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Seabird monitoring study at Coringa Herald National Nature Reserve

Report prepared for

Department of the Environment, Water, Heritage & the Arts

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Director of National Parks

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SEABIRD MONITORING PROGRAM - CORAL SEA ISLAND TERRITORY.

REPORT ON 2007 FIELD SEASON AND UPDATE OF HERALD CAYS LONGITUDINAL DATASETS FOR THE PERIOD 1992 TO 2007.

Executive Summary

Australia's Coral Sea Island Territory contains extensive seabird rookeries of great significance to the ecological balance of the Coral Sea region, with thirteen seabird species recorded breeding in the area. While some of these species (such as the red-footed booby (*Sula sula)*, least frigatebird (*Fregata ariel)*, great frigatebird (*Fregata minor)* and red-tailed tropicbird (*Phaethon rubricauda*) have an extensive distribution outside of Australian waters, they are uncommon within Australia. The islands and cays of the Coral Sea are important in that they contain a significant proportion of the region's breeding populations.

Coringa-Herald National Nature Reserve, which covers approximately 8860 sq km, was proclaimed as a National Nature Reserve under Commonwealth legislation on 16 August 1982. The reserve contains six sand cays and islets with fringing reef systems that have developed on the shallow shelves of the Coral Sea Plateau. A major reason for proclaiming these reserves was to protect the seabirds that breed in the region (ANPWS 1989).

We have been monitoring seabirds in the Coringa-Herald National Nature Reserve since 1992. The monitoring program established is centred on one islet, North East Herald Cay (NEH), with visits to other islets, principally South West Herald Cay (SWH), carried out as time permits. Data are principally collected during one visit to NEH each year, which is timed to coincide with periods of peak breeding activity for three species with important breeding populations in the region – red-footed booby, least frigatebird and greater frigatebird. Data collection has relied on a design and estimation methodology that is scientifically rigorous and developed specifically to monitor seabirds in the Coral Sea. An understanding of the seabirds in the region has been enhanced by the accumulation of long-term data sets — there are now 16-year and 5-year data sets available for NEH and SWH, respectively.

A patrol in August 2007 was undertaken to conduct an annual count of the nesting seabird populations on NEH and SWH. Counts of nesting birds in the three major habitats on NEH were completed during this patrol. SWH was also briefly visited where a count of nesting seabirds in *Argusia* shrubland was undertaken. Data collected on the patrol were incorporated with all data collected since 1992 and subsequently analysed for long-term trends. These long-term trends are reported upon in this report.

The breeding populations of most species examined on NEH appear to have remained stable during the period 1992 to 2007, although a significant drop in numbers of frigatebirds since 1998 has occurred. In 2007 the following number of pairs of species of particular interest counted or estimated to be breeding at the time of the survey were:

— Red-footed booby — 1094 (CI 824-1390) pairs in the *Pisonia/Cordia* and 431 pairs in the *Argusia* shrubland, a total of 1525 (CI 255-1 821) nesting pairs on NEH, and 839 pairs on SWH. On NEH most breeding birds were either nest-building or on nests with eggs, but breeding was more advanced on SWH with 29% of nests containing chicks. We assessed the number of birds breeding on NEH to be slightly above average for this year, and at usual levels for SWH.

— Great and least frigatebirds — 1456 (CI 978-2053) pairs in the *Pisonia/Cordia* and 338 pairs in the *Argusia* shrubland, a total of 1794 (1316-2391) nesting pairs on NEH. Most (84%) of these birds were on nests with large chicks. Of breeding birds that were identified to species level, 52% were great frigatebirds. *Argusia* counts at SWH (215 pairs) showed that breeding was at a similar stage to that on NEH, with 73% nests containing large chicks. Only great frigatebirds were breeding at SWH, as reported for previous years.

— Red-tailed tropicbirds — 174 pairs on NEH and 215 pairs on SWH.

— Masked booby — 10 pairs on NEH and 35 pairs on SWH. One hundred and thirty banded birds were resighted, 17 of which were at least 10 years or older. One bird, originally banded on Lord Howe Island, was also resighted, a movement of 1,900 km.

— Black noddy — as with frigatebirds, this species was stable from 1992 to 1997, and then declined between 1998 to 2006. The count in 2007 was 22,373 (CI 19,058-25,776) nests, the first time in nearly 10 years that the count had approached the level of the early 1990s.

The Coral Sea Seabird Monitoring Program continues to provide valuable insights into the avifauna of the Coral Sea National Nature Reserves. It is recommended that annual visits of approximately seven days in duration continue to count seabirds breeding in the Herald Cays. These visits should be timed to occur in July/August each year to standardise timing of counts. Visits to other islands such as South East Magdalene and Chilcott Cays to count seabirds to collect comparative data for the major breeding species should occur as resources permit. These islands should be visited briefly and surveyed using rapid count techniques appropriate for the dominant vegetation on each island. These visits should also be timed to occur in July/August.

Introduction

Australia's Coral Sea Island Territory has long been known to contain extensive seabird rookeries of great significance to the ecological balance of the Coral Sea region, with 13 seabird species recorded breeding in the area. While some of these species (such as the red-footed booby (*Sula sula)*, least frigatebird (*Fregata ariel)*, great frigatebird (*Fregata minor)* and red-tailed tropicbird (*Phaethon rubricauda*) have an extensive distribution outside of Australian waters, they are uncommon within Australia. The islands and cays of the Coral Sea are important in that they contain a significant proportion of the region's breeding populations.

Coringa-Herald National Nature Reserve, which covers approximately 8860 sq km, was proclaimed as a National Nature Reserve under Commonwealth legislation on 16 August 1982. The reserve contains six sand cays and islets with fringing reef systems that have developed on the shallow shelves of the Coral Sea Plateau. A major reason for proclaiming these reserves was to protect the seabirds which breed in the region (ANPWS 1989).

We have been monitoring seabirds in the Coringa-Herald National Nature Reserve since 1992 and have developed robust methodologies to serve this purpose. The monitoring program established is centred on one islet, North East Herald Cay (NEH), with visits to other islets, principally South West Herald Cay (SEH), carried out as time permits. Here we report the results of monitoring seabirds at NEH and SWH Cays from 1992 to August 2007. This program has been designed to document long-term trends in the region's seabird populations and focuses on seven species: least frigatebird *Fregata ariel*, great frigatebird *Fregata minor*, red-footed booby *Sula sula*, brown booby *Sula leucogaster*, masked booby *Sula dactylatra*, black noddy *Anous minutus*, and red-tailed tropicbird *Phaethon rubricauda*.

A patrol in August 2007 was undertaken to conduct an annual count of the nesting seabird populations on NEH. We also conducted surveys on one other islet, South West Herald Islet. This islet was briefly visited where a count of nesting seabirds in Argusia shrubland was undertaken. We also continued a mark-recapture study of masked boobies in the Herald Cays and searched for banded birds during fieldwork on SWH.

During the course of our work, we also collected marine debris on both NEH and SWH, and conducted systematic surveys to measure the presence and impact of scale insect *Pulvinaria urbicola* and the hawkmoth *Hippotion velox* on *Pisonia grandis* on NE Herald Island. These two aspects are reported upon in Appendices to this report.

METHODS

The methods employed in this study have been described extensively in previous reports and are included as Appendix 1 to this report. They are briefly summarised below. The methodology has been independently reviewed recently and endorsed as being soundly based (Hamann 2006).

North East Herald Cay (NEH — 16 56' 40 S, 149 11' 37 E) and South West Herald Cay (SWH — 17 00' 00 S, 149 08' 00 E) are small sand cays located some 400 km east of Cairns, Australia. The sites are within Australia's Coral Sea Islands Territory and are east of the Great Barrier Reef. Maximum elevation of the islands is about 5 m ASL. NEH Cay is one of only three forested cays located within the Coral Sea National Nature Reserves.

NEH Cay has been the site of most of the ornithological research activity in the Coral Sea National Nature Reserves. Hicks (1984) recognised three broad habitat classes on the island: — *Pisonia/Cordia* forest, *Abutilon* shrubland and *Argusia* shrubland/grassland. SWH, like many of the sand cays in the Coral Sea, is fringed with the shrub *Argusia argentea* and a grassy understorey (ANPWS 1989). This zone is well developed on the lee side of the island and extends up to 40 m wide, but is absent or poorly developed on the weather-exposed side.

To estimate numbers of breeding seabirds, different monitoring methods are employed to suit the habitat being surveyed. The methods used are summarised below:

Habitat	Island	Method	Species surveyed
***Pisonia/Cordia* forest**	**NEH**	Transect with 10 X 10m quadrats (n=415) Transect 1m wide	Red-footed booby Frigatebirds Black noddy Common noddy Wedge-tailed shearwater
***Abutilon* shrubland**	**NEH**	Transect with 10 X 10m quadrats Transect 1m wide	Red-footed booby Frigatebirds Wedge-tailed shearwater
	SWH	Not assessed	
***Argusia* shrubland**	**NEH**	Total nest counts	Red-footed booby Brown booby Masked booby Least Frigatebird Great Frigatebird Red-tailed tropicbird Common noddy
	SWH	Total nest counts	Red-footed booby Brown booby Masked booby Great Frigatebird Red-tailed tropicbird Common noddy

On NEH surveys have been carried out once each year since 1992 to 2007, excluding 1993, and were timed to occur during peak breeding of red-footed booby and

frigatebirds. To minimise the effect of different observers and time of day, we counted nests rather than birds present. During surveys, we intensively searched all quadrats in *Pisonia/Cordia* forest and *Abutilon* shrubland, and all *Argusia* shrubland habitat, for active nests of the target species. For each nest we recorded the species of bird and the stage of breeding.

On SWH only counts in *Argusia* shrubland were conducted.

Estimates of total breeding pairs in *Argusia* shrubland and *Pisonia / Cordia* forest were calculated for all breeding species on NEH. Line graphs showing longitudinal profiles of the estimated or total number of each species nesting each year with 95% confidence intervals (estimated by bootstrapping) were prepared. Only data for the principal species of interest are presented here. As these data probably reflect time of visit rather than the true population size, histograms showing stage of breeding in relation to each count were prepared, and the proportion of nests with large chicks calculated, to assist in data interpretation.

For SWH, estimates of total breeding pairs were calculated for all breeding species in *Argusia* shrubland only.

Wedge-tailed shearwaters *Puffinus pacificus* nest on NEH in burrows and breed during the summer. Since 2001 we have counted all burrow entrances observed within 1 m wide transects. Total length of transects has varied each year (>2000 m each year). These counts are used to estimate the total number of burrows used in the previous breeding season, but we do not report these data annually as the species is not a priority of the current study.

In 1999 we commenced an intensive banding study of the masked booby as an adjunct to the other work. This study aims to build on the data obtained on this species at North East Herald Cay over the past 16 years. Specifically, it is intended to examine population structure, pair and site fidelity, and levels of recruitment. This work is 'extra-curricular' to the main program and does not entail additional resources.

The Patrol Program for 2007

The program for 2007 was planned to meet the management goals and strategies for seabird research outlined in the *Coringa-Herald National Nature Reserve and Lihou Reef National Nature Reserve Management Plan* (Environment Australia 2000) i.e.

Management Goals

— Conduct and encourage research and monitoring that will increase knowledge of the natural … environments of the reserves, provide information to enhance management, and measure management success; and
— Ensure that research activities are appropriate and will not adversely impact on the conservation values of the Reserves.

Management Strategies

— Continue to monitor seabirds … to assess population status of these species and to improve information about the significance of the Reserves as breeding and nesting habitat for these species as part of the annual patrol program.

One trip was made to the Herald Cays in August 2007 to monitor seabirds.

RESULTS

Red-footed booby

At NEH cay the red-footed booby population has remained relatively stable at about 300 pairs in *Argusia* shrubland and 1000 pairs in the *Pisonia/Cordia* forest (Figure 1). Evidence is now emerging that indicates the number of birds breeding in the *Argusia* shrubland is increasing (figure 1). In 2007 we recorded 1094 (CI 824-1390) pairs in the *Pisonia/Cordia* and 431 pairs in the *Argusia* shrubland, a total of 1525 (CI 255-1821) nesting pairs. Most of these birds were either nest-building or on nests with eggs, and few (2%) contained large chicks, indicating that the time of the counts was similar to the timing of most of the historical counts for this species. We assessed the number of birds breeding to be slightly above average for this year.

Argusia counts at SWH (839 pairs) showed that breeding was at a more advanced stage to that on NEH, with 29% of nests containing chicks, and 38% of pairs incubating eggs. The number of birds breeding on SWH has remained stable since counts were initiated in 2003 (Figure 2).

Frigatebirds

Between 1992 and 1997 the frigatebird population on NEH was stable at around 3000 pairs in the *Pisonia/Cordia* forest, and 200 pairs in the *Argusia* shrubland (Figure 3). Numbers were significantly reduced after 1998 following the extreme ENSO event of 1998, and the population has not recovered to pre-1998 values to date. In 2007 we recorded 1456 (CI 978-2053) pairs in the *Pisonia/Cordia* and 338 pairs in the *Argusia* shrubland, a total of 1794 (1316-2391) nesting pairs. Most (84%) of these birds were on nests with large chicks, which indicated that the time of the counts was similar to the timing of most of the historical counts for this species since 1998. The number of birds breeding is slightly above the fitted trendline average for this year.

The fitted order-3 polynomial trendline in Figure 3 indicates a population decline and subsequent population stability at a lower level, but the R^2 value obtained (0.57) indicates the fit is not particularly good. Use of loglinear models with separate change points for the periods 1992-1997 and 1998-present time, or another smoothing function, may be more appropriate.

Identification of the great frigatebird and least frigatebird during nesting is difficult unless a parent is attending a nest. Once eggs have hatched and the chick no longer requires guarding, adults are rarely in attendance at nests. In these cases the nests are recorded as ‘frigatebirds’ and no species assigned. Because identification of chicks to species level is not possible, data on the species composition of the frigatebird population are poor, particularly for all years prior to 1998. Since then we have attempted to gather data on the species composition of the NEH frigatebird population.

Data collected for all years since 1999 (see below) indicate that c.40% (range 18-66%) of the birds breeding are great frigatebirds.

YEAR	GFB	LFB	Total	Total frigatebirds recorded	Sample Proportion %	Proportion GFB %
1999	24	102	126	217	58	19%
2000	19	10	29	59	49	66%
2001	25	51	76	158	48	33%
2002	14	62	76	324	23	18%
2003	9	10	19	226	8	47%
2004	36	156	192	245	78	19%
2005			**Insufficient data**			
2006	26	15	41	84	33	63%
2007	13	12	25	226	11	52%
Mean					39%	40%

Argusia counts at SWH (215 pairs) showed that breeding was at a similar stage to that on NEH (73% of pairs were on nests containing large chicks). Only great frigatebirds were breeding at SWH, as reported for previous years. The number of birds breeding on SWH has remained stable since counts were initiated in 2003 (Figure 4).

Black noddy

This species has not been the subject of the main study and counts have been made merely as an adjunct to the forest counts for frigatebirds and red-footed boobies. Black noddies mainly breed in the Pisonia/Cordia forest on NEH, and they do not breed on SWH because this vegetation type is not present. The population was stable with nest counts of around 20,000 (Figure 5) from 1992 to 1997. Nest counts from 1998 to 2006 ranged from 10-15,000, which was noticeably lower than in earlier years. The count in 2007 was 22,373 (CI 19,058-25,776) nests, the first time in nearly 10 years that the count had approached the level of the early 1990s.

It should be noted that these nest counts do not equate directly to the number of pairs breeding, as the assumption that each nest equates to a breeding pair is invalid. The counts therefore provide an index of abundance, which still provides a measure of population change over time. Black noddy pairs often build a series of nests during courtship (Fisk 1977, Higgins and Davies 1996). This behaviour is important in formation and maintenance of pair bonds but makes interpretation of nest count data problematic. There is also little information on its extent, and whether all pairs build multiple nests. Except for 1999 and 2000, there are no stage-of-nesting data to assess the relationship between nest counts and breeding pairs, or to assist in interpretation of inter-annual variation of estimates. However, the 'booby cam' data for those two years indicated that the majority of nests counted were empty at the time of the count – 56%

and 85% of nests were empty in 1999 and 2000 respectively. Of the occupied nests, c. 50% had chicks in 1999, and nearly all in 2000. It is therefore likely that breeding commences in late autumn / early winter and has finished by September each year, which is in contrast to the breeding cycle observed in the Capricorn Group (Great Barrier Reef) where breeding extends from October to March, with peak egg laying in November to mid December (Higgins and Davies 1996).

Red-tailed tropicbird

Red-tailed tropicbirds only breed in the Argusia shrubland and associated beach rock habitats, and the counts represent population estimates for both islands. At NEH, where the data series is more extensive, the population appears to be stable at between 200 to 250 pairs (Figure 6). Although the data series for SWH is less extensive, the population would also appear to be stable at a similar level (Figure 7). The main breeding season for this species runs from March to July. Counts over the past five years have been conducted when many birds have finished breeding, and the low numbers recorded between 1998 and 2003 for NEH (Fig.6) are unlikely to represent a population decline. The fitted trendlines indicates the population has been relatively stable since counts commenced at both sites. In 2007, 174 pairs were recorded breeding on NEH and 215 pairs on SWH — 62% and 73%, respectively, of nests located had large chicks. The Herald Cays support a population in excess of 500 breeding pairs of red-tailed tropicbirds and is the most important breeding site for this species in Eastern Australia.

Masked booby

Masked boobies are conspicuous birds of the shoreline of many Coral Sea islands, where they breed in low numbers. Whilst a maximum of 45 pairs have been recorded breeding on North East Herald Cay, more typically c.30 pairs can be found tending eggs and chicks close to the high tide mark. In 2007 there were 10 pairs nesting on NEH and 35 pairs on SWH.

As a result of limited banding carried out in earlier days and intensive banding effort since 2003, many of the birds carry bands. These can be read using a telescope or binoculars, avoiding the need to recapture individuals to obtain survival data.

Banding has now been carried out on both NE and SW Herald Islets. Results from this study reveal that there is regular movement between both islands, which is not surprising in view of the close proximity of the two Herald Cays. The banding study has shown that pairs remain faithful over many years and many pairs breed each year. Survival estimates have not been accurately calculated at this stage but mean annual adult survival is in excess of 90%.

This year 28 masked boobies were banded during the August 2007 patrol. Most of these birds were captured on SWH. One hundred and thirty one individuals previously banded were also re-sighted. Of these, 130 were of known age and 17 were at least 10 years or older (see table below). All had been originally banded on the Herald Cays, with the exception of one bird which had been banded at Lord Howe Island, 1900 km S of the Herald Cays. This is the second time a bird banded on Lord Howe Island has

been found in the Herald Cays, suggesting that Lord Howe Island birds may regularly disperse into the Coral Sea before returning to breed at their natal colonies.

		No of birds recaptured at age														
No. of birds		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**20**
Banded	28															
Recaptured	131		12	4	21	60	11	2	3			16				1
Total	159															

DISCUSSION

General comments

The patrol program to the Coral Sea NNRs and North East Herald Cay over the past 16 years continues to provide a valuable insight into the importance of this area to Australasian tropical seabirds. It confirms that, from a regional perspective, the Herald Cays of the Coral Sea contain a significant proportion of the region's breeding populations, particularly for red-footed booby, great frigatebird, least frigatebird and red-tailed tropicbird.

All of the species that we have examined have a defined breeding season. Most commence breeding at the end of the cyclone season in March-April, and continue during the cooler winter months, although the breeding season is not as well synchronised as that for many temperate seabird species. The wedge-tailed shearwater breeds in summer.

With the exception of frigatebirds and black noddies, at NEH the breeding populations of all species examined have remained stable during the period 1992 to 2007. The frigatebird population was stable at around 3500 pairs from 1992 until 1997, crashed dramatically between 1998-2001, and would now appear to be stabilising at around 1800 annual breeding pairs in the *Argusia* and Pisonia/Cordia habitats combined. Black noddies have followed a similar pattern, although this year nest counts were similar to those observed in the early 1990s (c. 20,000 nests).

It should be noted that, although this program has been able to detect significant population changes in frigatebirds and black noddies, the infrequent (annual) data collection protocol for species with loosely synchronised breeding seasons means there will always be a lag of few years before population declines can be detected with confidence. The long incubation and fledging period of frigatebirds, boobies and tropicbirds increases the chances that short visits to uninhabited breeding islands will occur during the breeding season and population counts can be made. However, interpretation of counts made during short 'windows of opportunity' also requires the collection of information on the stage of breeding at the time that counts are made. To facilitate comparisons between years, it is essential that the variability in the stage-of-breeding between counts be minimised by standardising counts to a fixed time each year. The best time to conduct counts to ensure that the focal species will be breeding

is April/May for red-tailed tropicbirds and July/August for frigatebirds and red-footed boobies.

After 16 years of annual surveys on NEH, the existing program has sufficient power to detect changes of 6-7% per annum (Hamann et al., 2006). It is a feature of long-term data sets for both birds and mammals that year to year variability is large relative to intra-year (sampling) variability. Therefore any inference made about long-term change needs to interpreted relative to inter-year variability, which is large. If these populations are to be monitored, it requires long-term approaches to counting protocols. For these reasons, effect sizes of less than 5% per annum will be achievable as the level of the study increases. Hamann et al. (2006) estimated that with another 10 years of data, power will increase such that detection of annual changes of less than 2.5% will be possible.

These characteristics of bird count data were recognized at the time the study was initiated. While concerns may be voiced that 5-10 years will have passed before low rates of population decline can be detected with certainty, the demographic characteristics (high survival, low fecundity) of the seabird species being monitored provide some buffering to rapid rates of decline and even extinction. If current survey levels are maintained, negative trends will be detected in sufficient time for a detailed analysis of the cause of decline to be carried out and appropriate management implemented. This is the situation that we currently have with frigatebirds — it is apparent that these species have declined, and we are now attempting to examine the reasons for this.

Frigatebirds

In previous reports we have discussed the possible causes of change to the frigatebird population. We believe that the decline in frigatebirds is linked to oceanographic influences and, in particular, rising sea surface temperatures associated with El Nino events. 1997 was an El Nino year accompanied by a large increase in SST, and it was at this time that the decline in frigatebirds occurred. Similar population crashes have been recorded for frigatebird populations in the eastern Pacific Ocean in association with El Nino events (Vandenbosch 2000). Analysis of Christmas Bird Count data for the Honolulu, Hawaii, area showed a population which dropped following the strong 1982-1983 ENSO (El Nino — Southern Oscillation) to 4% of its pre-ENSO value for great frigatebirds (*Fregata minor*) and to 35% for red-footed boobies (*Sula sula*). Interestingly in this study, the populations took more than a decade to regain their pre-ENSO values. Despite the return to conditions more favourable to seabirds in the Coral Sea, the frigatebird population has still not returned to its pre-1997 level. The influence of oceanography on frigatebird numbers is discussed in more detail below.

We have also detected changes in the distribution of nests of frigatebirds and red-footed boobies within the *Pisonia/Cordia* forest, which may due to structural changes in the vegetation of this habitat and the influence of the South East Trade Winds (SE Trades). In many locations where canopy breeding seabirds are exposed to regular strong winds such as the SE Trades, they seek sheltered sites within the canopy for nesting sites. For example, on Christmas Island, Indian Ocean, pairs of Abbott's booby *Sula abbotti* breeding within c.300 m northwest of forest clearings experienced exposure to the south-east trade winds. Within these areas breeding success was

significantly lower in sites with large canopy movement than in upwind areas. Experienced breeders moved nesting sites more often and there was a higher proportion of consistently unsuccessful sites than in other areas. Pairs unsuccessful at breeding were more likely to change nest site than successful breeders. Over a six-year period the distribution of nests changed following clearing for mining operations, resulting in more of the population nesting beyond 300 m of clearings and in areas formerly little used. In these areas, the intrusion of new pairs appeared to lower the breeding success of resident pairs (Reville *et al* 1990).

At the time the quadrat based survey of frigatebirds nesting in the *Pisonia* on NEH commenced (1992), the *Pisonia* was recovering from extensive damage caused by Cyclone Aivu. On many transects the *Pisonia* was shorter (height 2 m) than today (6-8 m), and for the frigatebirds (but not red-footed boobies), there was strong evidence of a density gradient from NW to SE across the island. This factor was taken into account in the sampling process and included as an additional covariate in the analysis of count data. However, it indicated that the frigatebirds were choosing nesting sites on the leeward side of the island, probably to avoid the wind and possibly canopy movement. It is possible that since the *Pisonia* has regrown, wind flow around much of the canopy has changed, effectively reducing the available nesting habitat. To test this, it should be possible to compare the spatial distribution of nesting frigatebirds in earlier years with the situation in recent years. It is our intention to undertake such an analysis as time permits.

Oceanographic influences

Interpretation of the results of the NEH data set is hampered by a lack of understanding of the oceanography of the area, which will most likely explain the inter-annual changes in breeding numbers observed for most species since the program commenced. In collaboration with Dr Chris Wilcox of CSIRO's Division of Marine Science in Hobart, we have investigated the possibility of obtaining oceanographic conditions for the region around the breeding colony, within the potential foraging range of frigatebirds and boobies, as a covariate for explaining the population trends. Previously, using satellite-based sea surface temperature data, we attempted to find the number of oceanographic features that might be associated with foraging areas, such as frontal zones. However, due to the frequency of cloud cover in the region, satellite-based data was frequently corrupted, and generally gave very unstable estimates of oceanographic conditions.

In 2007 DEWHA provided support for a more detailed analysis of oceanographic conditions in the Coral Sea (Wilcox et al. 2007). The oceanographic information that is available in the northern GBR region is somewhat limited as some of the satellite based sensors are affected by the extensive cloud cover in that region. However, some sensors are not affected by cloud cover, and CSIRO Marine and Atmospheric Research (CMAR) has developed estimates of quantities such as sea surface temperature, which are difficult to observe directly, from their relationship with reliably observable variables like sea surface height.

Wilcox et al. (2007) utilised oceanographic models, tied to empirical data from satellites and in-situ sensors, to identify correlations between oceanography and seabird breeding abundance. The data assembled for this study included the sea surface

height, sea surface temperature (statistically estimated), the average 12-hour wind speed, the average monthly wind speed, the average daily current velocity, a daily index of the frontal activity in the region, and an annual index of the Southern Oscillation activity. The data for these variables were extracted for each 1 degree latitude by 1 degree longitude box from a 10 degree by 10 degree area centered on NE Herald Cay. The available data were recorded at a variety of timescales from daily data to annual summaries, and the analysis used data at the finest temporal scale possible, but then summarized as a monthly mean and variance for each data type. For data types such as the Southern Oscillation Index, which were on longer timescales, these were used as is.

The average 12-hour wind speed came out as the single variable most strongly related to the NEH *Pisonia* counts. In particular, high average wind speeds over a three-month period, 18 months preceding the nest survey were related to higher nest counts. This relationship was the strongest of any of the relationships by far. A potential oceanographic mechanism may be increased oceanic mixing, resulting in higher nutrient levels, thus higher productivity and ultimately more abundant prey in the upper layers of the ocean where they are available to the birds. If true, this phenomenon could translate into better body condition and higher proportion of the population either 1) being in adequate condition to nest and attempt breeding or 2) surviving through to the breeding season when the count was taken. However, this is certainly a long chain of causation. Moreover, a note of caution is warranted when exploring a large number of potential driving variables – as the number of potential driving variables increases, one would expect to find some correlations by chance alone. While this does not mean that the effect of winds and potentially ocean mixing should be dismissed, finding a relationship with only a few of the lag/interval combinations for a particular variable should be treated with caution.

The frontal index also appeared to have some relationship with the number of *Pisonia* nests roughly six months later. The strongest relationship was with a lag of four months and an interval of four months. This relationship was positive, although the strength may be affected to some extent by an outlier with both a high frontal index and a high *Pisonia* count. Examining the data directly for lag-interval combinations that sum 8-10 months, this relationship appears to be generally a positive one – higher numbers of fronts in a month indicative of larger *Pisonia* counts. While there were some lag-interval combinations that show no relationship, there did not appear to be many conflicting negative correlations. Again this may well be indicative of increased mixing leading to higher forage abundance prior to the breeding season.

In general, some lag-interval combinations had stronger relationships with the *Pisonia* counts than others for many of the variables. There were three apparent patterns of lag-interval combinations frequently related to *Pisonia* counts. The first was lag-interval combinations that suggest an environmental relationship immediately before the breeding season. In these cases the lag-interval combination summed to less than four generally (i.e. lags < three months, paired with intervals of one to three months). Comparing within a data type, all of the variables had some stronger relationships in this time period. Second were combinations that summed to approximately nine months. These were some of the strongest patterns observed, with the frontal index in particular having an apparent relationship. Other variables that seemed to have a

relationship with *Pisonia* counts with a lag-interval sum of approximately nine months were sea surface temperature and height, and potentially horizontal current speed. Finally, a number of variables had relationships that appeared to be stronger in a relative sense about 18 months to two years — these included all of the environmental variables with the exception of the frontal index.

Wilcox et al (2007) point out that despite all of these apparent relationships, it is likely that they were actually all indices of a few underlying phenomena. Many of the variables were reasonably strongly correlated. For instance, the average 12-hour wind speed and sea surface temperature appeared to be related, although potentially not linearly. Two major phenomena that may be important in this respect were the amount of mixing between surface waters and the nutrient rich waters at depth, and the influence of the Southern Oscillation (ENSO), which may reduce this mixing. In general, the amount of mixing will increase with higher wind conditions and more abundant fronts. This mixing is expected to increase productivity, and eventually prey availability. ENSO events will result in warmer waters in the region, resulting in higher sea surface temperatures and heights. In addition, during ENSO events the boundary between the warm surface waters and the colder nutrient rich waters may be deeper, making mixing of nutrients to the surface less likely. Thus many of the oceanographic variables, such as sea surface temperature or wind velocity, may be indicators of mixing or regional ecological conditions that then drive prey dynamics. It is therefore not surprising that many of the factors measured were related to *Pisonia* counts, but that the relationships are not direct ones – instead they are indicators of regional phenomena which determine regional productivity.

Some correlations between oceanographic environmental variables and the frigatebird nest counts at NEH are therefore likely. While the analysis presented by Wilcox et al (2007) was an exploratory one, surface wind velocity and the number of frontal zones were identified as likely variables related to the phenomena driving frigatebird population dynamics. These environmental variables appeared to be related to nesting frigatebird population dynamics at roughly three timescales: immediately preceding the counts in the pre-breeding season, during the period just after the count in the preceding breeding year, and roughly a similar period two years in the past. The presence of these time-lagged signals is not surprising, as the body condition of the birds individually and the size of the population both act to “integrate” past environmental conditions, maintaining their signal/effects into the future. Future analysis could be expanded or improved by either increasing the sensitivity of the statistical models used, and/or improving the quality of the environmental covariates available. Improvement of the quality of environmental covariates is currently under development at CSIRO Marine and Atmospheric Research, but at the moment they are not available (Wilcox et al 2007).

Timing of counts

It is possible the timing of the survey each year affects the count. Birds are counted on their nests, and the months in which these counts have been undertaken has varied between years. In particular, most of the counts taken between 1994 and 1997 occurred earlier in the breeding season (June-July) when most nests contained eggs and few large chicks, whereas in 1992 and in recent years counts have been carried out at a time (usually August) when most nests contained large chicks (Figure 3). Since

breeding failures (due to a number of factors such as individual physical condition, breeding experience, resource availability etc) occur throughout a breeding season, and since once a failed nest is abandoned the nesting materials are rapidly scavenged by other nesting boobies or frigatebirds, nest counts made later in the breeding season will under-represent the number of birds that initiated breeding in a particular year. Although it is clear that there may be an effect of timing i.e the month in which the counts are conducted on the resulting nest counts, correcting for it is not necessarily straightforward as there are other factors that affect the nest counts. Wilcox et al. (2007) attempted such an analysis by directly correcting the count data using correction factors developed for this purpose. The pattern in the adjusted *Pisonia* counts was roughly similar to the raw counts (Wilcox et al. 2007), and for this reason we have not attempted to follow this approach here. The method used to adjust the count data was satisfactory for an exploratory analysis of oceanographic influences, but it ignored all underlying variation in the count data, which meant that any analysis assumes that the count data are known without error, when in fact they are estimated and potentially with substantial error. However, a more full statistical treatment of the data along the lines explored by Wilcox et al. (2007) may be warranted in time. In that case we would consider statistical modeling of the actual survey process itself, including the effect of the environmental variables. This does not require a change in the data collection protocols adopted for the survey, but rather a potential change in statistical analysis of the data.

RECOMMENDATIONS

We recommend:

- Annual visits of approximately seven days in duration continue to North-east Herald Cay to count seabirds breeding in the *Pisonia/Cordia* forest and the *Argusia* shrubland. These visits should be timed to occur in July/August each year.
- Total counts should be made in *Argusia* shrubland whenever North-East Herald Cay or other islands are visited. These surveys require only three to four hours to conduct, cause minimal impact to breeding birds, and provide valuable information on breeding cycles in areas which is rarely visited by other ornithologists.
- Maintenance marking of transects posts along all transects on North East Herald Cay should be carried out regularly to maintain a degree of ‘permanency’. Whilst quadrat markers generally remain in place, the identification mark (marker pen) on each post rapidly becomes illegible – it is a simple task to maintain this when transects are being walked. We are aware the transects are used for other purposes such as the insect control work and all researchers using the transects should be encouraged to carry out routine maintenance marking during the course of their work.
- The mark-recapture (banding) project for masked boobies on NE Herald Cay should continue, as it is providing significant data which will assist in determining vital rates (mean annual survival and other demographic parameters) for this species. This data can be collected by volunteers and requires an annual trip of seven days

duration (can be combined with annual seabird count). We will attempt our first analysis of this data following the collection of an additional year's data.

- When time and resources permit, a patrol should be scheduled to include both South East Magdalene and Chilcott Cays to collect comparative data for the major breeding species. These islands should be visited briefly and surveyed using rapid count techniques appropriate for the dominant vegetation on each island. These visits should also be timed to occur in July/August, although any visits between May-September would be useful.

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REFERENCES

ANPWS. 1989. *Coringa-Herald National Nature Reserve Plan of Management*. Australian National Parks and Wildlife Service: Canberra.

Baker, G.B., Taplin, A, Cunningham, R., Welsh, A, Donnelly, C. and Hallam, M. 2000. Seabird monitoring program on North East Herald Cay, Coral Sea. Analysis of data 1992 – 1999. Report to Marine Group, Environment Australia, Canberra (unpublished).

Cunningham, R., Chambers, R. and Donnelly, C. 1994. Coral Sea Reserves: North East Herald Islet Seabird Survey Statistical Analysis of 1994 July Survey. Report to Australian Nature Conservation Agency, Canberra (unpublished).

Cunningham, R., Welsh, A. and Donnelly, C. 1998. Coral Sea Reserves: 1998 bird census, 7-12th September, 1998. Report to Environment Australia, Canberra (unpublished).

Cunningham, R.B., Welsh, A.H. and Donnelly, C. 1997. Coral Sea Reserves monitoring seabird populations 1992-1996. Survey design and analysis. Report to Australian Nature Conservation Agency, Canberra (unpublished).

Dyer, P.K. 1999. Wedge-tailed shearwaters at Raine Island, Great Barrier Reef: population estimate and breeding status. Corella 23: 1-6.

Dyer, P.K. and Hill, G.J.E. 1992. Active breeding burrows of the wedge-tailed shearwater in the Capricorn Group, Great Barrier Reef. Emu 92: 147-151.

Environment Australia. (2000). Coringa-Herald National Nature Reserve and Lihou Reef National Nature Reserve Draft Management Plan. Environment Australia: Canberra.

Fisk, P. 1977. Sunbird 8: 45 – 61.

Hamann, M., Congdon, B., Gyuris, E., Lawler, I. and Schauble, C. 2006. Design of Research and Monitoring Programs for sea turtles and seabirds across the northern Marine Protected Area Estate. Contract RFT108/2005DEH. Report to Department of Environment and Heritage, Canberra. James Cook University: Cairns (unpublished).

Hicks, J. 1984. Lihou Reef and Coringa-Herald National Nature Reserves Field Trip October 1984. Report on cay studies. Report to Australian National Parks & Wildlife Service, Canberra (unpublished).

Higgins, P.J. and Davies, S.J.J.F. Davies (Eds) 1996. *Handbook of Australian, New Zealand & Antarctic Birds. Volume 3: Snipe to Pigeons*. Oxford University Press, Melbourne.

Hinchey, M.D. and Weston, J.G. 1989. Report of Coral Sea Patrol Coringa-Herald National Nature Reserve 9-19 September 1989 HMAS Townsville. Report to Australian National Parks and Wildlife Service (unpublished). ANPWS: Canberra.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration - stochastic model. Biometrika 52:225-247.

Reville, B.J., Tranter, J.D. and Yorkston, H.D. 1990. Impact of forest clearing on the endangered seabird Sula abbotti. Biological Conservation 51: 23 - 38.

Seber, G.A.F. 1965. A note on the multiple-recapture census. Biometrika 52:249-259.

Vandenbosch, R. 2000. Effects of ENSO and PDO events on seabird populations as revealed by Christmas Bird Count data. Waterbirds 23: 416-422.

Welsh, A.H., Cunningham, R.B. and Chambers, R.L. 2000. Methodology for estimating the abundance of rare animals: seabirds nesting on North East Herald Cay. Biometrics 56:22-30.

White, G.C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement, 120-138.

Wilcox, C., Dell, J. and Baker, B. 2007. A preliminary investigation on the relationship between variation in oceanography and seabird abundance in Coringa Herald National Nature Reserve. Report to Department of Environment & Water Resources. Latitude 42 Environmental Consultants Pty Ltd, Kettering, Tasmania (unpublished).

PEER-REVIEWED PAPERS RESULTING FROM THIS PROJECT

Boland, C.R.J., Double, M.C. and Baker, G.B. 2004. Assortative mating by tail streamer length in red-tailed tropicbirds *Phaethon rubricauda* breeding in the Coral Sea. Ibis 146:

Abstract: Pairs of red-tailed tropicbirds were paired assortatively according to tail streamer length. Pairs were not assorted according to the length of the second tail streamer, nor had they assorted according to the degree of assymmetry between the two tail streamers. Monomorphic sexual ornamentation and assortative mating in red-tailed tropicbirds appears to have arisen through mutual mate choice.

Congdon, B.C., Erwin, C.A., Peck, D.R., Baker, G.B., Double, M.C. and O'Neill, P. 2007. Chapter 14. Vulnerability of seabirds on the Great Barrier Reef to climate change, In Climate change and the Great Barrier Reef: a vulnerability assessment. eds J.E. Johnson, P.A. Marshall. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Australia.

Peck, D.R. and Congdon, B.C. 2004. Reconciling historical processes and population structure in the sooty tern *Sterna fuscata*. Journal of Avian Biology 35: 327-335.

Abstract: To test the influence of past vicariant events on population genetic structure of the sooty tern Sterna fuscata, we examined sequence variation in the mitochondrial control region of individuals from the Indo-Pacific and Atlantic Oceans. Our analyses indicate a rapid population expansion at a global scale during the past 100,000 years, consistent with global recolonisation during the interstade following the Pleistocene glacial maxima (125,000-175,000 years bp). We estimate islands of the Great Barrier Reef and Coral Sea were colonised no more than 16,000 years ago, most likely in association with the appearance of new breeding habitat following the final Pleistocene glacial retreat (19,000 -22,000 years bp). Our results suggest that ice sheets linked to major glacial events not only impact genetic structuring in temperate seabirds, but that sea level changes in the tropics associated with these same events have also significantly impacted contemporary genetic structuring in tropical seabird species.

Welsh, A.H., Cunningham, R.B. and Chambers, R.L. 2000. Methodology for estimating the abundance of rare animals: seabird nesting on North East Herald Cay. Biometrics 56:22 - 30.

Table 1. Objectives defined for seabird component of 2007 Patrol Program.

Patrol Tasks	Outputs
Seabird monitoring NE Herald Cay	
— Count all seabird species nesting in *Argusia* habitat and record stage of breeding	— Report prepared incorporating survey data and analysis
— Count all seabirds nesting along transects in the Pisonia / Cordia Forest and record stage of breeding	— Report prepared incorporating survey data and analysis
— Count all seabirds nesting along transects in the Abutilon shrubland and record stage of breeding	— Report prepared incorporating survey data and analysis
— Note that active nests will be counted in the field as a proxy for nesting pairs of birds	
— As time permits observe and record banded Masked Boobies on NEH to ascertain breeding pairs and to improve demographic knowledge	— Report on Masked Boobies observed and data analysis
Seabird monitoring SW Herald Cay	
— Count all seabird species nesting in *Argusia* habitat and record stage of breeding	— Report prepared incorporating survey data and analysis
— Note that active nests will be counted in the field as a proxy for nesting pairs of birds	
— As time permits observe and record banded Masked Boobies on SWH to ascertain breeding pairs and to improve demographic knowledge	— Report on Masked Boobies observed and analysis

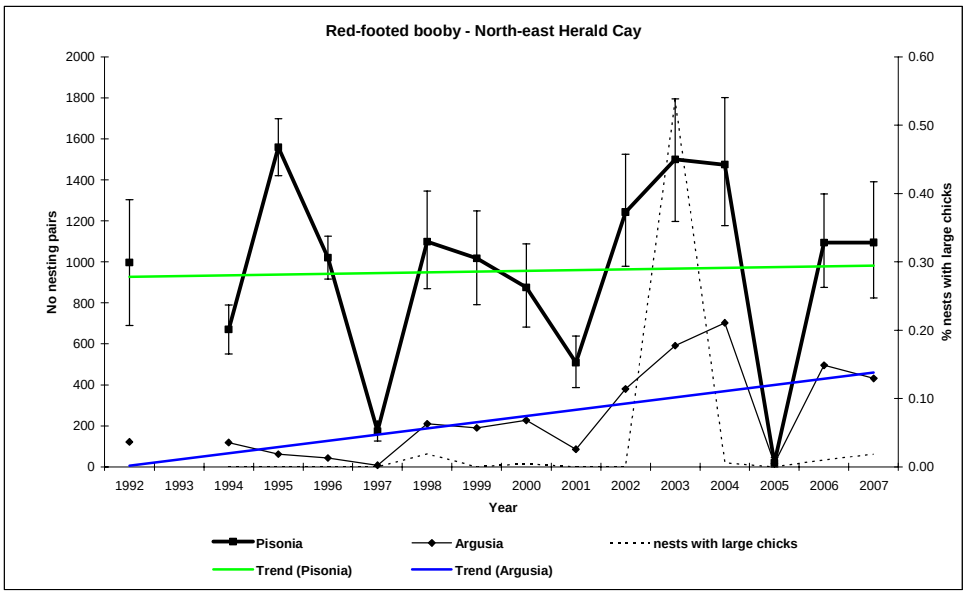

Figure 1. Red-footed booby. Annual estimated number of breeding pairs at NEH Cay, with 95% Confidence Intervals estimated by bootstrap procedures. Trendlines have been fitted using linear regression. The stage of breeding in *Argusia* habitat at the time the count was undertaken is shown as the proportion of nests containing large chicks.

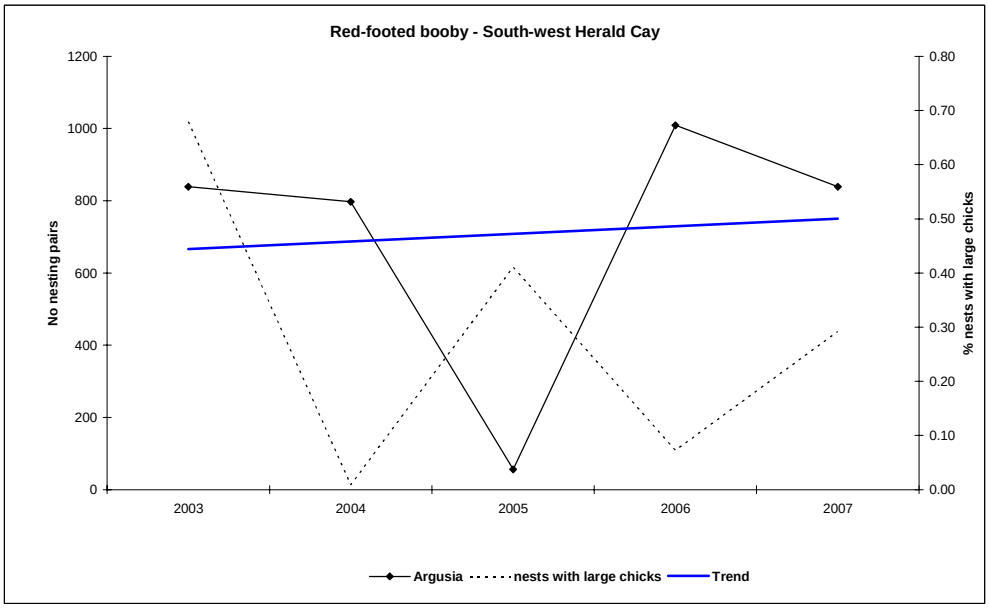

Figure 2. Red-footed booby. Annual estimated number of breeding pairs at SWH Cay. Trendlines have been fitted using linear regression. The stage of breeding at the time the count was undertaken is shown as the proportion of nests containing large chicks.

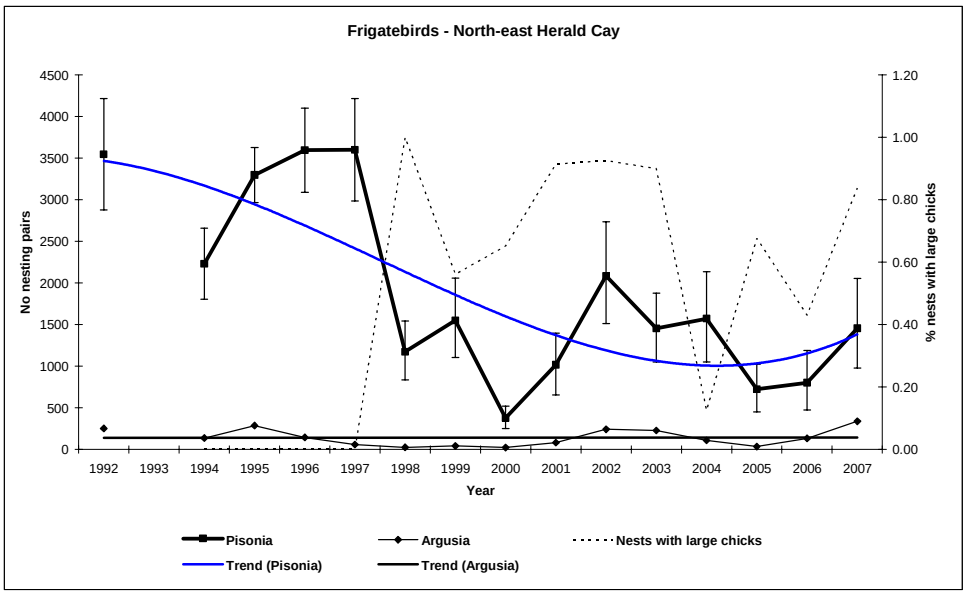

Figure 3. Frigatebirds. Annual estimated number of breeding pairs at NEH Cay, with 95% Confidence Intervals estimated by bootstrap procedures. Trendlines have been fitted using linear regression. The stage of breeding in Argusia habitat at the time the count was undertaken is shown as the proportion of nests containing large chicks

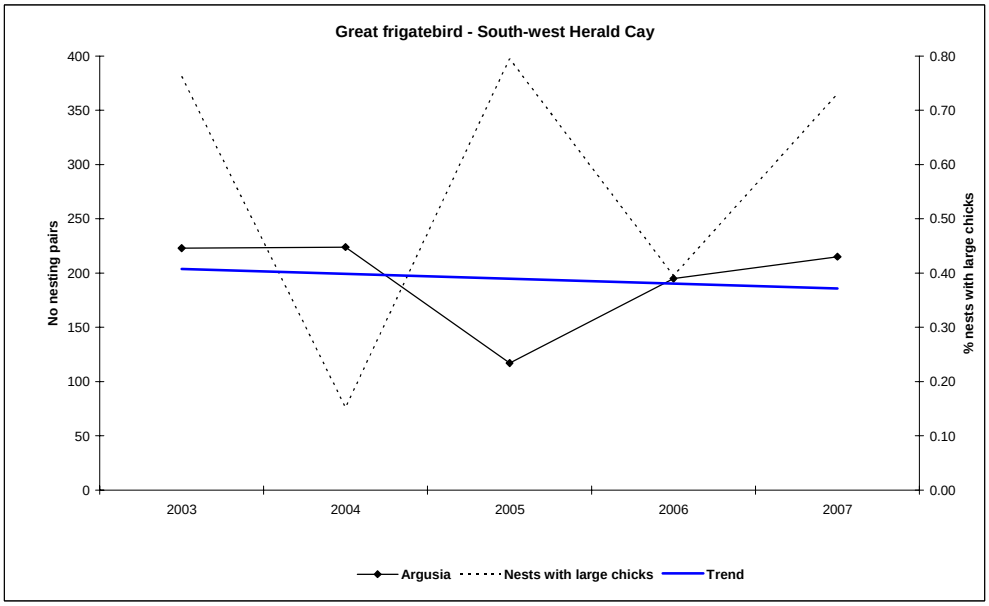

Figure 4. Great frigatebird. Annual estimated number of breeding pairs at SWH Cay. Trendlines have been fitted using linear regression. The stage of breeding at the time the count was undertaken is shown as the proportion of nests containing large chicks

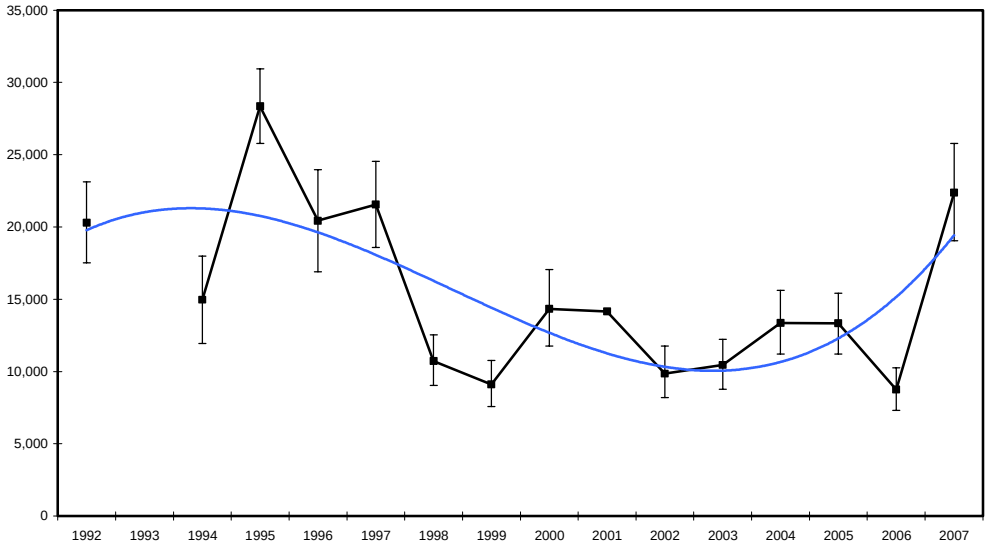

Figure 5. Black noddy. Annual number breeding at NEH Cay in 1992-2007, with fitted trendline. Confidence Intervals (95%) were estimated using bootstrap procedures.

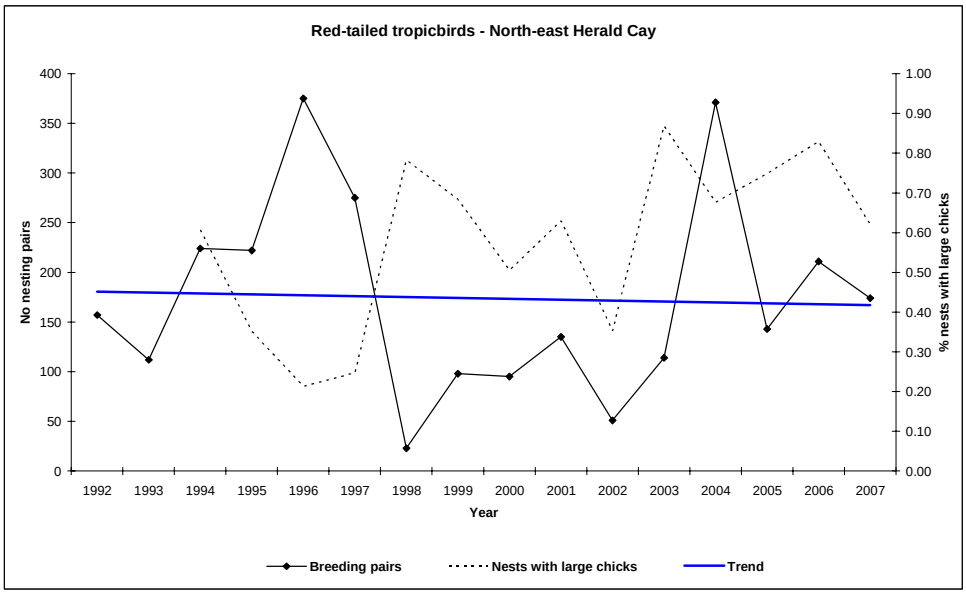

Figure 6. Red-tailed tropicbirds. Maximum annual counts of pairs breeding at NEH Cay, with fitted trendline. Also shown is stage of breeding at the time the count was undertaken, shown as the proportion of nests containing large chicks. Nesting occurs only in Argusia.

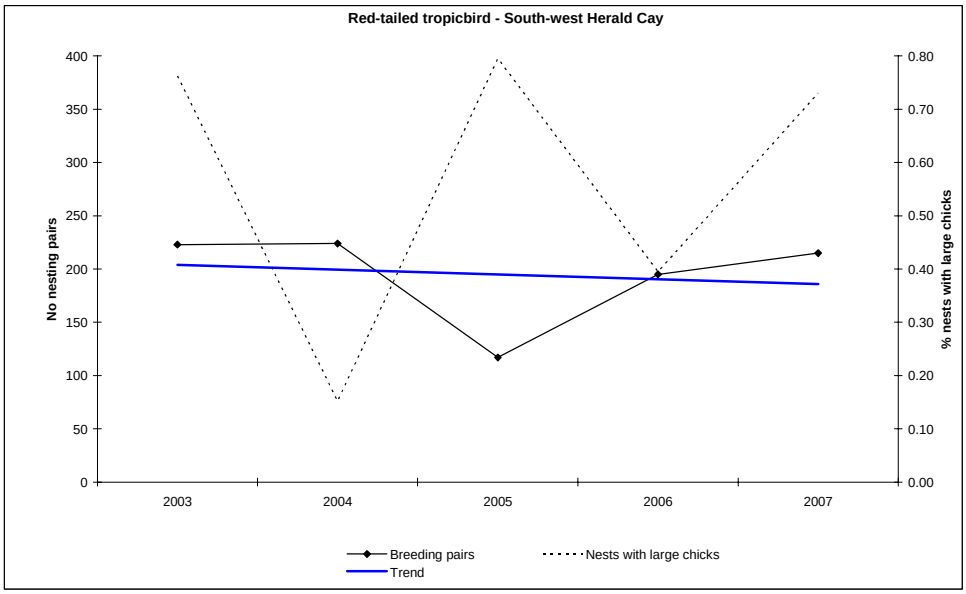

Figure 7. Red-tailed tropicbirds. Maximum annual counts of pairs breeding at SWH Cay, with fitted trendline. Also shown is stage of breeding at the time the count was undertaken, shown as the proportion of nests containing large chicks.

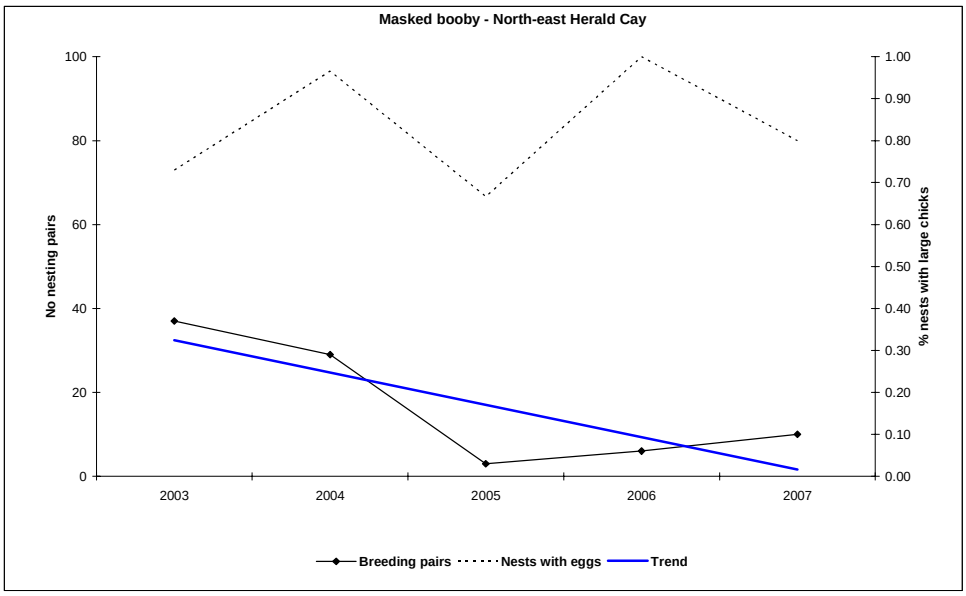

Figure 8. Masked booby. Maximum annual counts of pairs breeding at NEH Cay, with fitted trendline. Also shown is stage of breeding at the time the count was undertaken, shown as the proportion of nests containing eggs.

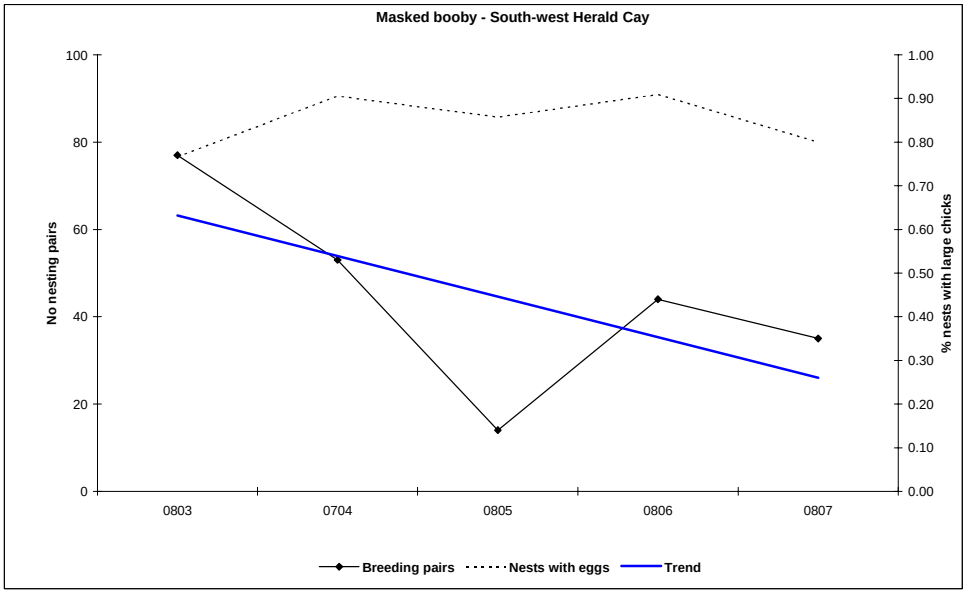

Figure 9. Masked booby. Maximum annual counts of pairs breeding at SWH Cay, with fitted trendline. Also shown is stage of breeding at the time the count was undertaken, shown as the proportion of nests containing eggs.

Appendix 1.

Detailed description of Methods used to survey birds in the Coral Sea National Nature Reserves

1. General

Study sites

North East Herald Cay (NEH — 16 56' 40 S, 149 11' 37 E) is a semi-circular shaped sand cay 1200 m long and 500 m wide located 400 km east of Cairns, Australia. South West Herald Cay (SWH — 17 00' 00 S, 149 08' 00 E) is an elongated oval sand cay 510 m long and 220 m wide located 9 km to the south west of North East Herald Cay. South East Magdelaine Cay (SEM — 16 35' S, 150 19' E). The sites lie in a remote oceanic environment within Australia's Coral Sea Islands Territory and are east of the Great Barrier Reef. Maximum elevation of the islands is 5 m ASL (ANPWS 1989, Environment Australia 2000).

NEH Cay and Magdelaine Cay are two of only three forested cays located within the Coral Sea National Nature Reserves, although the forest on the other of these (Coringa – SW Cay) was destroyed by the impact of scale insect attack.

North East Herald Cay

NEH Cay has been the site of most of the ornithological research activity in the Coral Sea National Nature Reserves. Hicks (1984) recognised three broad habitat classes on the island:

a. *Pisonia/Cordia* forest. Much of the cay is covered in low closed forest dominated by *Pisonia grandis* and *Cordia subcordata.* Towards the centre of the island tall *Pisonia* trees reach up to 6.5 m in height, although the canopy is lower on the forest margins, particularly on the exposed southern side where it is reduced to 1 to 1.5 m.

b. *Abutilon* shrubland. Small patches of grassland/herbfield dominated by *Abutilon indicum* and the creeping shrub *Ipomoea macrantha* occur in the centre of the island (*Abutilon* herbfield).

c. *Argusia* shrubland/grassland. The cay is fringed with the shrub *Argusia argentea* and a grassy understorey dominated by *Lepturus repens*, *Stenatophrum micranthum* and *Sporobolus virginicus (Argusia* shrubland*)* (ANPWS 1989). This zone is well developed on the northern side of the island and extends up to 40 m wide, but is absent or poorly developed on the weather-exposed eastern and southern sides.

The study site is subject to tropical cyclone events each year from December through to May, and these events have the potential to impact on the breeding of seabirds. The last major cyclone to directly impact the islands occurred in on 3 April 1989, when Tropical Cyclone Aivu caused extensive damage to the Pisonia / Cordia forest on NEH. TC Aivu passed over the cay with recorded windspeeds of 175 kph gusting to 245 kph (Hinchey and Weston 1989).

Sampling Design and Field Methods

To estimate numbers of breeding seabirds we employed different methods to suit the habitat being surveyed.

For the ***PisonialCordia*** **forest** on North East Herald Cay we developed a sampling design to estimate bird density, and then used these densities to derive population estimates.

Eleven transects at 100 m intervals were established, each running roughly East-West on a bearing of 120/300 degrees as determined by a magnetic compass. For each transect, quadrats measuring 10 x 10 metres were established using the transect line as the southern boundary. A total of 415 quadrats were established across all habitats, and vegetation mapped for all transects/quadrats. Of these, 316 quadrats occur in Pisonia/Cordia forest, which represent 13.2% coverage of this habitat.

Every year since 1992, at least 90 quadrats were surveyed. Quadrats for each survey were randomly selected, with 80% of all sampled quadrats remaining the same from one year to the next. Thus 80% of quadrats were selected from the quadrats in the previous year's survey (with probability proportional to the previous year's count) and 20% of quadrats were selected at random from the quadrats which were not included in the previous year's survey. This was designed to detect 'shifts' in nesting

patterns on the island, and permit estimates of change in nest density from year to year with standard errors approximately 20% greater than those achieved for estimates of nest density in a given year. The design requires that every five years a total count for all quadrats (i.e. a complete census) be undertaken to ensure that annual estimates for each species, which are based on counts in a sample of the total number of quadrats, can be related to the total area surveyed. The theory underlying the sampling design and analysis of data has been described by Welsh et al (2000).

Surveys were carried out once each year from 1992 to 2007, excluding 1993, and were timed to occur during peak breeding of red-footed booby and frigatebirds. This was not always achieved, as inter-annual variation and remoteness of the study site made predicting this time difficult. In early years the transects/quadrats were sampled but a total count of all transects was carried out from 1998 onwards, as well as in 1992 and 1994. The theory underlying the sampling design and approaches to analysis of data used in this study has been described by Welsh et al (2000).

To minimise the effect of different observers and time of day, we counted nests rather than birds present. Statistical analysis of quadrat survey data collected in July 1994 showed no difference between observers and no day effect on estimates of density of nests for frigatebirds or red-footed booby. Hence the precision of population or density estimation is not affected by choice of day and/or observer. For black noddy, there was evidence of observer differences but no day effect (Cunningham et al 1994).

During surveys we intensively searched selected/all quadrats for active nests of five species: red-footed booby, common noddy, black noddy, lesser frigatebird and greater frigatebird. For each nest we recorded the species of bird and, where possible, categorised the stage of breeding into the following classes:

1. Bird on nest - if no other information available.
2. Nest building – evidence of current nest construction.
3. Nest empty – nest appeared ‘fresh’, either being used or recently vacated.
4. Old nest – nest in a state of disrepair or obviously ‘out of use’.
5. Egg – egg in nest.
6. Small chick -chick naked or small and downy, lacking any pin feathers on wings.
7. Large chick - pin feathers evident or chick well feathered.
8. Fledgling – volant chick still dependent on parents.

When assessing the stage of breeding for a species, categories 1, 3 and 4 were excluded, and categories 7 and 8 lumped.

In practice, the height of nests in the *Pisonia/Cordia* forest precluded accurate assessment of the contents of most nests. Between 1999 and 2002 we used a small video camera mounted onto an extendable aluminium pole (‘booby cam’) to inspect the contents of all nests on six of the 11 transects. The use of ‘booby cam’ greatly enhanced the quality of data on stage of breeding in the forest habitat and permitted comparison with breeding in the *Argusia* shrubland for those years.

For the two frigatebird species, it was often impossible to identify the occupants of nest sites to species level because birds attending nests lifted off ahead of observers and thus prevented identification, or because nests contained large chicks that were unattended (frigatebird chicks cannot be distinguished without accurate knowledge of the age of the chick and morphometric measurements). In these cases, nests were ascribed to ‘unidentified frigatebird’.

***Argusia* shrubland** was systematically searched and a total count made of all nests found. Twenty four counts were carried out between 1992 and August 2007 on NEH, and covered every month except January and October. The stage of nesting was recorded, as for Pisonia/Cordia forest. Unlike the situation for the forest, the stage of breeding was easily assessed as most nests were less than 3 m high. Species breeding in this habitat were great and least frigatebird (data often combined), red-footed booby, red-tailed tropicbird, brown booby and masked booby.

The ***Abutilon* shrubland** was surveyed using the transect/quadrat search technique used for the Pisonia/Cordia forest. Only lesser frigatebirds and wedge-tailed shearwaters use this habitat.

South West Herald Cay and South East Magdelaine Cay

Only counts in *Argusia* shrubland were conducted on both of these islands. SEM Cay was not visited in 2007.

Data Analysis

For NEH the timing of breeding and length of breeding season were determined from analysis of stage-of-breeding data collected in the *Argusia* shrubland. Data were adequate for this purpose for three species: red-footed booby, red-tailed tropicbird and frigatebirds (both species combined). Data for all trips were pooled by month and monthly means calculated for four breeding classes – nest building, egg, small chick and large chick. Data on the stage of breeding in *Pisonia/Cordia* forest were too sparse to be analysed for all years except 1999-2006, when good accordance between both the *Argusia* and *Pisonia/Cordia* forest was achieved (B.Baker unpublished). From qualitative field assessment we found that timing of breeding for these species in *Argusia* shrubland is positively correlated with breeding in *Pisonia/Cordia* forest, and used this assumption when interpreting the results of counts.

Because black noddies only breed in the *Pisonia/Cordia* forest on NEH Cay, stage of breeding for this species was only assessed for 1999, 2000 and 2001, when the use of 'booby cam' permitted collection of an adequate sample for this purpose. However, in presentation of longitudinal trends we have chosen to only analyse nest count data for this species.

Estimates of total breeding pairs in *Argusia* shrubland and *Pisonia/Cordia* forest were calculated for all breeding species on NEH. Line graphs showing longitudinal profiles of the estimated or total number of each species nesting each year, with 85% confidence intervals for estimates, were prepared. Only data for the principal species of interest are presented. As these data probably reflect time of visit rather than the true population size, histograms showing stage of breeding in relation to each count were prepared to assist in data interpretation. This was determined from the NEH *Argusia* shrubland counts made at the time that counts in *Pisonia/Cordia* forest were conducted, and was plotted on the longitudinal species profiles as the proportion of nests containing large chicks.

For SWH and SEM estimates of total breeding pairs were calculated for all breeding species in *Argusia* shrubland only.

Count data for all Argusia shrubland surveys were based on a total count of all breeding birds and were easily computed. Nest count data for *Pisonia/Cordia* forest have been based on a total count of all breeding birds in the established transects/quadrats for 12 of the 15 years of the study, with 95% confidence intervals estimated by bootstrap procedures. At other times, only a sample of quadrats was counted, requiring more sophisticated analysis. In these years, data were analysed by developing a model to relate the nest abundance in each quadrat to the past history of nest abundance and the spatial location of the quadrat. As many quadrats contained no nests, the data had a high frequency of zero counts and so standard distributional assumptions were not met in the statistical analyses of the data. We developed a methodology (Welsh et. al, 1996) for appropriately dealing with data having this property. Essentially, the presence/absence of nests was first modelled using binary regression methods and then, conditional on presence, the abundance of nests was modelled using truncated count data regression models. These models were then used to predict the number of nests on each of the unsampled quadrats and these predictions aggregated with the observed counts from the sampled quadrats to obtain the predicted number of nests in all the quadrats. These predictions, often scaled to represent the number of nests per unit area, and the prediction standard errors that went with them, were the endpoints of the analysis. The number of active nests for the Pisonia/Cordia forest habitat was then calculated by applying the predicted value (or the total number of nests counted in years when all quadrats were counted) to the total area of habitat on the island.

Other Studies

Burrow counts

Wedge-tailed shearwaters *Puffinus pacificus* nest on NEH in burrows in the *Pisonia/Cordia* forest and *Abutilon* shrubland. Shearwaters breed during the summer months, a time that does not coincide with the peak breeding season of most other seabird species. As a consequence, no attempt was made to

count this species when birds were breeding. However, since 2001 we have counted all burrow entrances observed within 1 m wide transects on the outside of both the A and B lines of most transects. The number of burrows for the *Pisonia/Cordia* and *Abutilon* habitats was then used to calculate burrow density for each transect. The total number of burrows used in the previous breeding season was then calculated by multiplying the total area of habitat on the island by the mean burrow density for all transects. These data are not reported upon annually as the species is not a priority of the current study.

Mark/Recapture

In 1999 we commenced an intensive banding study of the masked booby as an adjunct to the other work. This study aims to build on the data obtained on this species at North East Herald Cay and South West Herald Cay over the past 10 years. Specifically, it is intended to examine population structure, pair and site fidelity, and levels of recruitment. This work is 'extra-curricular' to the main program and does not entail additional resources.

We aim to develop estimates of population size, survival and recruitment, with coefficients of variation (CVs) of estimates for any period which are < 20%. It is likely that a minimum of five years data will be required before estimates of survival and recruitment can be computed with this specified degree of precision.

Probability of capture, survival rate, population size and recruitment for each species will be estimated on an annual basis from capture-recapture data using the Jolly-Seber model (Jolly 1965, Seber 1965). Estimates will be obtained using program MARK (White and Burnham 1999).

Appendix 2.

NE Herald insect surveys

Systematic surveys were conducted to measure the presence and impact of scale insect *Pulvinaria urbicola* and the hawkmoth *Hippotion velox* on *Pisonia grandis* on NE Herald Island during a visit to North East Herald Cay during August 2007. Methods developed by Dr Chris Freebairn (see *The scale insect Pulvinaria urbicola and the hawkmoth Hippotion velox on Pisonia grandis on NE Herald Islet in the Coringa-Herald National Nature Reserve, May 2006*) were used during this survey. Both the leaf and branch end sampling techniques were conducted on each transect, at 50 metre intervals where *Pisona grandis* was present. Leaf damage from hawkmoth was also assessed by using percentage damage estimate. The presence or absence and number of ants and parasitoids (*Cryptolaemus* spp.) and other insects were recorded.

The survey was conducted 21-25 August 2007 by one team of four. Data were transcribed onto the data sheets and were attached to this report. These data were also forwarded to Dr Chris Freebairn. While comparative analysis of the condition of the *Pisonia* forest fell outside the scope of this project, our observations suggest that hawkmoth damage was relatively low and there was no large patches of defoliated trees as experienced in previous years.

Mealybugs *Ferrisia malvastra* were collected and forwarded to Chris Freebairn at his request. Mealybugs were generally found in Abutilon adjacent to forest edges. While patchily distributed, where mealybugs were found they tended to be in dense ‘populations’.

Appendix 3.

Marine Debris Survey Form

Coordinators name		**Sheet**	1	
Barry Baker	**Date (day/month/year)**	24	8	2007
Address	**Time: Start**	Debris collected over 6 days		
114 Watsons Rd Kettering 7155	**Description of area surveyed**	North East Herald Cay		
	Estimate width/length	2 km by 50 m. (from tideline to veg)		
Phone: 0418.626711 **Email:** barry.baker@latitude42.com.au				

Items recorded by: ~~Number - weight (kilos)?~~ ☐ Volume (Litres) ☑

Non-plastics			**Plastics**		
GLASS			**HARD PLASTICS**		
Bottles	1 X 1L, 1 X 0.5L, 1 X 0.47L	**3**	Bottles	**1 X medicine 2 X 1.25L 5 X 0.3L 1 X 1.5L 2 X 0.5**	**12**
Light bulbs/fluoro tubes		**3**	Drink straws		
Other glass			Bottle tops/caps	**19 X tops 1 X pump**	**20**
Fragments		**4**	6-pack' yokes		
	Total		Cartons, buckets	**1/4 oil drum**	**1**
ALUMINIUM, STEEL, TIN			Other hard plastic	**3 X pen 1 X peg 1 X lollypop stick 1 X comb**	**6**
Cans			Fragments		
Bottle tops/caps				Total	
Foil, trays			**FOAM PLASTICS**		
Drums			Cups, plates, trays		
Other metal items			Packaging	**5L**	**1**
Fragments			Insulation (incl.'Esky' materia	**5 X 1L**	**5**
	Total		Other foam plastic		
PAPER, CARDBOARD, TIMBER			Fragments		
Cartons				Total	
Paper			**PLASTIC SHEET & FIBRE**		
Timber			Plastic bags		
Other			Mesh, gauze - other woven		
	Total		Confectionary wrappers		
TEXTILE & FABRIC			Cigarette butts		
			Other		
	Total		Fragments		

MEDICAL/PERSONAL		Total	
Disposable nappies		**RUBBER**	
Syringes		Thongs	**8**
Sanitary items		Balloon	
Condoms		Other **3 X shoes, 1 X tennis ball**	**4**
Fragments/Other		Total	
		ROPE & CORD - non fishing	
Total		Total	

Fishing gear

NETTING			**LINE**		
Monofilament			Fishing line	**1.5m**	**1**
Trawl			Twine		
Other netting			Hooks/other tackle		
	Total			Total	
POTS			**BAIT**		
Pots or traps					
	Total				
OTHER					
Rope	**2 short fragments c.2cm**	**2**			
Buoys/floats	**small 0.3L**	**1**			
	Total			Total	

ITEMS OF FOREIGN ORIGIN		**SHIP NAME IDENTIFIED ITEMS ****	
Digital camera	**1**		
Cyalume stick	**1**		

** Debris which may identify a ship should be retained and reported to Australian Maritime Safety Authority FREECALL 1800 641 792 Fax: 02.6230.6868 email: eps@amsa.gov.au

SAFETY FIRST

Take care with sharp objects

Sealed drums should not be approached as they may contain hazardous materials - report to fire

SEND COMPLETED FORMS TO:

WWF Australia, Arufura Ecoregion Program, GPO Box 1268, Darwin NT 0801

Phone 1800 032 551 Fax: 08 8941 6494

This survey form is based on information from the Adopt-a-Beach Program, Ocean Watch & U.S.Center for Conservation

Published by Environment Protection and Heritage Council (formerly ANZECC) 2002

Marine Debris Survey Form

Coordinators name		**Sheet**	1	
Barry Baker	**Date (day/month/year)**	26	8	2007
Address	**Time: Start**		**Finish**	
114 Watsons Rd Kettering 7155	**Description of area surveyed**	South West Herald Cay		
	Estimate width/length	1.6 km by 50 m. (from tideline to veg)		
Phone: 0418.626.711				

Items recorded by: ☑ Number ☐ Weight (Kg) ☑ Volume (Litres)

Non-plastics			**Plastics**		
GLASS			**HARD PLASTICS**		
Bottles	**1 x 1L, 2 x 750 mls, 1 x 375 mls**	**4**	Bottles	**1 x 2L, 2 x 1.5L, 2 x 1L, 2 x 600mls, 1 x 500 mls, 1 x 200 mls, 2 x 750 ml detergent, 1 x 375 ml shampoo, 1 x 1.5L laundry detergent,**	**12**
Light bulbs/fluoro tubes	**600mm length unbroken**	**1**	Drink straws		
Other glass			Bottle tops/caps		**6**
Fragments			6-pack' yokes		
Total			Cartons, buckets	**1 x 750 ml container, 1 x 1L noodle box**	**2**
ALUMINIUM, STEEL, TIN			Other hard plastic		
Cans	**5 x spray cans (200g x 3, 150g X 1, 75g X 1)**	**5**	Fragments		**13**
Bottle tops/caps			Total		
Foil, trays			**FOAM PLASTICS**		
Drums			Cups, plates, trays		
Other metal items	**1 metal container with lid = 500ml**	**1**	Packaging		
Fragments			Insulation (incl.'Esky' material)		
Total			Other foam plastic		
PAPER, CARDBOARD, TIMBER			Fragments	**7 fragments = 3L**	**7**
Cartons			Total		
Paper			**PLASTIC SHEET & FIBRE**		
Timber			Plastic bags		
Other			Mesh, gauze - other woven		
Total			Confectionary wrappers		
TEXTILE & FABRIC			Cigarette butts		
			Other		
Total			Fragments		

MEDICAL/PERSONAL		Total	
Disposable nappies		**RUBBER**	
Syringes		Thongs	**4**
Sanitary items		Balloon	
Condoms		Other **1 soccerball = 2L**	**1**
Fragments/Other		Total	
		ROPE & CORD - non fishing	
		1 x 6m lengthhawser rope **1 x 2m length black 5 cm diameter** **1 x 30 cm length black rope - 5 cm diameter**	**3**
Total		Total	

Fishing gear

NETTING		**LINE**	
Monofilament		Fishing line	
Trawl		Twine	
Other netting		Hooks/other tackle	
Total		Total	
POTS		**BAIT**	
Pots or traps			
Total			
OTHER			
Rope			
Buoys/floats			
Total		Total	

ITEMS OF FOREIGN ORIGIN		**SHIP NAME IDENTIFIED ITEMS ****	
butterfly net	**1**		
ping pong ball	**1**		

** Debris which may identify a ship should be retained and reported to Australian Maritime Safety Authority

SAFETY FIRST
Take care with sharp objects
Sealed drums should not be approached as they may contain hazardous materials - report to fire

SEND COMPLETED FORMS TO:
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