of one month prior to migration. The east and middle of Roebuck Bay, was mostly frequented by colour banded birds while most satellite birds visited the west of the bay.

It proved to be possible for Red Knots to complete their 6000 km migration from Roebuck Bay to Bohai Bay, China, while carrying a satellite tag. Once firmly attached to the birds, the satellite tags worked beautifully and showed stopover over sites previously unknown to science.

Introduction

Roebuck Bay

Roebuck Bay ($18^0$00'S, $122^0$22'E) is an extensive (175 km^2) tidal mudflat area situated beside the town of Broome in the North-West Australian Kimberley region (see Fig. 1). Its intertidal flats are known to facilitate to a rich benthic invertebrate community (Pepping *et al*.1999). These invertebrates attract about 113,000 (Rogers *et al.*, 2011) shorebirds making Roebuck Bay one of the most important non-breeding sites along the East Asian-Australasian Flyway (EAAF) (Watkins 1993, Collins 1995, Rogers 1999, Rogers *et al.*, 2011). For twenty species of shorebird which use Roebuck Bay at a given moment during the year, the 1% Ramsar criteria is reached (Rogers 1999), meaning that 1% of the world population of a particular bird species or sub-species is present at Roebuck Bay at a single moment in time. Reaching the Ramsar status made Roebuck Bay a wetland of international importance (Rogers *et al.*, 2011) under the 1971 "Convention on Wetlands of International Importance especially as Waterfowl Habitat", Signed in the city of Ramsar, Iran (Davis 1994).

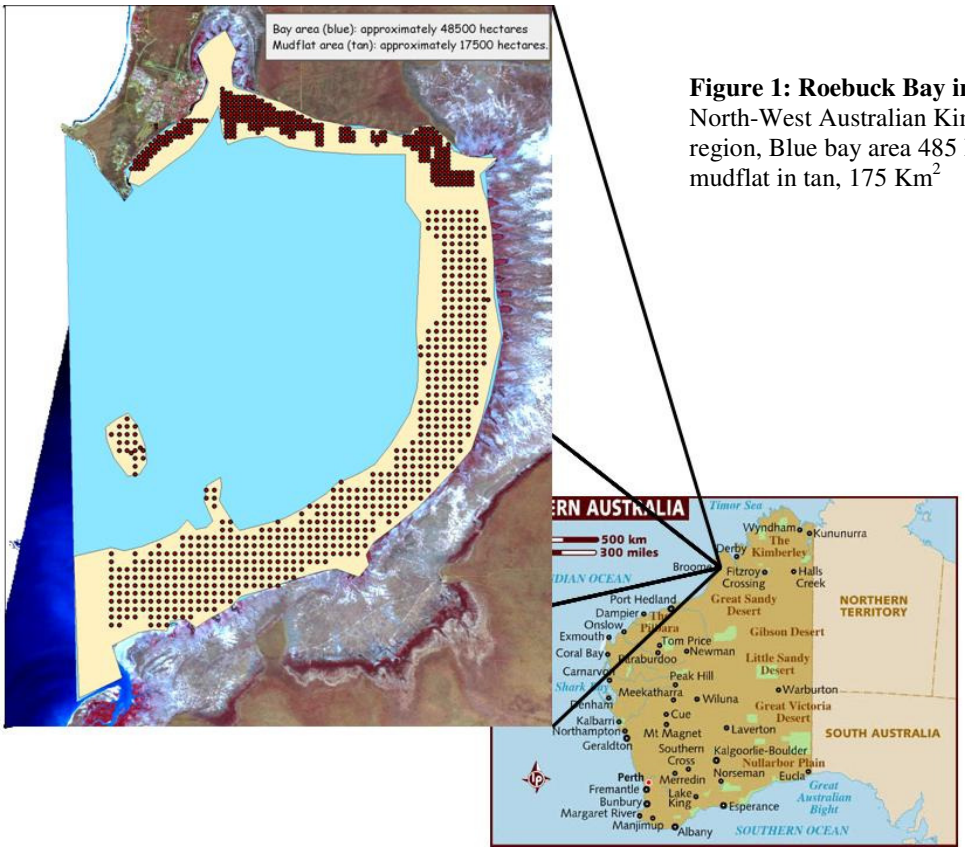


Figure 1: Roebuck Bay in the North-West Australian Kimberley region, Blue bay area 485 Km^2 and mudflat in tan, 175 Km^2

Strategy

One of the shorebird species that uses Roebuck Bay as a non-breeding site and for which the Ramsar criteria are met, is our focus species the Red Knot *Calidris canutus*. A highly specialized bivalve eating shorebird, with adaptations to its diet including a remote sense that detects interstitial water differences to locate buried prey (Piersma *et al.* 1995, 1998) and a strong muscular gizzard for cursing bivalves which are swallowed whole (Piersma *et al.* 1993C, van Gils *et al.* 2003, 2005).

Outside the breeding ground the Red Knot is strictly bound to coastal tidal mudflats (Piersma 2007). It was believed that there were an estimated 220 000 Red Knot in the EAAF (Bamford *et al.* 2008) but new evidence shows that this figure is much lower and should be in the order of ~105,000 Red Knots (Rogers *et al.*, 2010).

Red Knots do not participate in migration until they are in their second year of life. On average 17% (1998-2009) of Red Knots have been shown to be non-migratory juveniles (Minton *et al.* 2009) therefore the migrating population in the EAAF can be calculated as ~87,150 individuals (Rogers *et al.*, 2010). Roebuck Bay harbours a maximum of 2755 Red Knots (Rogers *et al.*, 2011).

After the Red Knots arrive from their migration on the shores of Roebuck Bay in September, they recuperate for a couple of months. During recuperation they moult into a dull gray basic plumage. Moulting is energy consuming and dependent on the birds' condition (González *et al.* 1996).

The basic plumage helps them to blend into their environment and shelters them from predation. From February onwards the Red Knots start to moult from the basic plumage to their alternate breeding plumage (Rogers *et al.* 2003). The alternate plumage may have a selective importance on the breeding grounds (Owens *et al.* 1994). Only the males with the most elaborate breeding plumage might find mates. The alternate plumage also camouflages the birds during incubation (Rogers *et al.* 2003). Fast moulting individuals reach their alternate plumage as early as the first week of May and can continue to fuel for the long upcoming journey (Battley *et al.* 2005).

The Red Knot adopts a 'long jump' migration strategy (Wilson & Barter 1998). This means that they leave North Western Australia in early or mid May and fly north to the coastal areas of the Yellow Sea (Wilson & Barter 1998, Barter 2002, Battley *et al.* 2005). A journey of approximately 5700km, after which the Red Knots mainly stop over in Bohai bay (Rogers *et al.*, 2010) in order to regain weight. The Red Knots stay on the Yellow Sea coast for approximately 3-4 weeks before travelling further north, to their breeding quarters in the High Arctic, another 4000-5000 km from the Yellow Sea (see Fig. 2) (Wilson & Barter 1998, Battley *et al.* 2005, Rogers *et al.*, 2010).

In the High Arctic, life is busy for the Red Knots from mid June to late July. They only have just under four weeks to court, mate, lay a clutch of four eggs and complete the incubation. It takes another 3 weeks before the hatchlings fledge and the fledglings and

parents can make the journey south, back to Roebuck Bay. The adult females are the first to leave the breeding grounds, since they are put under most pressure of laying eggs, followed by the adult males. The juveniles are the last to leave the breeding grounds and hence arrive later than their parents in Roebuck Bay, mostly during October (Rogers *et al.*, 2003). Both mature and juvenile birds moult to a dull grey non-breeding plumage after which a new cycle begins in February.

Red Knots in Australia have relatively small gizzards (Battley *et al.* 2005). The reason why they choose for not having larger organs and being able to process shellfish at greater rates may relate to large internal organs adding to the bird's heat load; having larger organs seems an impossible strategy under the scorching Australian sun (Battley *et al.* 2003). This strategy only allows for a slow rate of fuelling which takes 6 to 7 weeks (Battley *et al.* 2005). The slow rate of fuelling is probably the reason why recuperating, fuelling and moulting are hard to combine and can be observed in separate stages during the non-breeding period (Battley *et al.*, 2005).

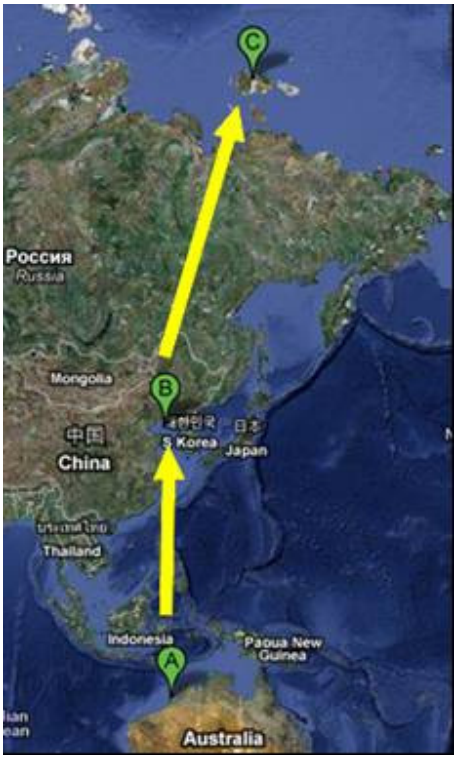


Figure 2: The East Asian-Australasian Flyway which the Red Knot follows from the non-breeding quarters at Roebuck Bay (A) to the stopover sites at the Yellow Sea (B) to the breeding area's on the New Siberian Islands (C) (Google earth).

Habitat use

Habitat use of shorebirds is highly influenced by prey availability (van de Kam *et al.* 2004). Tropical mudflats such as Roebuck Bay generally have a lower standing stock of prey items than the more temperate areas (Piersma *et al.* 1993b), but the species composition is more diverse (Dittmann 2002). In the tropics, prey items are distributed in a more homogeneous fashion (Leyrer *et al.* 2006) and the array of prey items taken by Red Knots is much higher in Roebuck Bay than in temperate regions such as the Dutch WaddenSea (Tulp & de Goeij 1994). This could be a reason why the non-breeding home-ranges of the Red Knots in Roebuck Bay (20km^2) (Rogers *et al.* 2006A) are much smaller than the home ranges of Red Knots in the Dutch WaddenSea (800 km^2) (Piersma *et al.*1993a; van Gils and Piersma 1999; van Gils *et al.* 2000, 2005). Tropical wetlands lack cold spells which do occur in winter at temperate regions (Leyrer *et al.* 2006). Therefore Knots in the tropics do not have to adapt to seasonal fluctuations of invertebrate prey availability and can rely on more or less constant food availability throughout the year (Piersma 1980; Piersma *et al.* 1993b). Warm tropic conditions cause basal metabolic rate to be lower because the bird does not have to keep itself warm (Piersma *et al.* 1996). It is believed that the consistency in food availability allows the Red Knots to stage on small well known area's (Leyrer *et al.* 2006). By staging on area's known to the birds the risk of being predated could also decrease (Rogers *et al.* 2006A). Red Knots are known to use roost sites close to their foraging grounds (Rogers *et al.* 2006A).

piersmai & rogersi

In the EAAF there are two subspecies of Red Knot which can be distinguished by differences in the colour and pattern of their breeding plumage (see Fig. 3) (Tomkovich 2001).*Calidris canutus piersmai*, has a reddish nape, deeply coloured brick-red under-parts and the solid brick-red extends behind the white thighs. The centres of the mantle feathers are black with red edges and small whitish tips. The scapulars have a broader black centre line and small brick-red spots (Rogers *et al.*, 2010 Hassell *et al. in Press*). *Calidris canutus rogersi* has peach coloured under parts, which are solid to level with the legs. Behind the legs there is little to no peachy flecking. The nape is a pale silvery-grey with some dark streaking. The upper parts look more silvery than black due to the broader gray-white tips of the feathers, although the feathers are black centred with a large terracotta-red spot on each side (Rogers *et al.*, 2010 Hassell *et al. in Press*).

In the beginning of our study period, all birds were in non-breeding plumage and were impossible to distinguish, the more they advanced into their breeding plumage the better identification on subspecies level could be made.

C.c. piersmai stages predominantly in NW Australia and breeds on the New Siberian Islands and *C.c. rogersi* stages predominately in SE Australia and New Zealand and breeds on the East-Siberian tundra's around Chukotka (Rogers *et al.*, 2010 Hassell *et al. in Press*). Approximately 50% of the worlds population of *C.c. piersmai* is found in the Kimberley (Rogers *et al.*, 2011).

Because of the shorter flight distance, *C.c. piersmai* might arrive at Bohai Bay (Chinese Yellow Sea) in slightly better condition than *C.c. rogersi*, but no such thing has been observed so far (Hassell, Boyle & Slaymaker 2011). This could suggest that *C.c. rogersi* stages more often between the non-breeding sites. It is speculated that *C.c. Piersmai* covers the flight from Roebuck Bay to Bohai Bay in a single non-stop flight (Battley *et al.* 2005), but recent work disputes this (Hassell *et al. in Press*). Both sub-species use Bohai Bay as a launching point for their several day lasting non-stop flight over inhospitable terrain (Rogers 2011). In preparation of this long-distance flight they forage intensivley, almost doubling their body mass in the course of a month (Rogers 2011).

Red Knots do not leave Roebuck Bay until early or mid May. Late departing individuals probable all belong to the *C.c.piersmai* subspecies (Battley *et al.*, 2005). *C.c. rogersi* arrives earlier in Bohai bay and it leaves earlier to its breeding grounds than *C.c. piersmai* (Hassell, Boyle & Slaymaker 2011). This is probable because *C.c. piersmai* breeds further north than *C.c. rogersi*. If *C.c. piersmai* was to arrive earlier its breeding grounds would be still covered in snow and ice (Rogers *et al.*, 2010).

Figure 3; Red Knots in breeding plumage: subspecies *Calidris canutus piersmai* on the left; the paler subspecies C.c. *rogersi* on the right. (© Photographs: Ian Southey, in: Rogers 2011).

Threats

At the moment the largest ongoing threat to the Red Knots in the EAAF is land reclamation and hereby destruction of suitable habitat in the Yellow Sea coastal areas (Rogers *et al.* 2006B,2010. Yang *et al.* 2011). Reclamation of the tidal flats is done to create arable lands for agriculture, industrial development, Mari-culture, salt works and freshwater reservoirs (Barter 2002). The Yellow Sea mudflat areas are important stopover sites for shorebirds to refuel during the long migration. Loss of this habitat could heavily reduce bird numbers along the EAAF (Rogers *et al.*, 2010), and the evidence that the impacts are severe is accumulating (Yang *et al.* 2011).

Contradictory to the well studied migration system which is used by Red Knots in the East Atlantic Flyway, which runs through Europe and Africa (Piersma and Davidson 1992; Nebel *et al*. 2000; Leyrer *et al.* 2009), the distribution within the EAAF is poorly known (Rogers *et al.*, 2010). It is therefore important to get a better understanding of the Red Knots patterns of staging and migration to ensure its survival for future generations.

Shorebirds roosting on the northern beaches of Roebuck Bay experience increasing disturbance by human visitors, dogs, and fishermen. When fishermen leave discarded fish scrapes on the beach, this attracts raptors such as brahmini, black and whistling kite and other scavengers (Rogers *et al.*, 2011). These pose a threat and therefore more disturbance to the shorebirds. Since 2000 anthropogenic disturbance levels have reached a point in which foraging along the northern beaches was too high to be profitable for the shore birds in Roebuck Bay (Rogers *et al.*, 2011). Disturbance levels peak in the dry-season, when there are more people concentrated in Broome due to the school holidays. Luckily Red Knots are migratory and are largely, except for the juvenile birds, absent in the dry-season.

The human population of Broome is growing and with a proposed marina and LNG hub disturbance is likely to increase (Rogers *et al.*, 2011). The township already caused an increase in surface water nutrients by water runoff. This may have caused increasing cyanobacteria blooms with negative effects on benthos living on the tidal flats close to the town (Estrella *et al.* 2011) the staple food of the Godwit (*Limosa lapponica*). In the end, nutrient enrichment caused Godwit foraging behaviour to differentiate (Estrella *et al.* 2011). This example shows how fragile linkages within ecosystems can be.

Methods

The goal of the overall research project was to get a better understanding of the spatial movements of Red Knots in the EAAF trough satellite tracking. The emphasis of this research is the comparison between birds carrying a satellite tag, versus non satellite tagged birds, in order to estimate the possible negative influence of the satellite tag. By following individually colour-banded Red Knots over time and comparing these with satellite tagged birds we try to provide data to explain part of this process.

Together with fellow master student Mo Verhoeven, I conducted fieldwork on the northern shores of Roebuck Bay between 26 January 2011 and 15 May 2011, after receiving some training from Chris Hassell on sub-species identification, breeding plumage and fat scores to see if we were consistent in our observations.

By use of a (Swarovski 20-60x zoom) spotting scope individual colour banded Red Knots were observed (up to a distance of 300m according to: Leyrer *et al.* 2006) during daylight hours on high tide roosts. On neap tides the birds stayed far out on the mudflats and were mostly out of reach for accurate observations. On spring tides the Bay was totally submerged and birds roosted inland (predominantly on "Kidneybean Claypan) where we could not follow them. Given this fact, observations could only be made on tides between 7.2 – 9m high.

During our observation sessions we noted down: location, abdominal profile and the percentage of breeding plumage, to show the spatial movements, fuelling and moult processes of the Red Knots in Roebuck Bay.

Before long distance migration, shorebirds such as the Red Knot store large amounts of fat (Drent & Piersma 1990, Evans & Davidson 1990), occasionally doubling their weight (Johnson 1985). Scoring abdominal profile is a useful visual measure for scoring the bird's condition based on looking at the birds profile and estimating the subcutaneous fat stored in the abdomen (Wiersma & Piersma 1995). Abdominal profile scores have the advantage of being quickly and easily obtained (Wiersma & Piersma 1995). As was done in previous studies (Wiersma & Piersma 1995, Battley *et al.* 2004) we used a categorical score between 1 and 5 (see Fig.4). A bird scored as 1 looks unhealthy famished and a bird scored as 5 is obese and bulbous.

We expect (as Battley *et al.* 2004 did for Great Knots) that there is limited flexibility in fuelling regimes between Red Knots; birds which run behind schedule will postpone their leaving date whereas birds in better condition leave earlier. When a bird can catch up in the fuelling, departure will be fairly synchronised. We hoped that tracking individual birds would increase insight in this matter.

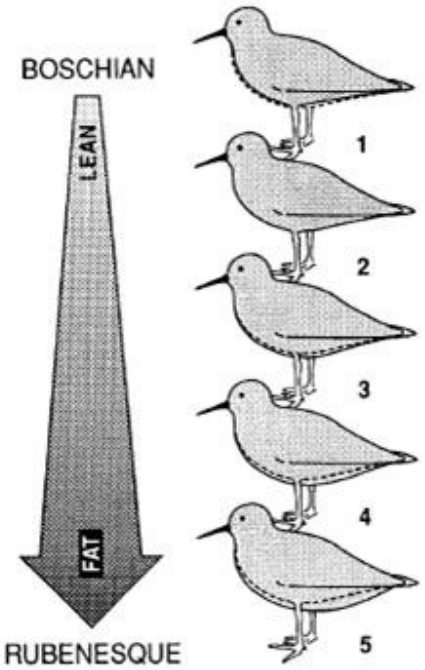


Figure 4. Fat scores in Red Knot.
Figure by; Wiersma & Piersma 1995

Scoring the intensity of alternate breeding plumage was done categorically. Using 6 categories; 0%, Trace, 25%, 50%, 75% and 100%, the bird was classed to the category with the nearest percentage. 0% was mainly given to non-breeding juveniles. Trace; was used if there was only a slight trace of breeding-plumage detectable and 100% was used if the bird was near- or in full breeding plumage. We assumed that individuals which are in better condition would reach the higher mould scores earlier in time.

For data purposes the visited beaches with the same habitat characteristics were pooled (see Fig. 5 and Tab.1), the pooling was made coarser to increase more profound data outcomes (see Tab. 2). Every day between 26 January and 15 May 2011, we worked the beaches on the northern shore of the Bay, from Quarry Beach to Little Crab Creek in a west to east trajectory. The rest of the bay, south of Little Crab Creek is nearly inaccessible and can only be reached by hovercraft, which was not available to us. The birds which exploit the food sources in the southern half of the bay use roosts south of Little Crab Creek, predominantly Bush Point (Rogers *et al.*, 2011) and were not expected to frequent the northern shores.

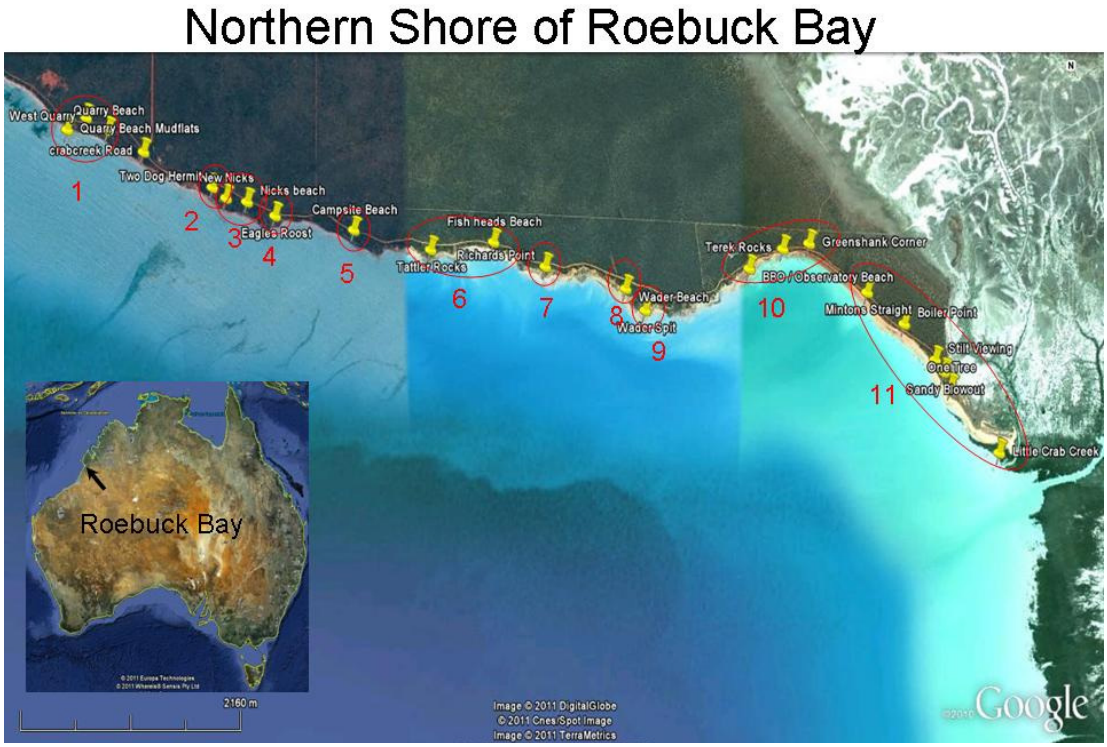


Figure 5: The northern shore of Roebuck Bay. Beaches are pooled for data purposes. © Google Earth.

Loc code	Actual beaches (alternative name)
1	West Quarry / Quarry Beach
2	Two-dog Hermit
3	New Nicks (private camp)/ Nicks Beach
4	Eagles Roost
5	Campsite Beach
6	Tattler Rocks / Fish Heads Beach
7	Richards Point
8	Wader Beach
9	Wader Spit (Fall Point)
10	BBO Beach / Observatory Beach / Terek Rocks / Greenshank Corner
11	Minton Straight / Boiler Point / Stilt Viewing / Sandy Blowout / One Tree / Little Crab creek

Table 1: Pooled beaches of Roebuck bay

(Loc code)	Beach name (alternative name)
1	West Quarry / Quarry Beach
2	Two-dog Hermit / New Nicks (private camp) / Nicks Beach / Eagles Roost / Campsite Beach
3	Tattler Rocks / Fish Heads Beach / Richards Point / Wader Beach / Wader Spit (Fall Point)
4	BBO Beach (Observatory Beach) / Terek Rocks / Greenshank Corner / Minton Straight / Boiler Point / Stilt Viewing / Sandy Blowout / One Tree / Little Crab creek

Table 2: Coarsely pooled beaches of Roebuck bay, to increase more profound data outcomes.

Colour bands

Before our arrival in January, 388 Red Knots had previously been colour banded in Western Australia by joint ventures of the Global Flyway Network (GFN) and Australian Wader Studies Group (AWSG) (Hassell 2010).

Within this study, researchers joined the "AWSG North West Australia Wader and Tern Expedition 2011", which ran from 19 February 2011 to 12 March 2011, and caught and colour banded an additional 197 Red Knots on 80-Mile Beach and Roebuck Bay (Minton *et al.* 2011). The expedition gave us the opportunity to get some hands-on experience in wader banding, scoring plumage and moult, bleeding and biometric measuring. Birds received a metal ring, a unique combination of four colour bands (blue, red, lime and yellow) and a yellow flag. Colour bands were made of 'Darvic' plastic and Solvent Cement was used to permanently close the flag and colour bands. The colour bands were always put on the tibia (two each) and in addition there are up to eight different flag positions (on either tibia, or tarsus). With 4 different kinds of colour bands and 8 different flag positions a total of (4^4 times 8 =) 2048 possible combinations can be made (see Fig. 6). This kind of colour banding is used in the Dutch WaddenSea since 1998 and has shown to give more accurate results than just metal banding (Brochard *et al.* 2002).

Figure 6: Colour banded Red knots.

Left: 3LRBY (flag position 3 followed by Lime, Red, Blue and Yellow colour bands.) this individual is in non-breeding plumage

Right: 3LRBR This individual is in near-full breeding plumage.

Gathered data (catch and resighting details) were imported in the already existing Ms Access database of the AWSG, which dates back to July 2006 when the first Red Knot was caught and outfitted with individually recognisable colour bands.

Satellite Tracking

In the past two decades satellite tracking has become a widely used tool in order to study the spatial movements of terrestrial, aquatic and areal vertebrates (e.g. Weimerskirch *et al.* 1992; Gudmundsson *et al*. 1995; McConnell & Fedak 1996; Morreale *et al.* 1996; Block *et al.* 1998; Boyd 1999; Polovina *et al.* 2000 & Hays *et al.* 2001). The technical advancements seen over the past decades made Satellite transmitters ever lighter and smaller.

On 1 and 3 April 2011 two small canon-netting expeditions were held and 44 Red Knots were caught and colour banded. Of these 44 individuals, 30 birds were identified to be adult birds. These adults were in their second year of life (or older) and were expected to participate in migration. The 14 "left over" juveniles where colour banded and released.

After the catch, the Red Knots were taken back to the Broome Bird Observatory (see Fig.5 #11) to be handled in an air-conditioned room. For the first time in (scientific) history, Red Knots were outfitted (16 on 1 April and 14 on 3 April) with a small (~ 25 x 15 x 7 mm and a 210 mm long antenna, weighing 5 g) Platform Terminal Transmitter (PTT) (Microwave Telemetry, Inc.). The PTT transmit signals to Argos satellites that in turn relay the information to ground-based processing stations where the animal's position is calculated (Argos 2011), showing their position on the globe trough Google Earth. In an ideal situation the PTT's have an accuracy of <1500m.

The PTT is outfitted with a tiny solar cell which charges the battery. PTT's were set to have a duty cycle of 10 hours in which the device is ON and transferring information (a Call-back) about its location and voltage of its battery to the satellite. After these 10 hours it switches OFF for 48 hours and the solar cell charges the battery.

The PTT was glued on the back of the bird after some scapular feathers were trimmed back (see Fig. 7). After the PTT was attached, some of the covert feathers were trimmed so that they could not obscure the solar panel. The whole procedure took on average 12-15 minutes per bird. A control group of captive Red Knots were held in the Royal Netherlands Institute for Sea Research (NIOZ), carrying dummy PTT's, which were retained for months. A blood sample for molecular sexing was taken and the birds were colour banded.

Figure 7:
A satellite tagged Red Knot
Colour-band code: 3YRYR
© A. Boyle

Upon release some of the PTT-birds suffered from wing strain caused by the stress of handling. The birds which did not fly off straight away were taken back to the air-conditioned lab, where the PTT was removed and reused on another Red Knot. The bird itself was then rehabilitated and was released when seemingly healthy.

From field observations of the PTT-birds we unfortunately know that 9 of the birds surely shed their PTT before departure from Roebuck Bay. These birds were resighted alive 1-14 days later but without a PTT. Field observations of these birds show no detrimental effects of the PTT's on the birds, they all appeared healthy and strong and showed natural behaviour.

The PTT's, which were never used before on Red Knot, worked beautifully and charged well. When a PTT was shed or the bird was dead the device was probably covered in the deep mud of Roebuck Bay, and stopped transmitting straight away. No birds were observed carrying a PTT which was not functioning. Nine of the PTT-birds possibly died within the first week after release, 2 more died 2,5 weeks later and another died 3 weeks after its release date. From these birds we have a lack of satellite data and visual observations.

So with 12 possible casualties (or sheds) and 9 surely shed PTT's this leaves 9 PTT-birds (out of 30) in and on the air.

Control Group

To test the possible influences that the indoor handling, the affixing of the PTT's and finally the PTT's themselves might have had on the birds, we needed a control group. The 14 individuals, left over in the PTT catches were unfortunately all juvenile birds (< 2 yrs) and did not make a suitable control group. The birds caught and handled closest in time were chosen as a control group. These were birds caught on 6 March 2011 when 24 Red Knots were caught, and on 11 March 2011 when 2 Red Knots were caught. Of these 26 birds, 2 proved to be juvenile birds and were excluded from the control group. The 24 birds were colour banded on the beach and a blood sample was taken.

The PTT-birds were followed over a timespan of one month (the time the last PTT-bird was observed in the bay at the 3rd of May 2011) after the last release date.

Comparative approach

The colour band sightings over the period from 1 January 2011 till 15 May 2011 were analysed to show the spatial use of the Northern shores of Roebuck Bay. The birds carrying a PTT were compared to the control group and both groups were followed for a time span of one month starting at 1 April till 3 may 2011. To compensate for the fact that the control group was caught and released earlier than the PTT-group and therefore had a longer time to adjust and recuperate from the catch prior to migration, we also looked at the month after their release (see Tab 3).

The Australian Governmental Bureau of Meteorology has a station situated in the Broome port; this station collects hourly measurements on the height of the tide, wind speed and temperature. The data of this station was obtained and was used to see if there were any abnormalities in the weather pattern during our surveys.

	PTT-Group	**Control group**
Number of individuals	30	24
Catch date's	1 & 3 April 2011	6 & 11 Mach 2011
Catch location	Eagles Roost & Quarry Beach (west)	Boiler Point & Campsite Beach
Release location	**BBO Beach**	Same as catch location
Group followed till	3 May 2011	11 April 2011 / 3 May 2011

Table 3. comparative approach of the PTT group vs. the control group

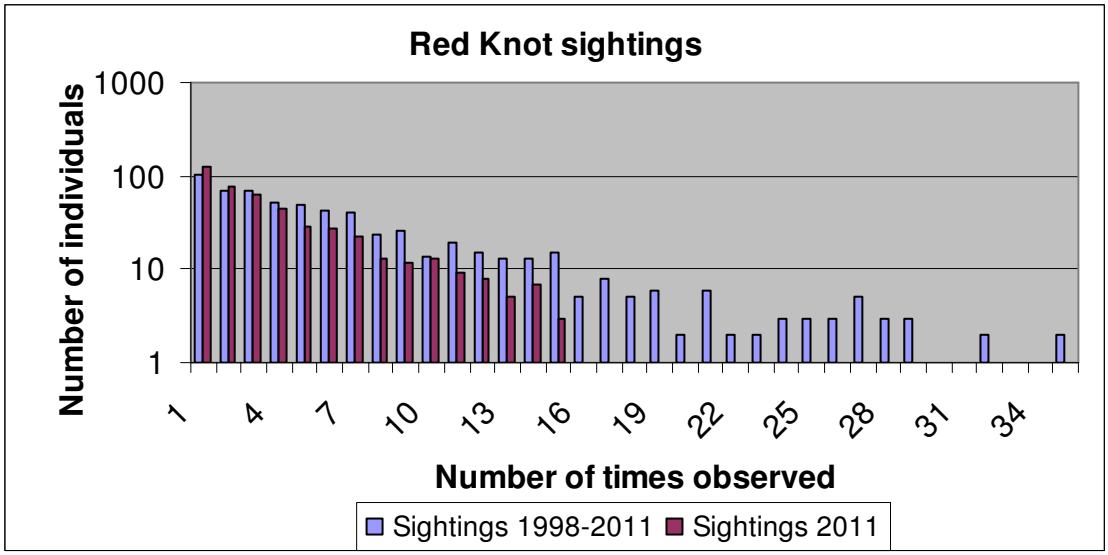
A note on the statistic comparison!!!!!

Statistics where executed in the program "R". We preformed chi-square tests to prove that birds preferred some beaches over others. The hypostasis that birds randomly visited a beach could therefore be overthrown.

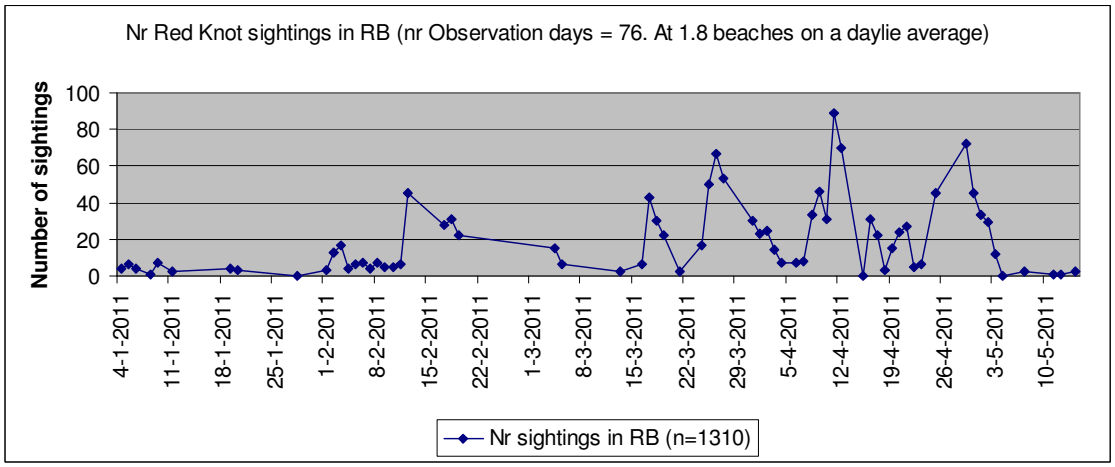
Results

Colour bands

The AWSG database dated back till 1 July 2006 when the first Red Knot catches were made. The database contained 810 individual Red Knots of which 629 individuals have been resighted once or more, with a max of 41 resightings. All 629 birds combined give a total of 4461 sightings (average 7 resightings). If we look at the resighting database with a start date on 1 January 2011 it contains 461 individual Red Knots with 1946 combined sightings (average 4,2 resightings) with 21 sightings maximum for an individual (see Graph 1). Of this 1310 sightings are made within Roebuck Bay on 76 observation-days (average ~18 Red Knots per observation-day) (see Graph 2).



Graph 1: Red Knot observations since 21 August 1998 till 15 May 2011. Blue bars illustrate all sightings and purple bar illustrates the 2011 only sightings. This gives the probability an individual is resighted.



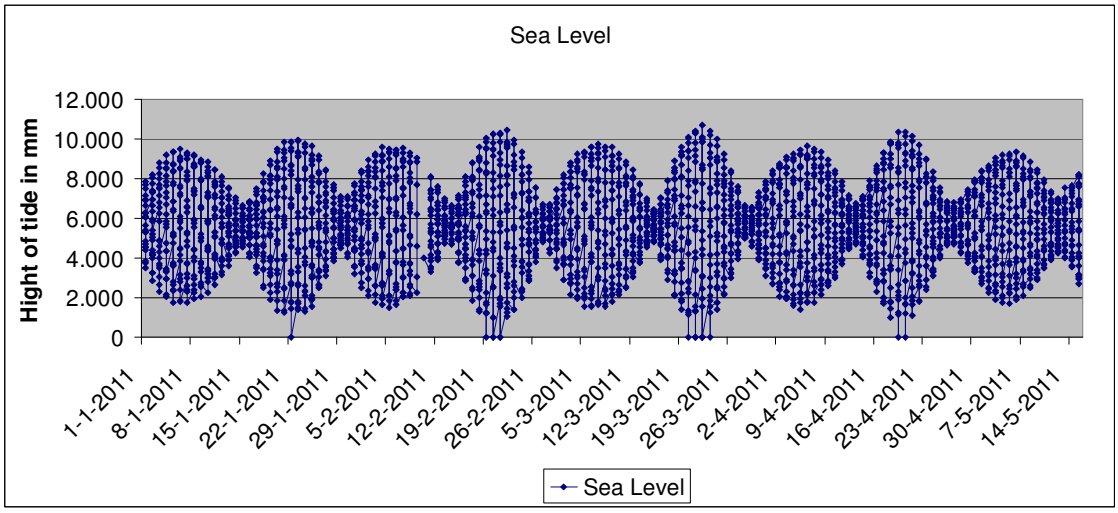
Graph 2: Red Knot sightings per observation day. From 20 February till 11 May researchers were occupied with a canon netting expedition at 80-mile Beach.

The observation efficiency increased in mid February and more birds were observed daily after then. This was not necessarily caused by the observers increased experience, getting to know the lay of the land in the Bay, where to find the Red Knots and increased knowledge in species recognition, but more to the Red Knots changing their plumage and becoming more obvious. In their non-breeding plumage Red Knots can look quite similar to Great Knots (*Calidris tenuirostris* which are colour-banded in the same fashion), so a more careful species determination was needed than when the Red knots were showing hints of Red Breeding plumage. Later on in the observation period, the brick red of the Red Knots would stand out in the enormous flocks of shorebirds frequenting Roebuck Bay. The Red Knots frequented on average ~1,82 beaches.

Although never resighted in Australia, the first Red Knot to have surely migrated to China was seen at Bohai Bay on 17 April 2011 by Matt Slaymaker & Adrian Boyle, the mass exodus of the Red Knot majority left Roebuck Bay in the last week of April and early May.

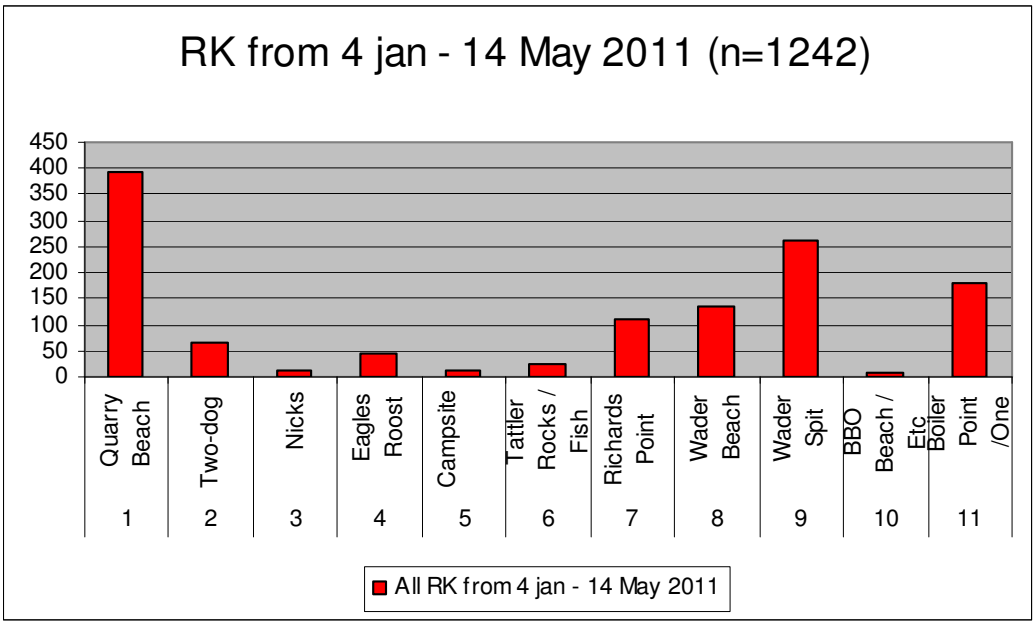
From 20 February till 11 May 2011 the main researchers were occupied with canon netting at 80-mile Beach, so fewer observations were made in Roebuck Bay.

The fact that at some days large scores of colour band sightings were generated and nearly non on the following days, were attributed to the large variations in tidal amplitude (see graph 3.) which are characteristic to Roebuck Bay. The tidal amplitude varies from 1m at a neap tide to 8-10m at a spring tide. At spring tides the birds would shelter in the mangroves or leave the bay altogether to seek refuge on the salt marshes of Roebuck Plains Cattle Station where they could not be followed on foot. On the salt marshes the birds were standing in high grass which obscured the colour bands.

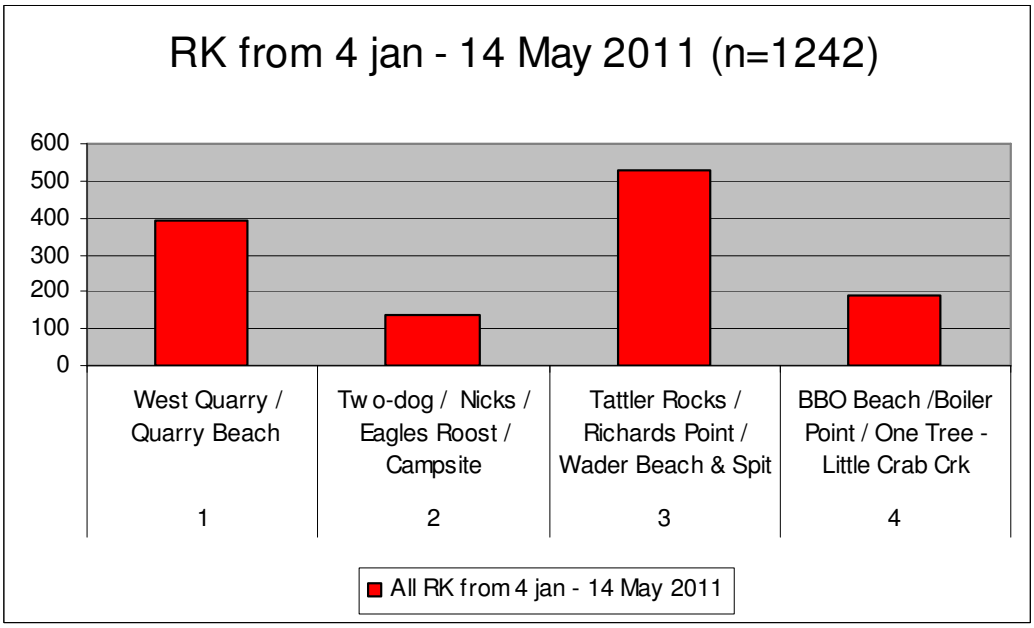


Graph 3: Sea level (in mm) per datum, every dot represents an hourly measurement. 9 & 10 February the water measuring device was defect, hence the gap in the graph. (Background data by: the Australian Governmental Bureau of Meteorology)

1242 colour banded Red Knots were observed in our study site and were mostly seen on Quarry Beach and in the middle of the bay (see graphs 4 and 5, figure 5 and table 1). The amount of birds scored on Quarry Beach can be attributed to the fact that this was our main focus site. Two-dog Hermit (site 2) was visited more often than Richards point and Wader Beach and Wader Spit but still yielded far less resightings. Boiler point (site 11) was frequented by huge scores of waders but the Red Knot seemed to prefer Wader Spit the most.

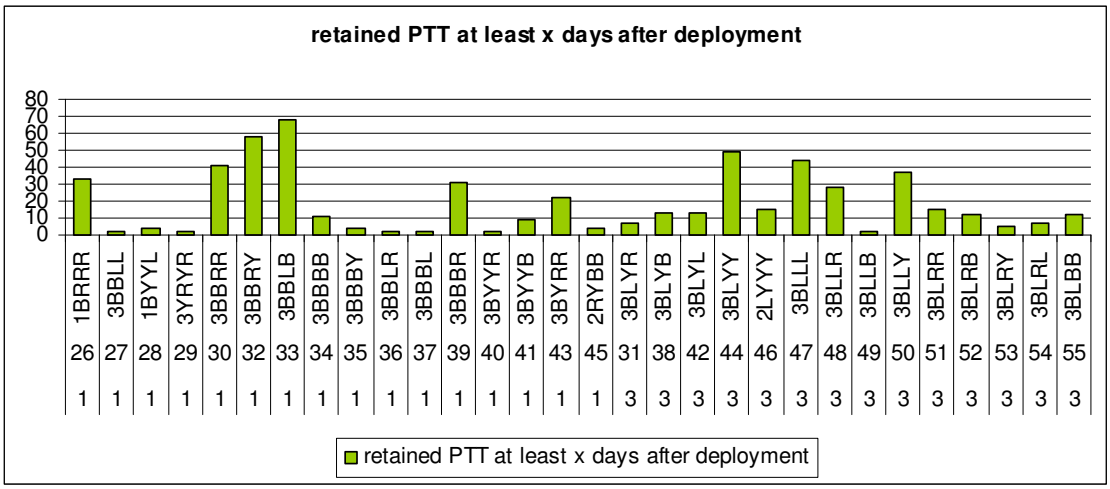


Graph 4: Red Knot sightings on the Northern shores of Roebuck Bay. The 1-11 categories are the pooling of the beaches and can be found in Fig 5. and Tab 1.



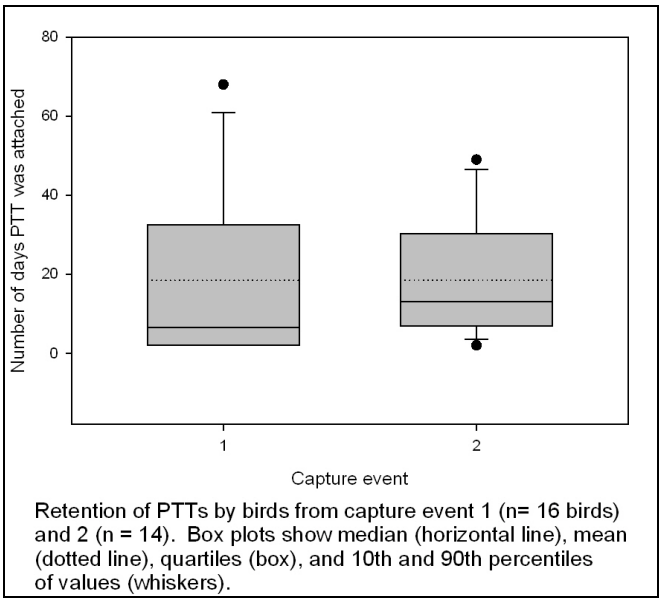
Graph 5: Red Knot sightings on the Northern shores of Roebuck Bay. The 1-4 categories are the pooling of the beaches and can be found in Fig 5. and Tab 2.

Based on data acquired from the PTT's movement sensors, we know how long an individual Red Knot carried a PTT (see graph 3). The total of 30 PTT-birds retained their PTT's for a combined 554 days. PTT numbers 26-30, 32-37, 39-41, 43 & 45 were released on 1 April 2011 and PTT numbers 31, 38, 42, 44 and 46-55 were released on 3 April 2011 (see graph 6.).



Graph 6: PTT retention time in days after deployment. On the X-axis is the colour band- combination (1BRRR) the PTT number (26) and the date of deployment (1 or 3) 1 or 3 April 2011.

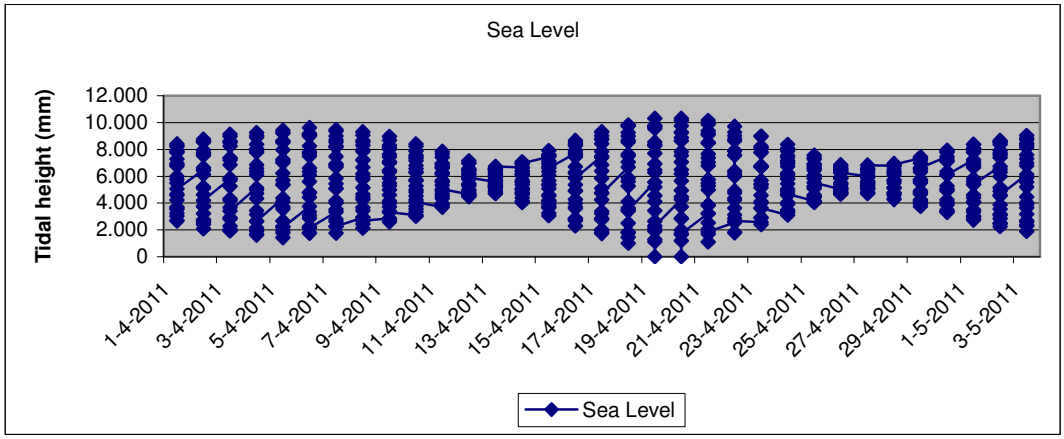
The mean number of days that a PTT stayed attached to a bird, was the same for birds from both capture events (~ 18 days) (see graph 3). However, the median was lower for birds from the first capture (seven days) vs. the second capture (13 days) (see graph 7).



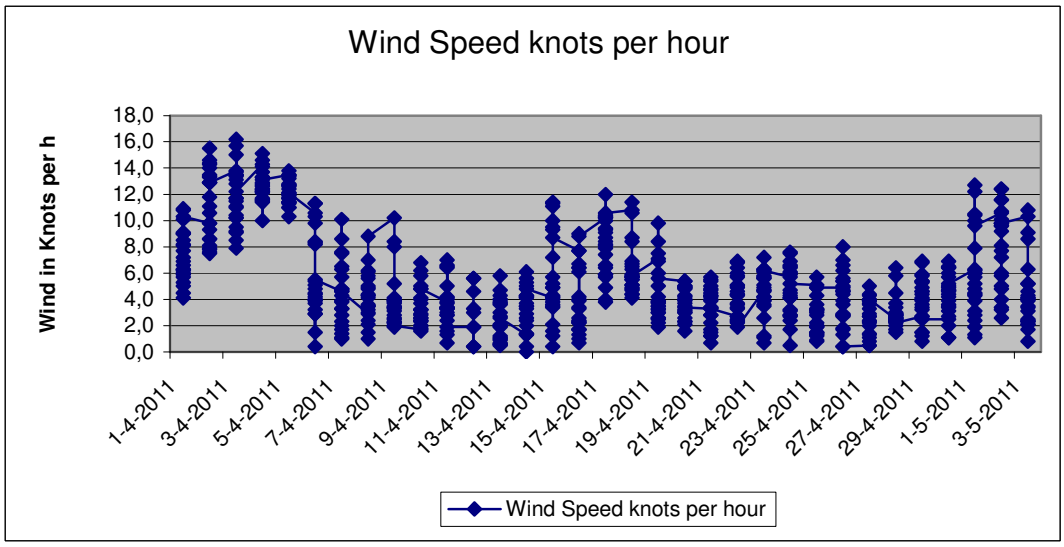
Graph 7: PTT Retention on Roebuck Bay Red Knots, Capture event 1 is 1 April 2011 and capture event 2 is 03 April 2011 (© Lee Tibbits, USGS).

This is consistent with our feelings that more birds from the first group had a difficult time adjusting to the capture and tagging and may have died soon after release.

The first week of April was a spring tide (see graph 8) and coincided with a moderate but above average (for this time in year) increase in wind speed. This wind, measured in knots, was only 16 knots strong which is (16 x 1.82=29,1 km/h =) about 5 Bft. Under normal conditions the winds are about 5 knots (5 x 1,82 = 9,1 km/h =), about 2 Bft (see graph 9). The air temperature dropped from about 30°C to 20°C.



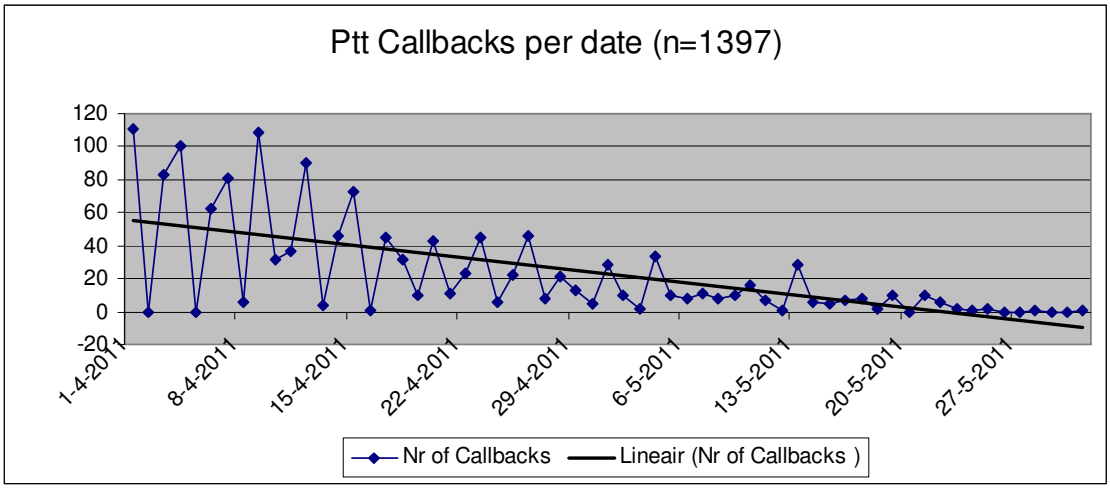
Graph 8: Sea level (in mm) per datum, every dot represents an hourly measurement (Background data by: the Australian Governmental Bureau of Meteorology).



Graph 9: Wind speeds (in knots per hour) per datum, every dot represents an hourly measurement (Background data by: the Australian Governmental Bureau of Meteorology).

Based on the rapid decline in resightings of PTT-group birds right around migration departure time, at the end of April, it is safe to say that most birds migrated (with or without their PTT) or at least they left Roebuck Bay. This suggests that there were few deleterious long-term effects of capture.

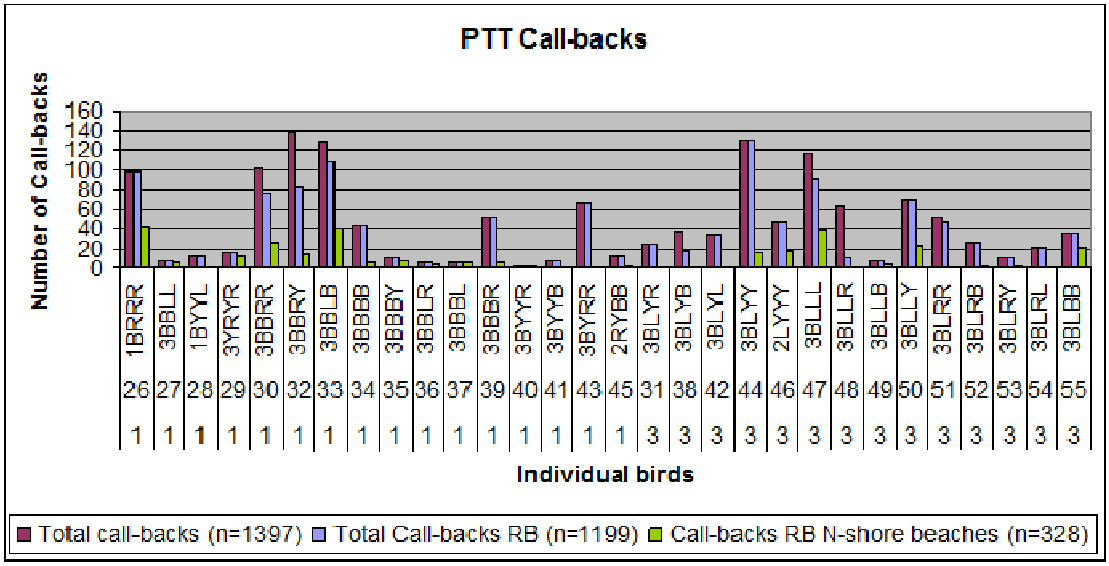
Of the 30 PTT's combined we received 1397 call-backs, from mainly Roebuck Bay, 80-Mile Beach, the mouth of the De Grey River, King Sound and several other non-Australian locations in the EAAF. The call-backs showed a downward linear trend as the birds shed their satellite tags and the tags got covered in mud (see graph 10)



Graph 10: PTT call-backs per date, the extreme amplitude of the blue line is caused by the ON/OFF regime of the PTT (10 hours ON, 48 OFF).

1199 call-backs came from within Roebuck Bay but only 328 of these came from our study site (see graph. 11), the north shore beaches, these were accessible to researchers and therefore call-backs made from these beaches could potentially be followed up by visuals.

The 871 remaining call-backs came from locations within the bay, such as: Broome port, Bush Point, Roebuck Plains, Kidneybean Claypan, flying above water or over the bush or too far out on the mudflats at low tide. These were outside our study area or simply inaccessible by our means, and were excluded from further analysis.



Graph 11: PTT Call-backs per individual Red Knot. On the X-axis is the colour band- combination (1BRRR) the PTT number (26) and the date of deployment (1 or 3) 1 or 3 April 2011. Total call-backs are all call-backs in flyway locations. The total call-backs RB are all call-backs within Roebuck Bay including inaccessible locations. Call-backs RB N-shore beaches is all beaches accessible in our study site.

Of the 9 airing PTT birds 4 definitely migrated, leaving 5 birds unaccounted for. Two birds from each capture group carried their PTT's during migration and made it all the way to Bohai Bay, China (3BBLB with and 3BLLR without a PTT, it lost it in Borneo). Two others at least got to Sarawak, Indonesia (3BLLL) and Quanzhou, China (3BBRY).

Of the 4 migratory Red Knots, 3 stopped over in Borneo (in what looked to be salt- or fish ponds), revealing a location unknown for Red Knots to stopover. The bird which went to Quanzhou was a re-trap. It is older than 12 years of age and must be a very experienced migrant. It flew trough Borneo, the Philippines and then to China, utilizing fish- and salt ponds along the way. The latest PTT call-back date was 30 May 2011, from the Chinese coast at Whenzou, 350km south of Shanghai.

The 5 unaccounted birds probably shed their PTT's just days prior to migration, the signals stayed in Roebuck Bay and the birds have not been resighted afterwards. We now know that it is possible for Red Knots to migrate while carrying a PTT. What is not clear is, whether the PTT's affect migratory behaviour.

PTT-birds vs. Control Group

During their stay in Roebuck Bay, the 30 PTT-birds were visually seen 86 times (2,87 average) and visited on average 2 different beaches. 10 of the PTT-birds where never observed during the period. If we exclude these birds from the analysis than the 20 remaining birds were on average seen 4.3 times and visited 3 different beaches (see Tab. 4).

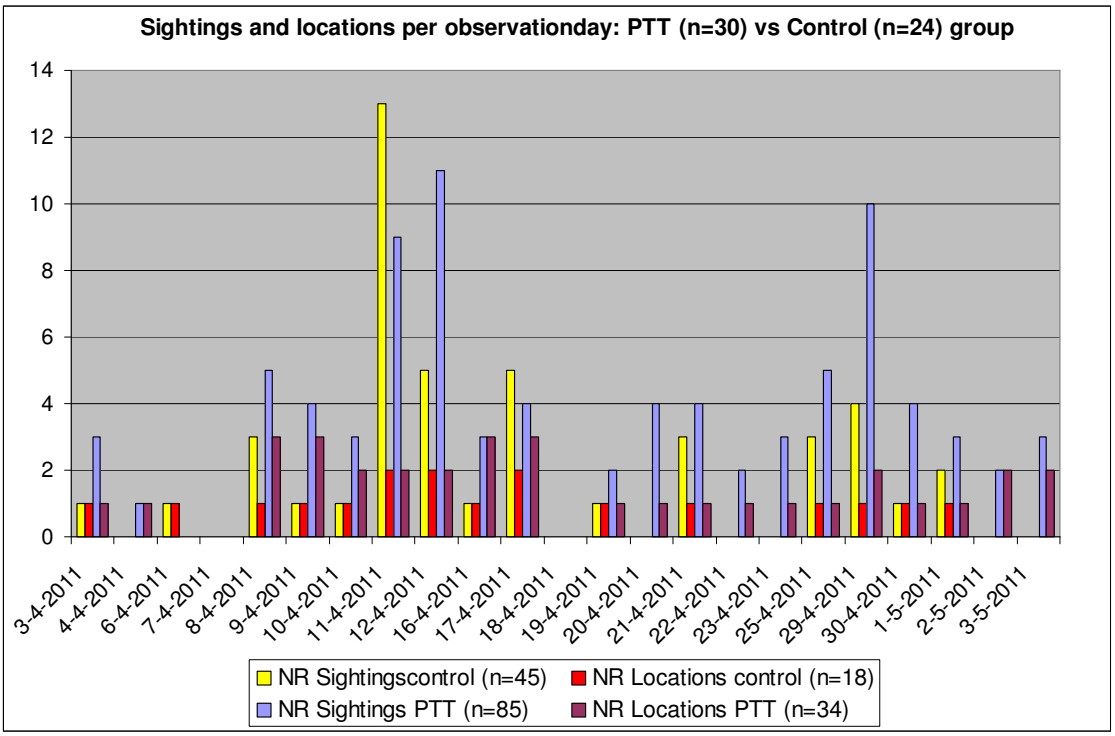
The 24 control birds were visually seen 58 times (2,42 average) and visited on average 1,0 different beaches after their release date. If we have a closer look at them and take the same period as the PTT-birds we have 54 visuals (2,25 average) and the birds visited on average 0,5 different beaches (see Tab. 4).

10 of the 24 control birds never had a visual sighting. If we exclude these from the analysis than the 14 remaining birds were on average seen 4,21 times and visited 2,36 different beaches in the month after their release (see Tab. 4).

	PTT Group	**Control group**
Number of individuals	30	24
Catch date's	1 & 3 April 2011	6 & 11 Mach 2011
Catch location	Eagles Roost & Quarry Beach (west)	Boiler Point & Campsite Beach
Release location	**BBO Beach**	Same as catch location
Group followed till	3 May 2011	11 April 2011 / 3 May 2011
Times visually seen (average)	86 times (2,87)	59 times (2,45) / 54 times (2,25)
Number of birds never visually seen	10	10
Number of china sightings	1	15 (5 individuals)
Date first China sighting	29-05-2011	30-05-2011

Table 4: comparison between the PTT and control group

We analyzed the resightings of both groups per date, to test the effects of the PTT on resighting and departure date. It showed that the control group was seen less often after mid April. This might indicate that the control birds had an easier and faster time fuelling and could migrate faster without the burden of the PTT. It also shows that after the first week of May the control birds had possibly left the Northern shores of Roebuck Bay while the PTT-birds were still there (see graph 12). The peak in sightings can be attributed to the Red Knots forming large pre-migration flocks which were easier to find in the bay.



Graph 12: PTT vs. control group sightings. Number of observations and number of visited locations (Y-axis), per day.

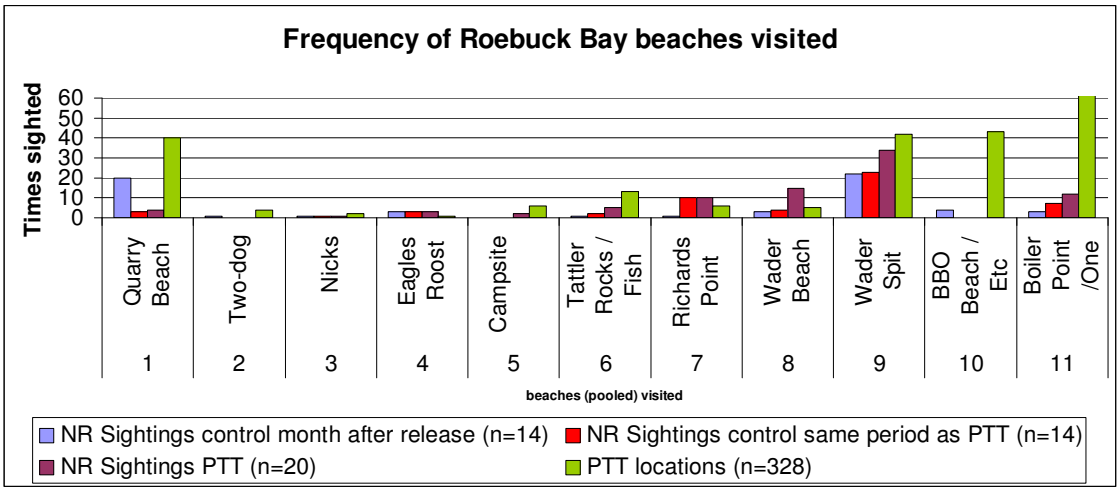
When we look at the control group in the same time period and a month after their release and observe the time they frequent a particular beach, we see that at most beaches the frequency of visits did not differentiate much.

At Quarry Beach, the control group was seen more often in the month after their release, and less often in the 1 April to 3 May period. This can be attributed to the fact that the cannon net catch of 3 April was made on that location. It can be possible that the birds avoided Quarry Beach for a couple of days, giving fewer sightings at that location.

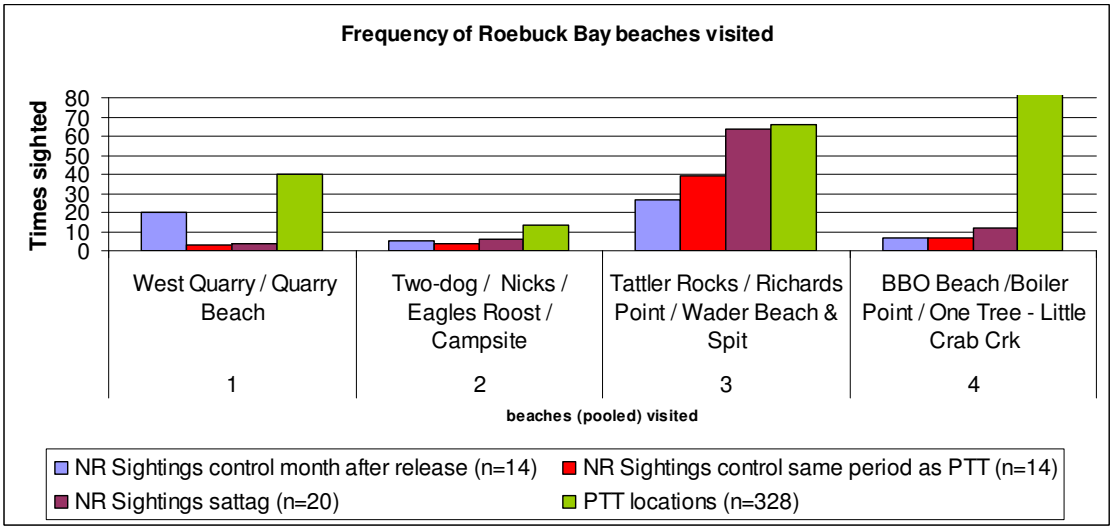
A lot of PTT call-backs came from the east side of Roebuck Bay, from BBO-Beach to One Tree, these sections were much lager than the other beach sections. An individual PTT-bird can easily be missed on such vast tracts of beach. It might be possible that the Red knots visited these beaches at night when the observers could not record them. At the Boiler Point / One Tree section 166 PTT call-backs were generated, this is over half of the 328 call-backs coming from the Northern Shores. This section could possible generate so many call-backs because this is where the birds seek refuge for spring tides, in the mangrove fringes on the bay's edge.

Surprisingly, a lot of PTT call-backs came from Quarry Beach, but not many PTT resightings were made there. Perhaps it is true that the PTT birds roosted here at night, although Rogers (2006) found that the birds of Quarry Beach left Roebuck Bay at night to roost on Cable Beach.

If we pool the beaches more crude (see graph 14) then the speculations about the beaches as stated above become only more profound. The data showed that Red Knots preferred certain beaches over others (P=<0,001 for both control as PTT group), the beaches frequented where really chosen. The 0-hypostasis that all beaches would be equally preferred can therefore be rejected.



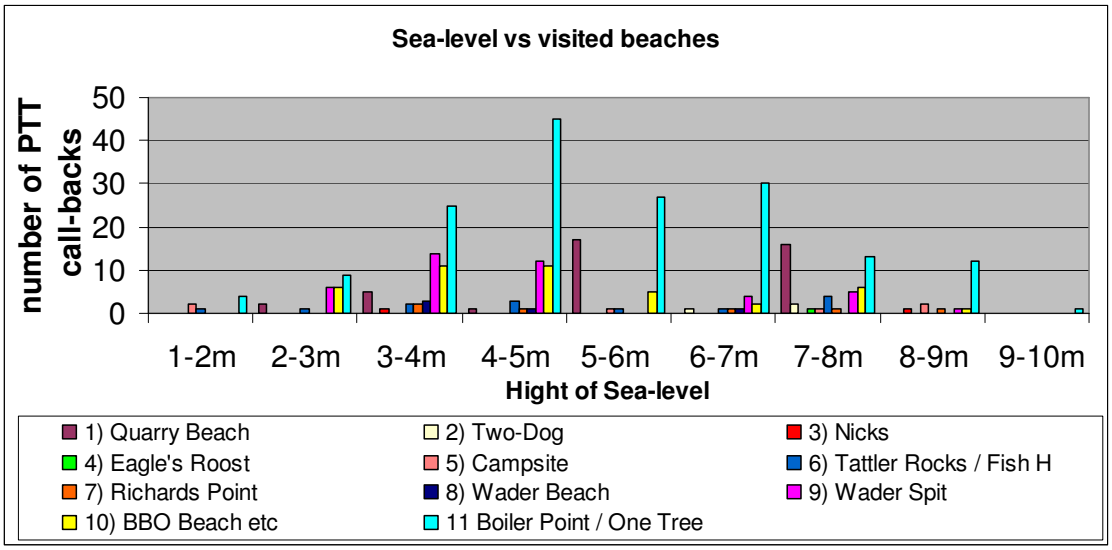
Graph 13: PTT call-backs and sightings combined with resightings of the control group per beach. The numbers 1-11 illustrate beach numbers as shown in Fig 5 & Tab 1. The most right green bar is actually holds 166 sightings; it was shortened to increase the readability of the graph.



Graph 14: PTT call-backs and sightings combined with resightings of the control group per beach. The numbers 1-4 illustrate beach numbers as shown in Fig 5 & Tab 2. The most right green bar is actually holds 209 sightings; it was shortened to increase the readability of the graph.

We assigned a beach location to every PTT call-back. With this we could see if the Red Knots preferred different beaches on different tidal heights. It showed that (see graph 15): Wader Spit was mostly visited on tides between 2-5m, BBO Beach was preferred on tides between 3-5m, Quarry Beach on tides between 5-8m. Boiler Point showed to be the hotspot of the bay at any tide and especially between 3-9m.

At the neap tides of 1-3m all the beaches seemed to score almost the same amount of Red Knot PTT call-backs. This was due to the tide being so far out that vast stretches of mudflat became available for shorebirds to forage on. The birds fanned out onto the mudflats and the beaches became disserted. A similar thing happened at spring tides higher than 8m when the birds left the bay to roost on the floodplains of Roebuck Plains Cattle Station and Kidneybean Claypan, as was also described by Rogers *et al.* in 2001.



Graph 15: The number of PTT call-backs made at a certain stage in the tidal amplitude (Sea level: Categorized per meter). The bars show the variations in the number of call-backs between the different beaches.

Of the Control birds, 5 were released with wing cramps after banding. Of these 5, four are amongst the 10 birds which up to present were never seen after release. The one with wing cramp which surely did survive was resighted over 3 times. Scanning for colour bands is still in progress, and "lost" birds might still show up in Roebuck Bay in years to come.

Discussion

In the overall research period, resighting intensity of the research crew was variable, on most days only 2 people were present in the bay but at other days our team was strengthened by help of mainly, Chris Hassell Adrian Boyle and Grant and Clare Morton.

Within this study researchers joined the "AWSG North West Australia Wader and Tern Expedition 2011", which ran between 19 February and 12 March 2011.
The first 4 days of April were filled with cannon-netting for PTT Knots and from 16-18 April researchers were occupied with scanning for Red Knots at 80-Mile Beach. During these periods the scanning for Red Knots at Roebuck Bay could not be preformed.
The presence and absence of observers in Roebuck Bay, is also visible for the more "historic" data in the data base.

The great tidal amplitude characteristic for Roebuck Bay made scanning work at neap and spring tides virtually impossible. Although we tried, the daily yield of read colour combinations was very low. On other days when the tide forced the birds onto small stretches of beach, large scores of colour bands were resighted, especially at Boiler Point.

As in any intertidal area on the globe the tidal regime in Roebuck Bay holds more hours per cycle where the tide is at "normal level", between 4-8, than it does for very low and very high water. This means that there are more points in the data where the birds are observed on "normal" tidal heights, and might create a bias in the shown beach preferences (see graph 15).

The pooling of the beaches was done by an AWSG format, to pool beaches with the same habitat characteristics. Some sections of beach are much larger than others (see Fig 5.) and could give a bias trough the dataset. We assumed all pools to be of equal importance when their pro's and cons were weighed against each other.

The control group and the birds wearing the PTT's were given a different treatment when handled after the catch and therefore the results might have been different when given the same treatment. The PTT birds were taken in an air-conditioned room and of course the attachment of the PTT itself which the control group did not receive. The control birds were handled and colour banded on the beach where they were caught, leading to a probable lower stress level

The majority of colour band sightings were made on Quarry Beach and Wader Spit. The bulk of the PTT call-backs came from the Boiler Point / One Tree section.
This could be a catch effect or an effect of the PTT as the PTT birds were caught at Quarry Beach and Eagles Roost. A similar thing is seen in the control group, the birds seem to avoid their catch location, and they might feel it is unsafe there.

As one would expect, colour band resightings were only made in daylight hours but the PTT's were still active gathering data during night, this is the reason that there are far more PTT call-backs than control group sightings. When a PTT went stationary on a

particular beach we went looking for it. When it became clear that birds shed their PTT's we actively searched for the remaining PTT-birds to note down the position of the PTT on the birds back. This could be a reason that the PTT-birds were more often resighted than the birds in the control group. Another reason might be that the PTT with its shiny surface stood out more within the large flocks of shore birds.

We observed Greater sand plovers (*Charadrius leschenaultia*) pecking the PTT's surface and harassing the PTT-birds, this might have forced the PTT-birds to the outside perimeters of the flocks, making them more observable. This could also make them more vulnerable to predation by raptors.

The days after the release of the PTT-birds, saw wind speeds of around 5 Bft, and a 10°C decrease in air temperature. Although this could gave an effect we did not assume this to be the case. Being shorebirds Red Knots are always under constant exposure of the elements and can cope with far severe conditions.

In ideal situations the PTT's have an accuracy of 1500m. This can mean that some birds were pooled in different beach categories or that they seemed to be above bush while actually being on the beach. Hopefully spatial accuracy can be improved in the near future, with the rapid advancement in PTT technology.

It seemed likely that the control group had an easier time fuelling when compared to the PTT-group. Most probable they left for migration days prior to the departure date of the PTT-birds.

It is not clear is if the PTT's affected migratory behaviour. PTT-birds stopped over more often then previously predicted, if this was caused by the burden of the PTT's or just normal stopover behaviour is unknown. The stopover location of the 3 birds in Borneo might have been caused by the burden of the PTT, but could also be attributed to tropical storm "Aere", which hovered around the Philippines for a week in May (ACTS 2011). The Red Knots might sense the area of low pressure and wait for the atmosphere to clear (Rogers 2011). Stopover sites for birds stressed by adverse weather, can have high conservation values (Rogers 2011). European Red Knots use small mudflats on the French coast as an emergency stop over site, which are thought to ensure the survival of 20% of the flyways population (Leyrer *et al.* 2009)

There is not a lot of data available on stopover sites between the Western Australian and the Yellow Sea coasts. The available data is hardly site specific. The behaviour of the PTT-birds might not be that unusual after all.

Despite constant monitoring of temperature and regular checks for stressed birds inside the holding / keeping cages, 5 of the control birds were released with wing cramp. A wing cramped bird could not open its wings well and walked far out onto the mudflats.

Cramp or stress myopathy (Minton 1993) seems to be caused by general heightened stress levels and can have human induced (catching and handling) as natural (miss strikes

by raptors) causes (Clark & Clark, 2002). It is not fully understood why some birds suffer from cramps and others do not. Larger species of waders (such as Red Knot) are easier affected by stress than the smaller species especially when they hold large pre-migratory fat deposits (Minton 1993). It is believed that birds suffering from cramps are weakened by other external factors such as endo-parasites (Melville 1982 in Redshank *Tringa totanus*) and that the stress of catching, handling and most importantly thermal stress (small keeping cages in hot conditions) causes cramp (Purchase & Minton 1982).

Catching-stress can be lethal even days later. Purchase & Minton (1982) found bar-tailed godwits (*Limosa lapponica*) unable to walk or fly, several kilometres away from the site of release and several days later. In some cases small doses of Valium were given to Red Knots which recovered the following day, sometimes after a deep long sleep (Piersma *et al.* 1991). In the field we believed that taking birds back into the camp would increase stress levels. We never treated any of the birds used in this study for cramps, instead of taking birds in we observed them and noted down their colour band combinations. We assured ourselves of their well being and made sure that the cramped birds were not taken by predators.

Post catch myopathy could speculatively be the cause, why within the first week after handling, 9 of the 30 PTT-birds were "lost". Of 11 birds out of the PTT-group, we have neither field visuals nor satellite data. Their PTT was probable shed or the bird might have died. Therefore we cannot be sure about their whereabouts or survival. Some of these birds might be resighted in the seasons to come but some will not.

It is hard to explain why the captive Red Knots held in the NIOZ retained their PTT's for so much longer than the ones in Roebuck Bay. The attachment surface of the dummy PTT's was less flat than that of the real ones. It could be possible that a different type of glue was used to fixate the PTT's or that other factors such as differences in temperature and higher salt concentrations in the tropics play a role in the deterioration of the glue layer. It can be speculated that wild birds get dirty more often and therefore preen there feathers more. It could be that wild birds peck the PTT's more often than the captive ones, or that the pecking is done by other bird species. We observed a Greater Sand Plover pecking the shimmering surface of a PTT solar panel carried by a Red Knot. Perhaps the Feather stubs on which the PTT was fixated moulted or were pulled out of the bird's skin, but since we have no visual data of this birds we cannot be sure about either outcome.

During the discussions in the field we thought of a possible effect of the glue on the skin. Perhaps the glue or the friction of the PTT itself would cause what is called "contact dermatitis", a skin blister. If the blister was big enough the whole bit of skin could be pulled of with a new layer of skin underneath, shedding the PTT. This could also happen when a bird was still fuelling on a very fast rate, the skin might have stretched causing the glue to expand or the skin might get to thin due to the stretching, blistering it and again losing the PTT.

Conclusions and Prospects

We now know that it is possible for Red Knots to make the 6000km migration to the Chinese Yellow Sea while carrying a 5g PTT. This offers vast opportunities to the research field of bird ecology.

The control group left on migration days prior than the PTT-birds, this could be a burden of the PTT. The PTT's showed Red Knot to stopover on sites previously unknown to science, such as: Sarawak, Indonesia and Borneo, the Philippines utilizing fish- and salt ponds en route.

Most Red Knots preferred Quarry Beach and the middle of the bay, especially Wader Spit, over other sections of Roebuck Bay. But most of the PTT call-backs came from Boiler Point.

With the ongoing habitat destruction due to land reclamations done within the Chinese coastal areas of Bohai Bay, it is of vital importance that more research is done to find safe havens for shore birds within the East Asian-Australasian Flyway. More birds need to be outfitted with PTT's and the colour banding and resighting efforts need to be continued and intensified.

Shorebird workers need to make the Australian Government aware of the fact that if Bohai Bay is lost it will have irreversible impact on the Australian avifauna. The Australian Government should persuade the Chinese not to reclaim Bohai Bay. Possible, as a last resort, Bohai Bay could be purchased by the World Wildlife Fund for Nature as a wetland reserve, before it is too late for the Red Knot and the other spectacular waders utilizing the EAAF.

Acknowledgements

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