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Seabird monitoring study at Coringa Herald National Nature Reserve 2012

Report prepared for

Department of Sustainability, Environment, Water, Populations and Communities

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SEABIRD MONITORING PROGRAM - CORAL SEA ISLAND TERRITORY.

REPORT ON 2012 FIELD SEASON AND UPDATE OF HERALD CAYS LONGITUDINAL DATASETS FOR THE PERIOD 1992 TO 2012.

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 8,860 square kilometres, 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. 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. 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 which 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 long-term data sets — there are now 20-year and 10-year data sets available for NEH and SWH, respectively.

A patrol in August 2012 was undertaken to conduct a count of the nesting seabird populations on NEH and SWH, and to assess the condition of survey infrastructure (transect markers) following extensive vegetation damage caused by *Cyclone Yasi*, a Category 5 tropical cyclone that had formed in the Coral Sea in February 2011. 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, the dominant vegetation type on the island, 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.

Cyclone Yasi had clearly struck the Herald Cays with ferocity and caused extensive damage to the vegetation on NEH, particularly the *Pisonia* and *Cordia* vegetation. The tops of most *Pisonia* trees had been sheared off and the *Cordia* felled, leaving a tangle of dead wood at ground level which covered many transect marker poles, particularly on the windward (south-west) side of the island. Traversing these

transects to locate poles, in some cases, was extremely difficult, but surprisingly, most were located. All poles were re-positioned to ensure they stood upright, and re-marked with transect and quadrat numbers.

It was apparent that there had been good rainfall since our last visit to the Herald Cays in 2009. The *Argusia* vegetation was in excellent condition and provided a distinct contrast to the large areas of dead and dying vegetation we observed in 2009. The *Pisonia* forest also showed extensive regrowth following the cyclone damage, although many parts of the canopy remain open, which may impact its suitability for breeding by birds such as red-footed booby and frigatebirds for a year or two, because of insufficient protection from the prevailing winds.

Count data for all species shows strong inter-annual fluctuations, but trends are now apparent for the breeding populations of most species examined on NEH.over the 20 year period (1992-2012) of the monitoring program. Both great and least frigatebirds, and black noddy, have declined at an annual rate of 7.7 and 3.8%, respectively, while the red-footed booby has increased by an annual rate of 3.8%.

In 2012 the following number of pairs of species of particular interest were counted or estimated to be breeding at the time of the survey:

— Red-footed booby. 1,239 (CI 1,020 — 1,463) pairs in the *Pisonia/Cordia* and 402 pairs in the *Argusia* shrubland on NEH, a total of 1,641 nesting pairs on NEH, and 835 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 28% of nests containing large chicks. The breeding population in the Herald Cays has increased by 38% since 1992 at an annual rate of increase of +3.3%.

— Great and Least Frigatebirds. 314 (CI 199-449) pairs in the *Pisonia/Cordia* and 105 pairs in the *Argusia* shrubland, a total of 419 (304—554) nesting pairs on NEH. Most (95%) 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. *Argusia* counts at SWH (84 pairs) showed that breeding was at a similar stage to that on NEH. Only great frigatebirds were breeding at SWH, as reported for previous years. The breeding population in the Herald Cays has declined by 89% since 1992 at an average growth rate of -7.7%.

— Red-tailed tropicbirds. The timing of the visit in 2012 was late in the breeding season for this species, and only 83 pairs were recorded breeding on NEH and 122 pairs on SWH.

— Masked booby. 33 pairs on NEH and 75 pairs on SWH. 126 individuals previously banded were re-sighted., 62 of which were at least 10 years or older, and one which was a minimum of 23 years old. All had been originally banded on the Herald Cays, with the exception of two birds, one that had been banded originally on Coringa Islet, and another that had been banded as a chick on Phillip Island (near Norfolk Island) in 2000 — a distance of 2,341 km.From the banding data mean annual adult survival is estimated to be in excess of 90%, a value that would be expected for a long-lived species with a stable population.

— Black noddy. The count in 2012 was 5,277 (CI 4,030—6,648) nests, the lowest recorded since monitoring commenced. The breeding population in the Herald Cays has declined by 67% since 1992 at an average growth rate of 3.81%.

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 8 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 standardize 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.

1. 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 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 8,860 square kilometres, was proclaimed as a National Nature Reserve under Commonwealth legislation on 16 August 1982. The reserve contains 6 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 2012. 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 2012 was undertaken to conduct an annual count of the nesting seabird populations on NEH and SWH. We also continued a mark-recapture study of masked boobies in the Herald Cays and searched for banded birds during fieldwork.

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 will be reported upon by others — the marine debris data were collated by SEWPAC officers Anna Farnham and Maryanne Humphreys, and data sheets for insect presence were collated by the seabird team and have been subsequently forwarded to SEWPAC for analysis.

2. METHODS

2.1 General

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 kilometres 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 3 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 2012, excluding 1993, 2010 and 2011. Surveys 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. Tables and 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, data showing stage of breeding in relation to each count were collected, 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. There is no *Pisonia* / *Cordia* forest on SWH.

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 1m 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.

2.2 Analysis of Population Trend

Trend analyses were run using software program TRIM (TRends and Indices for Monitoring Data; Pannekoek and van Strien, 1996), using the linear trend model with stepwise selection of change points (missing values removed) with serial correlation taken into account but not overdispersion. Following Delord et al (2008), we analysised overall population trends for each species by combining the time-series with missing observations, and made a log-linear regression model with Poisson error terms. To obtain the overall estimated breeding numbers on the monitored sites for each species, we used the population size estimates together with their standard errors obtained from the TRIM analysis. Because we were interested in identifying the changes in population trends across years, we started the analysis with a model with change points at each time-point, and used the stepwise selection procedure to identify change points with significant changes in slope based on Wald tests with a significance-level threshold value of 0.01 (Pannekoek and van Strien, 1996). We took into account over-dispersion and serial correlation since they can have important effects on standard errors, although they have usually only a small effect on the estimates of parameters (Pannekoek and van Strien, 1996). No covariate was used. Annual population rates of changes were calculated, for each species, using the relationship:

$r = \ln \lambda = \ln N_{t-1} / N_t$

where N_t and N t+1 are the number of pairs breeding in year *t* and *t + 1* respectively (taken to be the number of breeding birds counted in year *t* and *t + 1*) and λ the population growth rate (Caughley, 1980). It was assumed that all the nesting birds were detected. N_{t+1}, N_t and λ were given by TRIM. All population size estimates are presented ±1 SE or ± 95% confidence intervals.

TRIM classifies trends by converting the multiplicative overall slope estimate in TRIM into one of the six categories shown below. The category depends on the overall slope as well as its 95% confidence interval.

Strong increase - increase significantly more than 5% per year (5% would mean a doubling in abundance within 15 years). Criterion: lower limit of confidence interval > 1.05.

Moderate increase - significant increase, but not significantly more than 5% per year. Criterion: 1.00 < lower limit of confidence interval < 1.05.

Stable - no significant increase or decline, and it is certain that trends are less than 5% per year. Criterion: confidence interval encloses 1.00 but lower limit > 0.95 and upper limit < 1.05.

Uncertain - no significant increase or decline, but not certain if trends are less than 5% per year. Criterion: confidence interval encloses 1.00 but lower limit < 0.95 or upper limit > 1.05.

Moderate decline - significant decline, but not significantly more than 5% per year. Criterion: 0.95 < upper limit of confidence interval < 1.00.

Steep decline - decline significantly more than 5% per year (5% would mean a halving in abundance within 15 years). Criterion: upper limit of confidence interval < 0.95.

2.3 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 over the last 17 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.

2.4 Patrol Program for 2012

The program for 2012 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.

<u>Management Goals</u>

- *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*.

<u>Management Strategies</u>

- *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 from 16 - 23 August 2012 (excluding travel) to monitor seabirds. The field team consisted of Barry Baker, Mark Holdsworth, Sue Robinson, Samantha Fox, Robbie Gaffney and Chelsea Holdsworth (all working with Latitude 42), together with SEWPAC officers Anna Farnham and Maryanne

Humphries. Logistical support was provided by the Australian Customs Service, via the captain and crew of the patrol boat *ACV Dame Roma Mitchell*.

3. RESULTS

3.1 Impact of Cyclone Yasi

Cyclone Yasi, a large and severe (Category 5) tropical cyclone, formed in the Coral Sea and crossed the Australian coastline between Cairns and Ingham on 2 February 2011. It struck the Herald Cays on the same day and clearly caused extensive damage to the vegetation on NEH, particularly the *Pisonia* and *Cordia* vegetation. The tops of most *Pisonia* trees had been sheared off and the *Cordia* felled, leaving a tangle of dead wood at ground level which covered many of the transect marker poles, particularly on the windward (south-west) side of the island. Traversing these transects to locate poles, in some cases, was extremely difficult, but surprisingly, most were located. All poles were re-positioned to ensure they stood upright, and re-marked with transect and quadrat numbers.

It was apparent that there had been good rainfall since our last visit to the Herald Cays in 2009. The *Argusia* vegetation was in excellent condition and provided a distinct contrast to the large areas of dead and dying vegetation we observed in 2009. The *Pisonia* forest also showed extensive regrowth following the cyclone damage, although many parts of the canopy remain open, which may impact its suitability for breeding by birds such as red-footed booby and frigatebirds for a year or two, because of insufficient protection from the prevailing winds.

3.2 Red-footed booby

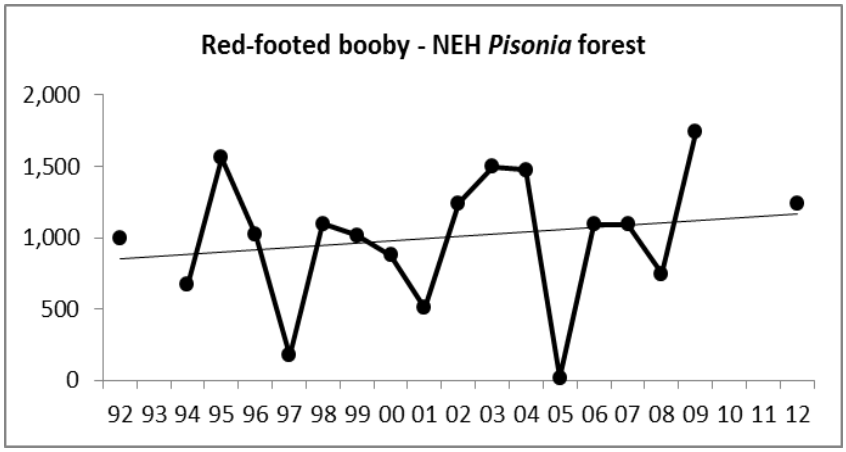
From 1992 to 2012 the breeding population at NEH increased (+38%). The stepwise procedure for selection of change points indicated six significant change points (1997, 1998, 2004, 2005, 2008 and 2009; all $p < 0.01$ for Wald tests) (Tables 1 and 2, Fig. 1). The population size estimates computed from the model indicate a stable population across the last twenty years with inter-annual differences and an annual rate of increase of +3.3% ($\lambda = 1.033 \pm 0.014$, CI 95% 0.977–1.089; assessed by TRIM as a Moderate Increase).

In 2012 we estimated there was 1,239 (CI 1,020— 1,463) pairs in the *Pisonia/Cordia* and 402 pairs in the *Argusia* shrubland. 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.

Argusia shrubland counts at SWH (835 pairs – Table 3, Figure 2) showed that breeding was at a more advanced stage to that on NEH, with 28% of nests containing large chicks, and a further 11% of pairs with smaller chicks. The number of birds breeding on SWH shows strong inter-annual differences and an annual rate of increase of 10.5% ($\lambda = 1.105 \pm 0.006$, CI 95% 1.080–1.131; assessed by TRIM as a Strong Increase).

Table 1. Estimated annual breeding pairs of red-footed booby, frigatebirds and black noddy breeding in *Pisonia/Cordia* forest on North East Herald Cay from 1992 - 2012, with 95% Confidence Intervals. Confidence intervals have been calculated by bootstrapping where raw count data are available. No data are available for 1993, 2010 and 2011.

		Red-footed booby			Frigatebirds			Black noddy		
Year	**Month**	**Count**	**CIL**	**CIU**	**Count**	**CIL**	**CIU**	**Count**	**CIL**	**CIU**
1992	Nov	**996**	not estimated		**3,547**	not estimated		**20,294**	not estimated	
1993			no data			no data			no data	
1994	Jul	**670**	not estimated		**2,232**	not estimated		**14,957**	not estimated	
1995	Jun	**1,559**	not estimated		**3,298**	not estimated		**28,352**	not estimated	
1996	Aug	**1,020**	not estimated		**3,597**	not estimated		**20,433**	not estimated	
1997	Jun	**174**	not estimated		**3,600**	not estimated		**21,553**	not estimated	
1998	Sep	**1,098**	**869**	**1,345**	**1,173**	**836**	**1,544**	**10,720**	**9,021**	**12,540**
1999	Jul	**1,017**	**791**	**1,248**	**1,551**	**1,107**	**2,059**	**9,105**	**7,586**	**10,765**
2000	Aug	**875**	**682**	**1,087**	**379**	**251**	**521**	**14,336**	**11,756**	**17,038**
2001	Aug	**508**	**386**	**637**	**1,017**	**656**	**1,396**	**14,155**		
2002	Aug	**1,242**	**978**	**1,525**	**2,085**	**1,512**	**2,735**	**9,857**	**8,191**	**11,762**
2003	Aug	**1,499**	**1,197**	**1,795**	**1,454**	**1,049**	**1,879**	**10,449**	**8,770**	**12,238**
2004	Jul	**1,474**	**1,177**	**1,802**	**1,572**	**1,049**	**2,136**	**13,365**	**11,202**	**15,616**
2005	Aug	**19**	**0**	**45**	**723**	**450**	**1,023**	**13,327**	**11,221**	**15,417**
2006	Aug	**1,093**	**875**	**1,332**	**803**	**476**	**1,190**	**8,755**	**7,297**	**10,243**
2007	Aug	**1,094**	**824**	**1,390**	**1,456**	**978**	**2,053**	**22,373**	**19,058**	**25,776**
2008	Sep	**745**	**501**	**995**	**518**	**270**	**809**	**15,305**	**12,937**	**17,814**
2009	Oct	**1,740**	**1,463**	**2,028**	**1,315**	**764**	**2,002**	**15,065**	**12,494**	**17,878**
2010			no data			no data			no data	
2011			no data			no data			no data	
2012	Aug	**1,239**	**1,020**	**1,463**	**314**	**199**	**449**	**5,277**	**4,030**	**6,648**



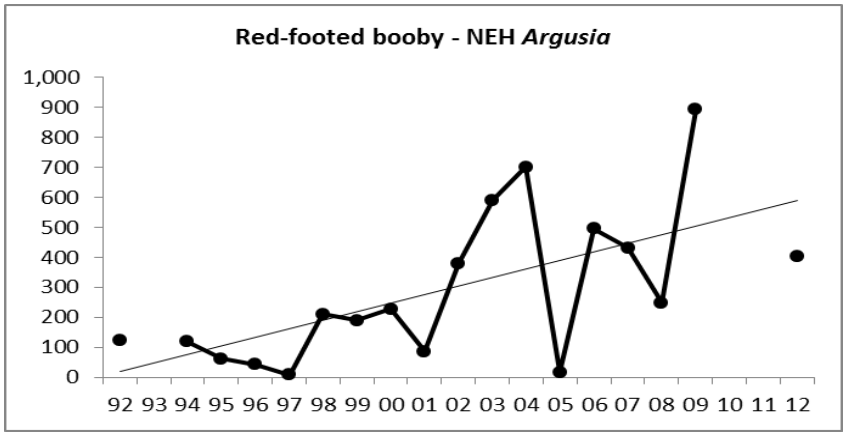


Figure 1. Red-footed booby. Annual estimated number of breeding pairs at NEH Cay in *Pisonia/Cordia* forest (top) and *Argusia* shrubland (bottom). Trendlines have been fitted using linear regression.

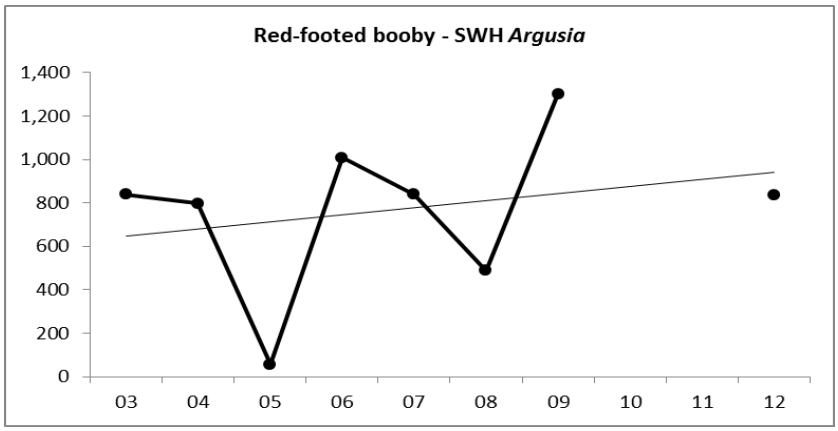


Figure 2. Red-footed booby. Annual estimated number of breeding pairs at SWH Cay in *Argusia* shrubland. Trendlines have been fitted using linear regression.

Table 2. Estimated number of breeding pairs of red-footed booby, frigatebirds and red-tailed tropicbirds breeding in *Argusia* shrubland on North East Herald Cay from 1992 - 2012, and the proportion of nests containing large chicks. No data are available for 1993, 2010 and 2011.

		Red-footed booby		Frigatebirds		Red-tailed tropicbird	
Year	Month	Count	Large chicks (%)	Count	Large chicks (%)	Count	Large chicks (%)
1992	Nov	**122**	0.16	**252**	0.98	**157**	0.84
1993		no data		no data			
1994	Jul	**119**	0	**137**	0	**224**	0.61
1995	Jun	**62**	0	**287**	0	**222**	0.35
1996	Aug	**43**	0	**145**	0	**375**	0.21
1997	Jun	**8**	0	**58**	0	**275**	0.25
1998	Sep	**210**	0.02	**24**	1.00	**23**	0.78
1999	Jul	**190**	0	**41**	0.56	**98**	0.68
2000	Aug	**227**	0	**23**	0.65	**95**	0.51
2001	Aug	**86**	0	**82**	0.91	**135**	0.63
2002	Aug	**380**	0	**242**	0.93	**51**	0.35
2003	Aug	**591**	0.54	**228**	0.90	**114**	0.87
2004	July	**702**	0.01	**108**	0.13	**371**	0.68
2005	Aug	**17**	0	**34**	0.68	**143**	0.75
2006	Aug	**495**	0.01	**134**	0.43	**211**	0.83
2007	Aug	**431**	0.02	**338**	0.84	**174**	0.62
2008	Sep	**248**	0.02	**154**	0.95	**70**	0.51
2009	Oct	**894**	0.11	**337**	0.80	**2**	0.00
2010		no data		no data		no data	
2011		no data		no data		no data	
2012	Aug	**402**	0.02	**105**	0.53	**83**	0.52

3.3 Frigatebirds

The number of frigatebirds breeding annually on NEH has decreased by 89% between 1992 and 2012 (Tables 1 & 2; Figure 3). The stepwise procedure for selection of change points indicated six significant change points (1997, 1998, 1999, 2007, 2008, 2009; all $p < 0.01$ for Wald tests). The long-term trend can be separated into two major periods of decline: (1) a dramatic decrease in the late 1990s, followed by (2) a slower but significant and continuing decline until 2012.

The annual breeding population size estimates computed from the model indicated an average growth rate of -7.7% per year (($\lambda = 0.923 \pm 0.013$, CI 95% 0.872–0.975; assessed by TRIM as a Steep Decline) between 1992 and 2012.

Table 3. Estimated annual breeding pairs of red-footed booby, frigatebirds and red-tailed tropicbirds breeding in *Argusia* shrubland on South West Herald Cay from 2003 — 2012, and the proportion of nests containing large chicks. No data are available for 1993, 2010 and 2011.

		Red-footed booby		Great Frigatebird		Red-tailed tropicbird	
Year	Month	Count	large chicks (%)	Count	large chicks (%)	Count	large chicks (%)
2003	Aug	839	0.68	223	0.76	46	0.76
2004	Jul	797	0.01	224	0.15	11	0.15
2005	Aug	56	0.41	117	0.79	56	0.79
2006	Aug	1009	0.07	195	0.39	81	0.39
2007	Aug	839	0.29	215	0.73	88	0.73
2008	Sep	489	0.55	111	0.95	59	0.80
2009	Oct	1301	0.45	257	0.96	31	1.00
2010		no data		no data			
2011		no data		no data			
2012	Aug	835	0.28	84	0.68	122	0.74

In 2012 we estimated there were 314 (CI 199-449) pairs in the *Pisonia/Cordia* and 105 pairs in the *Argusia* shrubland, a total of 419 nesting pairs. Half (53%) of these birds were on nests with large chicks, which indicated that the time of the counts was earlier in the breeding season than most of the historical counts for this species since 1998. The total number of birds breeding in 2012 was the lowest number recorded breeding at NEH since 2000 (Figure 3), and this may be due in part to the loss of breeding habitat and subsequent exposure to prevailing winds in the *Pisonia/Cordia* following the impact of Cyclone Yasi. Such an effect was not apparent for red-footed boobies, which are more inclined to build nest just under the canopy of the *Pisonia/Cordia* where their nests may be afforded greater protection from wind.

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 is 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 most years since 1999 indicate that c.40% (range 18—66%) of the birds breeding on NEH are great frigatebirds.

Argusia counts at SWH (84 pairs), where only great frigatebirds breed, showed that breeding was at a more advanced stage to that on NEH (68% of pairs were on nests containing large chicks). Analysis of trend at SWH should be interpreted with caution as the data time-series is shorter (2003 -2012) and contains only eight data points. Superficially, the population appears to be declining (Figure 4), with the number of

birds breeding annually decreasing by 62% between 2003 and 2012. However, if the 2012 data point is removed, assessment of the rate of the decline is significantly reduced. The annual breeding population size estimates computed from the model indicated an average growth rate of -6.3% per year (λ = 0.937 ± 0.001, CI 95% 0.935–0.937; assessed by TRIM as a Steep Decline) between 2003 and 2012, and -1.3% per year (SE 0.0006, λ = 0.987 ± 0.001, CI 95% 0.985–0.989 assessed by TRIM as a Moderate Decline) between 2003 and 2009.

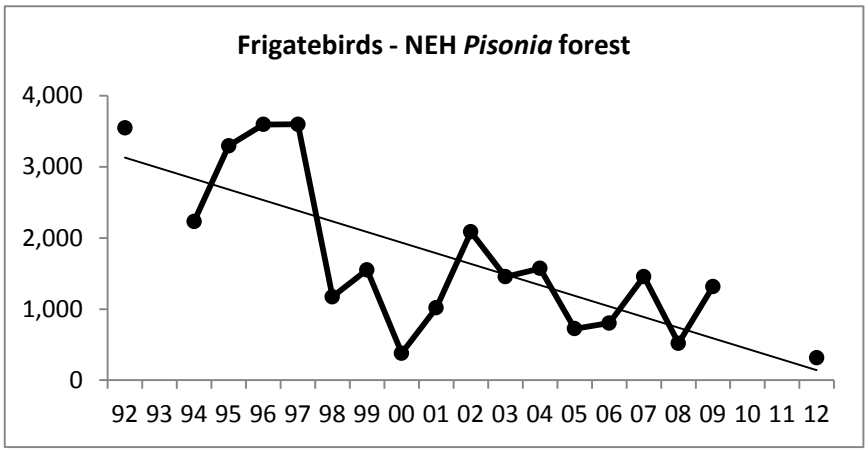
3.4 Black noddy

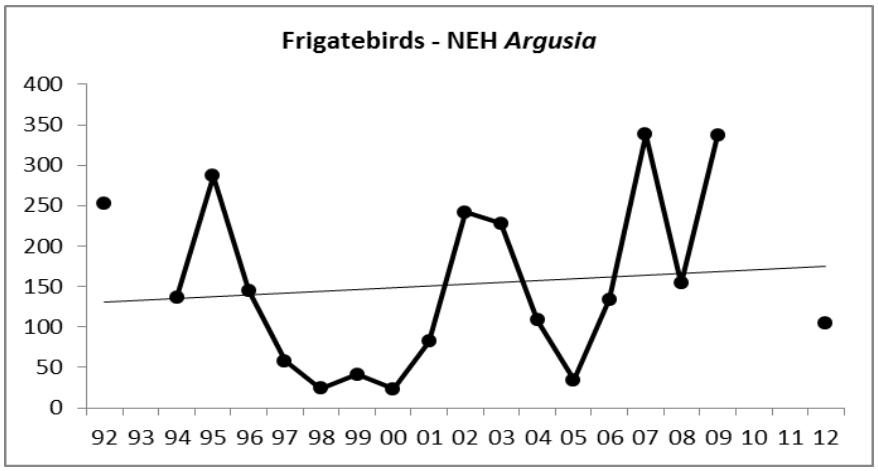
This species has not been the subject of the main study and counts have been made merely as an adjunct to the forest counts for frigatebirds and red-footed boobies. Black noddies mainly breed in the *Pisonia / Cordia* forest on NEH, and they do not breed on SWH because this vegetation type is not present.

The number of birds breeding annually on NEH decreased by 67% across the period of the study. The annual breeding population size estimates computed from the model indicated an average growth rate of -3.8% per year (λ = 0.962 ± 0.004, CI 95% 0.935–0.937, assessed by TRIM as a Moderate Decline) between 1992 and 2012. Typical of many seabird populations, inter-annual fluctuations of breeders were evident, but two important change periods are evident — (1) between 1992 and 1997 the breeding population increased moderately at an annual growth rate of 4.1% (Tables 1; Figure 5), and (2) a decline at an annual rate of -2.8% between 1997 to 2012.

The estimated number of nests in 2012 was the lowest ever recorded (5,277, CI 4,030—6,648) nests, which may have been due to habitat loss following Cyclone Yasi, or an artifact of the timing of breeding in 2012.

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 is still a useful 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 (Appendix 1) 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).





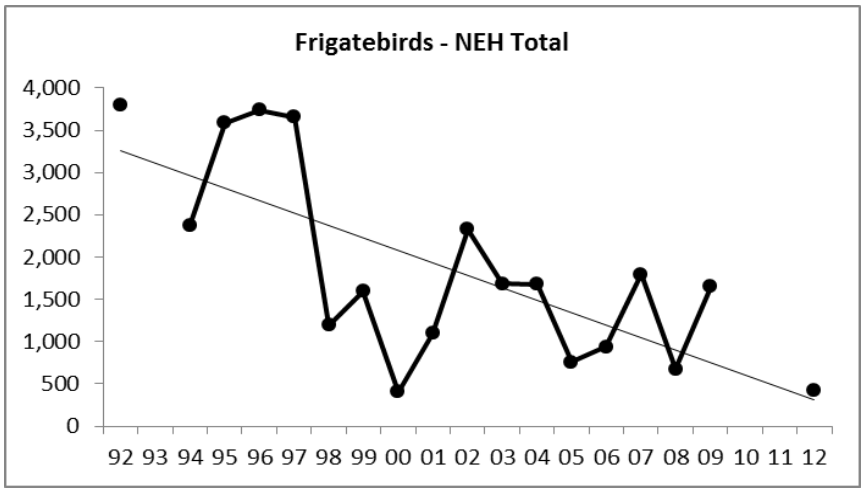


Figure 3. **Frigatebirds**. Annual estimated number of breeding pairs at NEH Cay in *Pisonia/Cordia* forest (top), *Argusia* shrubland (middle) and the total (bottom panel). Estimates for the *Pisonia/Cordia* have been estimated by sampling, with 95% confidence intervals estimated by bootstrap procedures where raw data was available. Counts undertaken in Argusia are direct counts. Trendlines have been fitted using linear regression.

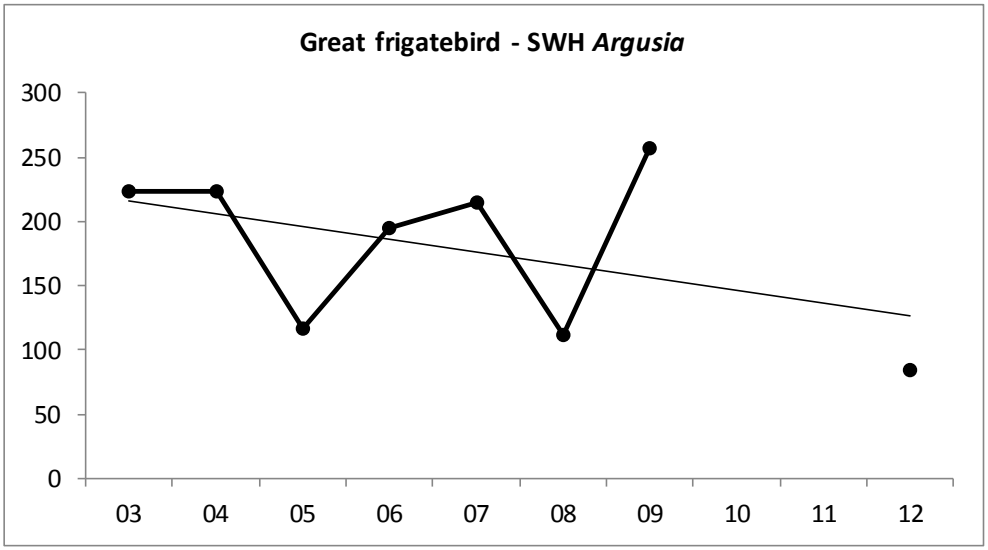


Figure 4. **Great frigatebird**. Annual estimated number of breeding pairs at SWH Cay. Trendlines have been fitted using linear regression.

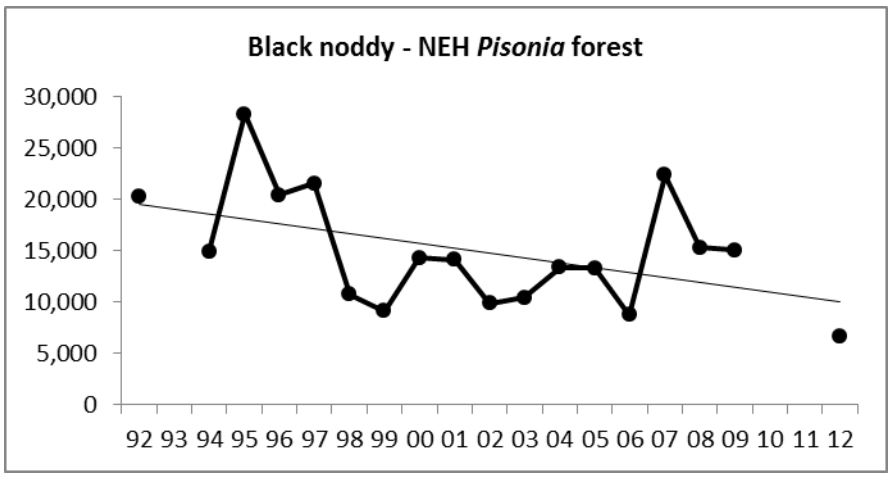
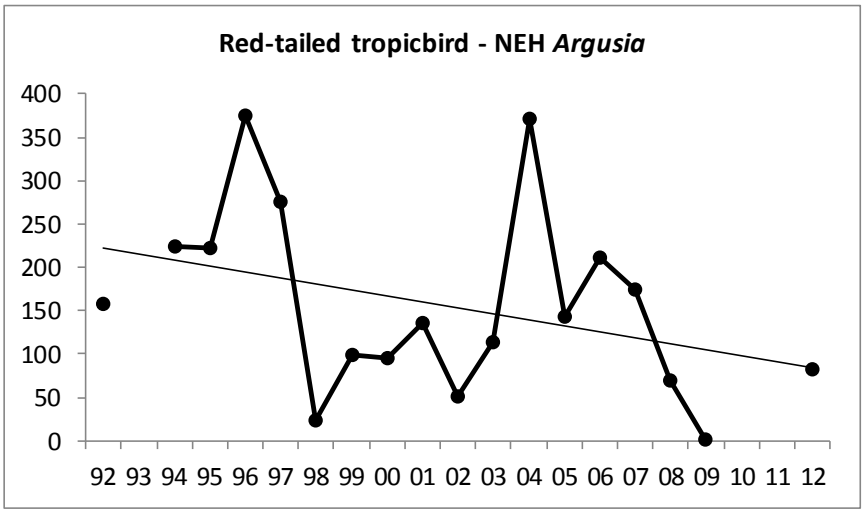


Figure 5. Black noddy. Annual number of nests at NEH Cay in 1992-2008, with fitted trendline. Confidence Intervals (95%) were estimated using bootstrap procedures.

3.5 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. Trend analysis for both NEH and SWH indicates a steep decline at NEH (annual growth rate -10.5%, λ = 0.895 ± 0.013, CI 95% 0.844–0.946) and a strong increase (annual growth rate 12.1%, λ = 1.121 ± 0.006, CI 95% 1.058–1.183) at SWH (Tables 2 & 3;

Figure 6). However, caution needs to be exercised in accepting these conclusions. The main breeding season for this species runs from March to July. The last six counts (2005—2012) have been conducted when many birds have finished breeding, and the low numbers recorded between 1998 and 2003, and in 2008, 2009 and 2012 for NEH (Fig.6) are unlikely to represent a population decline. Based on surveys carried out in earlier years, the Herald Cays support a population in excess of 500 breeding pairs of red-tailed tropicbirds and are the most important breeding site for this species in Eastern Australia. The population is most likely stable. However, it would be useful at some stage in the future to confirm that this is the case by conducting a few surveys earlier in the breeding season should the opportunity arise.



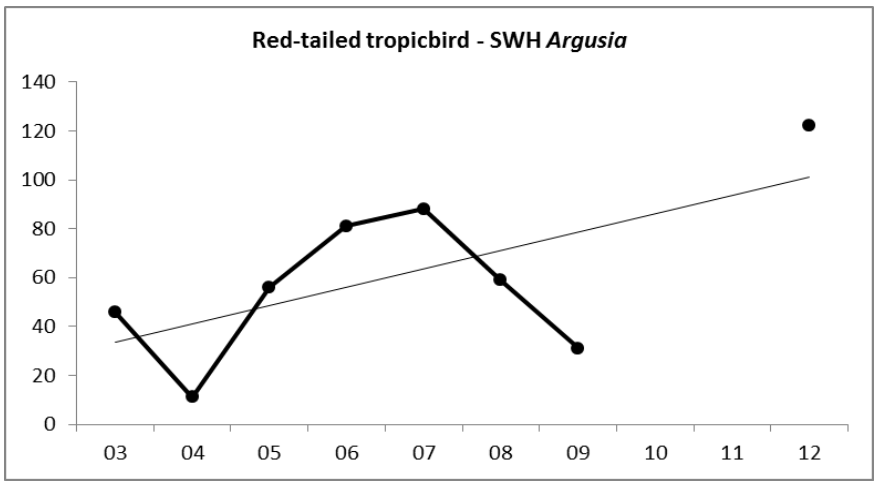


Figure 6. Red-tailed tropicbirds. Maximum annual counts of pairs breeding at NEH (top panel) and SWH (bottom panel) Cays, with fitted trendline. This species only breeds in Argusia shrubland.

3.6 Masked booby

Masked boobies are conspicuous birds of the shoreline of many Coral Sea islands, where they breed in low numbers. 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 NEH and SWH. 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.

In 2012 71 masked boobies were banded during the August 2012 patrol. Most of these birds were captured on SWH. One hundred and twenty six individuals previously banded were also re-sighted or recaptured. All of these birds are of a known minimum age: 62 were at least 10 years or older (see table below), including one bird that was a minimum of 24 years old. All had been originally banded on the Herald Cays, with the exception of two birds, one (24 years old) that had been banded originally on Coringa Islet, and another that had been banded as a chick on Phillip Island, near Norfolk Island, in 2000 — a distance of 2341 km with a bearing of 301 degrees.

		No of birds at age													
No. of birds		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**15**	**16**	**23**
Banded	71	71														
Recaptured	126			13	11	4	3	18	2	12	50	8		2	1	1
Total	197	71		13	11	4	3	18	2	12	50	8		2	1	1

The banding and resighting data has been previously used to examine survival in this species (Baker and Holdsworth 2009). This analysis showed that mean annual adult survival is 96.7%, a value that would be expected for a long-lived species with a stable population. There did not appear to be any difference between survival of males and females. Survival differed by year. Annual estimates of survival for males, females and all sexed birds, together with standard errors and the estimated probability of recapture for years 2001 to 2006, inclusive, are shown below:

Year	**Male**	**SE**	**Female**	**SE**	**All sexed**	**SE**	**Probability of Recapture**	**SE**
2001	**0.966**	0.049	**0.979**	0.035	**0.971**	0.028	**0.516**	0.064
2002	**0.975**	0.054	**1.000**	0.000	**1.000**	0.000	**0.707**	0.049
2003	**0.986**	0.041	**0.948**	0.048	**0.962**	0.032	**0.589**	0.033
2004	**0.964**	0.040	**0.953**	0.046	**0.957**	0.032	**0.420**	0.034
2005	**0.957**	0.067	**0.874**	0.073	**0.917**	0.054	**0.488**	0.047
2006	**0.941**	0.103	**0.886**	0.108	**0.916**	0.088		

DISCUSSION

The monitoring program in the Coral Sea NNRs and North East Herald Cay over the last 20 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 which 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.

All species studied show strong inter-annual fluctuations and distinct trends, although trends were not consistent between species. While the breeding populations of frigatebirds and black noddies at NEH declined, breeding red-footed boobies increased during the period 1992 to 2012. Both frigatebird and black noddy populations were stable or grew from 1992 until 1997, but then crashed dramatically between 1998—2001, and continued to decline to the present time. The decline during the late 1990s coincided with a large El Nino Southern Oscillation event, but the likely causes of the subsequent decline of frigatebirds and noddies is uncertain. The total number of birds of both species breeding in 2012 was the lowest recorded at NEH since the monitoring program commenced (Figure 3), and this may be due in part to the loss of breeding habitat and subsequent exposure to prevailing winds in the *Pisonia/Cordia* following the impact of *Cyclone Yasi*. Further surveys will determine if this is a short or long term effect.

Wilcox et al (2007) conducted a preliminary analysis on the relationship between variation in oceanography and seabird abundance using data collected through the Coral Sea monitoring programme.They found that the average 12 hour wind speed was the single variable most strongly related to the *Pisonia* counts. In particular, high average wind speeds over a 3 month period, 18 months preceding the nest survey were related to higher nest counts. A potential oceanographic mechanism to explain this effect 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 a 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 (Wilcox et al 2007).

Although this program has been able to detect significant population changes in red-footed boobies, frigatebirds and black noddies, it should be noted that 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 20 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 recognised 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 annual 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.

It is possible the timing of the survey each year effects 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 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

As in previous reports we recommend:

- annual visits of approximately 8 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 are made in *Argusia* shrubland whenever North-east Herald Cay or other islands are visited. These surveys require only 3 to 4 hours to conduct, cause minimal impact to breeding birds, and provide valuable information on breeding cycles in areas which are 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 8 days duration (can be combined with annual seabird count);
- a study to examine foraging range of breeding masked and red-footed boobies be conducted to determine if these species forage largely within the Reserve, as we would expect, and therefore the value of annual count data and survival estimates as an indicator of ecosystem health; and
- 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 that occur there. 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.

ACKNOWLEDGEMENTS

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valuable suggestions on the approach used in the monitoring program. Ross Cunningham, Alan Welsh and Christine Donnelly assisted with the experimental design and data analysis for the *Pisonia* count data. Chris Freebairn provided the protocols for collecting data on insect damage to the *Pisonia* forest. We also thank SEWPAC officers Anna Farnham and Maryanne Humphries for their assistance during the planning and implementation of the 2012 survey. Funding for this project was provided through SEWPAC. The assistance of the Australian Department of Customs, and in particular the officers and crew of the *ACV Dame Roma Mitchell*, in providing safe transport to the Herald Cays in 2012, is gratefully appreciated.

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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 last 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.

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 3 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 ***Pisonia / Cordia* 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 metre 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 represents 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 to 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 eleven 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 which 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 are 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 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 which go 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 s ummer months, a time which 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 observe d within 1m 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 p revious 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.