Report to the Ningaloo Turtle Program on:

Consolidation of the Ningaloo Turtle Program:

Development of a statistically robust and cost efficient survey design

November 2008

By Andrea U. Whiting

PO Box 376u
Charles Darwin University
NT 0815 Australia
Ph / Fax 08 8932 7607
Mobile 0417 913 547

PREFACE

This report was written for the Ningaloo Turtle Program, a collaboration between the Department of Environment and Conservation (DEC), Cape Conservation Group (CCG) and the World Wide Fund for Nature (WWF Australia) and was funded under the NHT Grant “Community Turtle Conservation Through Cross-Regional Collaboration/ State Id Number 053010, Commonwealth Id Number 53456”.

Data used in this report were provided by the Ningaloo Turtle Program, and were extracted from the Ningaloo Turtle Program Turtle Database.

The project is undertaken under a data sharing agreement stating that the Ningaloo Turtle Program retains all rights to the data, and the data was provided for use for the purposes of this contract.

The ownership of intellectual property regarding analyses and methodology used within this report remains with Andrea Whiting, and methods used within this report to may not be published elsewhere without prior permission.

This report should be cited as “Whiting, A. U. (2008). ‘Consolidation of the Ningaloo Turtle Program: Development of a statistically robust and cost efficient survey design’. Report to the Ningaloo Turtle Program, 51pp.”

Glossary

Term	Definition
Turtle Track	One ‘turtle track’ is the combination of an up and a down track
Clutch Frequency	The number of clutches laid by one female in a nesting season
Inter-nesting interval	The number of days between laying a clutch and the first return to the beach to lay a subsequent clutch within the same season
Remigration interval	The number of years between nesting seasons for an individual female
Nesting success	The percentage of tracks resulting in deposition of eggs

ACKNOWLEDGEMENTS

The Ningaloo Turtle Program (NTP) is a collaborative effort of the Western Australian Department of Environment and Conservation (DEC), the Cape Conservation Group (CCG) and WWF Australia. The data used in this report are the result of a team effort of many contributors and supporters. The NTP would like to acknowledge the following persons: NTP Steering Committee members and founders of the program Roland Mau (DEC) and Susie Bedford (CCG), co-founders David Waayers and Raquel Carter (formerly WWF now DEC); other members of the Ningaloo Steering Committee Jutta Wildforster (CCG) and Paul Gamblin (WWF), former NTP Steering Committee member Richard McLelland (WWF), past and present sponsors including Threatened Species Network, Rangelands NRM Coordinating Group, CoastWest, Coastcare/Landcare Australia, BHP Billiton, Murdoch University, Department of Defence, the Tony and Lisette Lewis WildlifeLink Foundation and the Shire of Exmouth; the Project Officers for the Community Turtle Conservation through Cross-Regional Collaboration Project including Amy Lewis, Cath Samson and Raquel Carter; the NTP Volunteer Coordinators including Natalie Bool, Tristan Simpson, Claire O'Callaghan, Allison Richards, Kim McGrath and Sharon McKinna-Jones; the significant contributions made by Keely Markovina, Lyn Irvine and Michelle Hughes, the long-term committed community members Jack Hines, Susie Ferrari and Susie Noonan and the many other Trainers, Assessors, Team Leaders and Volunteers who have participated in the NTP over the last 8 years. Also thanks to past and present DEC (Exmouth) staff, who help to set up the remote camp at Bungalup each year, particularly Steve Owen and the rangers. The NTP would also like to acknowledge the Yinigudira, Thanlanyji and Baiyungu people as custodians of these lands. Thanks to Scott Whiting for providing helpful comments on this report.

EXECUTIVE SUMMARY

The Ningaloo region supports substantial nesting for green turtles (*Chelonia mydas*), and loggerhead turtles (*Caretta caretta*) and lower density nesting for hawksbill turtles (*Eretmochelys imbricata*).

The Ningaloo Turtle Program has monitored nesting sea turtle activities on the Jurabi coastline over the past seven nesting seasons, with varying amounts of survey coverage and survey effort.

These data were analysed using linear regression and non-parametric models to determine sampling error associated with estimated annual track count abundance from different sampling regimes.

Modeling showed that monitoring effort could be substantially reduced while retaining a reasonable level of error, and having low impact on the ability to detect trends in the population. Monitoring conducted for as few as 14 days, whether conducted intensively during the peak of the nesting season, spread throughout the nesting season or conducted on random days, had mean error of ~ 10 % in estimating annual nesting abundances for green and loggerhead turtles; and mean error of ~ 30% for hawksbill turtles.

The minimum length of monitoring required to estimate annual nesting abundance for green, loggerhead and hawksbill turtles were:

Species	Mean + SD Error (%)	Inc in time to detect trend (%)	Minimum monitoring regime	Total no days monitoring
Green	5	0	5 weeks monitoring mid season;	35
			24 days monitoring (weekends)	24
	10	0	3 weeks monitoring mid season	21
			12 days monitoring (weekends)	12
	20	1	2 weeks monitoring mid season	14
			8 days monitoring (weekends)	8
	30	5	2 weeks monitoring mid season	14
			8 days monitoring (weekends)	8
Loggerhead	5	0	8 weeks monitoring mid season	56
	10	0	6 weeks monitoring mid season	42
	20	4	2 weeks monitoring mid season	14
			10 days monitoring (weekends)	10
	30	11	2 weeks monitoring mid season	14
			8 days monitoring (weekends)	8
Hawksbill	5	0	10 weeks monitoring mid season	70
	10	0	9 weeks monitoring mid season	63
	20	4	8 weeks monitoring mid season	56
	30	11	6 weeks monitoring mid season	42
			24 days monitoring (weekends)	

Monitoring regimes would ideally occur both intermittently throughout the season and intensively mid-season to increase the confidence in abundance estimates.

Monitoring would ideally occur at areas with high density nesting including Graveyards, Hunters, Lighthouse Bay, Navy Pier, Tandabiddi, Bungelup, Carbaddaman, and Boat Harbour sections.

Monitoring would ideally include an assessment of nesting success using visual observations of the turtle, to reduce the error in estimating annual nesting abundance estimates.

By combining nesting success estimates from observing turtles, with track counts conducted intermittently throughout the season and intensively mid-season, the amount of survey effort required will be substantially reduced while retaining a statistically robust survey design.

CONTENTS

INTRODUCTION

Background

The Ningaloo region supports substantial nesting for green turtles (*Chelonia mydas*), and loggerhead turtles (*Caretta caretta*) and lower density nesting for hawksbill turtles (*Eretmochelys imbricata*). All three species are "threatened" under the *EPBC Act 1999* [Cth] and "rare or likely to become extinct" under the *Wildlife Conservation Act 1950* [WA]. Consequently, conservation actions and population monitoring are beneficial to assist their long-term survival.

The Ningaloo Turtle Program has monitored nesting sea turtle activities on the Jurabi coastline over the past seven nesting seasons (2001-02 to 2007-08 seasons; Carter *et al.* 2004; Richards *et al.* 2005). Monitoring included identifying turtle activities by counting tracks, identifying tracks to species, estimating whether the track resulted in successful egg deposition, identifying predation of eggs and monitoring presence of predators. Monitoring occurred during the peak of nesting between November and March each year. Survey coverage and survey effort varied between the years (Table 1), and included a consistent monitoring effort over the last three years at beaches within the North West Cape and Bundera/Ningaloo Divisions.

Population dynamics of nesting sea turtles

The lifecycle of all cheloniid sea turtles (including green, loggerhead and hawksbill turtles) is similar (Musick and Limpus 1997). Starting at the nesting beach, hatchling turtles enter the water and disperse across the surface waters on the open ocean where they spend approximately five years. After this, turtles will use one to several foraging areas as they develop, until they reach their adult foraging habitat where they will generally spend the remainder of their life. From this habitat, female turtles will generally make breeding migrations every 1 to 9 or more years (e.g., Limpus 1985; Hughes 1995; Miller 1997; Broderick *et al.* 2002; Hawkes *et al.* 2005), while male turtles may make breeding migrations every year or every two years (Miller 1997). With each breeding migration, female turtles will generally lay 1 to 8 clutches (Limpus 1985; Dodd 1988; Johnson and Ehrhart 1996; Miller 1997) at intervals of approximately two weeks (Miller 1997). The number of clutches laid and intervals between breeding will vary between species, populations and years (Miller 1997; Broderick *et al.* 2001, 2003; Solow *et al.* 2002), and are dependent on environmental factors including water temperatures and climatic conditions described by the Southern Oscillation (Limpus and Nicholls 1988; Hays *et al.* 2002). The number of clutches laid per season and the frequency of nesting are important parameters in estimating the abundance of the nesting female population, but both require intensive monitoring to quantify.

Monitoring sea turtle populations

Monitoring of sea turtle populations is most commonly restricted to the nesting beach, where the number of nesting activities or the number of nesting females are used as an index for population function (Schroeder and Murphy 1999). Although monitoring one demographic state is not desirable for robust population censuses (Williams *et al.* 2002), the trade-off in effort required to assess abundance of nesting adults for nesting migratory populations has resulted in it being a more commonly measured population parameter, and forms a reliable, albeit limited population index.

To maximize the information gained, and minimize error in estimating population size, nesting sea turtle populations are ideally monitored through intensive long-term capture-mark-recapture studies conducted throughout the entire nesting season. However, due to financial or logistical constraints (such as from high density nesting, long nesting seasons or large nesting areas), this is often not feasible. In these situations much shorter or periodic intervals are required, and may comprise of a count survey rather than a capture-mark-recapture approach.

Developing a monitoring strategy which minimizes error in estimating annual nesting abundance for sea turtles requires an understanding of: seasonal length, seasonal distribution (shape of the nesting season), inter-nesting intervals, clutch frequencies, remigration intervals, and annual variability in the aforementioned variables. With this information, error associated with sampling regimes can be modeled to develop a monitoring regime with estimated error within defined boundaries. This will allow confidence in estimating population size, and in detecting trends in the nesting population.

To gain an estimate of the adult female turtle population, and therefore be confident in comparing inter-annual estimates, several conversion factors are needed (Figure 1). Each conversion factor can have a high or low associated error (Figure 1) depending on how much information is available on the nesting turtles for that year. Ideally, the most accurate and precise assessment of the number of actively breeding females in the population will allow for the most confident detection of trends in the population.

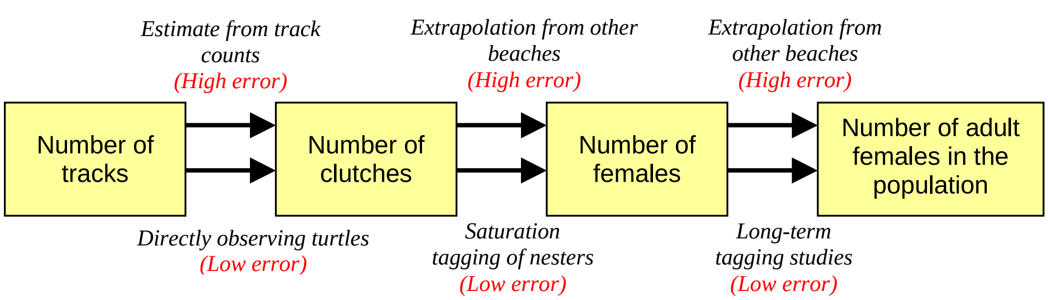

Figure 1. Conversion factors used in population modeling of nesting turtles

Scope of this report

This report works in conjunction with the first four goals of the Ningaloo Turtle Program, which are to:

1. **Identify key nesting beaches.**
2. **Monitor populations and assess trends at key index sites.**
3. **Identify the level of feral predation threats on nests**
4. **Implement effective protection of important nesting beaches in cooperation with the management agency.**
5. Generate and maintain community support for the program and for the conservation of marine turtles and their habitats.
6. Educate visitors and the community about marine turtles.
7. Manage visitor turtle interactions through education and interpretation and by promoting sustainable ecotourism.

(Carter *et al.* 2004)

This report aims to provide an analysis of available data in order to provide a statistically robust and cost-effective survey design for future monitoring. This report aims to provide feasible options to reduce spatial and temporal scales in monitoring while minimizing the compromise on sampling error, and maximizing the accuracy and precision of data collected.

METHODOLOGY

Study site

The coastline of the Ningaloo Region is approximately 260 km long and consists of sandy beaches interrupted by rocky shores and mangroves (Figure 2). The spread in nesting across large areas of coastline creates logistical difficulties in accessing every turtle each night. There is also more potential for turtles to move between nesting beaches, given the close proximity of adjacent nesting beaches. Consequently, track count surveys across the coastline is a useful tool to gain a representation of the number of nesting females each night.

As tagging studies have not defined the range of nesting areas for each turtle (nesting fidelity), the Ningaloo Region coastline is considered one rookery for the purposes of this report.

Current monitoring methodology

Turtle tracks have been monitored within the Ningaloo region systematically since the 2001-02 nesting season (Cape Conservation Group 2004). Monitoring has occurred across much of the coastline, but the survey coverage and survey effort has varied between years (see Table 1).

Monitoring included identifying turtle activities by counting tracks, identifying tracks to species, estimating whether the track resulted in successful egg deposition, identifying predation of eggs and monitoring presence of predators (Cape Conservation Group 2004). Monitoring was often conducted by volunteers who had varying degrees of experience. This is likely to have an impact on the accuracy of species identification and assessing whether a track resulted in successful nest deposition.

Given the inherent error in determining whether a nesting attempt resulted in a clutch of eggs being laid when the eggs are not seen, this report focuses on the total number of tracks as an index and may be better converted to the total number of clutches by watching nesting turtles to determine nesting success. This focus was chosen, so that modeling scenarios are still valid if more reliable estimates of nesting success are obtained. Although our focus on the total number of tracks may have error in converted to the number of nesting turtles caused by variations in nesting success throughout the season, the seasonal variations in nesting success were not large, and likely to be comparable to error caused by assessing nesting success from tracks.

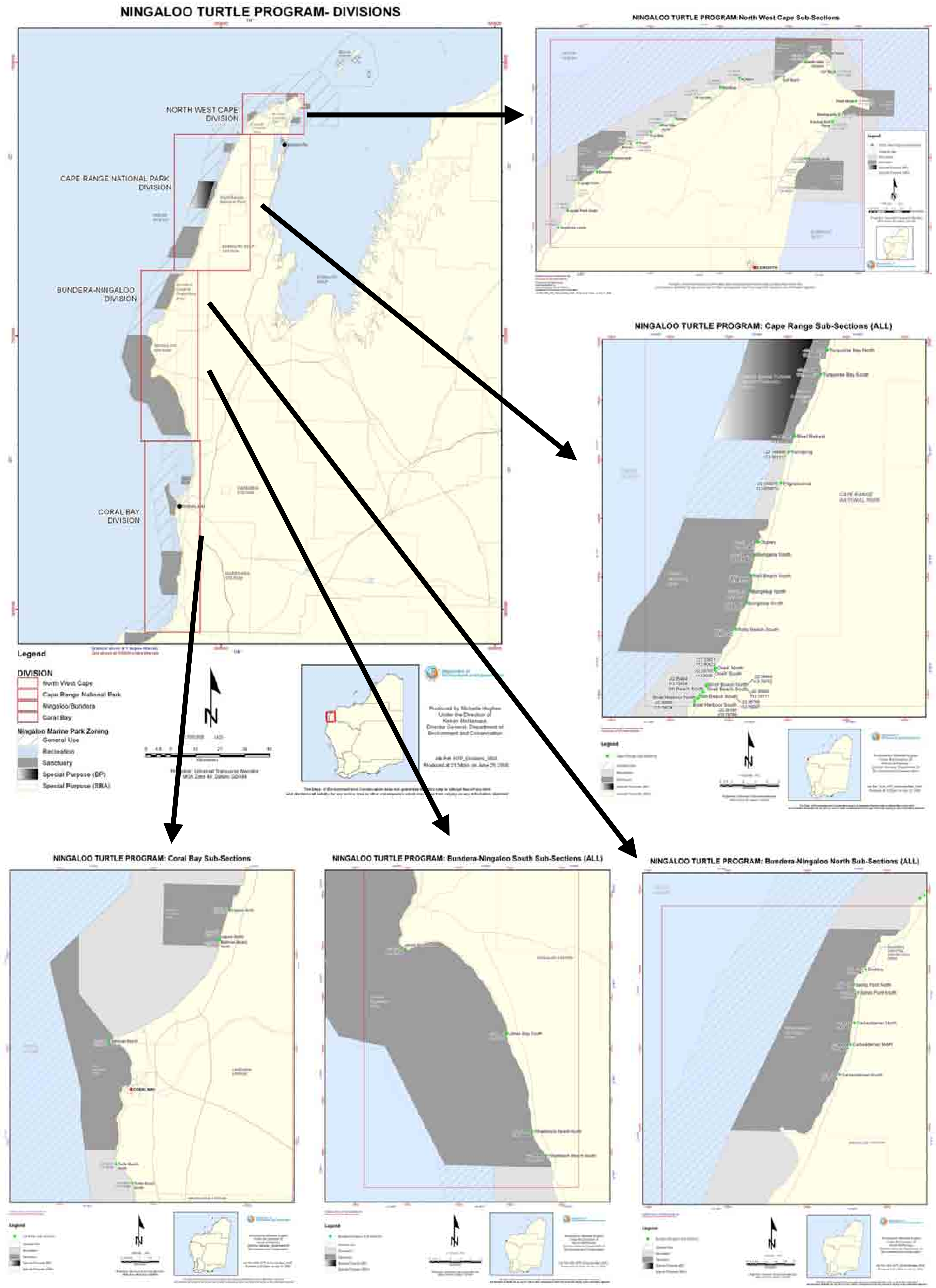

Figure 2. Map of the Ningaloo Region, showing Divisions, Sections and SubSections referred to throughout this report. Maps produced by Michelle Hughes under the direction of Keiran McNamara, Director General Department of Environment and Conservation.

Data limitations and error

A major limitation to the accuracy of the data used to detect population size is the methodology used to determine nesting success, by visually assessing tracks in the sand. This method of identification is associated with inherent error, which may be exacerbated by moderate or high density nesting (Schroeder and Murphy 1999), or nesting in areas where nests are partially obscured (Eg. areas with vegetation, sticks or rocks). A more accurate method to determine nesting success would require nighttime surveys where turtles are observed (with minimal disturbance) and nesting success is recorded. Although this is relatively more labor intensive, a sampling regime can be adopted to determine nesting success periodically throughout the season (recommendations are listed within this report). Using a survey sample conducted throughout the season on a sample of the entire survey area is more likely to give an unbiased sample (Schroeder and Murphy 1999). The recorded nesting success from observing egg deposition can then be compared with nesting success determined from examining tracks to determine the magnitude of error association with this methodology. Another possible technique to determine nesting success is to dig down to quantify the presence or absence of eggs (Schroeder and Murphy 1999). However, given that not everybody will be able to find eggs even when they are present, this may cause bias to the assessment of nesting success and may impact on the development of the eggs.

Potential sources of error in the data collected include:

- Error in identifying species from tracks
- Error in assessing nesting success from tracks
- Missing tracks by survey error or from wind or tide removing signs of tracks
- Transcription error

Population estimates for the “entire nesting season” have additional error in estimates for dates outside 1 December to 28 February, as monitoring did not occur daily for the full extent of monitoring. As such, arbitrary start and end dates and shapes of the nesting season outside the monitoring times were used for this analysis.

Additional sources of error in determining population size are from the individuals not being tagged and followed through their nesting season, and as such variables such as clutch frequencies, inter-nesting intervals and remigration intervals are missing. Given the reasonably high density of nesting across large areas of coastline, determining these variables would require immense survey effort across the coastline and are probably not feasible to determine accurately within the Ningaloo Region (especially if turtles are moving substantial distances between nesting attempts). Instead, data for clutch frequencies, inter-nesting intervals and remigration intervals can be estimated from other nesting studies, and ranges can be used for conversions of the number of clutches laid to the number of nesting females and the total breeding female population.

Table 1. Number of nights surveyed for beaches within the Ningaloo Region (see Figure 2 for location of beach division and sections).

Division	Section	SubSection	Distance	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	Total
Bundera/Ningaloo	Boat Harbour	Alli Beach	0.4				51				**51**
		Boat Harbour	0.3				51				**51**
		One K	0.2				50				**50**
		Shell Beach	0.1				51				**51**
	Bungelup	Bungelup*	-	1			2				**3**
		Bungelup Beach	1.1		1	25	49	38	40	47	**200**
		Neils Beach	1.3	1		23	50	38	40	47	**199**
		Rolly Beach	2.4	1		1	51	38	40	46	**177**
	Carbaddaman	Carbaddaman North	1.4		2		51				**53**
		Carbaddaman South	2.0		2		51				**53**
		Doddys	1.2		2		51				**53**
		Sandy Point	0.6		1		51				**52**
	Janes Bay	Janes Bay	12.8	6	13	24	12	29	22	5	**111**
	Norwegian Bay	Norwegian Bay*	-		2	1					**3**
	Whaleback Beach	Whaleback Beach*	-			7	8				**15**
Cape Range*	Bloodwood	Kurrajong	-			2					**2**
		Pilgramunna	-			2					**2**
	Turquiose Bay	Turquiose Bay	2.2			16					**16**
Coral Bay	Batemans Bay	Batemans Bay	7.7		103	100	117	51	73	45	**489**
	Lagoon	Lagoon	1.9		103	100	116	51	73	45	**488**
	Turtle Beach	Turtle Beach	1.2		56	100	66	49			**271**
Gnarraloo Bay / Quobba*	Red Bluff	Red Bluff	0.8		1	20					**21**
North West Cape	Graveyards	Brooke - Graveyards	1.7	19	30	79	91	90	86	84	**479**
		Five Mile North - Five Mile Carpark	0.8	17	60	125	95	95	87	84	**563**
		Graveyards - Burrows	1.5	14	30	81	90	90	85	84	**474**
		Trisel - Five Mile Carpark	1.3	23	45	91	98	93	83	84	**517**

Table 1 cont.

Division	Section	SubSection	Distance	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	Total
	Hunters	Hunters - Mauritius	1.6	13	89	88	91	91	85	84	**541**
		Jacobz South - Wobiri	2.1	16	73	87	90	90	86	84	**526**
		Mauritius - Jacobz South	1.8	26	86	88	90	90	85	84	**549**
	Lighthouse Bay	Mildura Wreck - North West Carpark	1.3	5	36	42	66	85	71	84	**389**
		North West Carpark - Surf Beach	1.9	13	38	45	66	86	72	84	**404**
		Surf Beach - Hunters	3.2	14	53	50	83	89	79	83	**451**
	Navy Pier*	Bundegi Boat Ramp - Bundegi Jetty	0.7			18					**18**
		Bundegi Jetty - Point Murat	1.5			27					**27**
		Point Murat - VLF Bay	2.6			25					**25**
		VLF Bay - Mildura Wreck	1.7	1		16					**17**
	Tandabiddi	Burrows - Jurabi Point	1.5	21	29	1		85	85	84	**305**
		Jurabi Point - Jurabi Point South*	2.1	5	29	1			1		**36**
		Jurabi Point South - Tandabiddi Leads*	1.4	1	28	1					**30**
		Tandabiddi Leads - Tandabiddi*	-	3	29						**32**
Serrurier Island*	Norwegian Bay				1						**1**
	Serrurier E	S4 - S6	2.8						4		**4**
		S6 - S2	2.8						4		**4**
	Serrurier S	S2 - S2	1.5						4		**4**
	Serrurier W	S2 - S3	1.9						4		**4**
		S3 - S4	2.1						4		**4**
Waroora Station*	Elles Camp	Elles Camp	-			3					**3**
	Waroora Homestead	Waroora Homestead	-			3					**3**
Grand Total				**200**	**942**	**1292**	**1738**	**1278**	**1213**	**1158**	**7822**

**Data are too few for use for temporal and spatial sampling models.*

Temporal distribution of nesting

A complete time series was required for data sampling to ensure that days with no monitoring were not sampled as zero counts; and that sampling was consistent between species, beaches and years. To generate a complete time-series for analyses, missing data were interpolated using the mean of the two preceding and two proceeding days. Where data were only missing for sections of the beach, data were generated using the mean of the following two methods: 1) the mean of the two preceding and two proceeding days; and 2) a prediction was made on nesting abundance using the relative abundance of nesting within that division using relative abundances in Figures 16 -19. For example, if data for green turtles were only available for the Graveyards section (39.2% of total nesting), the relative abundances of nesting at Hunters (30.6%), Lighthouse Bay (8.9%), Navy Pier (1.3%) and Tandabiddi (18.5%) were used to estimate nesting within these sections.

Data used for temporal sampling were limited to years and sections where most data were available. This was generally limited to the 2003-04 to 2007-08 nesting seasons, and most analyses focused on nesting at the North West Cape Division due to the greater effort in monitoring, and relatively high nesting abundances.

This report uses the population size from 1 December to 28 February as the target population size, as most of the data are only available for this time period. To determine the total track counts throughout the nesting season, an extrapolation from the predicted target population to total annual nesting abundance is needed. This requires an estimate of the length of the nesting season, and is less accurate than estimating nesting abundance from 1 December to 28 February.

<u>*Total population size estimates*</u>

Error in estimating population size of the actively breeding nesting population compose of:-

- Error in extrapolating from track counts to annual track counts
- Error in determining nesting success, and therefore extrapolating to annual clutches laid
- Error in determining clutch frequency, and therefore determining annual nesting females
- Error in determining remigration intervals, and therefore estimating the total actively breeding nesting population

Without capture-mark-recapture studies (tagging individuals), the latter two cannot be determined, and must be estimated from knowledge of other populations. Furthermore, to accurately determine clutch frequency a capture-mark-recapture with high capture success would be needed, which is logistically time consumptive and more difficult than the current monitoring methodology. Clutch frequencies and inter-nesting intervals could alternatively be determined using satellite telemetry, where transmitters are attached to a sample of turtles early in the nesting season (on their first arrival).

Generalized additive models with defined start and end points were used to estimate the proportion of nesting occurring between 1 December and 28 February. Although daily data were few between October-November and March-April, I used an estimate from the available data to define start and end points of 15 November and 15 March and 1 November and 31 March. Generalized additive models were fit to the available data, using weighted start and end points of 1.0 with all other data weighted at 0.1.

Sampling effort required

Sampling designs were investigated for full-season monitoring, mid-season monitoring, monitoring intermittently throughout the season and monitoring throughout the season with effort concentrated during the peak of the season (Figure 3).

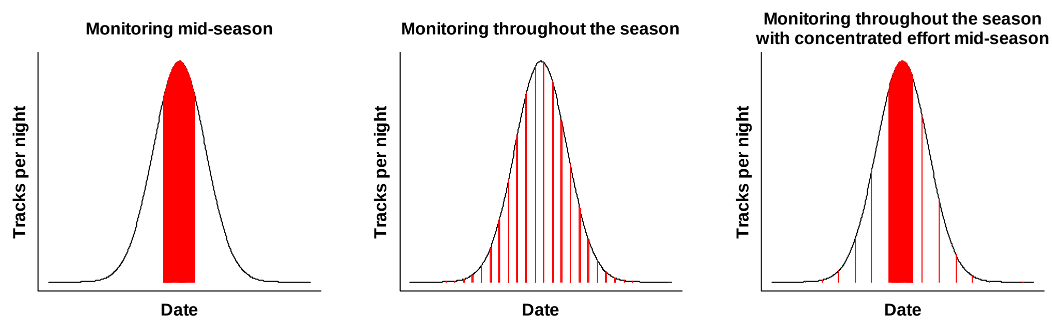

Figure 3. Different types of sampling designs based on either monitoring mid-season, monitoring throughout the season or monitoring throughout the season with effort concentrated at the peak of the nesting season.

Sampling designs investigated were limited to the range where most data were collected and there were sufficient years to test models. This range was limited to between 1 December and 28 February, and may be extrapolated to full-season counts using the results from the generalized additive models.

Temporal scales of monitoring investigated included:

1. Monitoring every day mid-season
    a. from 2 to 15 January (2 weeks)
    b. from 15 December to 15 January (1 month)
    c. from 22 December to 22 January (1 month)
    d. from 15 December to 30 January (1.5 months)
    e. from 7 December to 7 February (2 months)
    f. from 1 December to 28 February (3 months)

2. Monitoring for two consecutive days per week throughout the season*
    a. from 1 December to 28 February (3 months)
    b. from 7 December to 7 February (2 months)
    c. from 15 December to 30 January (1.5 months)
    d. from 15 December to 15 January (1 month)
    e. from 22 December to 22 January (1 month)

* NOTE- For monitoring for two consecutive days per week throughout the season, I assume that each days count only count the tracks from the previous night. This may require an additional survey the day before to cross all existing tracks, if fresh tracks cannot be discerned from tidal variation. Additionally, error in annual nest abundance from monitoring one day per week was investigated for cases where the previous nights tracks were not clearly discernable from older tracks.

For monitoring intermittently throughout the season, monitoring was investigated for each combination of days with that monitoring regime to increase the power of the analysis. For example, for monitoring two days per week, we investigated samples starting on day 1, day 2, day 3, day 4, day 5 and day 6 to give all combinations of two day per week sampling.

Spatial distribution in nesting

The spatial distribution in nesting was investigated for the North West Cape and Bundera/Ningaloo divisions by combining all available data to gain relative abundance estimates. As data were not available for all divisions, sections and sub-sections for all years, relative abundance estimates were often conducted for a sample of data, and these samples were often not consistent between years. For example, relative abundance estimates for sections within the Bundera/Ningaloo division were calculated using the 2004-05 nesting season only, whereas relative abundance estimates within the Bungelup section were calculated using the 2004-05 to 2007-08 nesting seasons as more data were available. The precision of relative abundance estimates is directly related to the amount of data available (shown in Table 1).

Spatial synchrony in nesting

Spatial synchrony in nesting between adjacent beaches was investigated using both cross correlation analyses and linear regression models. Cross correlation analyses provide a measure of correlation and identify potential lags in correlation. The cross correlation analyses were conducted using variables pre-whitened by using the residuals derived from a first order autoregressive model (Chaloupka 2001) and were conducted using the *ccf* function in R (R Development Core Team 2007). Regression analyses were conducted for data for each season, and choice of model fit from the linear and non-linear regression models investigated was conducted using the Akaike Information Criterion (AIC).

Synchrony in nesting between beaches could not be detected when nesting densities were low, so daily data were pooled (daily, weekly, fortnightly and monthly scales) to determine strength of correlation.

Predicting annual track counts

Annual nesting abundances were predicted using both a direct correlation between the partial season counts and the total seasonal count (eg. Linear regression), and by predicting nesting abundance throughout the season using a curve fitting approach and summing to give the total seasonal count.

Several curve-fitting techniques exist for describing the temporal distribution of nesting turtles; parametric models can be used to constrain the shape of the nesting season to a predefined shape (eg. Girondot *et al.* 2006; Gratiot *et al.* 2006); or non-parametric models can be used which do not constrain the shape of the curve and allow the curve to fit to the available data. Although both model types can provide reasonable fits for nesting turtle data, parametric models have the disadvantage of forcing the data to fit to a given shape. For both parametric and non-parametric models, setting the start and endpoints of the nesting season are essential when models are fit to data for part of the nesting season.

Given the greater flexibility of non-parametric models, greater ease in gaining a good fit and the comparable goodness of fits with good parametric models (Koch *et al.* 2006; Whiting unpublished data), I used a non-parametric approach using generalized additive models (GAMs) for estimating annual abundance from curve fitting. Generalized additive models were used to fit a cubic smoothing spline to the incomplete daily track count data using the *mgcv* package in R (Hastie and Tibshirani 1990; Bjorndal *et al.* 1999; Wood 2006). The fitted function was then used to predict the number of nesting attempts throughout the season, and was summed to give an estimate of the annual number of tracks per year. The amount of smoothing used with the GAMs can be either unconstrained, allowing the simulation to find the best smoothing parameter, or constrained to a degree of smoothing. Using a higher degree of smoothing is favoured when assessing annual nesting abundance from sampled data as outliers have less influence on the shape of the nesting season. However, the lower degree of smoothing is a good graphical way to show cyclic trends in the data when full-season data are available, and to avoid sampling at intervals equal to the trend cycles and cause a biased population estimate.

<u>*Model goodness of fits*</u>

Comparisons in goodness of fits between linear regression models with one (y=a*x) and two (y=a*x + b) parameters were conducted using the Akaike Information Criterion (AIC) with residual sum of squares:

$$\text{AIC} = n\ln\left(\frac{RSS}{n}\right) + 2k + const.$$

where k is the number of parameters, n is the sample size, and RSS is the residual sum of squares, and *const.* is a constant (Maindonald and Braun 2007).

Both linear regression models and GAMs were fitted to sampled data, and model fit was compared using the mean and standard deviations in error between model predictions and annual track count abundances.

Nesting success

The influences of species, section, year and time within the year on nesting success were investigated using generalized linear models with a binomial distribution and logit link function. The date each year was converted to Ordinal Date (number of the day in the year) to compare the time within the year between years.

Sampling error in estimating nesting success from partial season data was investigated so that sampling methods could be obtained to measure nesting success from observations of turtles rather than tracks. We used the recorded nesting success data for sampling, which may underestimate error if the true nesting success has greater variation than that recorded from assessing tracks. Partial counts were investigated for five to 100 turtles per section with monitoring occurring over three to 20 days. For each sample, the Ordinal Date of monitoring was chosen randomly and nesting success was calculated from a random sample of turtles within that night.

Sampling error in estimating nesting success was calculated for green, loggerhead and hawksbill turtles nesting on three sections (Graveyards, Hunters and Lighthouse Bay) within the North West Cape division for 2003-04 to 2007-08 nesting seasons. The calculations of sampling error were limited to these data due to length and coverage of monitoring required. This covered approximately 78.7%, 13.4% and 44.2% of the nesting populations for each species (green, loggerhead and hawksbill turtles respectively) between 1 December and 28 February each year.

Trend detection

As an ultimate goal of conservation (and one of the aims of the Ningaloo Turtle Program) is often to assess trends in population and provide conservation measures to limit decline in population numbers, we provided an assessment of the impact of sampling error on assessing trends in the population.

Detecting trends in any population is dependent on:-

- Duration of the study
- Rate of change per unit of time
- Coefficient of variation
- Significance level
- Power

(Gerrodette 1993)

For example, an increase in the coefficient of variation will lead to either:

- an increase in the duration of study, OR
- an increase in the rate of change per unit of time, OR
- a decrease in the significance level, OR
- a decrease in power.

For sea turtle studies, the large annual variation in nesting abundance (corresponding with a high coefficient of variation) means that many decades are often needed to detect trends in turtle populations with any confidence. The amount of variation in nesting abundance between years varies between species, with green turtles being more susceptible to environmental stochasticity and therefore having larger annual variation than loggerhead or hawksbill turtles (Broderick *et al.* 2001).

Using the coefficient of variation for annual track abundance for green, loggerhead and hawksbill turtles nesting at the North West Cape, we estimated the number of years of monitoring needed to detect a given rate of change for a significance level of 0.05 and 0.1 and power of 0.9 and 0.8 using TRENDS software (Gerrodette 1993). We investigated the impact of sampling error on trend detection, by applying random error to 1000000 replicates of track count data to obtain an estimate of the new coefficient of variation. Random error was generated using the means and standard deviations equal to the sampling error means and sampling error standard deviations investigated, and was applied randomly in a positive or negative manner. We used the new coefficients of variation to estimate the impact of sampling error on the ability to detect trends in annual nesting turtle abundances.

Analyses were conducted using R software (R Development Core Team 2007), JMP software (www.jmp.com), Microsoft Excel, and TRENDS software (Gerrodette 1993).

Temporal distribution of nesting

The temporal distribution of nesting for green (Figure 4 and Figure 6), loggerhead (Figure 7 and Figure 8) and hawksbill turtles (Figure 10 and Figure 12) indicate that nesting occurs throughout the 1 December to 28 February periods. Given the reasonably high numbers of turtles already nesting on 1 December and still nesting on 28 February, and the one off counts from some sections prior to 1 December and after 28 February, the nesting season appears to extend outside the 1 December to 28 February timeframe. Since daily track count data were not consistent outside these days, reliable estimates of the proportion of nesting occurring outside of the 1 December to 28 February period were not available. However, results from generalized additive models indicate that between 82 and 94% of nesting for all species occurs between 1 December and 28 February (Table 2).

Table 2. Predicted percentage of nesting occurring between 1 December and 28 February at the North West Cape Division for green, loggerhead and hawksbill turtles. Predictions were made using generalized additive models (GAMs) using weighted endpoints of either 15 November and 15 March or 1 November and 31 March. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04. Data shown in red are interpolated as no data were available.

Species	**Mean ± SD for % of nesting occurring between 1-Dec and 28-Feb**			
	$GAM_{k=4}$ 15 Nov-15 Mar	$GAM_{k=unspecified}$ 15 Nov-15 Mar	$GAM_{k=4}$ 1 Nov-31 Mar	$GAM_{k=unspecified}$ 1 Nov-31 Mar
Green	93.0 ± 0.8	92.1 ± 1.6	82.2 ± 1.4	85.1 ± 4.0
Loggerhead	92.4 ± 0.4	94.2 ± 2.1	82.4 ± 1.0	89.9 ± 6.2
Hawksbill	93.7 ± 2.3	91.9 ± 4.0	82.6 ± 2.3	85.6 ± 8.5

There were few records of unidentified tracks between 1 December and 28 February (N= 250 for all seasons combined for the North West Cape Division). If turtle species did not influence the ability to identify tracks and unidentified tracks had the same species composition as tracks identified, this would cause an increase in nesting abundance by 0.4%.

The influence of unidentified turtles is likely to have little impact on the temporal modeling, as the temporal distribution of unidentified turtles (Figures 13-15) did not appear different to temporal distributions for green, loggerhead and hawksbill turtles (Figures 4-12).

Green turtle (*Chelonia mydas*) nesting

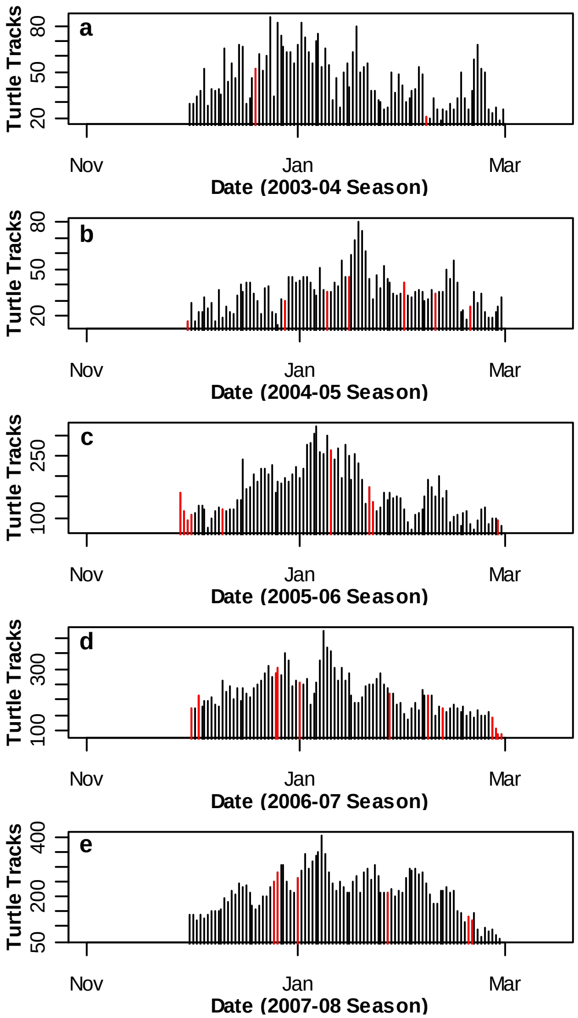

Figure 4. Nesting abundance for green turtles within the North West Cape division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04. Data shown in red are interpolated as no data were available.

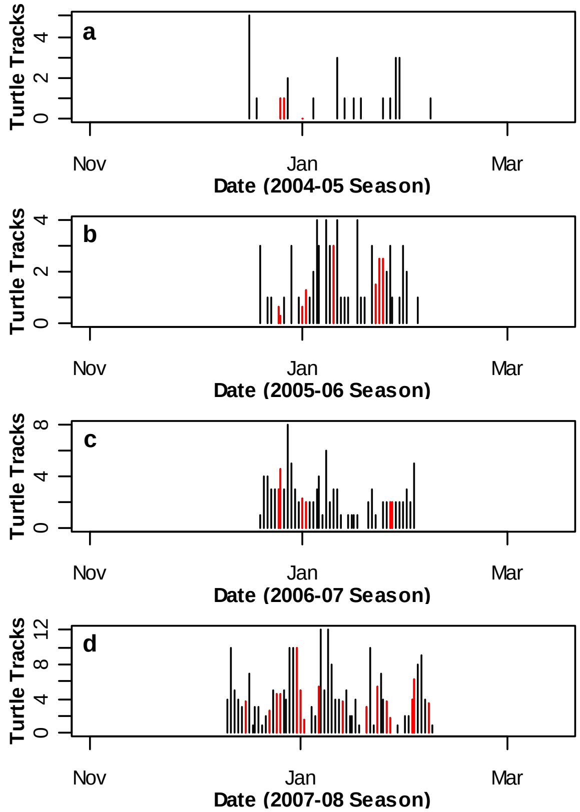

Figure 5. Nesting abundance for green turtles within the Bundera/Ningaloo division. Sections included Boat Harbour, Bundelup and Carbaddaman for 2004-05; and Bungelup for 2005-06, 2006-07 and 2007-08. Data shown in red are interpolated as no data were available.

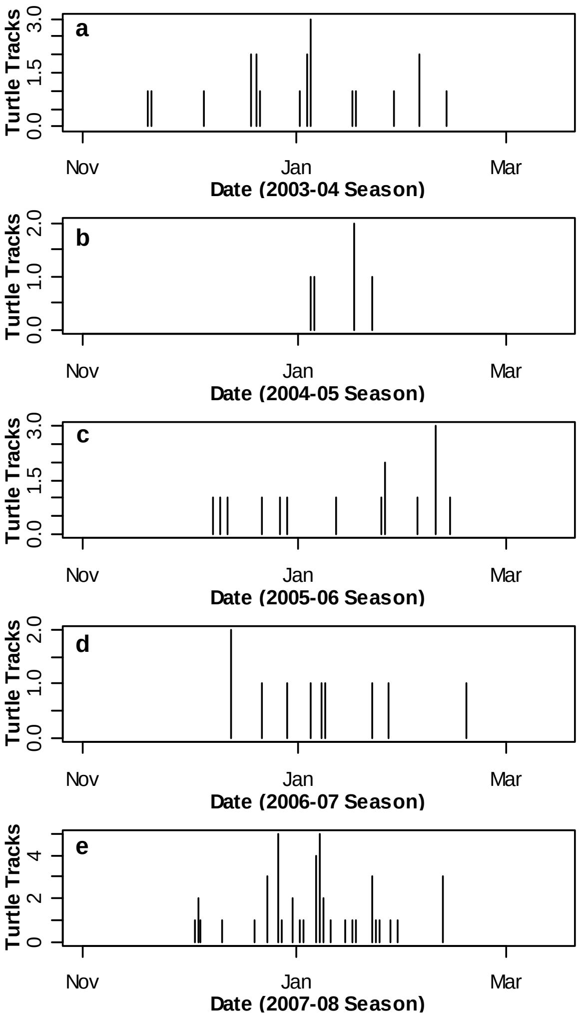

Figure 6. Nesting abundance for green turtles within the Coral Bay division. Sections included Batemans Bay and Lagoon.

Loggerhead turtle (*Caretta caretta*) nesting

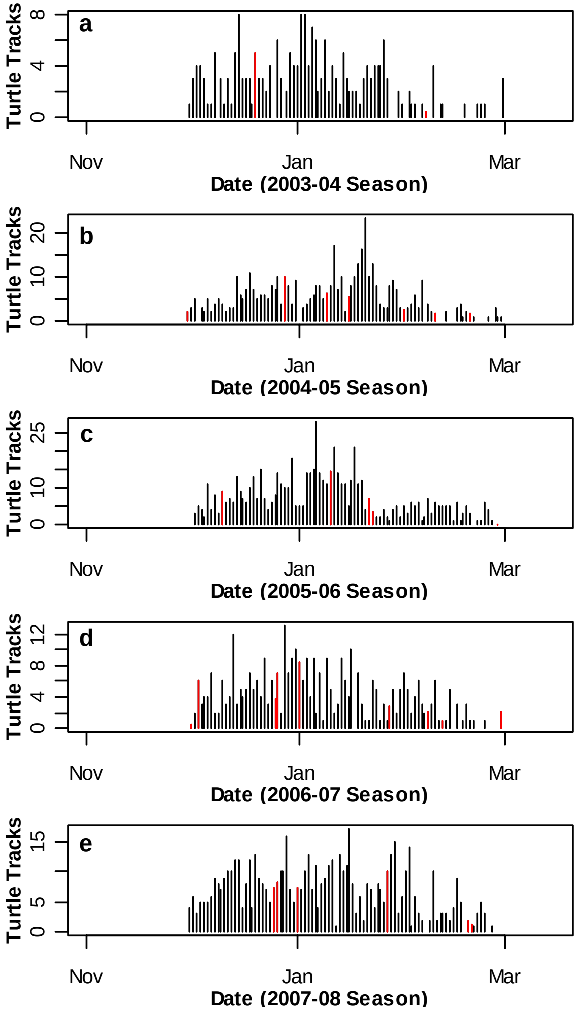

Figure 7. Nesting abundance for loggerhead turtles within the North West Cape division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04. Data shown in red are interpolated as no data were available.

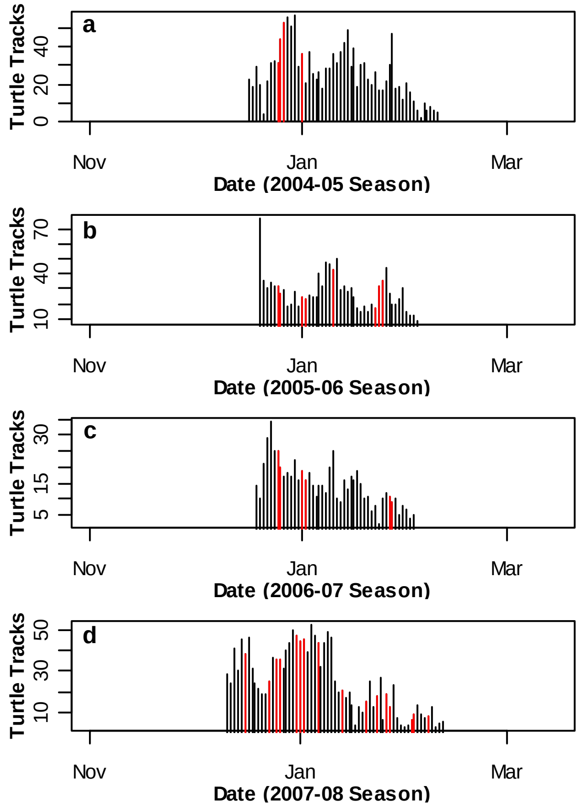

Figure 8. Nesting abundance for loggerhead turtles within the Bundera/Ningaloo division. Sections included Boat Harbour, Bundelup and Carbaddaman for 2004-05; and Bungelup for 2005-06, 2006-07 and 2007-08. Data shown in red are interpolated as no data were available. Note- the 77 track count in 2005-06 may be overestimated, perhaps occurring as a count of several previous days data as it was there were no surveys on the preceding days.

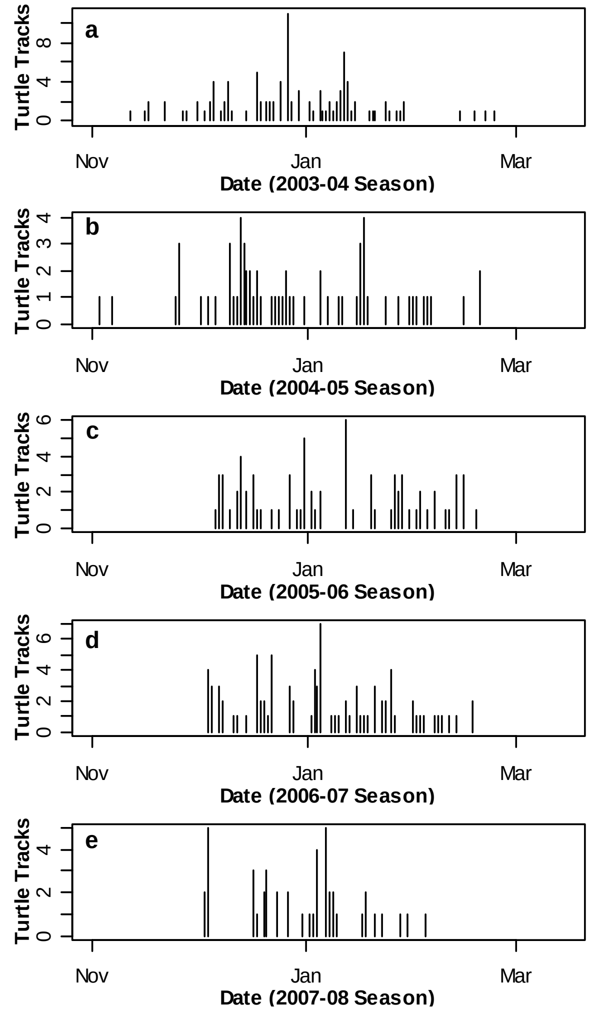

Figure 9. Nesting abundance for loggerhead turtles within the Coral Bay division. Sections included Batemans Bay and Lagoon.

Hawksbill turtle (*Eretmochelys imbricata*) nesting

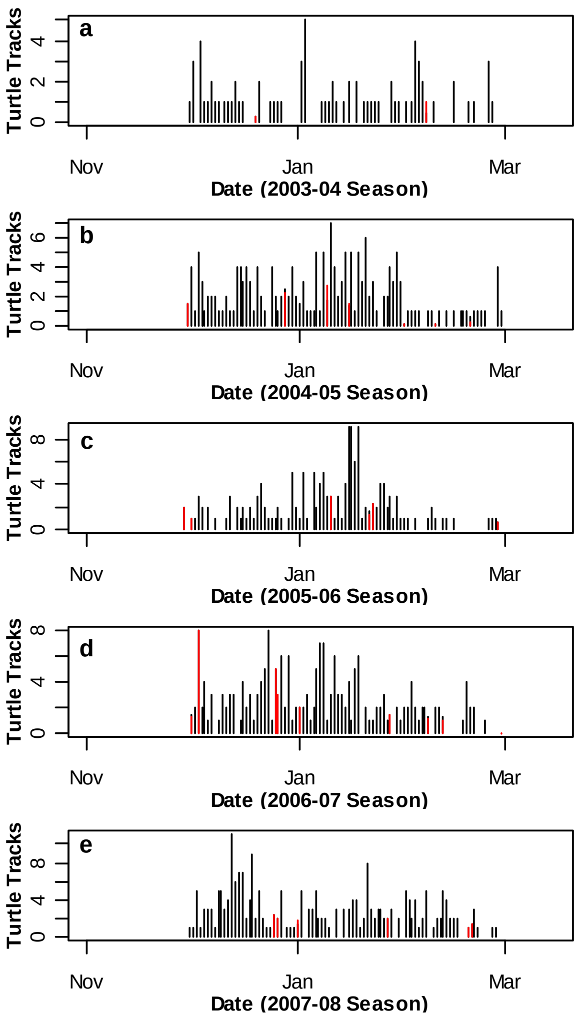

Figure 10. Nesting abundance for hawksbill turtles within the North West Cape division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04. Data shown in red are interpolated as no data were available.

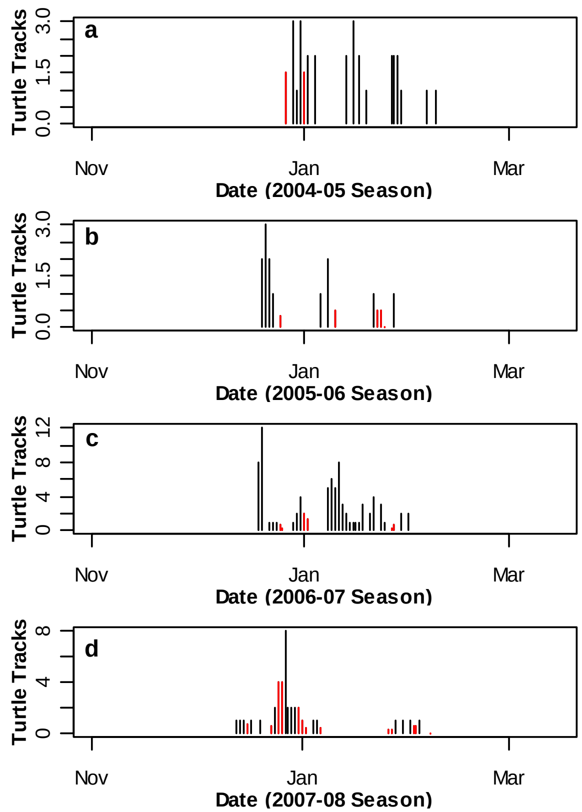

Figure 11. Nesting abundance for hawksbill turtles within the Bundera/Ningaloo division. Sections included Boat Harbour, Bundelup and Carbaddaman for 2004-05; and Bungelup for 2005-06, 2006-07 and 2007-08. Data shown in red are interpolated as no data were available.

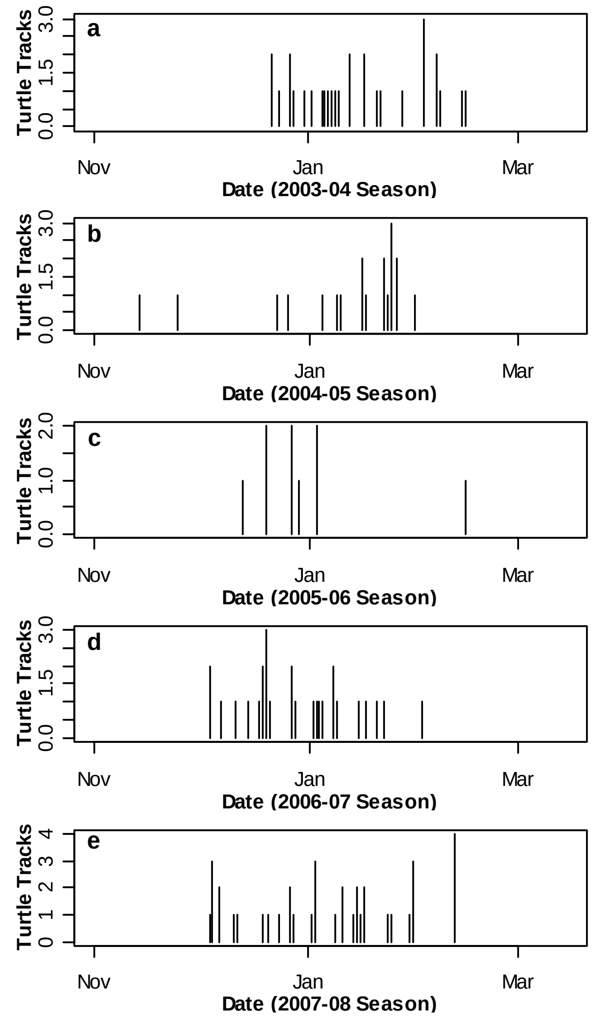

Figure 12. Nesting abundance for hawksbill turtles within the Coral Bay division. Sections included Batemans Bay and Lagoon.

Unidentified turtle nesting

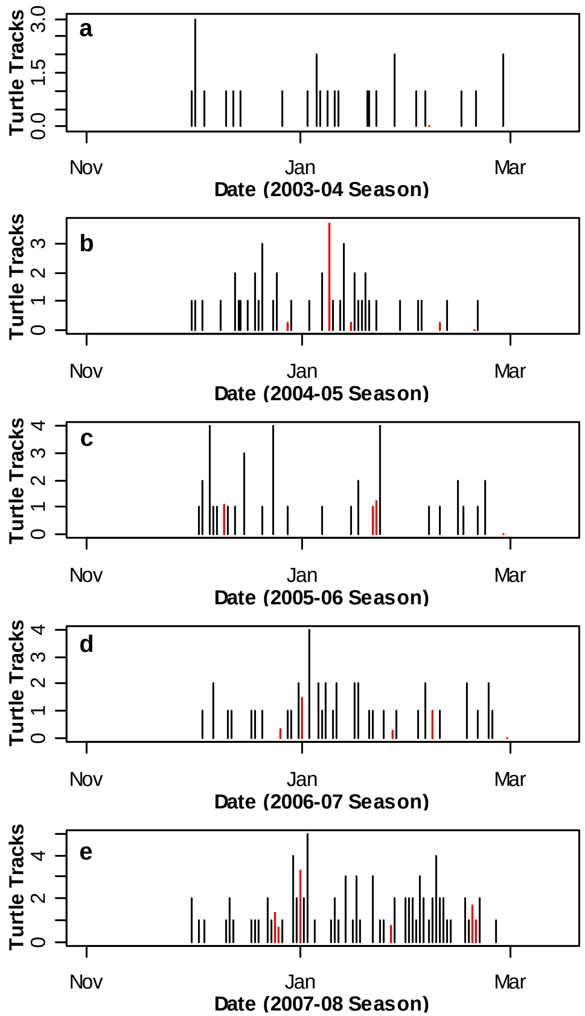

Figure 13. Nesting abundance for unidentified turtles within the North West Cape division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04. Data shown in red are interpolated as no data were available.

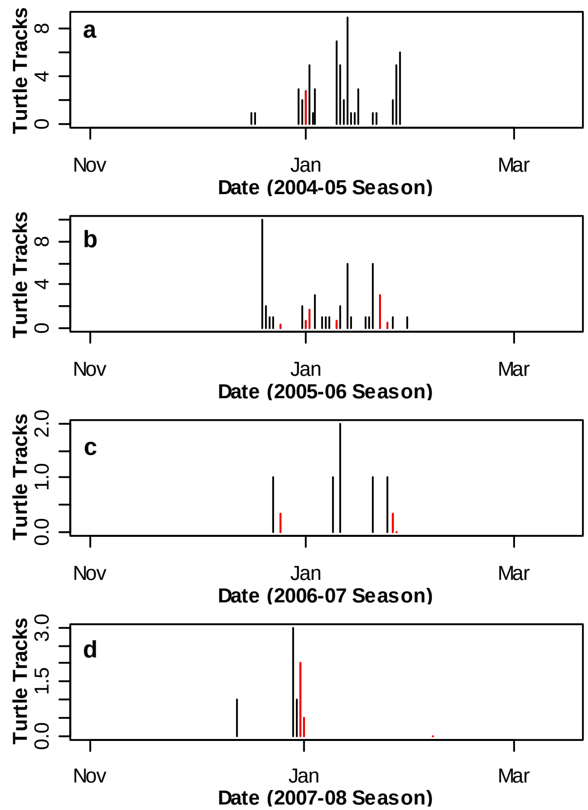

Figure 14. Nesting abundance for unidentified turtles within the Bundera/Ningaloo division. Sections included Boat Harbour, Bundelup and Carbaddaman for 2004-05; and Bungelup for 2005-06, 2006-07 and 2007-08. Data shown in red are interpolated as no data were available.

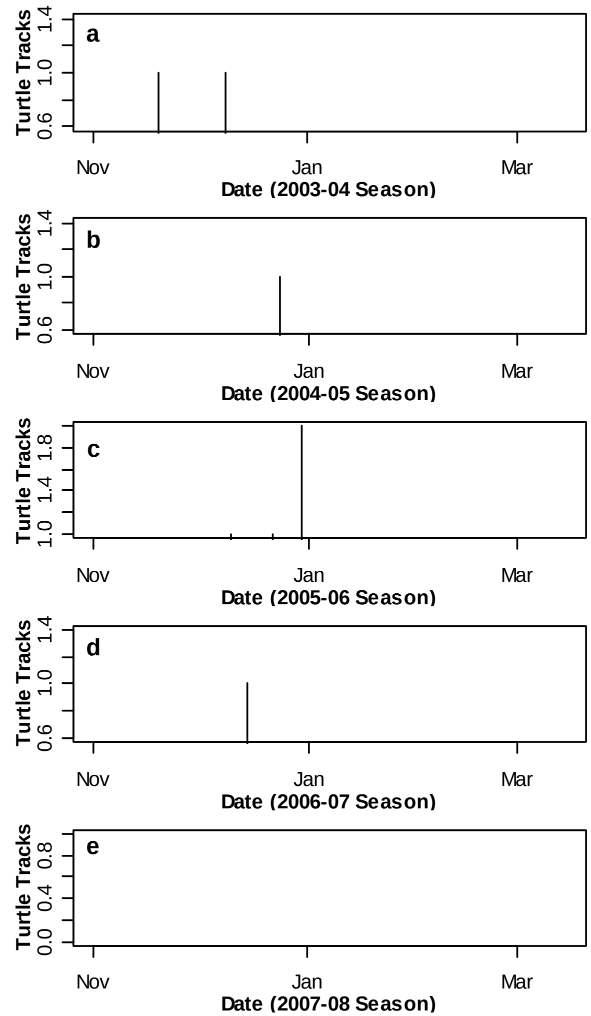

Figure 15. Nesting abundance for unidentified turtles within the Coral Bay division. Sections included Batemans Bay and Lagoon.

Spatial distribution of nesting

For the North West Cape and Bundera/Ningaloo Divisions, nesting by green turtles and hawksbill turtles predominantly occurred at the North West Cape Division (98.4% and 89.7% of nesting respectively; Figure 16 and Figure 17), and nesting by loggerhead turtles predominantly occurred at the Bundera/Ningaloo region (82.8% of nesting; Figure 18).

The relative abundance of nesting at Cape Range, Gnarraloo Bay / Quobba, Serrurier Island and Waroora Station divisions could not be predicted with much confidence as there were few days of monitoring at these locations (Table 1).

The relative abundance of nesting for green and loggerhead turtles within the Coral Bay Division was low. When compared to nesting at the North West Cape and Bundera/Ningaloo Divisions, nesting for green turtles at Coral Bay contributed to ~ 0.7% of total nesting (range of estimate= 0.2-1.4%); and nesting for loggerhead turtles at Coral Bay contributed to ~3.6% (range of estimate= 3-4.6%). Nesting for hawksbill turtles at Coral Bay contributed to ~12.9% of total nesting (estimated range= 9.6-18.4%).

There was little difference in the distribution between sections of nesting by unidentified species of turtles (Figure 19). This indicates that there would be little impact from unidentified turtles on the spatial distribution of nesting unless there is an unlikely site-specific bias in species for unidentified turtles.

Distribution of clutches laid for Green Turtles

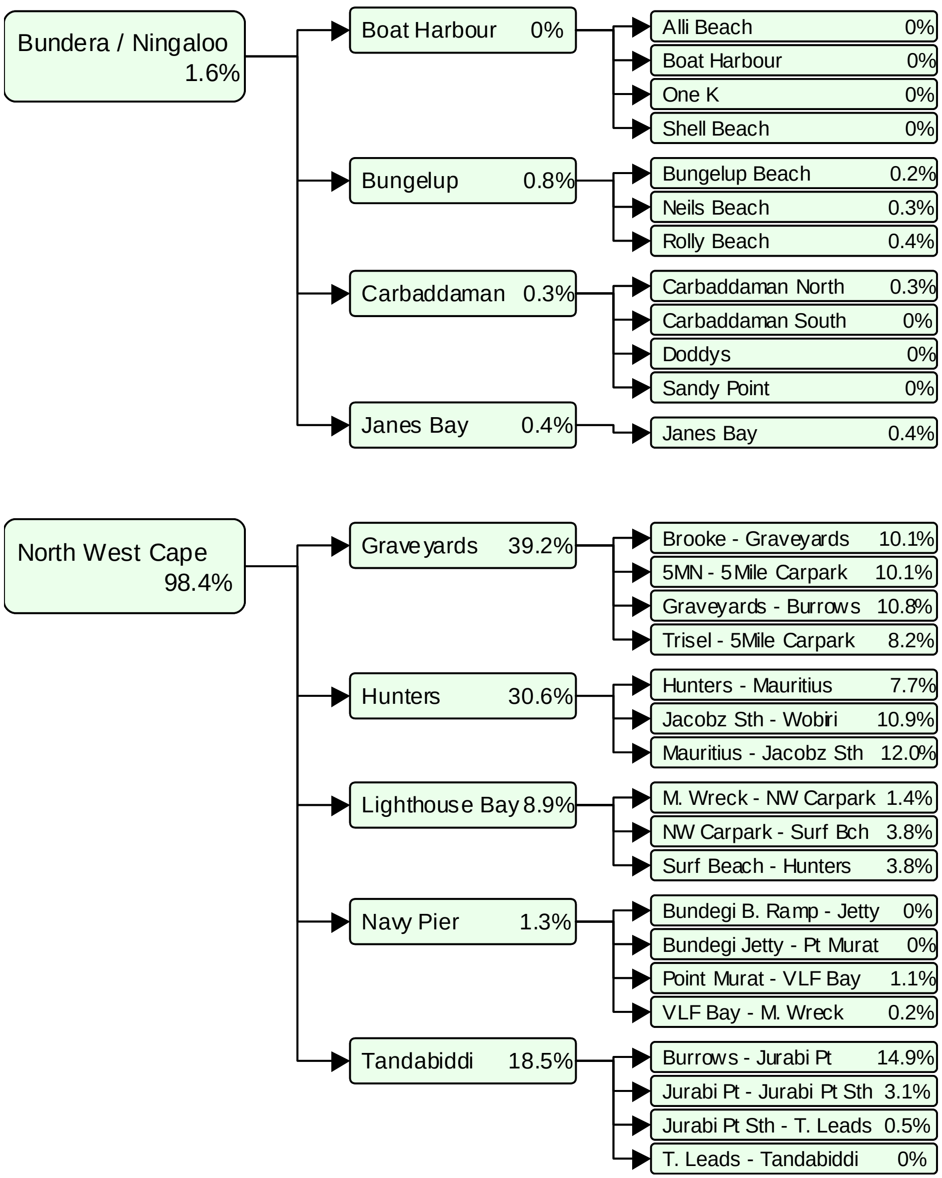

Figure 16. Relative distribution of clutches laid for Green Turtles, *Chelonia mydas*

Distribution of clutches laid for Hawksbill Turtles

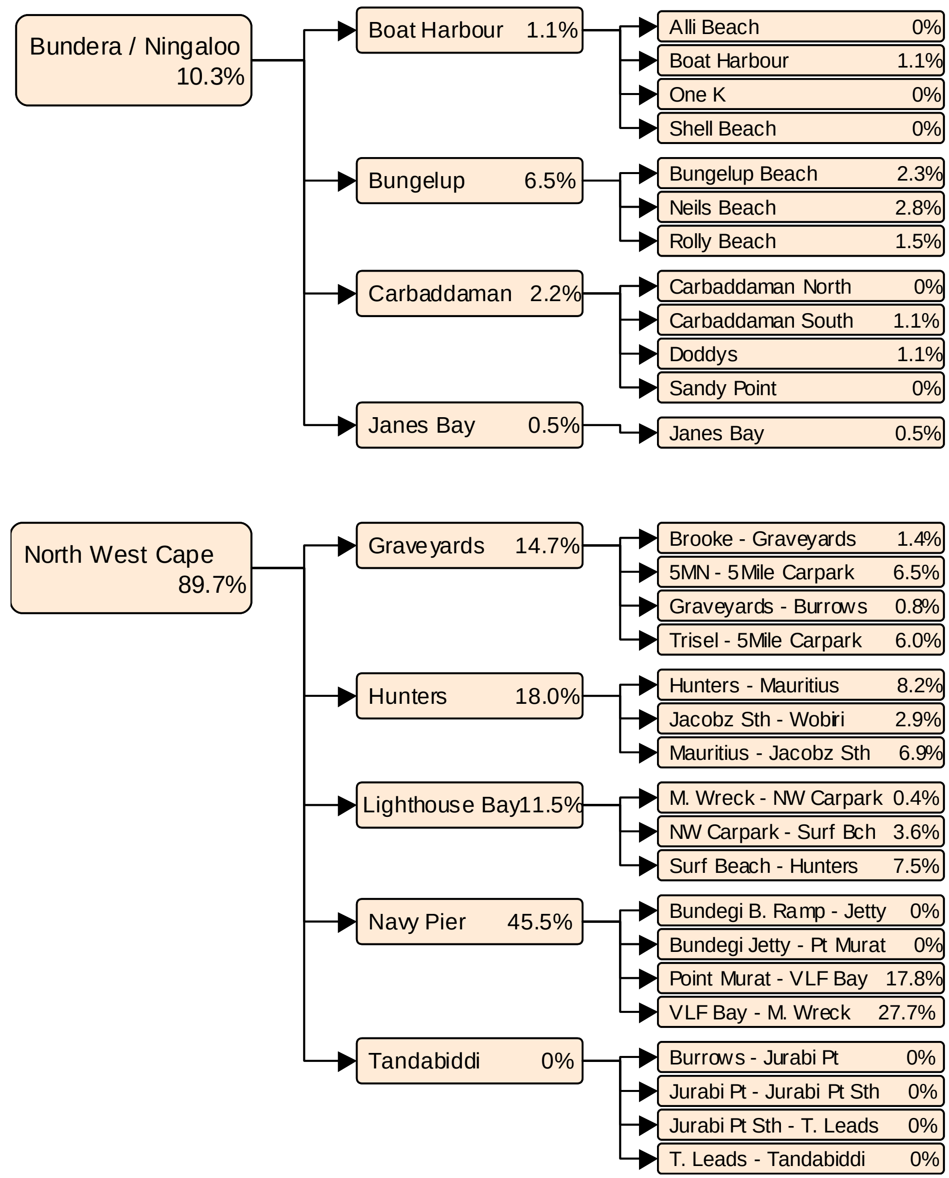

Figure 17. Relative distribution of clutches laid for Hawksbill Turtles, *Eretmochelys imbricata*

Distribution of clutches laid for Loggerhead Turtles

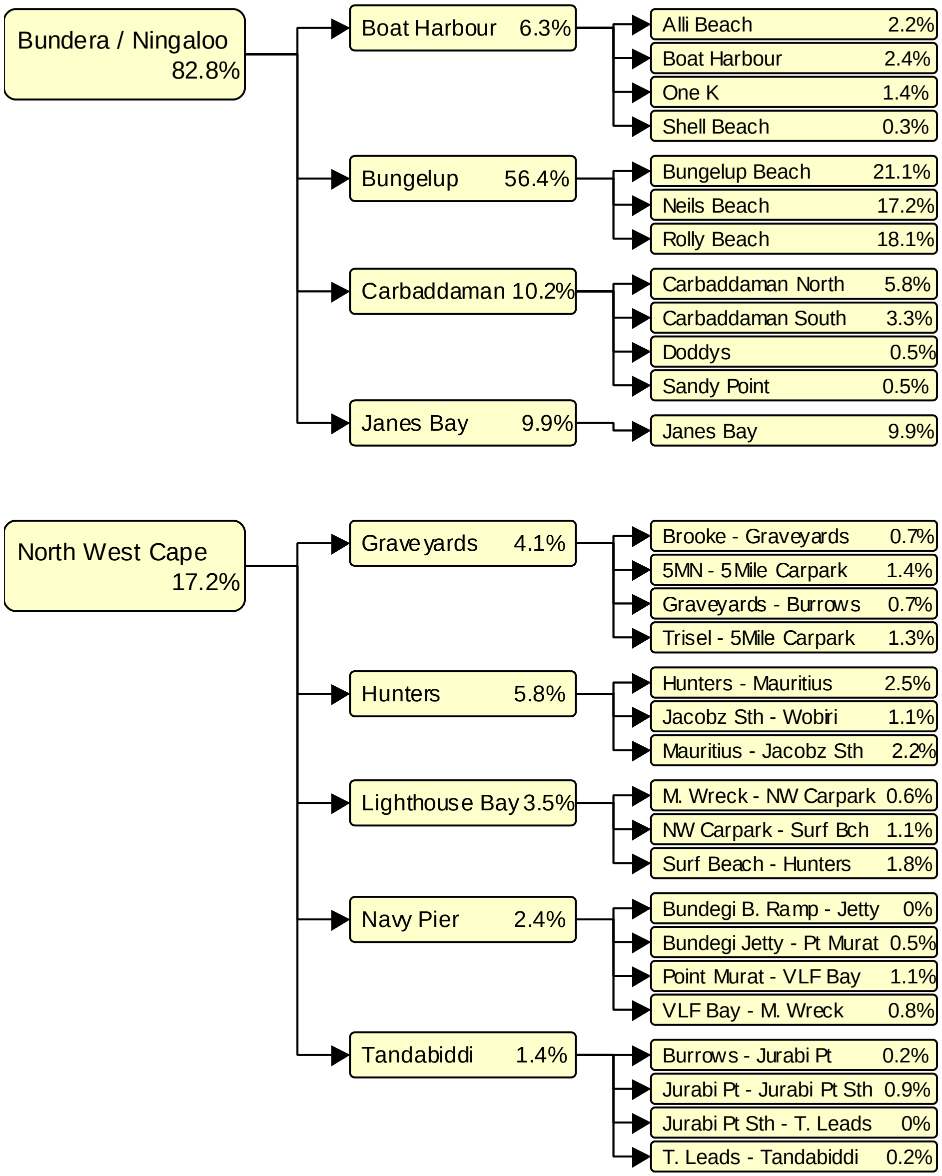

Figure 18. Relative distribution of clutches laid for Loggerhead Turtles, *Caretta caretta*

Distribution of clutches laid for Unidentified Turtle Species

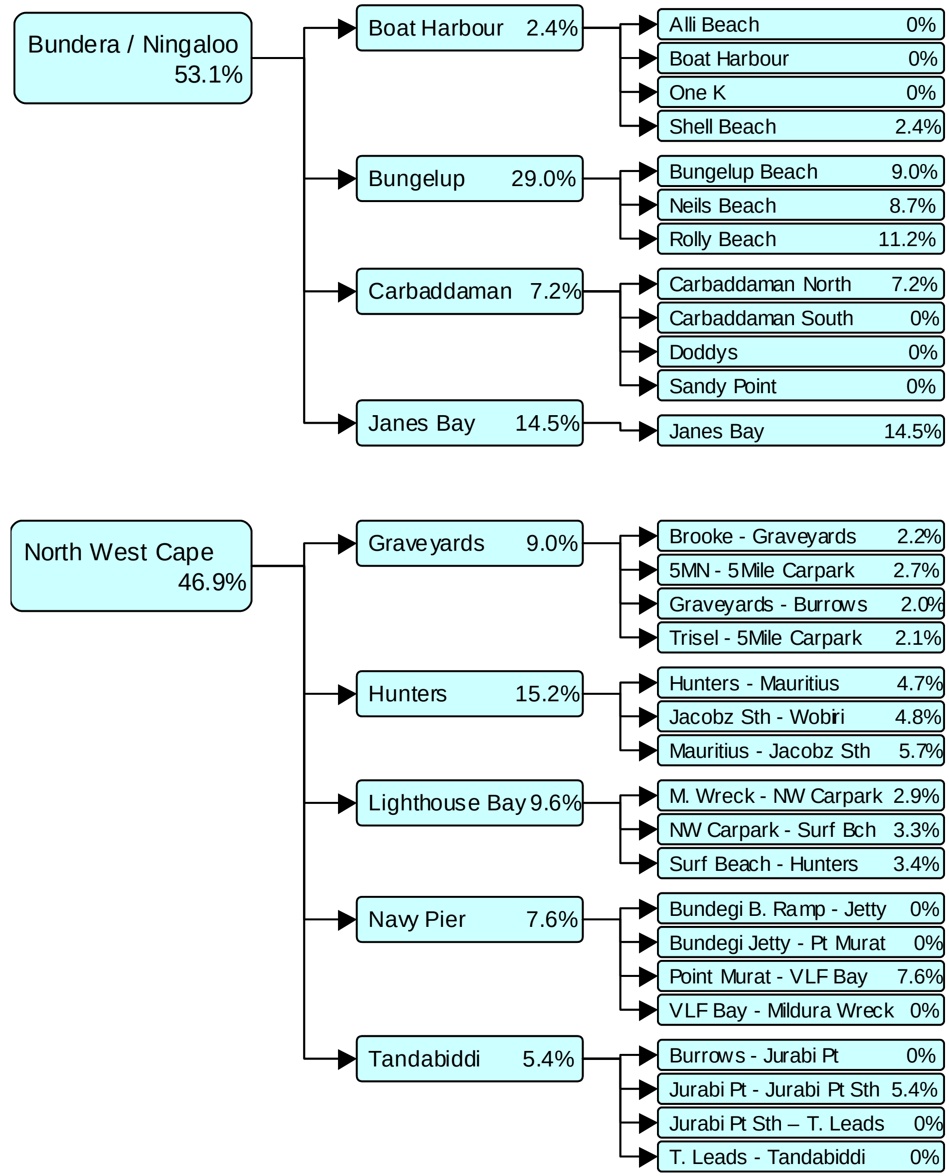

Figure 19. Relative distribution of clutches laid for Unidentified turtle species

Spatial synchrony in nesting

Determining spatial synchrony in nesting between sections required a substantial number of track counts at each beach. Spatial synchrony in nesting was stronger for green turtles than for hawksbill or loggerhead turtles (possibly due to higher nesting abundance; Table 3). Spatial synchrony between sections for green turtles was also stronger in larger nesting seasons, and required less grouping than smaller nesting seasons in the number of days to detect a significant correlation in nesting between sections.

There was considerably higher error in predicting daily or weekly nesting abundances, than for annual nesting abundances, so data from each year were pooled to predict annual abundances at other beaches (see Table 3).

There was less error in extrapolating from sections with a greater number of track counts to sections with less track counts than extrapolating the other way (Table 3).

Table 3. Error in predicting annual nesting abundance for green, loggerhead and hawksbill turtles from abundance at one section using linear regression. Sections were only included where 4 or more years of data were available.

		Error in abundance estimates		
Data available	**Data predicted**	**Green**	**Loggerhead**	**Hawkbsill**
By Section				
Graveyards	Hunters	16 ± 13	26 ± 17	28 ± 9
Hunters	Graveyards	25 ± 24	12 ± 13	31 ± 29
Graveyards	Lighthouse Bay	5 ± 4	17 ± 14	48 ± 13
Lighthouse Bay	Graveyards	73 ± 75	37 ± 58	18 ± 13
Hunters	Lighthouse Bay	2 ± 2	7 ± 6	20 ± 8
Lighthouse Bay	Hunters	22 ± 16	33 ± 41	41 ± 32
Boat Harbour	Bungelup	NA*	NA*	NA*
Bungelup	Boat Harbour	NA*	NA*	NA*
Boat Harbour	Carbaddaman	NA*	NA*	NA*
Carbaddaman	Boat Harbour	NA*	NA*	NA*
Bungelup	Carbaddaman	NA*	NA*	NA*
Carbaddaman	Bungelup	NA*	NA*	NA*
Batemans Bay	Lagoon	232 ± 228	13 ± 7	15 ± 2
Lagoon	Batemans Bay	36 ± 15	82 ± 40	40 ± 19

* Not applicable as data are unavailable to make predictions.

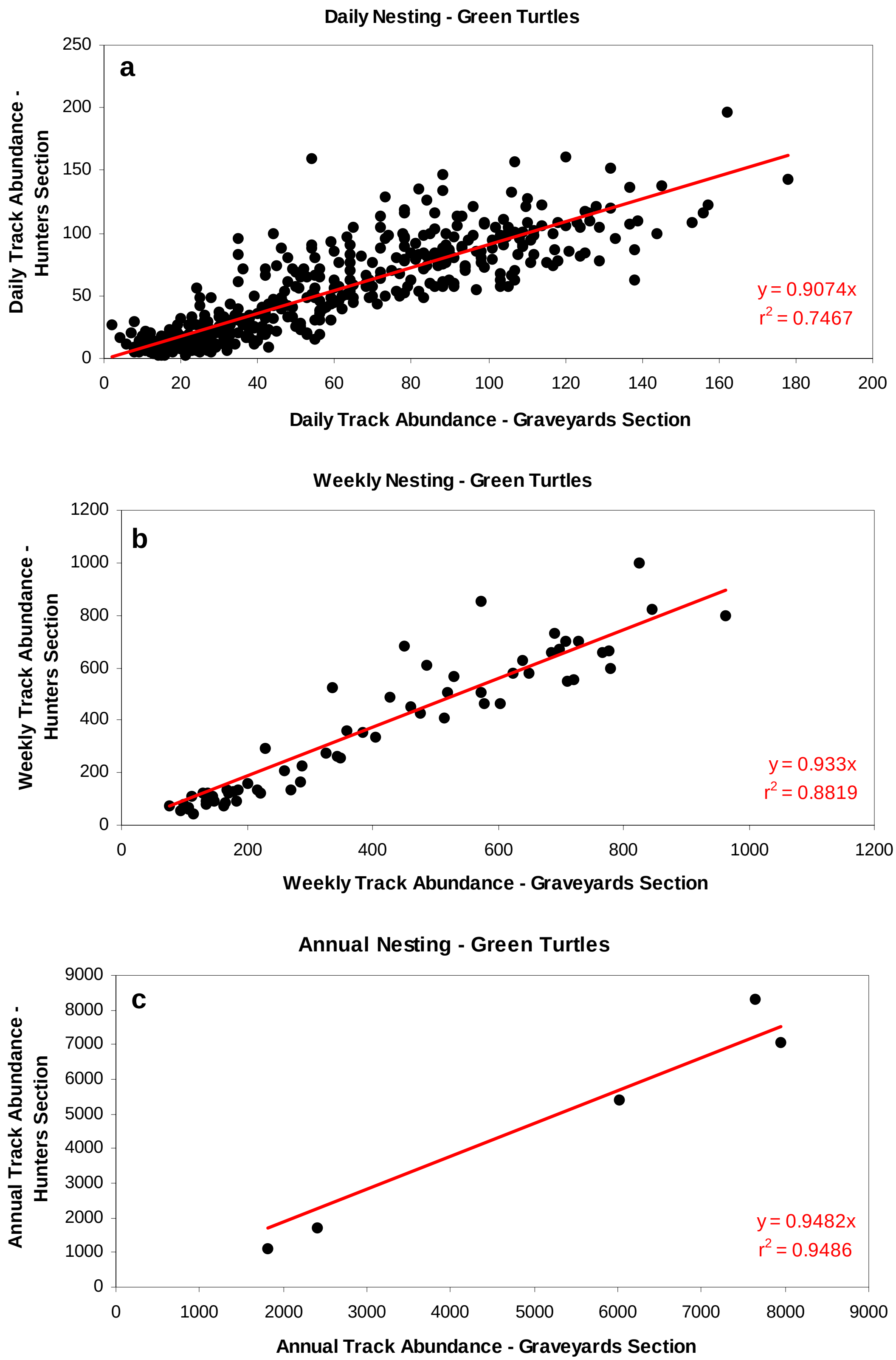

Figure 20. Example of linear regression fit between Graveyards and Hunters Sections for green turtle track abundance for a) daily data; b) weekly data and c) annual data. Note- the increasing goodness of fit corresponding with a higher r^2 as more days of data are grouped for the analyses.

Cross-correlation analysis found no consistent correlations in nesting by green turtles between sections of beach, when using 1, 2 or 3- day grouping (Eg., Figure 21). However, when 4 or more days of track counts for green turtles at each section were grouped, there were consistent significant correlations in nesting between beach sections (Figure 21). This correlation occurred at lag= 0, meaning that the track counts at section 1 for four days were correlated to the track counts at section 2 for the same four days.

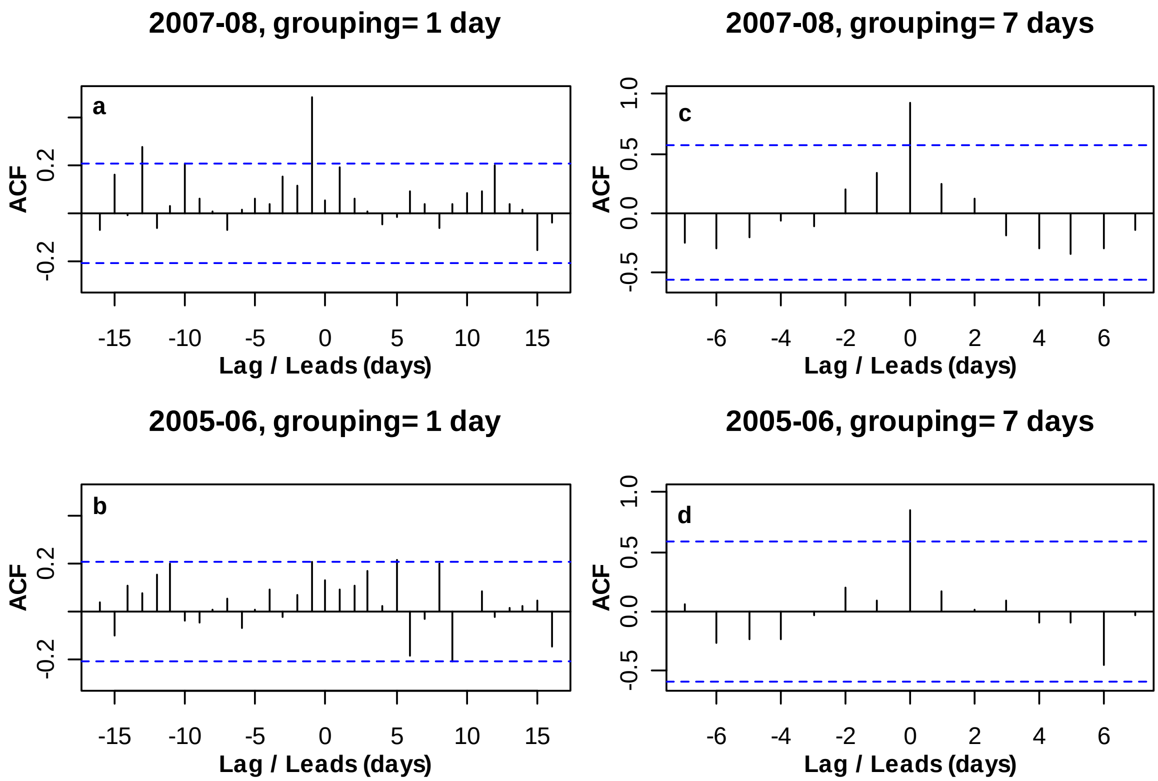

Figure 21. Cross-correlation analysis for green turtles at Graveyards and Hunters Sections for the 2007-08 and 2005-06 nesting seasons. Daily correlations shown in a) and b) show irregular significant differences between years with lags of –1 and 0; whereas when data were grouped by week (c and d), consistent correlations at lag=0 were seen.

Cross-correlation analysis for nesting between sections for both loggerhead and hawksbill turtles showed that greater grouping (7-14 days) was required to obtain significant correlations between sections.

Predicting annual track counts

Mid-season monitoring

Linear regression showed a strong correlation between counts of turtle tracks in the middle of the season and the annual counts of turtle tracks for both green and loggerhead turtles (Figure 24a,b). The correlation for hawksbill turtle tracks was weaker (Figure 24c), resulting from the relatively low abundance and less regular seasonal nesting patterns.

Survey error was minimized when monitoring was conducted during the peak of the nesting season. Although the peak of the nesting season appeared to vary slightly between species (Figure 22), surveys centred on 7 January minimized survey error across all species. If monitoring is conducted specific to only one species, surveys would minimize error when centred on 7 January for green turtles, 7 January for loggerhead turtles and 9 January for hawksbill turtles (Figure 22). When surveys were conducted either early or late in the nesting season, considerably fewer turtles were encountered (Figure 23) and considerably higher survey error was observed.

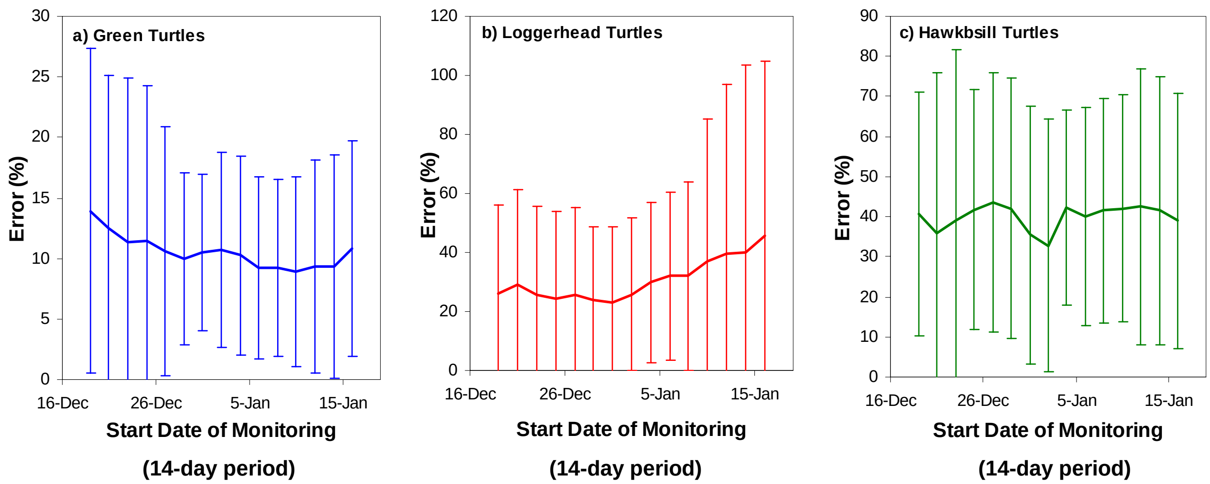

Figure 22. Error in extrapolating from two weeks monitoring mid-season to full-season counts using linear regression for a) green, b) loggerhead and c) hawksbill turtles during the middle of the nesting season. Lines refer to mean error, and bars refer to standard deviations. *Note: Counts before and after these times have higher error than shown within these graphs.*

Figure 25 shows the difference in the number of turtles encountered and the prediction of full-season track counts for two weeks of monitoring occurring early in the nesting season (red and blue) and at the peak (purple) of the nesting season. These linear regression models can be used to predict annual nesting when a partial season track count is conducted. For example, a track count from 1-14 December counting 1000 turtles correlates with annual nesting of ~8000 turtles, whereas a track count from 2-15 January of 1000 turtles correlates with an annual nesting population of ~ 4500 turtles.

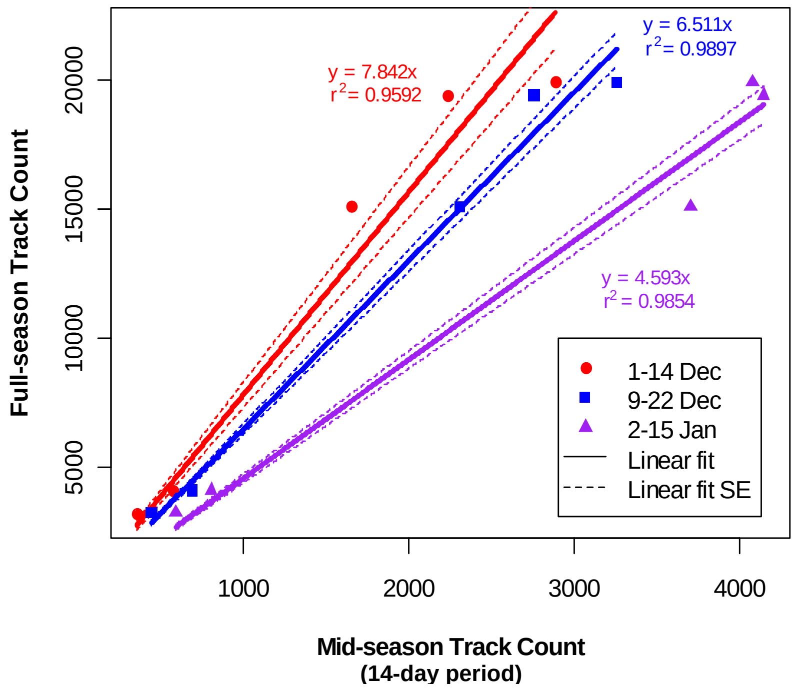

Figure 23. Linear regression between a two-week long mid-season track count and full-season track counts for green turtles. Data are from nesting from the North West Cape Division at Graveyards, Hunters, Lighthouse Bay and Tandabiddi sections for 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04.

The strong correlations between mid-season and full-season track counts (r^2 values shown in Figure 26), for most monitoring regimes show that linear regression models can provide close approximations of annual nesting when using a sampled survey regime. The error in abundance estimates can be predicted for annual nesting abundances from the goodness of fit for existing data, for mid-season track counts within the range of values seen between the 2003-04 and 2007-08 nesting seasons. The survey errors associated with values outside these bounds are unknown.

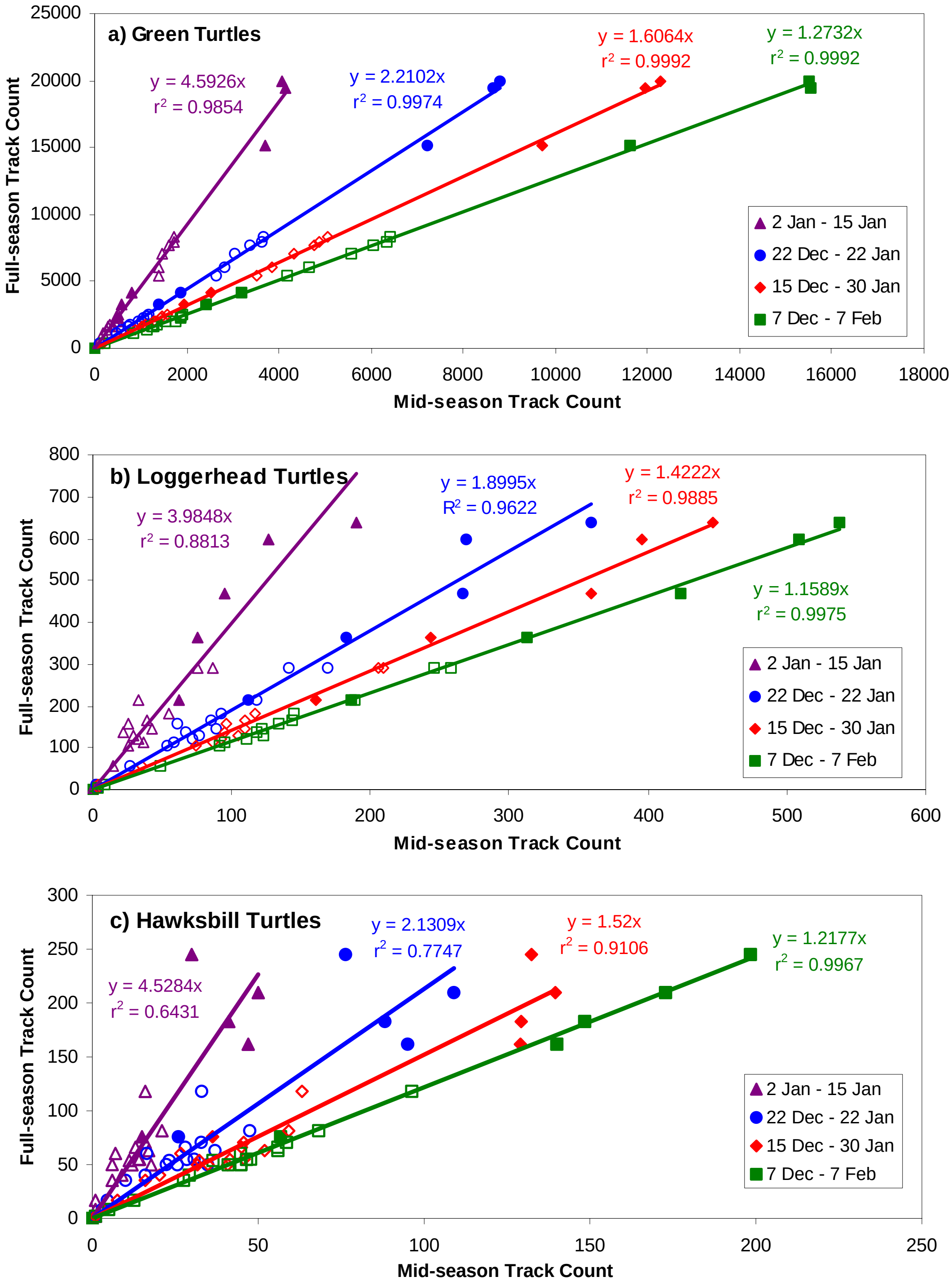

Figure 24. Linear regression between mid-season and full-season counts for a) green turtle tracks, b) loggerhead turtle tracks and c) hawksbill turtle tracks on the North West Cape Division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04. Solid shapes refer to correlation between all sections and the full-season track count, whereas open shapes refer to correlations between individual sections and that sections full-season track count. Data shown with open shapes were not included in the regression due to pseudoreplication.

Although the substantial amount of loggerhead nesting (82.8%; Figure 17) occurs at within the Bundera/Ningaloo division, and there are no full-season track counts for Bundera/Ningaloo, the similar linear relationship between Bundera/Ningaloo and North West Cape for correlations between mid-season counts and counts from 20 Dec – 2 Feb (Figure 25) indicate that extrapolating the relationship between mid-season and full-season nest counts to neighbouring beaches appears justified.

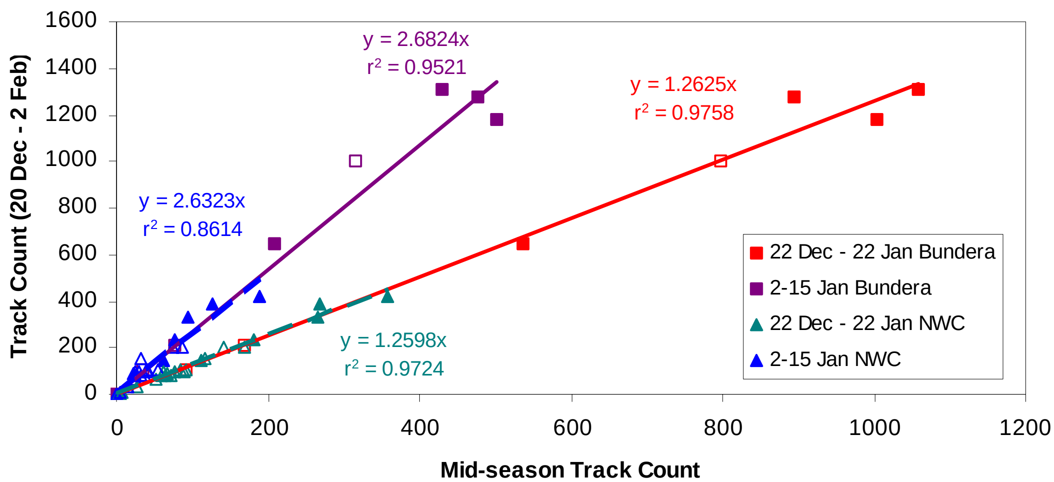

Figure 25. Linear regression between mid-season track counts and track counts from 20 Dec – 2 Feb for loggerhead turtles at Bundera/Ningaloo and the North West Cape (NWC).

Error in estimating annual nesting abundances was calculated for data from each section separately (grouped by section; Figure 26), and for data from several sections (grouped by division; Figure 26). When every section was monitored (grouped by division), and therefore a higher proportion of the annual tracks were counted, survey error was consistently lower than if monitoring only occurred at one section.

Survey error was most influenced by total survey effort (the total coverage in beaches and in time), and there was little difference in survey error if fewer beaches were monitored for more days, or more beaches were monitored for fewer days. For example, Figure 26 shows that survey error for 21 days of monitoring at all three sections was comparable to 63 days of monitoring at one section.

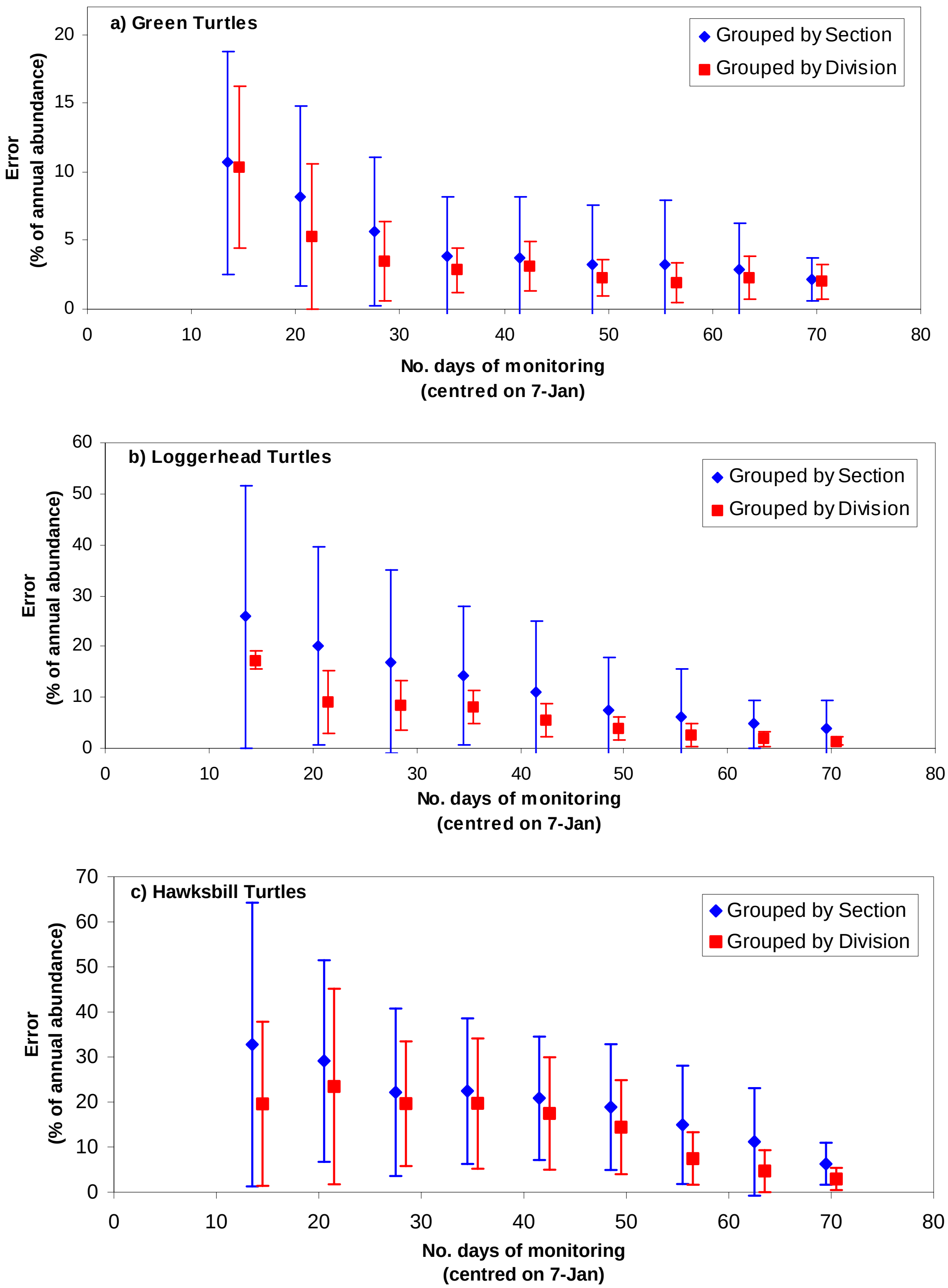

Figure 26. Mean error and error SD for estimating annual track counts for a) green turtles, b) loggerhead turtles and c) hawksbill turtles from partial season track counts conducted during the peak of the nesting season. Linear regression was used for extrapolation. using linear regression for extrapolation. Error is calculated from nesting from the North West Cape Division at Graveyards, Hunters, Lighthouse Bay and Tandabiddi sections for 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04. Data are shown for two week to ten weeks of monitoring and values are slightly offset for legibility.

<u>*Monitoring intermittently through the nesting season*</u>

Monitoring intermittently through the nesting season has the potential to increase the error in counting the number of tracks from the previous night if tracks are not marked the previous day, or significant tidal variation mean that tracks from the previous night are clearly discernable from other tracks. No account for measurement error has been made in these analyses and they assume that tracks counted are a true indication of nesting the previous night. If, however, tracks persist for the five days between monitoring, a count of the total weekly tracks could be used with similar precision in assessing annual abundance to the full-season monitoring.

When comparing error between monitoring intermittently through the nesting season and monitoring intensively mid-season, error in estimating annual track counts was consistently lower (with the exception of 14 days for hawksbill turtles) when monitoring was spread throughout the season than when monitoring was only conducted during the 'peak' of the nesting seasons (cf. Table 4 and Figure 26).

Table 4. Mean error and error SD for estimating annual track counts (grouped by division and sorted by mean error) for green turtles, loggerhead turtles and hawksbill turtles from partial season track counts conducted for <u>two days per week throughout the nesting season</u>. Linear regression was used for extrapolation. Error is calculated from nesting from the North West Cape Division at Graveyards, Hunters, Lighthouse Bay and Tandabiddi sections for 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04.

Species	Sample	N_{days}	N_{rep}	Regression equation	r^2	Mean error (%)	SD error (%)
Green	1 Dec – 28 Feb	26	5	y=3.4674x	0.9983	2.4	1.8
Green	1 Dec – 28 Feb	24	7	y=3.6379x	0.9964	2.9	1.9
Green	7 Dec – 7 Feb	18	6	y = 4.4552x	0.9948	3.7	3.3
Green	15 Dec – 30 Jan	12	7	y = 6.1524x	0.9933	4.6	3.9
Green	15 Dec – 30 Jan	14	4	y = 5.4546x	0.9941	4.7	3.9
Green	22 Dec – 22 Jan	10	3	y = 6.9581x	0.9946	6.3	7.5
Green	22 Dec – 22 Jan	8	7	y = 8.6703x	0.9846	6.5	5.6
Loggerhead	1 Dec – 28 Feb	26	5	y = 3.4241x	0.9447	6.9	4.8
Green	15 Dec – 15 Jan	10	3	y = 7.1374x	0.9909	7.2	6
Loggerhead	15 Dec – 30 Jan	14	4	y = 4.9558x	0.8951	7.8	7.3
Loggerhead	1 Dec – 28 Feb	24	7	y = 3.546x	0.9014	8.2	7.1
Loggerhead	7 Dec – 7 Feb	18	6	y = 3.9456x	0.905	8.6	6.7
Green	15 Dec – 15 Jan	8	7	y = 8.8138x	0.9883	8.6	10.1
Loggerhead	15 Dec – 15 Jan	10	3	y = 6.1752x	0.8703	9	7.3
Loggerhead	22 Dec – 22 Jan	10	3	y = 6.3069x	0.8239	10.8	9.7
Loggerhead	15 Dec – 30 Jan	12	7	y = 5.3071x	0.8342	11	7.7
Loggerhead	15 Dec – 15 Jan	8	7	y = 7.5392x	0.7711	11.6	9.8
Hawksbill	15 Dec – 15 Jan	10	3	y = 6.9046x	0.691	13	12.3
Hawksbill	1 Dec – 28 Feb	26	5	y = 3.5682x	0.8516	13.7	14.6
Hawksbill	1 Dec – 28 Feb	24	7	y = 3.6496x	0.8466	13.8	12.5

Table 4 cont.

Species	Sample	N_{days}	N_{rep}	Regression equation	r^2	Mean error (%)	SD error (%)
Hawksbill	7 Dec – 7 Feb	18	6	y = 4.3417x	0.8087	16	26.7
Loggerhead	22 Dec – 22 Jan	8	7	y = 7.1483x	0.6415	17.1	10.3
Hawksbill	22 Dec – 22 Jan	10	3	y = 7.2679x	0.4885	17.2	16.1
Hawksbill	15 Dec – 30 Jan	14	4	y = 5.2404x	0.6034	18.4	17.5
Hawksbill	15 Dec – 30 Jan	12	7	y = 5.9183x	0.3601	39.6	90.7
Hawksbill	22 Dec – 22 Jan	8	7	y = 8.2468x	0.0428	43.1	70.5
Hawksbill	15 Dec – 15 Jan	8	7	y = 8.9289x	0.1294	58.3	133.7

Model goodness of fits

Both generalized additive models and linear regression models gave good predictions of annual nesting abundance. There was no significant difference between the precisions of linear regression models (Figure 24) or generalized additive models (Figure 28) in estimating annual track count abundances (Eg. Figure 27; t= 2.35, P= 0.25), when monitoring was conducted either intensively mid-season or intermittently throughout the season.

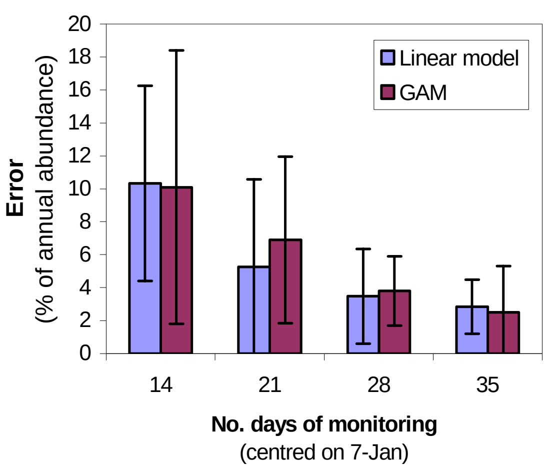

Figure 27. Difference between linear regression model and GAM in predicting annual track abundance for green turtles, for data grouped by division. Data used for analyses were from green turtles from 2003-04 to 2007-08 nesting at the North West Cape Division.

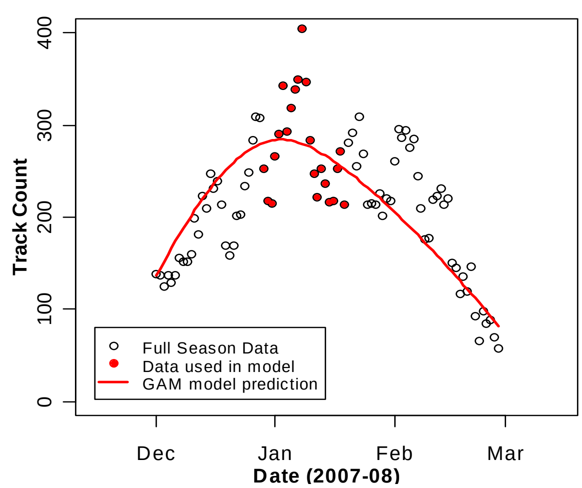

Figure 28. Example of a generalized additive model fit for green turtle track abundance at the North West Cape Division. Red line refers to model fit. Hollow circles refer to full-season track count data and red circles refer to partial season data used to predict nesting abundances.

Generalized additive models with a high degree of smoothing were favoured over generalized additive models with less smoothing when partial season track count data were analysed as the predicted shape of the nesting season was less influenced by outliers. Figure 29 shows the difference in predictions of nesting for generalized additive models with high and low levels of smoothing. The lower degree of smoothing is useful to show any cycles in the data. For example, Figure 29c shows an ~ 12 day periodicity in green turtle track counts for the 2007-08 nesting season. If monitoring was to occur at 12 day intervals, then estimates in annual track abundance could be substantially overestimated or underestimated depending on the start dates of monitoring (Figure 30).

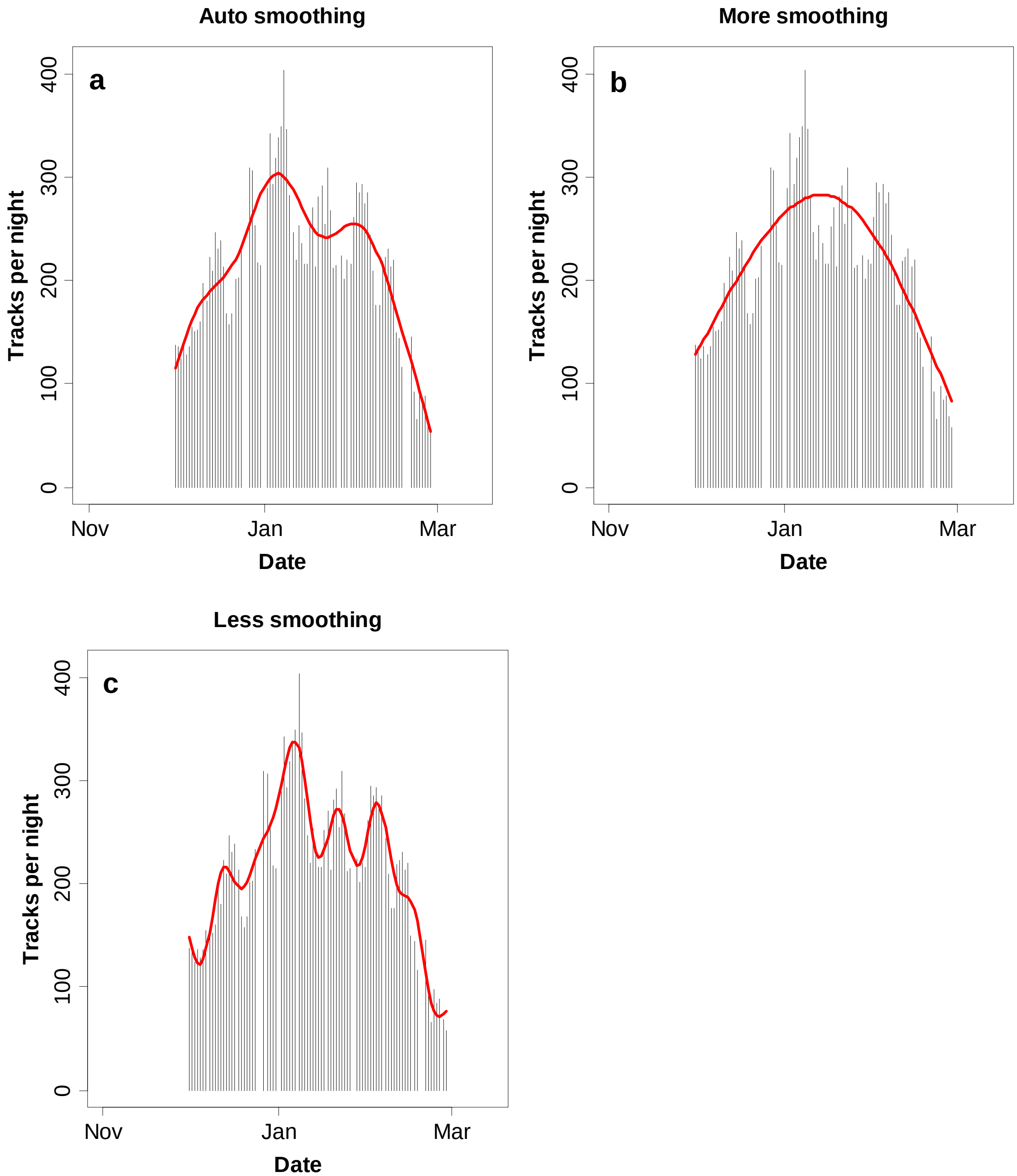

Figure 29. Difference in model fits using different degrees of freedom: a) degrees of freedom was not specified, degrees of freedom= 7; b) degrees of freedom= 4; c) degrees of freedom= 15 for green turtles nesting at North West Cape (Graveyards, Hunters, Lighthouse and Tandabiddi sections) during the 2007-08 season.

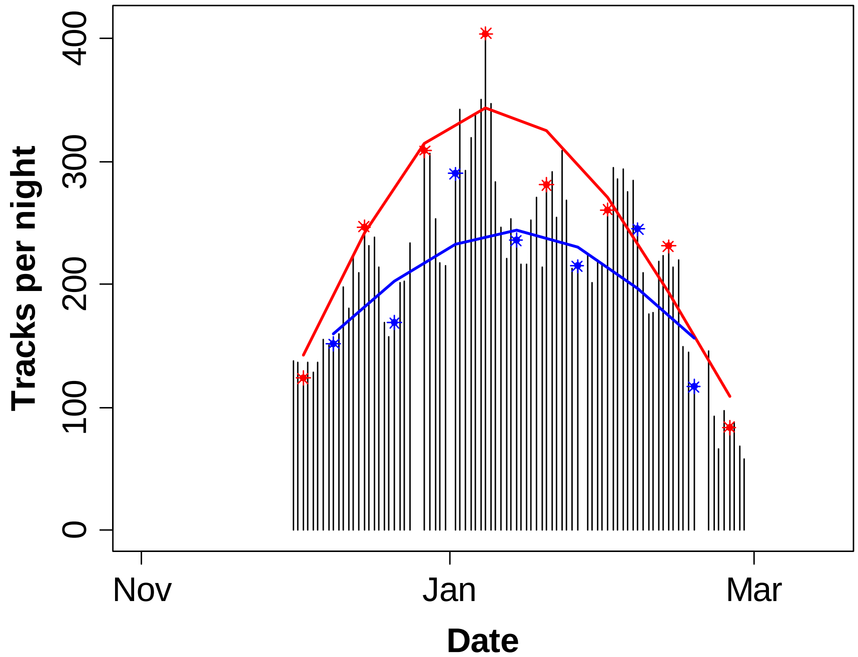

Figure 30. Example of difference in GAM for data collected on cyclic highs (red) and lows (blue). Data= green turtles nesting at North West Cape (Graveyards, Hunters, Lighthouse and Tandabiddi sections) during the 2007-08 season.

A reasonably regular periodicity in nesting was observed each year for green turtles (Figure 31). For green turtle nesting, the length of the period and the timing within the season of the period varied slightly between the years (Figure 31). This periodicity is unlikely to affect precision of nesting abundance estimates for monitoring regimes investigated in this report as the minimum number of survey days investigated for intensive mid-season surveys (14-days) cover a whole period of nesting; and the survey frequency for intermittent monitoring throughout the season (every 7 days) does not have the same frequency as the period lengths shown in Figure 31.

Periodicity in nesting abundance for loggerhead (Figure 32) and hawksbill turtles (Figure 33) was less apparent. Loggerhead turtles showed periodicity in nesting for only one season (2004-05 season), with period length of ~ 10 days (Figure 32). Hawksbill turtles showed periodicity in nesting for only one season (2005-06 season), with period length of 8-9 days (Figure 33). For loggerhead and hawksbill turtles, the observed periodicities are unlikely to affect precision of nesting abundance estimates for monitoring regimes investigated in this report, as the minimum number of survey days investigated for intensive mid-season surveys (14-days) cover a whole period of nesting; and the survey frequency for intermittent monitoring throughout the season (every 7 days) does not have the same frequency as the period lengths shown in Figures 32 and 33.

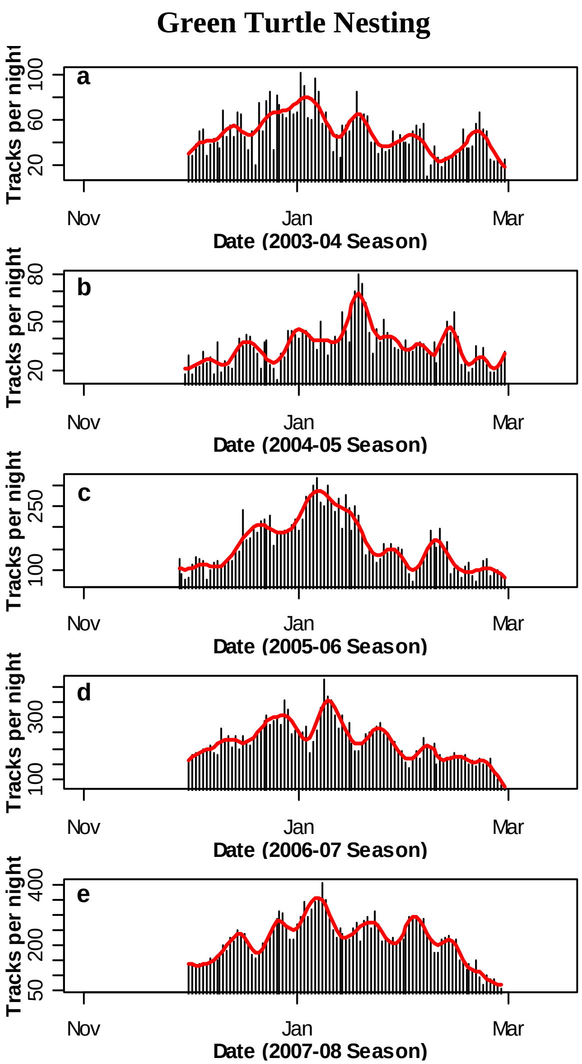

Figure 31. Nesting periodicity for green turtles within the North West Cape division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04.

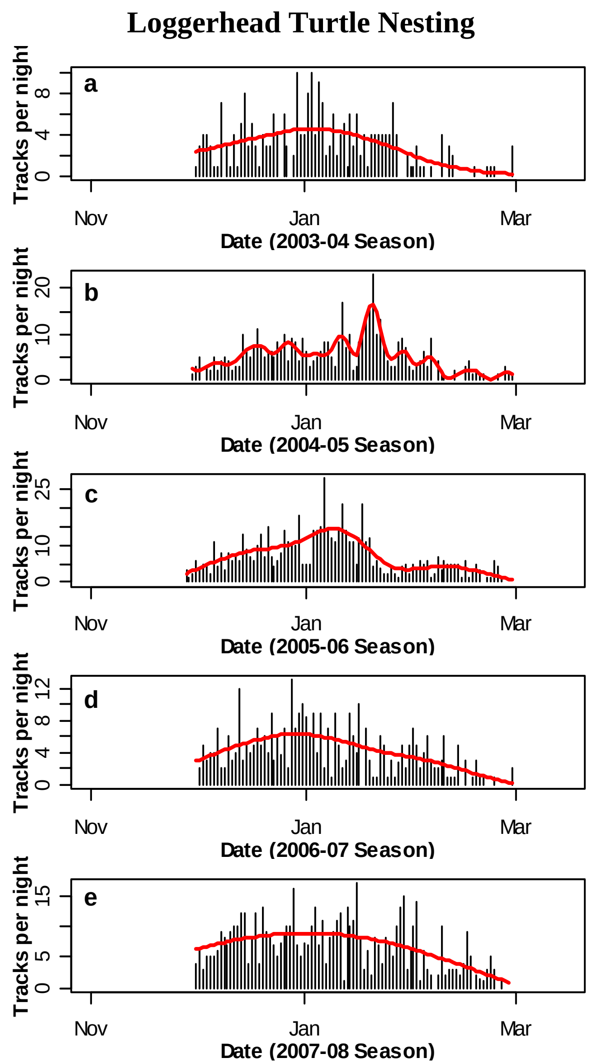

Figure 32. Nesting periodicity for loggerhead turtles within the North West Cape division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04.

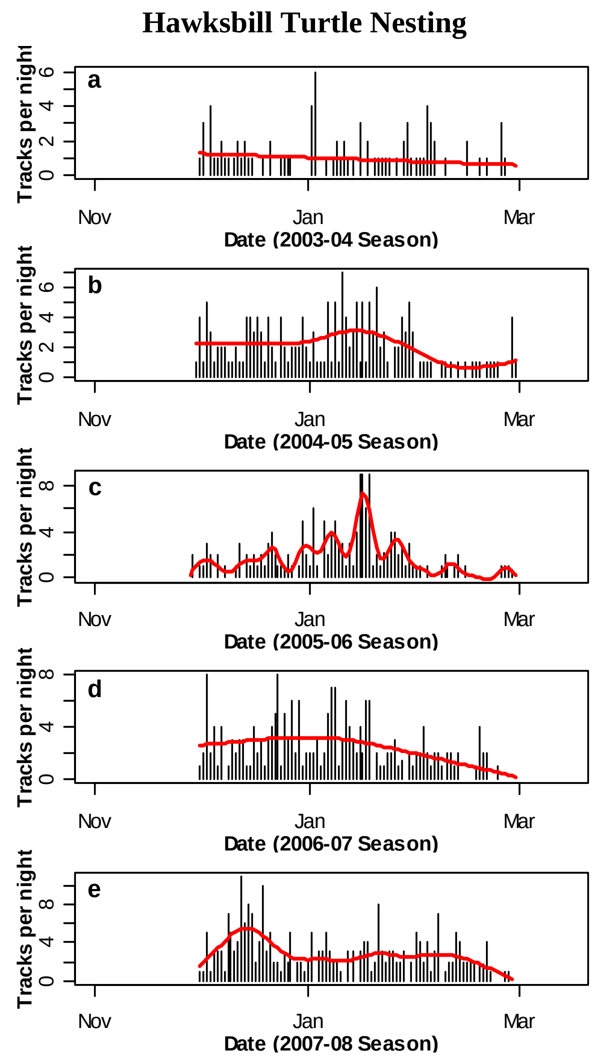

Figure 33. Nesting periodicity for hawksbill turtles within the North West Cape division. Sections included Graveyards, Hunters, Lighthouse Bay and Tandabiddi for the 2005-06, 2006-07 and 2007-08 nesting seasons; Graveyards, Hunters and Lighthouse Bay sections for 2004-05; and Graveyards and Hunters sections for 2003-04.

Nesting success

Assessing nesting success using tracks

Nesting success for turtles nesting at Ningaloo Region has only been determined previously by visual assessment of tracks (Table 5; Figure 34). This methodology has the potential to be biased and inaccurate if personnel are inexperienced; there is moderate or high density nesting; or nests are partially obscured by vegetation, sticks, rocks, animal tracks or sand flicked from turtles nesting nearby.

Nesting success recorded showed inter-annual variation, with patterns of variation consistent between the species (for years where green turtles had high nesting success, so did loggerhead and hawksbill turtles; Figure 34). Unfortunately, nesting success cannot be verified from any other data collected, as biases from visual assessment may have the same consistencies in variations.

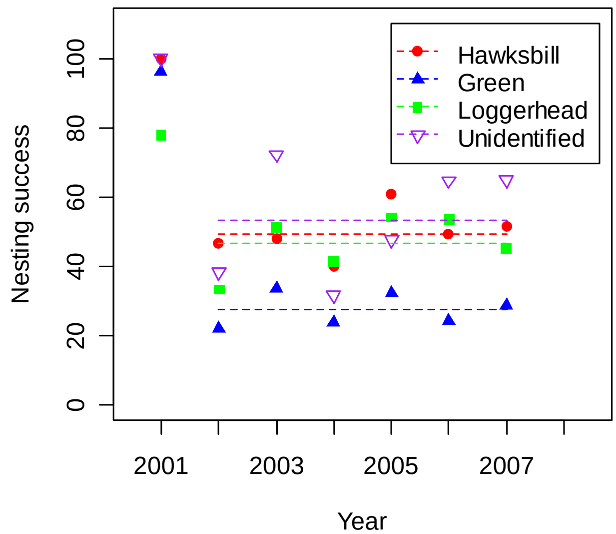

Figure 34. Nesting success for North West Cape and Bundera/Ningaloo Divisions. Dashed lines show mean values from 2002-2007. The 2001 year was not included when calculating the mean due to the disparity with the other data. This disparity may have been caused by survey error, as it was the first year of monitoring.

Table 5. Nesting success determined by visual assessment of tracks for green, loggerhead and Hawksbill Turtles.

Year	Green Turtle Nesting Success		Loggerhead Turtle Nesting Success		Hawksbill Turtle Nesting Success	
	Mean	SD	Mean	SD	Mean	SD
2003	34.8	19.6	55.5	40.0	51.2	47.5
2004	24.5	17.1	37.4	36.9	41.7	45.3
2005	31.9	14.0	52.5	36.5	64.0	43.9
2006	22.4	8.4	46.0	38.9	46.7	43.9
2007	27.0	11.3	41.2	36.0	53.9	42.4
Mean	28.1	14.1	46.5	37.6	51.5	44.6

For the recorded nesting successes, Location (as sections within North West Cape), Species, Ordinal Date and Year all had significant effects on nesting success (Table 6). This indicates that monitoring nesting success at several sites over several days would decrease bias, and therefore more accurately assess nesting success.

Accuracy in determining nesting success would also be increased by spreading assessments throughout the nesting season, or monitoring period (whichever is shortest). This is due to seasonal variations that may occur during the nesting season. An example of this type of variation in nesting success is shown in Figure 35 for the 2005-06 nesting season for green turtles, where nesting success is during February than during December of January.

Table 6. Generalized linear model showing influence of Species, Section, Year and Ordinal Date on recorded nesting success. Location data are for sections within the North West Cape.

Factor	df	ChiSquare	P>ChiSquare
Species	3	455.9	P<0.001
Section	2	396.0	P<0.001
Year	4	530.7	P<0.001
Ordinal Date	93	108.1	P<0.001

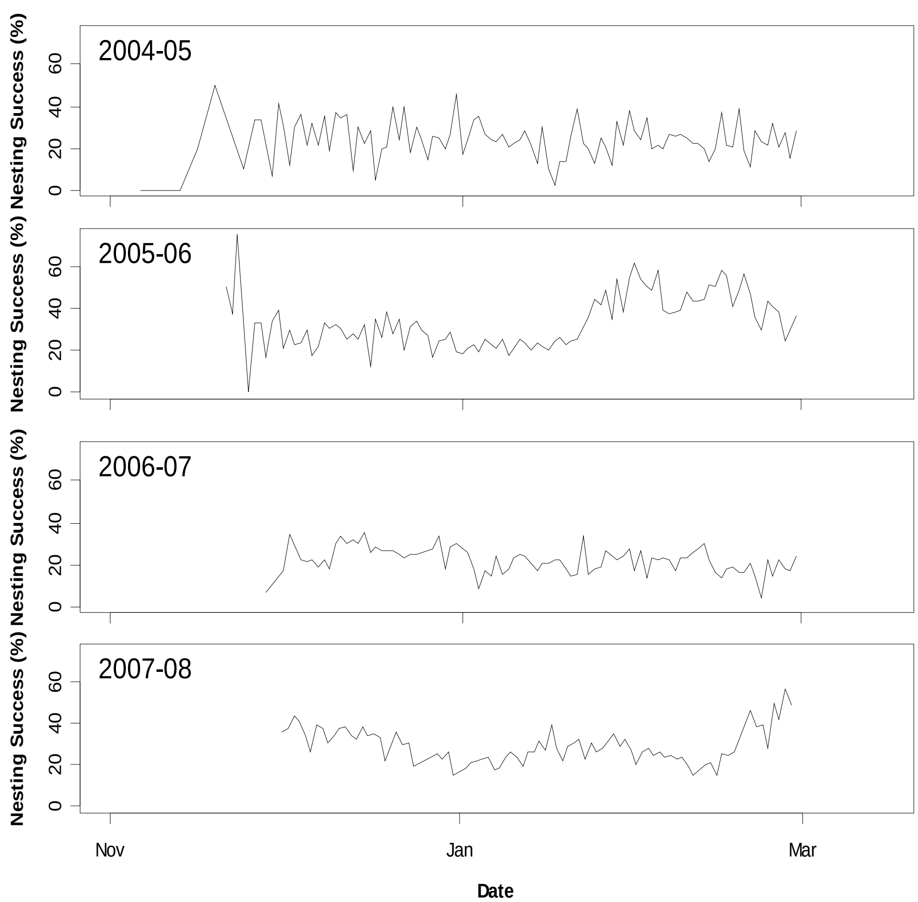

Figure 35. Nesting success for green turtles at the North West Cape Division (Graveyards, Hunters and Lighthouse Bay sections) showing within and between season variations in recorded nesting success.

Assessing nesting success by watching turtles

Simulation models were used to determine sampling regimes to assess nesting success by watching nesting turtles, instead of assessing nesting success from tracks. Alternatively, if nesting success is still obtained by visual assessment of tracks, these simulation models provide an indication of error in sampling nests for nesting success, which will reduce survey time as surveyors will not need to walk to the nest and assess nesting success for every turtle track.

Simulation models using random sampling throughout the season to sample from recorded nesting success data, gave an estimate of sampling error for the ranges of data recorded. Although the sampling error obtained from these simulations relate to nesting success recorded using visual observations of tracks, a similar sampling error is expected if the true nesting success data have approximately similar spread in the data.

Given that Species, Section, Ordinal Date and Year all had a significant affect on recorded nesting success (Table 6), sampling error was minimized when sampling occurred at each section for each species and each year. Our simulation models reflected this by determined from nesting success taken from each section for each species and each year for a random sample of days within the year.

Sampling error for nesting success

Determining nesting success for green turtles was optimized with regard to effort when > 20 turtles were recorded per section (Figure 36), with > 5 days of monitoring used per section (Figure 37), resulting in a mean of 6.1% and s.d. of 4.7% error in determining nesting success.

Figure 36 and Figure 37 show the error in calculating nesting success for the number of turtles per section, and the number of monitoring days per section when 60, 90 and 150 turtles are monitored. These graphs can be used in conjunction to obtain the best sampling regime for each sample size. For example, Figure 36 shows that sampling 20 turtles per section has a mean error of ~ 6% with range of mean ~5-7%. Figure 37a shows how many days this monitoring should be spread over to minimize sampling effort, showing that error was substantially reduced if monitoring was spread over at least 5 days.

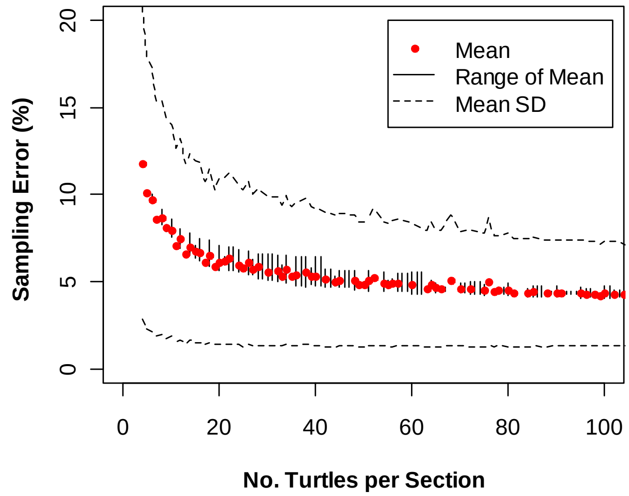

Figure 36. Error in calculating nesting success for green turtles at the North West Cape Division (Graveyards, Hunters and Lighthouse Bay sections) during the 2004-season with effort spread equally among the beaches, and spread randomly throughout the season.

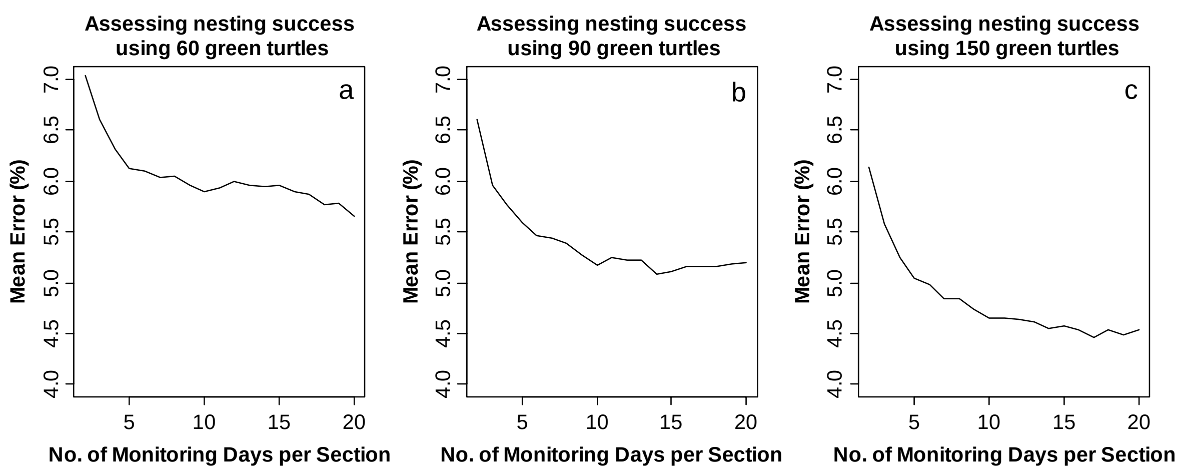

Figure 37. Mean sampling error in calculating nesting success for green turtles during the 2004-05 season showing error associated with spread in monitoring over 2-20 days for total sample sizes of a) 60 turtles, b) 90 turtles and c) 150 turtles. Error in nesting success was simulated from 10,000 samples of data for green turtles nesting at Graveyards, Hunters and Lighthouse Bay with effort spread equally among the beaches, and spread randomly throughout the season.

Trend detection

The ability to detect trends in the nesting turtle data depends on the coefficient of variation and the number of years of study. The coefficient of variation is a measure of the spread of the data and is calculated as:

$$CV = \frac{SD}{Mean}$$

The coefficient of variation was estimated for the five years of data for nesting at North West Cape, with the assumption that all variation is due to natural variation in nesting abundance rather than from trends in the data. The coefficient of variation for green turtles (CV= 0.56) was higher than for loggerhead (CV= 0.29) or hawksbill (CV= 0.30) turtles (Figure 38), indicating that a fewer years would be needed for studies of loggerhead and hawksbill turtles than for green turtles to detect similar trends in the population with the same confidence and power.

The variation between years in nesting abundance for turtles nesting at Ningaloo may not have captured the full spread in nesting variation due to the relatively low number of years of sampling (N= 5).

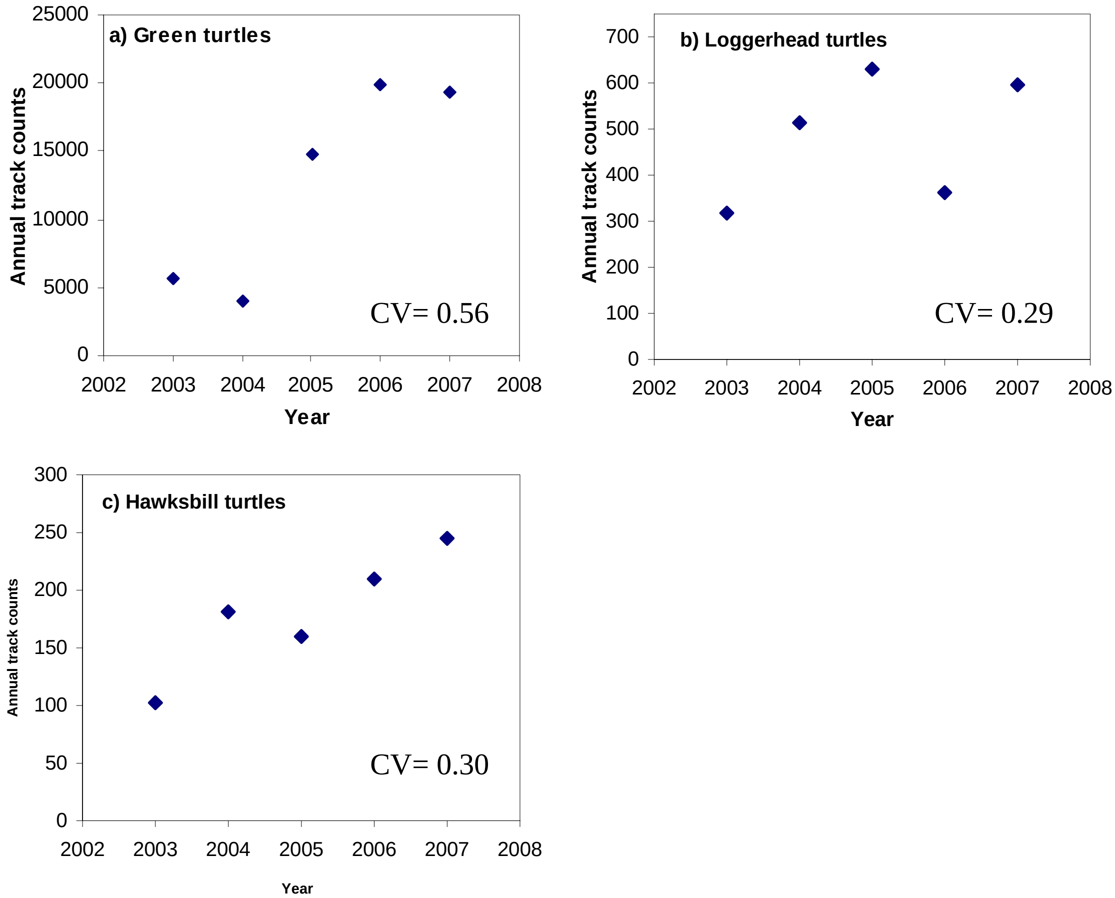

Figure 38. Annual track count abundance for a) green, b) loggerhead and c) hawksbill turtles nesting at the North West Cape Division. Data are for Graveyard, Hunters, Tandabiddi and Lighthouse Bay sections and are calculated using data interpolation when data were missing. CV refers to the coefficient of variation. CV refers to the coefficient of variation and assumes no trend in the data.

The calculated coefficient of variation above may be biased given the relatively low number of years for full-season track counts, as the full spread in annual nesting abundances may not have been detected. An indication of precision in calculating the coefficient of variation can be seen by changes to the coefficient of variation as successive years of data are added. For green turtles, the coefficients of variations for successive years of data were 0.32 (2 years); 0.59 (3 years); 0.61 (4 years) and 0.53 (5 years), indicating there was little change in the coefficient of variation when calculating from 3 to 5 years of data.

The coefficient of variation for green turtles at Ningaloo was within the lower range of coefficients of variation for green turtle nesting abundance. A study of 16 populations of green turtles with at least 5 years of counts per study found a mean coefficient of variation of 0.91 (range= 0.25 – 1.8; Broderick *et al.* 2001). The coefficient of variation for loggerhead turtles at Ningaloo was similar to the mean coefficient of variation for ten populations of loggerheads (mean= 0.28, range= 0.1 – 0.45; Broderick *et al.* 2001). The coefficient of variation for hawksbill turtles at Ningaloo was within the lower range of coefficients of variation for ten populations of hawksbill turtle nesting abundance (mean= 0.45, range= 0.2 – 0.9; Broderick *et al.* 2001).

Using the coefficient of variation for each species, significance levels of 0.05 and 0.1, power of 0.8 and 0.9, Table 7 shows the estimated the number of years of study required to detect annual population declines of 3-30%. It is important to note that Table 7 shows the amount of decline per year, which equates to a much larger decline in the total population over several years of monitoring (Eg. 3% per year decline for 20 years equates to 45% overall decline over 20 years).

Table 7. The number of years required to detect a linear population decline, with given power and significance. P= Power; α= Significance level.

Annual population decline	Number of years required to detect change								
	Green (CV= 0.56)			Loggerhead (CV= 0.29)			Hawkbsill (CV= 0.30)		
	P=0.9, α = 0.05	P=0.8, α = 0.05	P=0.8, α = 0.1	P=0.9, α = 0.05	P=0.8, α = 0.05	P=0.8, α = 0.1	P=0.9, α = 0.05	P=0.8, α = 0.05	P=0.8, α = 0.1
1%	>50	>50	51	42	38	34	43	39	35
2%	38	35	32	26	24	22	27	24	22
3%	29	26	24	20	18	17	20	19	17
5%	20	19	17	14	13	12	15	13	12
10%	13	12	11	9	9	8	9	9	8
15%	10	9	8	7	7	6	7	7	6
20%	9	8	7	6	6	5	6	6	5
25%	8	7	6	6	5	5	6	5	5
30%	7	6	6	5	5	4	5	5	4

As the coefficient of variation increased (eg. green turtles compared with loggerhead turtles), either the number of years required to detect a change in the population, or the rate of detectable change in the population increased (assuming power and significance levels are kept constant). The magnitude of these changes are shown in Figure 39 for coefficients of variation from 0.1 – 2.2.

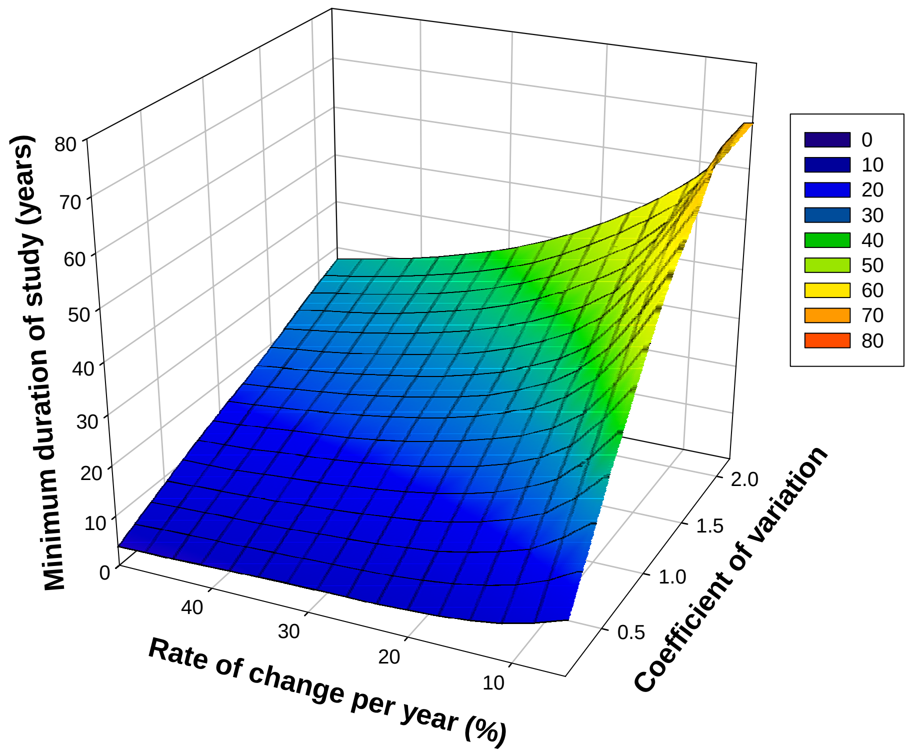

Figure 39. Influence of different coefficient of variations on the minimum duration of study and rate of detectable change per year for power of 0.9 and confidence level of 0.05. Data were calculated using TRENDS software, Gerrodette 1993).

Any error in calculating annual nesting abundance may increase the coefficient of variation, and therefore result in either:-

- an increase in the amount of years required to detect a trend; or
- an increase in the minimum detectable rate of change in the population; or
- a decrease in significance level; or
- a decrease in power.

When error is calculated as a percentage, error has the same effect on the above variables for all coefficients of variation. For example, Figure 40 shows the impact of 5-100% error in annual nesting abundances on the coefficient of variation for coefficients of variations starting at 0.56 and 0.91.

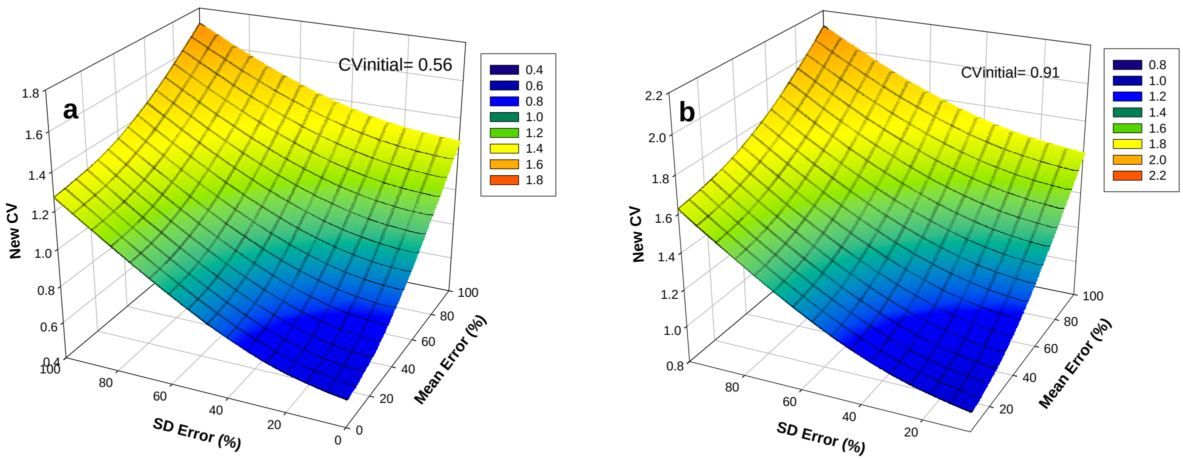

Figure 40. Influence of the mean and standard deviation of the error in annual abundance estimates on the coefficient of variation (CV) for initial CVs of a) 0.56 and b) 0.91. Note: the similar effect on both CVs for the same error.

To put into context the impact of sampling error on population function estimates, Table 8 shows the impact of sampling error on the number of years required to detect a given population trend for green, loggerhead and hawksbill turtles. Table 8 shows that a relatively high error (50% error in population estimates) will still have a relatively low impact on the ability to detect population trends, by increasing the number of years required to detect a decline in the population by only 3 years. This is equivalent to an increase by 15% in the total number of years required to detect population change if there was no error in the population.

Table 8. Changes in the duration of study to detect trends in the population for sampling errors of 3-140%.

Error Mean ± SD (%)	Green turtles: Change in duration (%)	Green turtles: Change in duration (No. Years)	Loggerhead turtles: Change in duration (%)	Loggerhead turtles: Change in duration (No. Years)	Hawksbill turtles: Change in duration (%)	Hawksbill turtles: Change in duration (No. Years)
3	0	0	0	0	0	0
5	0	0	0	0	0	0
10	0	0	0	0	0	0
15	0	0	0	0	0	0
20	1	0	4	~ 1 year	4	~ 1 year
25	4	~1 year	7	~ 2 years	8	~ 2 years
30	5	~2 years	11	~ 2 years	11	~ 2 years
35	7	~2 years	16	~3 years	14	~ 3 years
40	11	~2 years	19	~ 4 years	18	~ 4 years
45	13	~3 years	24	~ 5 years	22	~ 5 years
50	15	~3 years	26	~ 5 years	27	~ 5 years
60	21	~ 4 years	36	~ 6 years	34	~ 6 years
70	28	~ 5 years	42	~ 7 years	40	~ 7 years

Table 8 cont.

Error Mean ± SD (%)	Green turtles Change in duration (%)	 Change in duration (No. Years)	Loggerhead turtles Change in duration (%)	 Change in duration (No. Years)	Hawksbill turtles Change in duration (%)	 Change in duration (No. Years)
80	33	~ 6 years	53	~ 9 years	52	~ 9 years
90	39	~ 7 years	64	~ 13 years	60	~ 12 years
100	46	~ 8 years	72	~ 15 years	70	~ 14 years
120	52	~ 9 years	85	~ 16 years	81	~ 15 years
140	62	~ 12 years	98	~ 16 years	95	~ 16 years

DISCUSSION

This report provided a statistically robust and cost efficient survey design to detect trends in the population and estimate annual nesting population size. Recommended designs will considerably reduce the amount of survey days required, and still obtain relatively accurate data.

Temporal distribution of nesting

Sampling error is minimized when the largest proportions of data were consistently collected, so temporal distribution of nesting aimed to maximize the number of tracks encountered, with a sampling regime that obtains similar proportions of the nesting population between years.

There was some variation between years in the seasonal distribution of nesting, shown by generalized additive models in Figures 31-33. Although this seasonal variation was accounted for in the modeling scenarios, combining a mid-season track count with an intermittent survey throughout the year would be beneficial to detect any seasonal changes in nesting.

The distribution of tracks where the turtle species was unidentified is unlikely to have a large impact on the temporal distribution of nesting for green, loggerhead or hawksbill turtles as there were relatively few missed tracks and they had a similar temporal distribution to nesting seasonality. However, in the unusual scenario that track identification was heavily biased by species, and for example all unidentified tracks corresponded to nesting activities by hawksbill turtles, these nesting activities could cause a 28% increase in the true population of nesting hawksbill turtles. The higher nesting abundance of green and loggerhead turtles means that the maximum impact for these species is much lower – 0.4% for green turtles and 11% for loggerhead turtles.

Analyses of temporal distribution of turtle nesting were limited to 2003-04 to 2007-08 years for nesting at the North West Cape, as data spanned the longest timeframe and there were few days were no census was conducted and data were unavailable. Extrapolating from these data to other areas was favoured rather than conducted analyses on fewer data, as seasonality and the ability to estimate population size from partial samples did not appear to differ between nesting Divisions (eg. North West Cape and Bundera/Ningaloo divisions, Figure 25).

Spatial distribution of nesting

The spatial distribution of nesting amongst sections and sub-sections within the North West Cape, Bundera/Ningaloo and Coral Bay Divisions, indicates areas of relative importance for monitoring.

Monitoring of green turtles would preferably cover ~ 95 % of nesting by occurring at all sections within Graveyards, Hunters, and Lighthouse Bay Sections, and within Burrow-Jurabi Point and Jurabi Point-Jurabi Point South sub-sections within the Tandabiddi section.

Monitoring of loggerhead turtles would preferably occur in the Bungelup, Carbaddaman and Boat Harbour sections, which covers ~ 70 % of loggerhead nesting, with an additional ~14 % from monitoring the above sections in the North West Cape. Note- although ~ 10 % of nesting occurs on Janes Bay, the track density was lower than for other species due to the long section length (12.8 km).

Monitoring of hawksbill turtles would preferably occur in the Navy Pier, Graveyards, Hunters and Lighthouse Bay sections, which covers ~ 90 % of hawksbill nesting.

Spatial synchrony in nesting

There was significant spatial synchrony in nesting between beaches, indicating that nesting on adjacent beaches could be predicted with an associated error.

Detecting changes in spatial abundance of nesting is important to provide a reference point for the monitored nesting turtle population. This would require periodically monitoring other sections of beach to check that nesting abundances are comparable to index monitoring beaches. As there is spatial synchrony in nesting between beaches when monitoring is conducted for 4-7 days, sporadic monitoring of 4-7 consecutive days at neighboring beaches will provide an indication as to whether spatial nesting distributions are changing, and therefore whether perceived changes in nesting populations are real or whether turtles are moving to adjacent nesting areas. For example, if nesting is concentrated on 3 sections of beach, and for some reason (Eg., increased lighting or human disturbance) turtles are no longer nesting at that beach, a short survey of neighboring areas should detect the changes in spatial distributions of nesting, and survey techniques can be adapted to additionally encounter these turtles.

Predicting annual track counts

For green and loggerhead turtles, a track count survey of all sections conducted during the middle of the season for 2-3 weeks or intermittently through the season on successive weekends (>8 days in total), provided a mean error of less than 10% (SD~ 10%). This is a low error in sampling, relative to the inter-annual variability in nesting and has low impact on the ability to detect trends in the population (see discussion below under “Trend detection”). Survey effort required to obtain similar errors was considerably higher for hawksbill turtles, due to their relatively low nesting abundance and the comparatively larger nightly variation in nesting. Using a survey of 14 days, mean error for hawksbill turtles (~30%, SD~35%) was still relatively low, and would also have low impact on the ability to detect trends in the population.

An increase in survey effort greater than 14 days would ideally occur as a combination between mid-season monitoring and monitoring intermittently through the nesting season. This would reduce mean error, but more importantly, would increase confidence in the precision of estimates by providing two distinct estimates of population size within the one nesting season. Using a combination of mid-season monitoring and intermittent monitoring throughout the nesting season would also detect any seasonal changes in the nesting population, and would therefore give much greater confidence in estimates.

The survey error in assessing nesting success from visual observations of nests is likely to have a much greater impact on annual nesting abundance estimates. A combination of temporal sampling of track abundance and sampling of turtles for nesting success (see discussion below under “Nesting Success”, will decrease survey effort required, and is likely to decrease current error in estimating the number of clutches laid per year. This will give a more cost effective sampling design with lower total error in abundance estimates than the current monitoring methodology of monitoring tracks every morning from 1 December to 28 February and assessing nesting abundance from visual observation of the nest.

When predicting annual nesting abundance from partial season track count data, estimating abundance using both generalized additive models and linear regression models would increase the confidence in predictions, by providing several estimates of population size. For example, if generalized additive models predicted annual abundance of 200 turtles, and linear models predicted annual nesting abundance of 210 turtles, and the mean expected error from sampling regimes was > 5%, then greater confidence can be given to the abundance estimates.

Nesting success

The method of assessing nesting success means that the collected data has inherent error in assessing the number of clutches laid per year. Without a method to test the accuracy of track identification, the amount of error in assessing nesting success is a matter of speculation. Nesting success can more accurately be estimated by watching nesting turtles on the beach at night. It is important to conduct these surveys using techniques which aim to minimize the disturbance to turtles, as nesting success would otherwise be biased by human presence. These techniques aim to have no disturbance on turtles by them being oblivious to our presence. This includes minimizing the use of lights, not approaching the turtle too closely prior to egg deposition, and not making rapid movements nearby turtles. Given that the nesting process is typified for all species of turtles, watching the movements of turtles using moon and star light is often sufficient to detect when laying has begun (the turtle is relatively still and makes some slight rocking movements). The turtle should then be approached carefully to confirm nesting success by visual assessment of eggs. When conducted nesting success studies, a random sample of turtles should be encountered during their entire nesting process. This can be achieved by randomly choosing turtles as they are making their way up the beach, and these turtles should be watched until they leave the beach. Choosing a turtle that is already on the beach will reduce time but is likely to have bias if nesting success is correlated with nesting duration (ie. If turtles are on the beach longer, are they more or less likely to lay a clutch of eggs?).

Sampling error for assessing nesting success was calculated from nesting success data determined from observing tracks. If observations of nesting turtles find that the error in estimating nesting success is substantial, the accuracy and precision of estimates may differ from estimates shown in this report. For example, greater seasonal trend variation, greater daily variation, or greater variation within the night in nesting success will require a greater number of days to be sampled in order to obtain similar sampling error estimates for nesting success calculations.

Nesting success estimates from visually observing turtles can then be used as an estimate of nesting success for the year, and therefore the time taken to complete morning track count surveys would be considerably reduced as tracks could just be counted rather than requiring an assessment of nesting success. Alternatively, if nesting success is still recorded during morning studies, the nesting success estimates from visually observing turtles can be used to assess the accuracy in nesting success obtained by visually assessing tracks. If there is a significant discrepancy, more observations of turtles at night should be made to identify potential causes of the discrepancy. These nighttime surveys should also increase the accuracy with which people assess nesting success, by increasing their experience with what successful and unsuccessful nesting attempts look like.

Trend detection

For trend detection, reasonably large sampling errors of around 50% of the population still had relatively little impact on the number of years required to detect trends or the magnitude of detectable trends. This is due to the high inter-annual variability in marine turtle nesting, and the varying proportions of the total breeding female population seen in any year. This variability is inherent to the biology of marine turtles, where turtles skip years between breeding and are more likely to breed under certain environmental conditions when food availability is high (eg. see Broderick *et al.* 2001). The only way to overcome this in population studies of nesting turtles is by determining the relative percentage of the total population nesting in any one year. The most reliable method to do this is by intensive capture-mark-recapture studies where a high proportion of the annual nesting females are marked and an estimate of total population size can be made (Cormack 1964; Jolly 1965; Seber 1965).

Total population size estimates

Given the relatively large area of coastline, with reasonably high levels of nesting occurring across it, a capture-mark-recapture study would require considerable survey effort to gain appreciable percentages of the nesting turtle population. Additionally, if a capture-mark-recapture study is limited to a section of the nesting beach, the amount of movement in nesting for females within the season and between seasons would need to be estimated. These factors will cause considerable error in population estimates from capture-mark-recapture studies. This error is likely to cause similar variation (coefficients of variation) to track count abundance estimates and is therefore not likely to increase the ability to detect trends unless considerable effort in monitoring surveys is undertaken.

Clutch frequencies and inter-nesting intervals could be more easily (but more expensively) determined for a sample of turtles using satellite telemetry, where transmitters are attached to a sample of turtles early in the nesting season (on their first arrival).

Alternatively, the total population size can be estimated using several years of nesting abundances and data from the literature for clutch frequencies and remigration intervals. For example extrapolating from annual nesting for green turtles, and using a mean clutch frequency for green turtles of 2.93 clutches (sd= 0.28; Miller 1997) and remigration interval of 2.86 years (Miller 1997), produces total population estimates ranging from 800 – 5000 turtles. If the proportion of the total population cannot be more accurately predicted each year, then several years of estimates are required to gain an accurate assessment of the total size of the population.

Additional monitoring objectives

If additional activities (such as protecting nests from predation) are undertaken, then the objective of monitoring would change from the ability to estimate population abundance to the ability to encounter the maximum number of clutches under threat. To accurately assess this, an analysis of the spatial and temporal distribution of clutches under threat would be required.

RECOMMENDATIONS FOR FUTURE RESEARCH

Further research would be desirable to:-

- Determine the accuracy in track identification
- Determine nesting success by observing females to determine the accuracy of determining nesting success
- Quantify nesting at the peripheries of the nesting season (before 1-December and after 28-February) to determine nesting abundances relative to the annual nesting population

REFERENCES

Bjorndal, K. A., Wetherall, J. A, Bolten, A. B., and Mortimer, J. A. (1999). Twenty-six years of green turtle nesting at Tortuguero, Costa Rica: an encouraging trend. *Conservation Biology* **13**, 126-134.

Broderick, A. C., B. J. Godley, and G. C. Hays (2001). Trophic status drives interannual variability in nesting numbers of marine turtles. *Proceedings of the Royal Society of London* **268**, 1481-1487.

Broderick, A. C., Glen, F., Godley, B. J., and Hays, G. C. (2002). Estimating the number of green and loggerhead turtles nesting annually in the Mediterranean. *Oryx* **36,** 227-235.

Broderick, A. C., Glen, F., Godley, B. J., and Hays, G. C. (2003). Variation in reproductive output of marine turtles. *Journal of Experimental Marine Biology and Ecology* **288**, 95-109.

Cape Conservation Group (2004). Ningaloo Community Turtle Monitoring Field Guide, Cape Conservation Group**:** 66p.

Carter, R., McGrath, K., Waayers, D., and Mau, R. (2004). Ningaloo Community Turtle Monitoring Interim Annual Report 2003-2004, Wordwide Fund for Nature, Exmouth, Western Australia.

Chaloupka, M. (2001). Historical trends, seasonality and spatial synchrony in green sea turtle egg production. *Biological Conservation* **101**, 263-279.

Cormack, R. M., 1964. Estimates of survival from the sighting of marked animals. *Biometrika*. **51**, 429-438.

Dodd, C. J. (Jr.), (1988). 'Synopsis of the biological data on the loggerhead sea turtle *Caretta caretta* (Linnaeus 1758).' (U.S. Fisheries and Wildlife Service Biological Report No 88 (14))

Gerrodette, T. (1993). TRENDS: Software for a power analysis of linear regression. *Wildlife Society Bulletin* **21**, 515-516.

Girondot, M., Rivalan, P., Wongsopawiro, R., Briane, J. P., Hulin, V., Caut, S., Guirlet, E., and Godfrey, M. H. (2006). Phenology of marine turtle nesting revealed by statistical model of the nesting season. *BMC Ecology* **6**: 11.

Gratiot, N., Gratiot, J., Kelle, L., and de Thoisy, B. (2006). Estimation of marine turtles nesting season from incomplete data: Statistical adjustment of a sinusoidal function. *Animal Conservation* **9**, 95-102.

Hastie, T. J., and Tibshirani, R. J. (1990). 'Generalized additive models.' (Chapman and Hall: London)

Hawkes, L. A., Broderick, A. C., Godfrey, M., and Godley, B. J. (2005). Status of nesting loggerhead turtles *Caretta caretta* at Bald Head Island (North Carolina, USA) after 24 years of intensive monitoring and conservation. *Oryx* **39**, 65-72.

Hays, G. C., Broderick, A. C., Glen, F., Godley, B. J., Houghton, J. D. R., and Metcalfe, J. D. (2002). Water temperature and internesting intervals for loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles. *Journal of Thermal Biology* **27**, 429-432.

Hughes, G. R. (1995). Nesting cycles in sea turtles - typical or atypical? In 'Biology and conservation of sea turtles'. (Ed. K. A. Bjorndal) pp. 81-89. (Smithsonian Institution Press: Washington)

Johnson, S. A., and Ehrhart, L. M. (1996). Reproductive ecology of the Florida green turtle: Clutch frequency. *Journal of Herpetology* **30**, 407-410.

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

Koch, A. U., Chaloupka, M., Guinea, M. L., Limpus, C. J., Pilcher, N., Whiting, S. D., and Ali, L. (2006). Maximizing population information from various beach census regimes. In ‘Book of Abstracts. 26th Annual Symposium on Sea Turtle Biology and Conservation’. (Eds. Frick, M., Panagopoulou, A., Rees, A. F. and K. Williams) p. 301 (International Sea Turtle Society, Athens, Greece.)

Limpus, C. J. (1985). A study of the loggerhead sea turtle, *Caretta caretta*, in eastern Australia. Ph.D. Thesis thesis, University of Queensland.

Limpus, C. J. and N. Nicholls (1988). The Southern Oscillation regulates the annual numbers of green turtles, *Chelonia mydas*, breeding around northern Australia. *Australian Wildlife Research* **15**(2),157-161.

Maindonald, J. H. and Braun, J. (2007). ‘Data analysis and graphics using *R*: An example-based approach.’ (Cambridge University Press: Cambridge UK).

Miller, J. D. (1997). Reproduction in sea turtles. In ‘The biology of sea turtles’. (Eds. Lutz, P. L. and J. A. Musick) pp. 51-81 (CRC Press, Boca Raton, Florida).

Musick, J. A., and C. J. Limpus (1997). Habitat utilization and migration in juvenile sea turtles. In ‘The biology of sea turtles’. (Eds. Lutz, P. L. and J. A. Musick) pp. 137-164 (CRC Press, Boca Raton, Florida).

R Development Core Team (2007). R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria. Available online: http://www.R-project.org

Richards, A., Mau, R., Macgregor, K., and Bedford, S. (2005). Ningaloo Turtle Program, Western Australia: Annual Report 2004-2005. Ningaloo Turtle Program, Exmouth, Australia.

Schroeder, B., and Murphy, S. (1999). Population surveys (ground and aerial) on nesting beaches. In ‘*Research and management techniques for the conservation of sea turtles*’. (Eds. Eckert, K. L., Bjorndal, K. A., Abreu-Grobois, F. A. and M. Donnelly), pp. 45-55 (IUCN/SSC Marine Turtle Specialist Group Publication No. 4). Available online: http://www.iucn-mtsg.org/Publications/Tech_Manual/Tech_Manual_en/08-schroeder&murhpy.pdf

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

Solow, A. R., Bjorndal, K. A., and Bolten, A. B. (2002). Annual variation in nesting numbers of marine turtles: the effect of sea surface temperature on re-migration intervals. *Ecology Letters* **5**, 742-746.

Williams, B. K., Nichols, J. D., and Conroy, M. J. (2002). ‘Analysis and management of animal populations. ’ (Academic Press: San Diego, California).

Wood, S. N. (2006). ‘Generalized Additive Models: An Introduction with R.’ (Chapman and Hall / CRC: Boca Raton)