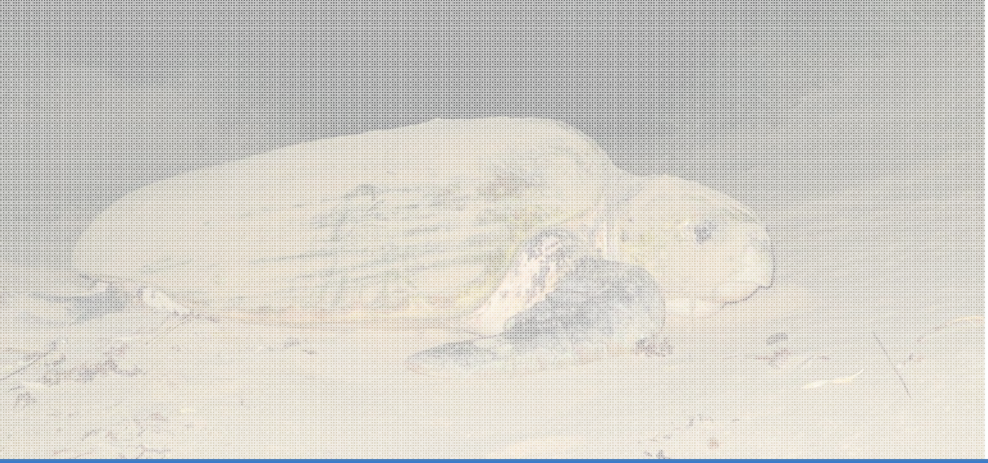

Estimating abundance and detecting trends for green, loggerhead and hawksbill turtles nesting within the Ningaloo region: 2013-14 to 2015-16 seasons.

2016

By Andrea Whiting

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Report to the Department of Parks and Wildlife, Exmouth WA

August 2016

By Andrea Whiting
PO Box 1212
Bentley DC, WA 6983
Ph 0417 913 547
Email au.whiting@gmail.com

Preface and scope

This report was produced for the Ningaloo Turtle Program, a collaboration between the Department of Parks and Wildlife and the Cape Conservation Group. Data used in this report were provided by Keely Markovina and Peter Barnes (Department of Parks and Wildlife) for production of this report.

This report presents data analyses estimating annual abundances, trends in the time-series data, nesting success and temporal and spatial changes in nesting abundances.

Further results and detailed methodology can be found in the Ningaloo Turtle Program annual reports and the Turtle Track Monitoring Field Guide. These are available online at http://www.ningalooturtles.org.au/

Executive summary

- Continuous daily monitoring occurred for approximately four weeks in each of the 2013-14, 2014-15 and 2015-16 seasons, corresponding with an expected error in estimating annual nesting abundance of ca. 7%, 14% and 35% for green, loggerhead and hawksbill turtles respectively.
- Over the last 13 years, green, loggerhead and hawksbill nesting activity appears to have remained stable with no significant positive or negative trends in nesting abundance for any species, with an estimated annual average of ca. 17 500 green turtle tracks, 2 200 loggerhead turtle tracks and 470 hawksbill turtle tracks nesting on the monitored beaches in the Cape Range and North West Cape divisions.
- Approximately 15 104 to 33 721 green turtles, 991 to 2 763 loggerhead turtles and 351 to 791 hawksbill turtles are in the breeding population that nest within the Cape Range and North West Cape Divisions, representing globally significant populations for all species.
- There appeared to be little variation between years in the peak of the nesting season with peak nesting occurring between late December and early January each year since consistent monitoring began in the 2003-04 season.
- There was little variation in spatial distribution of annual nesting abundance between core monitored sections for green turtles and loggerhead turtles between the 2005-06 and 2015-16 seasons.

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Introduction

Three species of sea turtles nest regularly within the Ningaloo region: green turtles, loggerhead turtles and hawksbill turtles and all form part of globally significant populations for each species. All three species are protected under state and Commonwealth legislation and are internationally listed on the IUCN red list. Green turtles nesting within the Ningaloo region belong to the North West Shelf stock (Dethmers *et al.* 2006), which host some of the largest green turtle nesting aggregations in the Indian Ocean and is one of the largest populations of green turtles remaining globally (Limpus 2007). Loggerhead turtle nesting in Western Australia belongs to a distinct genetic stock to eastern Australia (Dutton *et al.* 2002), and along with nesting on Dirk Hartog Island in Shark Bay form one of the most abundance loggerhead turtle nesting female populations in the world (Reinhold and Whiting 2014). Hawksbill turtle nesting within the Ningaloo region are thought to belong to the Western Australian stock (Vargas *et al.* 2016) and forms part of one of the world's largest nesting hawksbill populations (Limpus 2009). The nesting habitat of turtles nesting within the Ningaloo region is protected within the Ningaloo Marine Park but eggs and hatchlings are still vulnerable to threats occurring on mainland beaches in Australia such as from predation.

Well-designed long-term monitoring is important for long lived species with non-annual breeding behaviours such as sea turtles, as there is often substantial inter-annual variability in abundances and only a relatively small portion of the population is nesting in any given year. For sea turtles, monitoring abundance has often been focused on the nesting beach where they are easily accessible and provides the most consistent approach to monitoring abundance of the species. Sea turtles are usually monitored on nesting beaches using either a capture-mark-recapture approach or a track count approach.

Given the temporal and spatial spread of turtles nesting within the Ningaloo region, the Ningaloo Turtle Program adopted a track count census approach in 2001 where sections of beach are monitored the morning after the nightly turtle nesting activity using tracks and marks left in the sand. During the early years of using this approach, monitoring spanned up to three months at some sections and was used to provide baseline data for future monitoring (Whiting 2008). The study period was refined in the 2009-10 season to focus on two main nesting areas where nesting abundance was concentrated and monitor daily during a four week period at the peak of the nesting season. This track count approach provides a more cost effective solution compared to an intensive capture-mark-capture approach, allowing more surveys over wider spatial scales and longer temporal period with the same resources. However, this track count approach has limitations over marking individuals as population parameters including immigration, emigration, recruitment and deaths cannot be detected. The accuracy and confidence in population abundance estimates using track counts is also limited because abundance estimates are made daily from evidence of nesting activity from the visual appearance of tracks. Each interpretation of the track introduces some error and may be biased by the skills of the observer, with potential observer error in species identification and whether the track resulted in egg deposition.

This report analyses nesting statistics for the last three nesting seasons, focusing on deriving annual nesting abundances and population abundance, assessing nesting trends, nesting success and any temporal or spatial changes in nesting abundance.

Methods

Data are analysed herein for nesting activity for the 2013-14, 2014-15 and 2015-16 nesting seasons occurring within the North West Cape (Graveyard, Hunters, Lighthouse Bay and Tandabiddi sections) and Cape Range (Bungelup section). During these seasons, monitoring was focused during a block period of approximately four weeks centred at the presumed peak of nesting activity within the nesting season. During this period, daily counts were recorded assigning each track to a species and nesting outcome (suspected nest or false crawl). Outside these times, sporadic monitoring occurred (see Table 1). Monitoring followed standard protocols described in detail in the NTP Annual Report 2016.

Nightly nesting activity

Nightly nesting abundance was plotted for the 2013-14, 2014-15 and 2015-16 seasons, and annual nesting abundances were estimated for tracks and suspected nests. Annual nesting abundance was estimated using two methods: a) a linear regression model correlating nesting abundance in the intensive nesting period with annual nesting abundance (nesting between 15-November and 15-March derived from almost full-season monitoring conducted between 2003-04 and 2007-08 seasons, Whiting 2008); and b) a generalized additive model used to predict the annual nesting abundance throughout the season.

The functions used for the linear regression models were calculated from analyses of five years of data where almost full-season counts were conducted (2003-04 through to 2007-08 seasons). Counts were then extrapolated to full-season monitoring using calculations from Whiting (2008), assuming the full-season extends from 15 November to 15 March.

Generalized additive models were used to fit a cubic smoothing spline with 4 degrees of freedom to the daily track count data using the *mgcv* package in R (Bjorndal et al. 1999; Hastie and Tibshirani 1990; Wood 2006). Generalized additive models were fit to the available data, using start (15 November) and endpoints (15 March) weighted by 100 with all other data weighted by 0.1. 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.

Outliers

Data for the block monitoring periods in 2014-15 and 2015-16 were used without manipulation, as daily track counts occurred and all sections and sub-sections in the core monitoring area were monitored. During the 2013-14 season, two days were not monitored during the block monitoring period. For linear regression models, data for these two days were predicted using the means of the previous and the subsequent night's nesting as per Whiting *et al.* (2014).

For monitoring outside of the block monitoring period where not all sections or sub-sections were monitored, data were interpolated using the relative percentage of nesting occurring in that area and extrapolating to an estimate of nesting across the entire study area. Data were only included in analyses where spatial coverage spanned areas that were expected to contain 50% of the nightly nesting abundance for that species. Data with less than 50% of expected nesting activity was plotted in the nightly track count graphs, but was excluded when fitting the models and calculating annual nesting abundance.

Data outside of the intensive monitoring period was used to estimate annual nesting abundance with the Generalised Additive Models. We excluded points which were considered to be outliers from these calculations, when there was a higher than expected difference in nesting activity between two subsequent nights.

Spatial distribution and data interpolation

The spatial distribution of nesting within the monitored sections was calculated for all monitoring days (Table 2 and Table 3), showing the percentage of nests within each sub-section for each species each year. When surveys only covered a subset of the core sections and sub-sections (see Table 1), data for the full coverage was interpolated using the spatial distribution of nesting for that species and season using the relative abundances shown in Table 2 and Table 3.

Table 1. Monitoring dates for sections and sub-sections in the North West Cape and Cape Range Divisions between 2013-14 and 2015-16 seasons.

Year	Division	Monitoring period*	Section	Sub-section
2013-14	North West Cape	23-24/11/2013, 8/12/2013, **16/12/2013-12/1/2014 (excluding 26/12/2014)*,** 15-16/2/2014, 1-2/3/2014	All sections (ie. Graveyards, Hunters, Lighthouse Bay, Tandabiddi)	All sub-sections
		9-10/11/2013	Graveyards, Hunters, and Tandabiddi only	All sub-sections
		9-10/11/2013	Lighthouse Bay	Surf Beach – Hunters
		7/12/2013	Graveyards, Hunters and Lighthouse Bay only	All sub-sections
		24/10/2013, 7/11/2013	Graveyards	Trisel – Five Mile Carpark
		28-29/10/2013		Five Mile North - Five Mile Carpark
		5-6/11/2013, 10-11/12/2013		Five Mile North - Five Mile Carpark & Trisel - Five Mile Carpark
		4/11/2013 14/12/2013		Five Mile North - Five Mile Carpark, Trisel - Five Mile Carpark & Graveyards – Burrows Brooke – Graveyards & Graveyards – Burrows
	Cape Range	**16/12/2013-12/1/2014 (excluding 26/12/2013 and 1/1/2014)***	Bungelup	All subsections (ie. Neils Beach, Bungelup Beach and Rolly Beach)
		24/10/2013, 3-15/2/2014, 17/2/2014 and 19-20/2/2014		Bungelup Beach & Neils Beach
		18/2/2014		Neils Beach
2014-15	North West Cape	8/11/2014, 22-23/11/2014, 6-7/12/2014, **15/12/2014-11/1/2015*,** 1/2/2015, 14-15/2/2015, 1/3/2015	All sections (ie. Graveyards, Hunters, Lighthouse Bay, Tandabiddi)	All sub-sections
		9/11/2014, 31/01/2015, 28/2/2015	Graveyards, Hunters, Tandabiddi	All sub-sections
		9/11/2014, 31/01/2015	Lighthouse Bay	Surf Beach - Hunters
		24/11/2014, 26-27/11/2014	Tandabiddi	Burrows - Jurabi Point
		24/11/2014, 27/11/2014	Graveyards	Five Mile North - Five Mile Carpark & Graveyards - Burrows
		4/11/2014, 12/12/2014, 26/11/2014	Graveyards	Five Mile North - Five Mile Carpark, Trisel - Five Mile Carpark & Graveyards - Burrows
		5/11/2014	Graveyards	Five Mile North - Five Mile Carpark
		6/11/2014, 9/12/2014	Graveyards	Five Mile North - Five Mile Carpark & Trisel - Five Mile Carpark
		25/11/2014	Graveyards	Trisel - Five Mile Carpark, Graveyards - Burrows & Brooke - Graveyards
		10/12/2014	Graveyards	ALL
	Cape Range	11/12/2014, **15/12/2014-11/1/2015***	Bungelup	All subsections (ie. Neils Beach, Bungelup Beach & Rolly Beach)
		22/1/2015, 20/2/2015		Bungelup Beach & Neils Beach

Table 1 cont.

Year	Division	Monitoring period*	Section	Sub-section
2015-16	North West Cape	7-8/11/2015, 22/11/2015, 1/12/2015, 6/12/2015, **14/12/2015-10/1/2016* (excluding 18/12/2015),** 30-31/1/2016, 13-14/2/2016, 27-28/2/2016	All sections (ie. Graveyards, Hunters, Lighthouse Bay, Tandabiddi)	All sub-sections
		2/11/2015, 18-20/11/2015, 23-25/11/2015, 2/12/2015	Graveyards	Five Mile North - Five Mile Carpark and Trisel - Five Mile Carpark
		14/11/2015	Graveyards	Graveyards - Burrows
		17/11/2015, 4/12/2015, 12/12/2015	Graveyards	Trisel - Five Mile Carpark
		8-9/12/2015, 11/12/2015	Graveyards	Five Mile North - Five Mile Carpark, Trisel - Five Mile Carpark and Graveyards - Burrows
		21/11/2015, 5/12/2015, 18/12/2015	Graveyards, Hunters, Tandabiddi	All sub-sections
		21/11/2015	Lighthouse Bay	Surf Beach - Hunters
		5/12/2015	Lighthouse Bay	Surf Beach - Hunters and Mildura Wreck - North West Carpark
		18/12/2015	Lighthouse Bay	Surf Beach - Hunters and North West Carpark - Surf Beach
	Cape Range	10/12/2015, **14/12/2015-7/1/2016*,** 9-10/1/2016	Bungelup	All subsections (ie. Neils Beach, Bungelup Beach and Rolly Beach)
		8/1/2016		Rolly Beach only

** refers to block monitoring period where daily nesting activity was recorded*

Table 2. Spatial distribution (%) of nesting per species within the Cape Range Division (Bungelup Section) for days where all three sub-sections were monitored

Season	Species	Spatial distribution (%)			N
		Bungelup Beach	Neils Beach	Rolly Beach	
2013-14	Green	17.6	26.5	55.9	34
	Hawksbill	33.3	30.3	36.4	33
	Loggerhead	26.9	32.8	40.3	673
	Unidentified	55.6	27.8	16.7	18
2014-15	Green	5.9	76.5	17.6	17
	Hawksbill	31.3	35.8	32.8	67
	Loggerhead	30.1	32.3	37.6	705
	Unidentified	28.6	42.9	28.6	14
2015-16	Green	22.2	0.0	77.8	18
	Hawksbill	30.0	20.0	50.0	20
	Loggerhead	37.5	32.3	30.2	798
	Unidentified	100.0	0.0	0.0	3

Table 3. Spatial distribution (%) of nesting per species within the North West Cape Division for days where all sections and sub-sections were monitored

Season	Species	Spatial distribution Graveyards (%)					Spatial distribution Hunters (%)				Spatial distribution Lighthouse Bay (%)				Spatial distribution Tandabiddi (%)		
		Brooke - Graveyards	Five Mile North - Five Mile Carpark	Graveyards - Burrows	Trisel - Five Mile Carpark	Graveyards Total Counts	Hunters - Mauritius	Jacobz South - Wobiri	Mauritius - Jacobz South	Hunters Total Counts	Mildura Wreck - North West Carpark	North West Carpark - Surf Beach	Surf Beach - Hunters	Lighthouse Bay Total Counts	Burrows - Jurabi Point	Tandabiddi Total Counts	Grand Total
2013-14	Green	29.6	23.9	20.0	26.5	2777	32.5	29.6	37.9	2586	15.3	41.6	43.1	1025	100	567	6955
	Hawksbill	16.7	25.0	8.3	50.0	12	61.5	7.7	30.8	39	9.7	51.6	38.7	31			82
	Loggerhead	25.8	25.8	6.5	41.9	62	55.6	13.0	31.4	169	6.3	51.6	42.2	64	100	5	300
	Unidentified	16.7	33.3	50.0	0.0	6	0.0	0.0	100.0	1	33.3	66.7	0.0	3	100	8	18
2014-15	Green	27.5	23.4	19.9	29.2	757	25.0	33.2	41.9	757	19.8	49.8	30.4	257	100	131	1902
	Hawksbill	23.1	34.6	7.7	34.6	26	62.8	7.0	30.2	43	4.2	62.5	33.3	48	100	2	119
	Loggerhead	17.9	35.7	19.6	26.8	56	53.3	14.5	32.2	152	5.2	60.3	34.5	58	100	3	269
	Unidentified	60.0	20.0	20.0	0.0	5	33.3	66.7	0.0	9	50.0	0.0	50.0	2	100	1	17
2015-16	Green	23.2	22.0	29.7	25.1	824	23.2	43.8	33.0	712	10.5	48.1	41.4	181	100	169	1886
	Hawksbill	15.8	26.3	10.5	47.4	19	47.1	15.7	37.3	51	7.1	21.4	71.4	28	100	3	101
	Loggerhead	8.8	35.2	3.3	52.7	91	54.6	12.6	32.8	119	7.1	33.3	59.5	42	100	5	257
	Unidentified	0	0	0	0	0	0	100	0	1	0	100	0	1	0	0	2

Results

Estimating annual nesting abundance for the entire season

During the last three seasons, the estimated annual number of clutches laid per year within the monitored sections was highest in 2013-14 for green turtles with 4640 clutches, followed by 1587 clutches in 2015-16 and 1384 clutches in 2014-15 seasons. Loggerhead clutch abundance was highest during the 2015-16 season, with an estimated 1274 clutches, followed by 1136 in the 2014-15 season and 922 in the 2013-14 season. Hawksbill clutch abundance was highest during the 2014-15 season with an estimated 224 clutches, followed by 197 clutches in the 2013-14 season and 184 clutches in the 2015-16 season.

Nightly nesting abundance for the 2013-14, 2014-15 and 2015-16 seasons are shown in Figure 1 - Figure 3, with the red trend lines showing the shape and peak of the nesting season using a generalized additive model. The green and blue lines in these figures highlight that full survey coverage did not occur during these nights, and counts were interpolated using mean spatial distribution of nesting. Sporadic counts in late October / early November for the 2013-14, 2014-15 and 2015-16 seasons indicated reasonably high nesting activity (Figure 1 - Figure 3), although few sections were monitored during these times so there was substantial data extrapolation used to estimate these counts.

Outside the intensive monitoring period where there were surveys on consecutive nights, the count on the first night was significantly higher than the next night's nesting for green turtles, but not for loggerhead or hawksbill turtles (Table 4) during the 2013-14 to 2015-16 seasons. As the first night needs to assess whether tracks are from the previous night or older, this indicates tracks for green turtles may have been counted for several days of nesting activity rather than just the previous night.

To assess the differences between nesting abundance in consecutive nights, data were available for 15 nights, comprising 12 nights monitoring at North West Cape and 3 nights monitoring at Cape Range. Data were only included in the analyses when there was at least 4 days since the previous count so the counts were not biased by tracks being marked as already counted. This means that the recorders need to be able to assess the last nights activity from activity occurring within at least the previous four day period.

Table 4. Paired t-test investigating significant differences in counts of nesting tracks between subsequent days for monitoring occurring outside the intensive survey period for the 2013-14 to 2015-16 seasons.

Species	Mean 1st night	Mean 2nd night	T value	d.f.	P
Green	63.2	52.8	2.64	14	<0.01
Loggerhead	8.4	8.3	0.20	14	0.42
Hawksbill	2.6	2.4	0.20	14	0.42

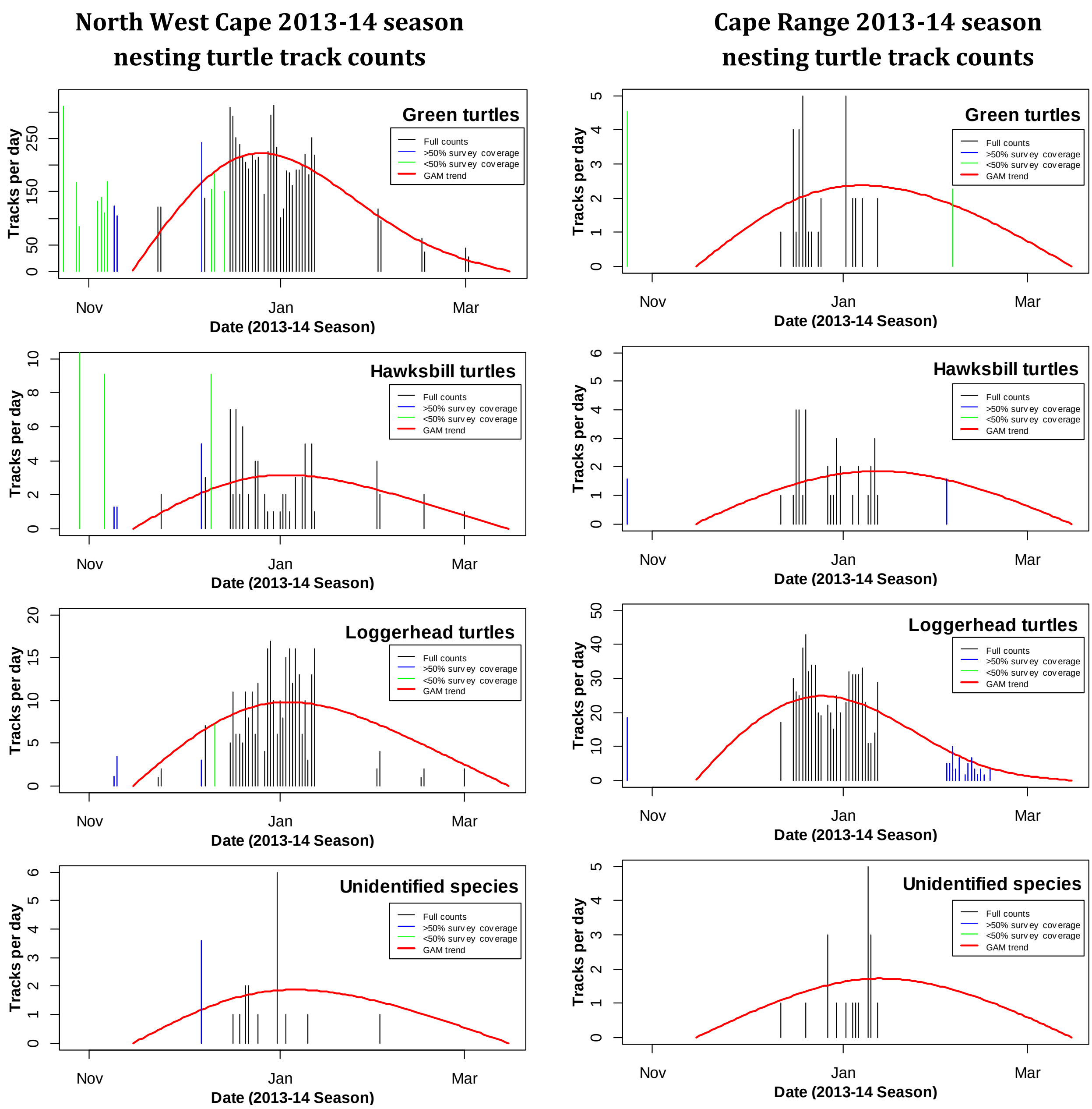


Figure 1. Nesting abundance and seasonal distribution fit for green, hawksbill, loggerhead and unidentified turtle species during 2013-14. Red line refers to generalized additive model fit with 4 degrees of freedom and null endpoints of 15-November (green turtles) and 15-November(other species) and 15-March weighted at 1000 and all other data weighted at 1. Black lines show counts where all sections are monitored. Blue lines show interpolated data where there is an expected coverage of greater than 50% of nesting activity and green lines show data where there is an expected coverage of less than 50% of nesting activity.

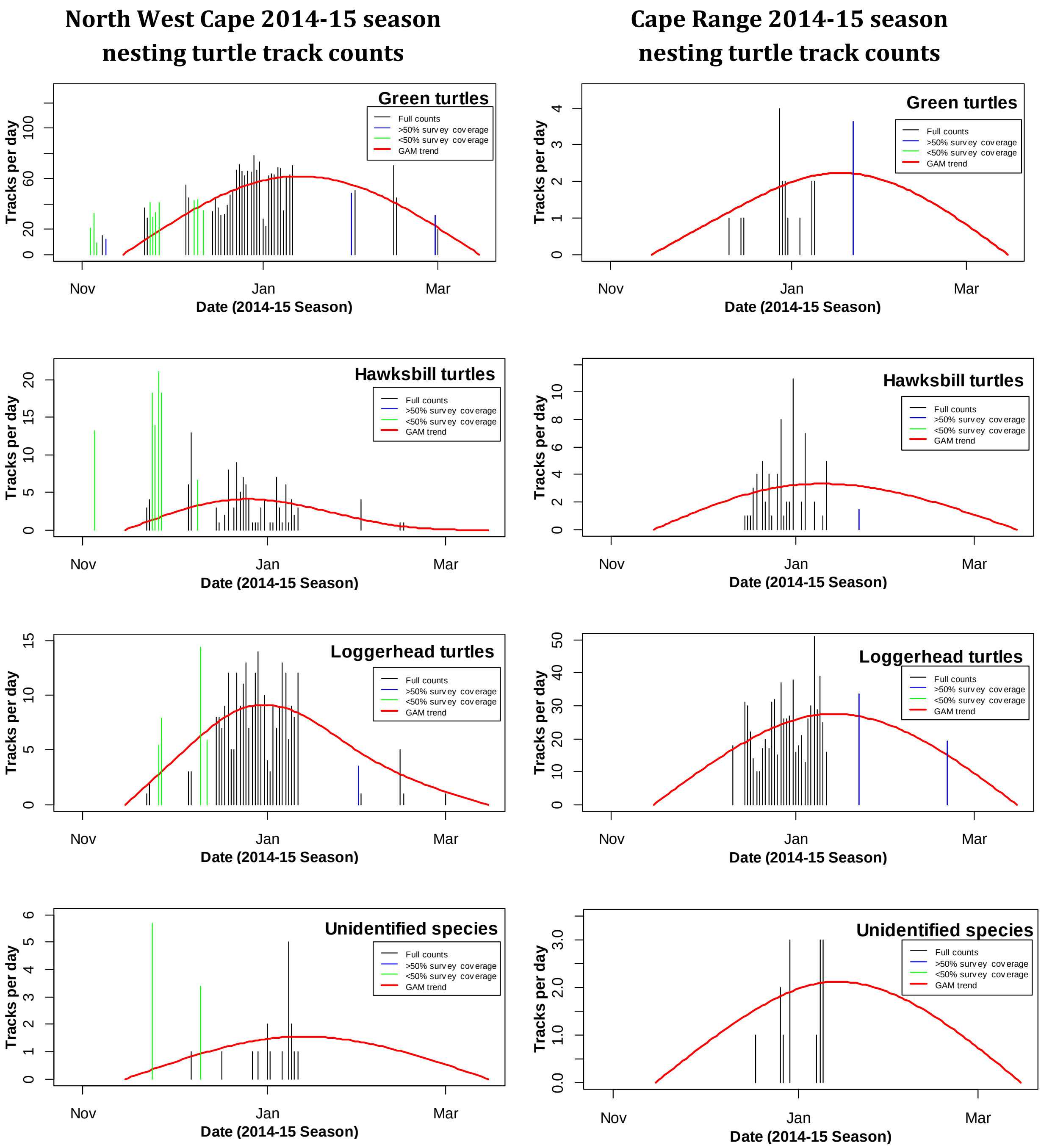


Figure 2. Nesting abundance and seasonal distribution fit for green, hawksbill, loggerhead and unidentified turtle species during 2014-15. Red line refers to generalized additive model fit with 4 degrees of freedom and null endpoints of 15-November and 15-March weighted at 1000 and all other data weighted at 1. Black lines show counts where all sections are monitored. Blue lines show interpolated data where there is an expected coverage of greater than 50% of nesting activity and green lines show data where there is an expected coverage of less than 50% of nesting activity.

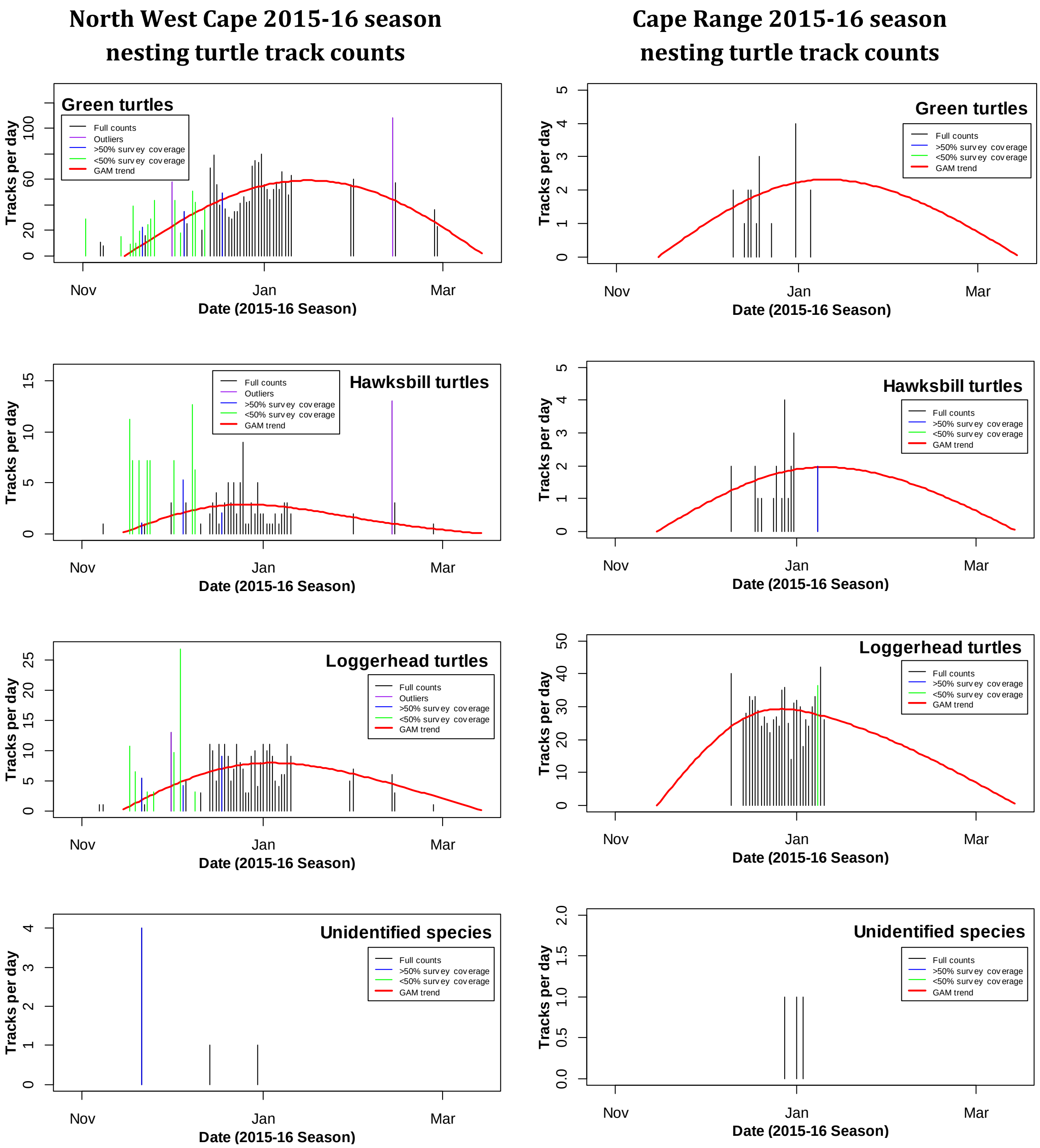


Figure 3. Nesting abundance and seasonal distribution fit for green, hawksbill, loggerhead and unidentified turtle species during 2015-16. Red line refers to generalized additive model fit with 4 degrees of freedom and null endpoints of 15-November and 15-March weighted at 1000 and all other data weighted at 1. Black lines show counts where all sections are monitored. Blue lines show interpolated data where there is an expected coverage of greater than 50% of nesting activity and green lines show data where there is an expected coverage of less than 50% of nesting activity.

Trends in annual nesting abundance

Predicted annual nesting abundance was stable over the past 12 to 13 years, with no significant linear trends in nesting abundance (tracks or suspected nests) for any species at any division ($P>0.1$). The mean number of tracks per season for North West Cape and Cape Range divisions combined was 17 505 (s.d.= 17 704) for green turtles, 2 181 (s.d.= 615) for loggerhead turtles and 474 (s.d.= 249) for hawksbill turtles.

Long-term nesting data for the annual estimated number of suspected nests and tracks are shown in Figure 4 and Figure 5. The number of tracks and suspected nests for species that could not be identified remained low throughout the last three seasons (Figure 6).

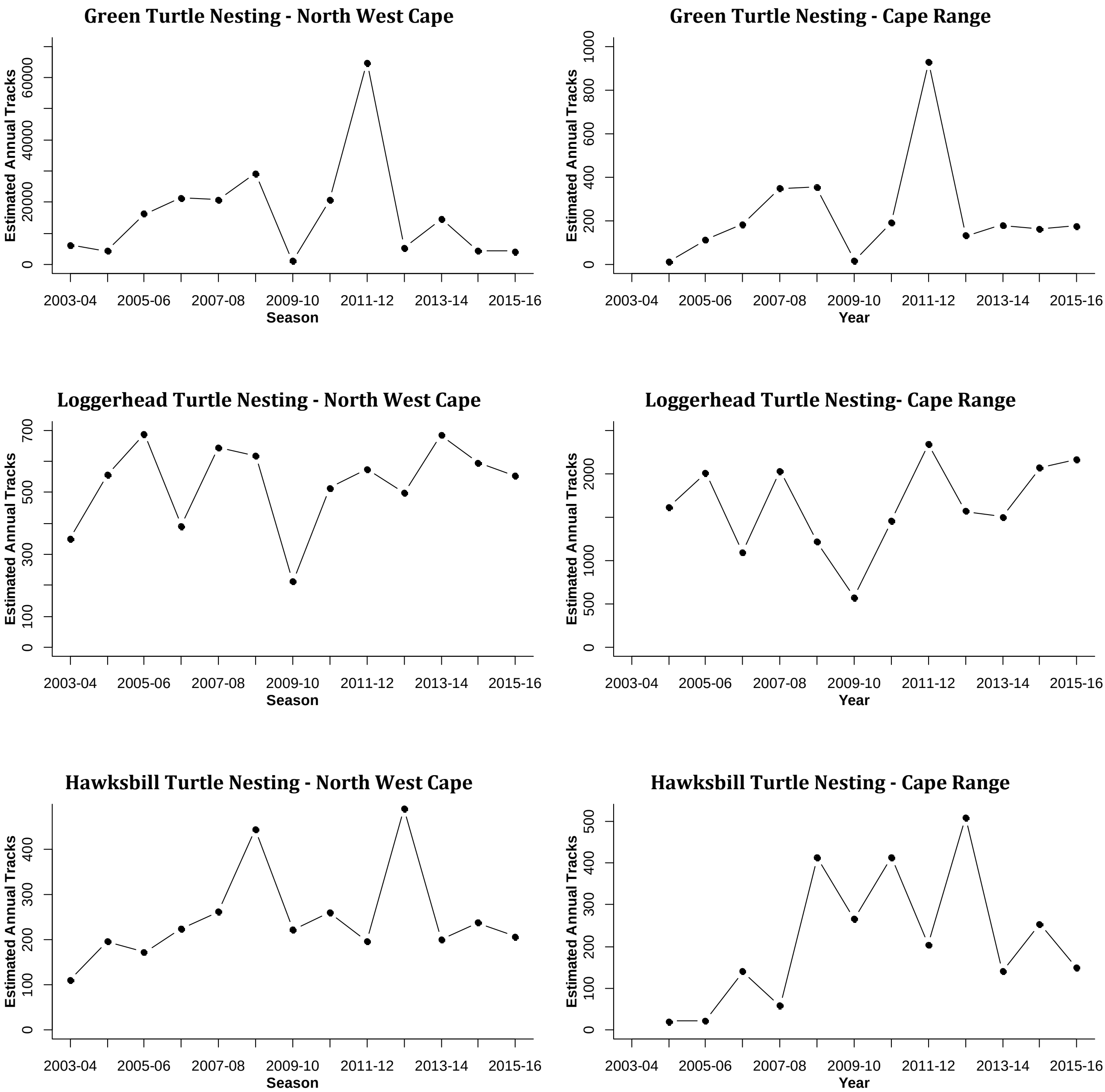


Figure 4. Estimated number of turtle tracks (combined false crawls and suspected nests) for turtle nesting activity at North West Cape and Cape Range divisions within the Ningaloo Region. Annual abundances were calculated for each season’s nesting, assuming the season is mostly restricted to between 15 November and 15 March. Data for the 2003-04 to 2007-08 seasons were calculated using interpolation and generalised additive models described in Whiting (2008). Data for the 2008-09 to 2015-16 seasons were calculated using both linear regression models and generalized additive models and the means of both methods are displayed.

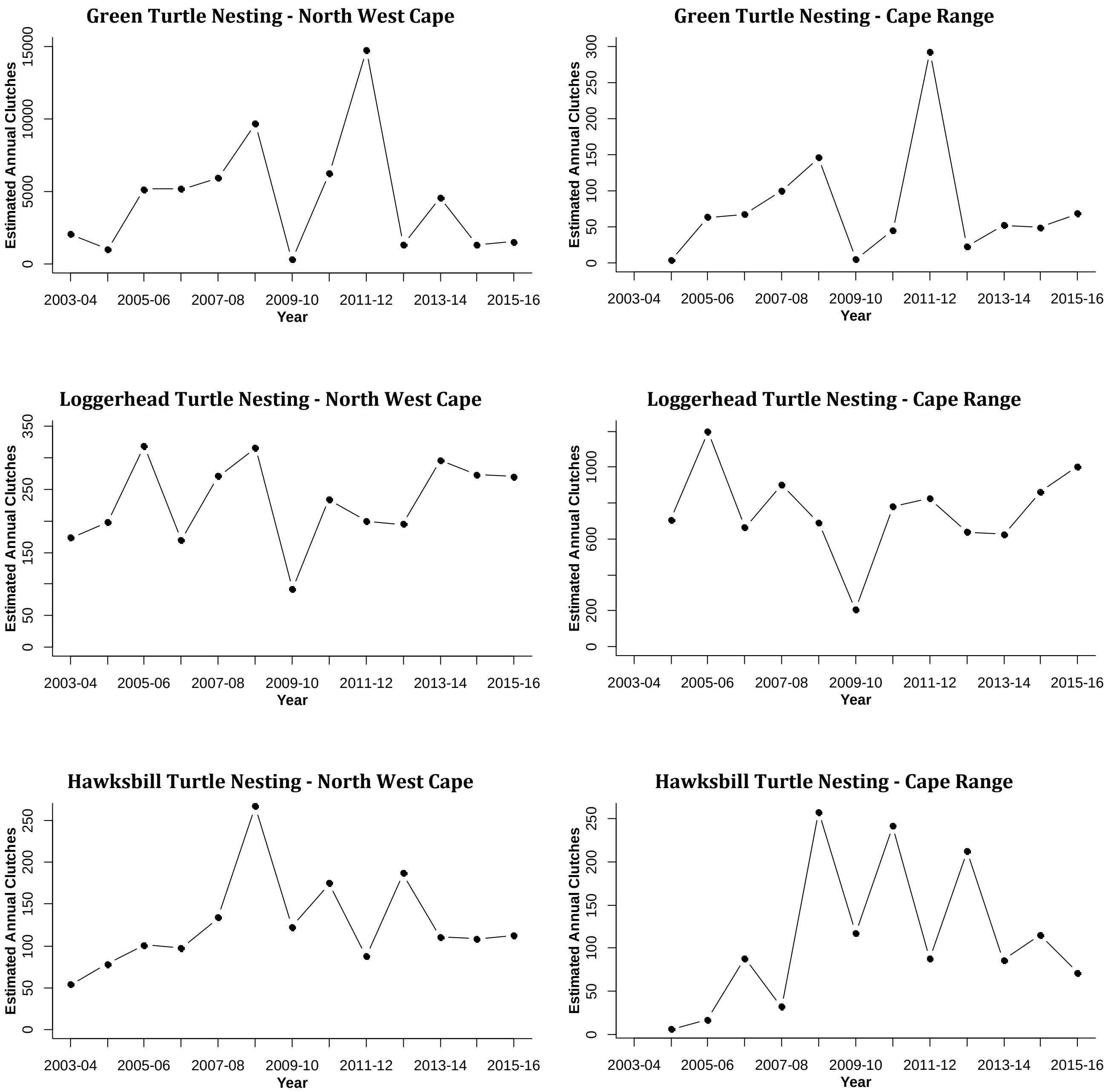


Figure 5. Estimated number of suspected nests laid for turtles nesting at North West Cape and Cape Range divisions within the Ningaloo Region. Annual abundance data were calculated for each season's nesting assuming the season is mostly restricted to between 15 November and 15 March. Data for the 2003-04 to 2007-08 seasons were calculated using interpolation and generalised additive models described in Whiting (2008). Data for the 2008-09 to 2015-16 seasons were calculated using both linear regression models and generalized additive models and the means of both methods are displayed.

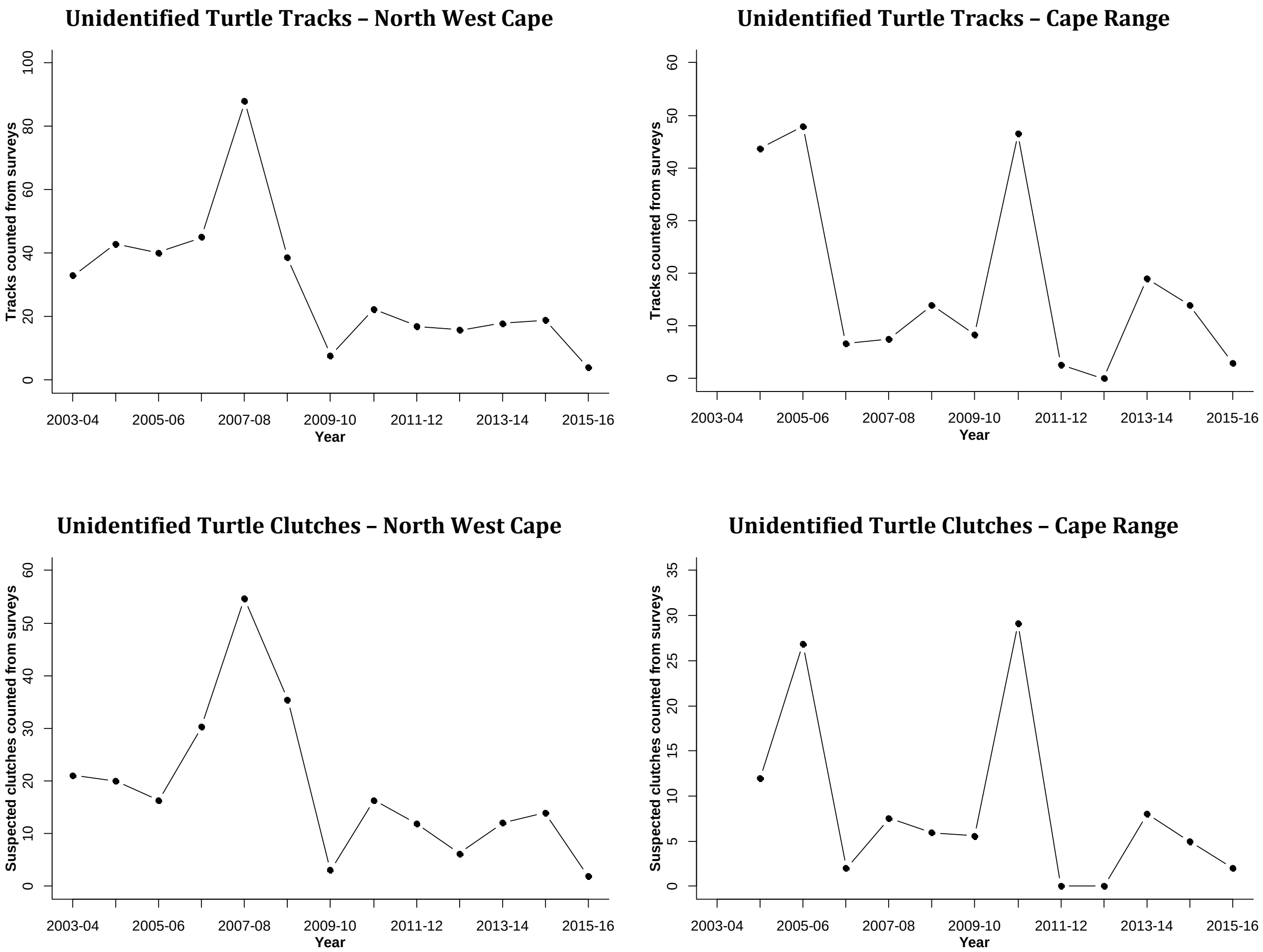


Figure 6. Number of tracks and number of suspected nests laid for unidentified turtle species nesting at North West Cape and Cape Range divisions within the Ningaloo Region. These are absolute counts rather than annual estimates using modelling, and reflect the trend in nesting rather than estimated abundance.

Estimates of abundance of the breeding turtle population

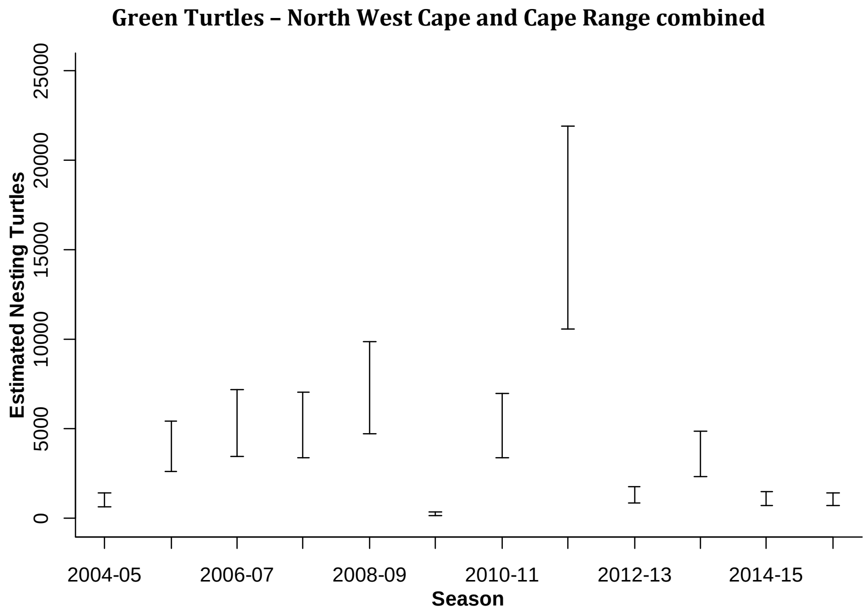
There is substantial uncertainty in estimating the number of turtles in the breeding population at Ningaloo, as conversion parameters (including number of clutches per female per year and number of years between breeding seasons per female) are not known for the population and vary substantially between populations (Table 5 and Table 6). Furthermore, the accuracy of estimating nesting success has not been verified by seeing eggs (apart from one study on loggerhead turtles during the 2012-13 nesting season, Whiting *et al.* 2013) and so the error in nesting success estimates is not known. An estimate of the number of turtles nesting per season was calculated for green turtles using 3-6.2 clutches per season, 3-5.5 clutches per season for loggerhead turtles and 3-5 clutches per season for hawksbill turtles (Figure 7), and assumed no influence on population size from immigration, emigration, births or deaths. The range of numbers of clutches per season were based on studies from other locations in Australia and globally (Table 5). These are broad estimates given the uncertainty of the conversion parameters, but show there are approximately 15 104 - 33 721 green turtles, 991 - 2763 loggerhead turtles and 351 - 791 hawksbill turtles that nest within the Cape Range and North West Cape Divisions (Table 7).

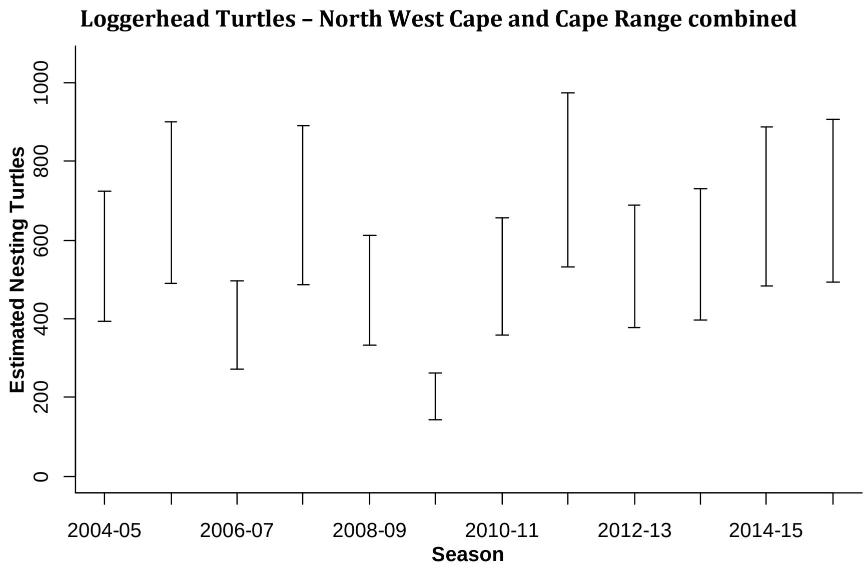
Table 5. Mean numbers of clutches per female per season for green, loggerhead and hawksbill turtles

Species	Location	Mean	SD	Range	N	Reference
Green	Global (IUCN proxy)	3				Seminoff (2004)
	Heron Island, Australia	5.06	1.99	1-9	878	Limpus (2007)
	Bramble Cay, Australia	6.2	2.1	1-10	684	Limpus *et al.* (2001)
Loggerhead	Global (IUCN)			3-5.5		Casale and Tucker (2015)
	Mon Repos, Australia	3.41	1.21	1-6	1207	Limpus (1985)
Hawksbill	Global (IUCN)			3-5		Richardson *et al*. (1999) and Mortimer and Bresson (1999) cited in Mortimer and Donnelly (2008)
	Milman Island, Australia	>2.4	1.37	1-6	2731	Miller *et al.* (2000), Dobbs *et al.* (1999) and Loop *et al.* (1995) cited in Limpus (2009)
	Campbell Island, Australia	~3				Limpus *et al.* (1983) cited in Limpus (2009)

Table 6. Mean number of years between breeding seasons for green, loggerhead and hawksbill turtles

Species	Location	Mean	SD	Range	N	Reference
Green	Heron Island, Australia	5.78	1.48	1-9	518	Limpus *et al.* (1994)
	Raine Island, Australia	5.35	1.52	1-8	2094	Limpus *et al.* (2003)
Loggerhead	Global (IUCN)	2.5 - 3				Schroeder *et al.* (2003) cited in Casale and Tucker (2015)
	Mon Repos, Australia	3.82	1.84	1-10	325	Limpus (1985)
Hawksbill	Milman Island, Australia	5.00	1.54	2-9	435	Miller *et al.* (2000) and Dobbs *et al.* (1999) cited in Limpus (2009)
	Varanus Island, Australia	3.7	1.2	1-6	49	Pendoley (1999), Robinson (1990) and Prince (1994) cited in Limpus (2009)





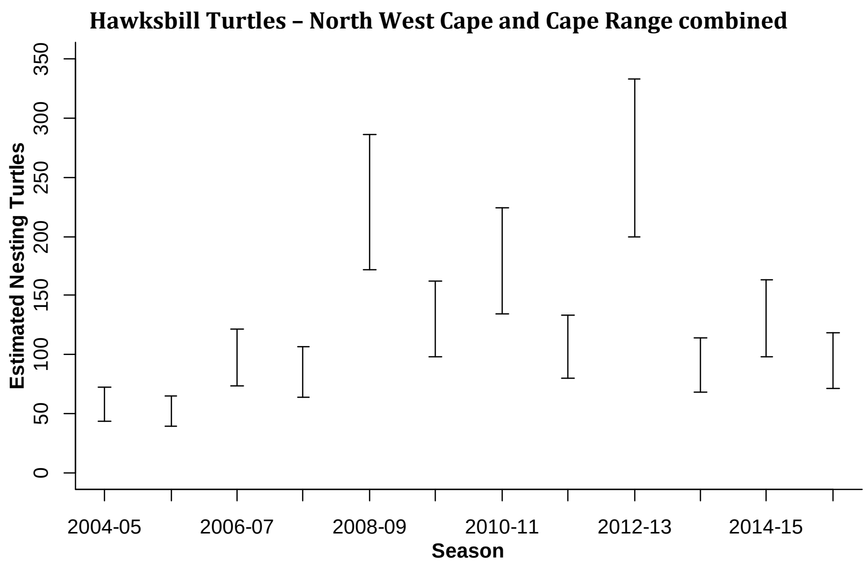


Figure 7. Estimates of abundance of nesting turtles using the minimum and maximum mean clutches laid per female per year.

Table 7. Estimate of the number of nesting females in the breeding population that nest within the North West Cape and Cape Range divisions of Ningaloo. The lower and upper turtle estimates are calculated using the lower and upper estimates of turtle nesting each year, shown in Figure 7.

Species	Mean years between breeding	Lower Nesting Turtle Estimate	Upper Nesting Turtle Estimate
Green	5.35	15104	31214
	5.78	16317	33721
Loggerhead	2.5	991	1818
	3.8	1507	2763
Hawksbill	3.7	351	585
	5	475	791

Variation in temporal distribution of nesting

There appeared to be little variation between species and years in peak nesting activity with the Generalised Additive Models showing peak nesting late December through to early January (Figure 1 - Figure 3). This was mainly based on the intensive monitoring nesting outside of the intensive monitoring period was low.

Nesting success

Nesting success was highest for hawksbill turtles (mean= 50.4%, s.d.= 7.2), followed by loggerhead turtles (mean= 44.9%, s.d.= 7.1) and green turtles (mean= 28.5%, s.d.= 4.5) (Figure 8). There were no significant linear trends in nesting success for green, loggerhead or hawksbill turtles (P>0.1). Nesting success for the 2013-14, 2014-15 and 2015-16 nesting seasons were all within one standard deviation of the mean, with the exception of green turtles in the 2015-16 season which was within 1.63 standard deviations of the mean (Figure 8). There was substantial nightly variation in nesting success between nights ranging from 0 to 100% (Figure 9).

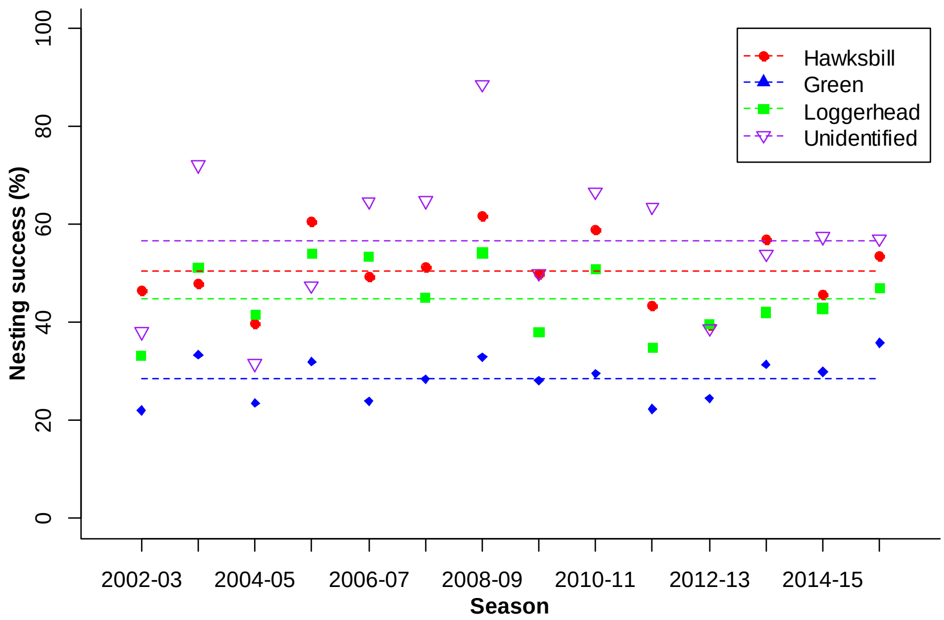


Figure 8. Nesting success from 2002-03 to 2015-16 for hawksbill, green and loggerhead turtles and unidentified turtle species nesting within the North West Cape and Cape Range divisions at Ningaloo.

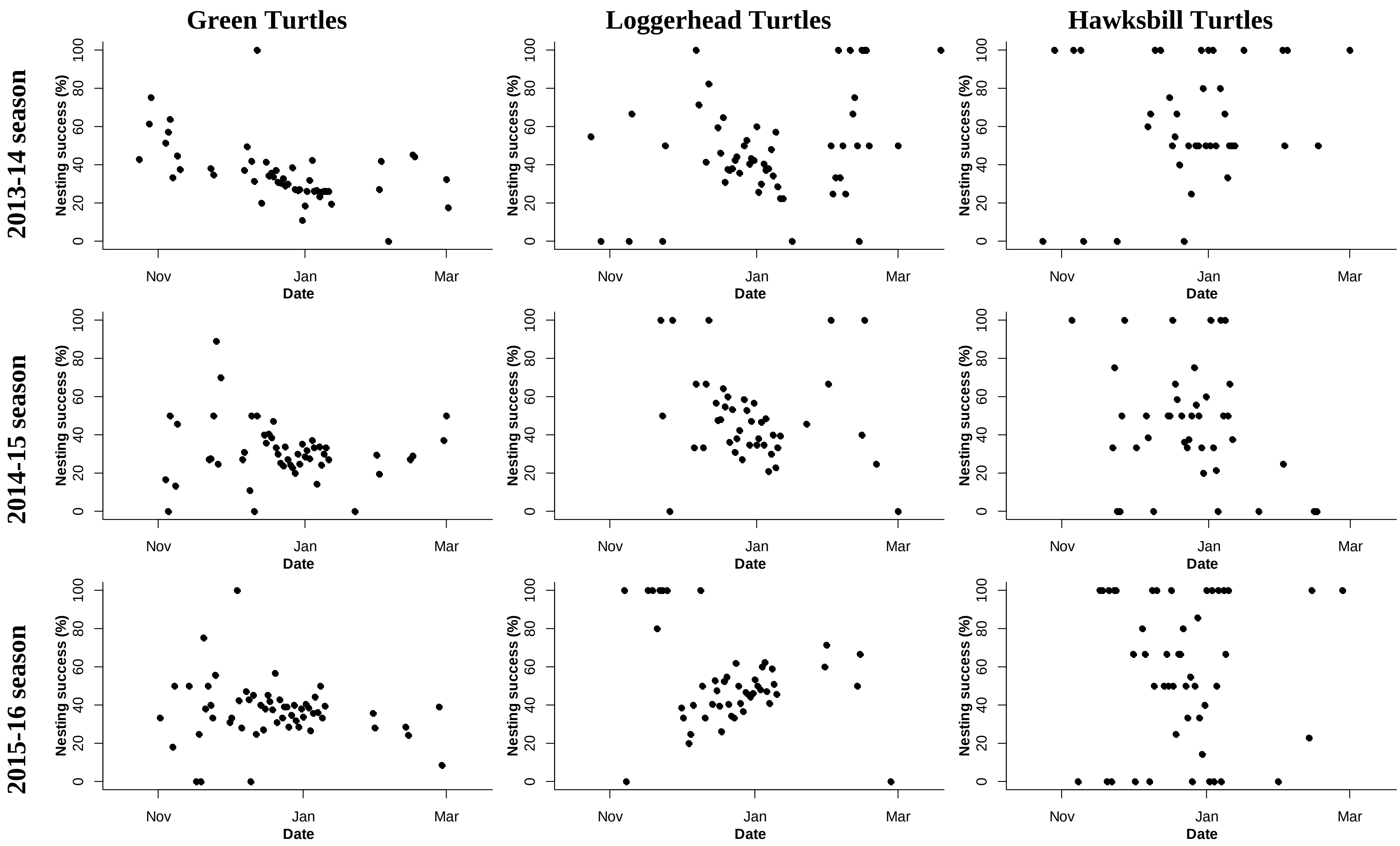


Figure 9. Nightly variation in nesting success (percentage of clutches laid of total tracks on the nesting beach) for green, loggerhead and hawksbill turtles for the 2013-14 to 2015-16 seasons.

The time-series data for nesting success was significantly cross-correlated between species with zero lag (Figure 10), indicating that nesting success is fluctuating in synchrony between the species.

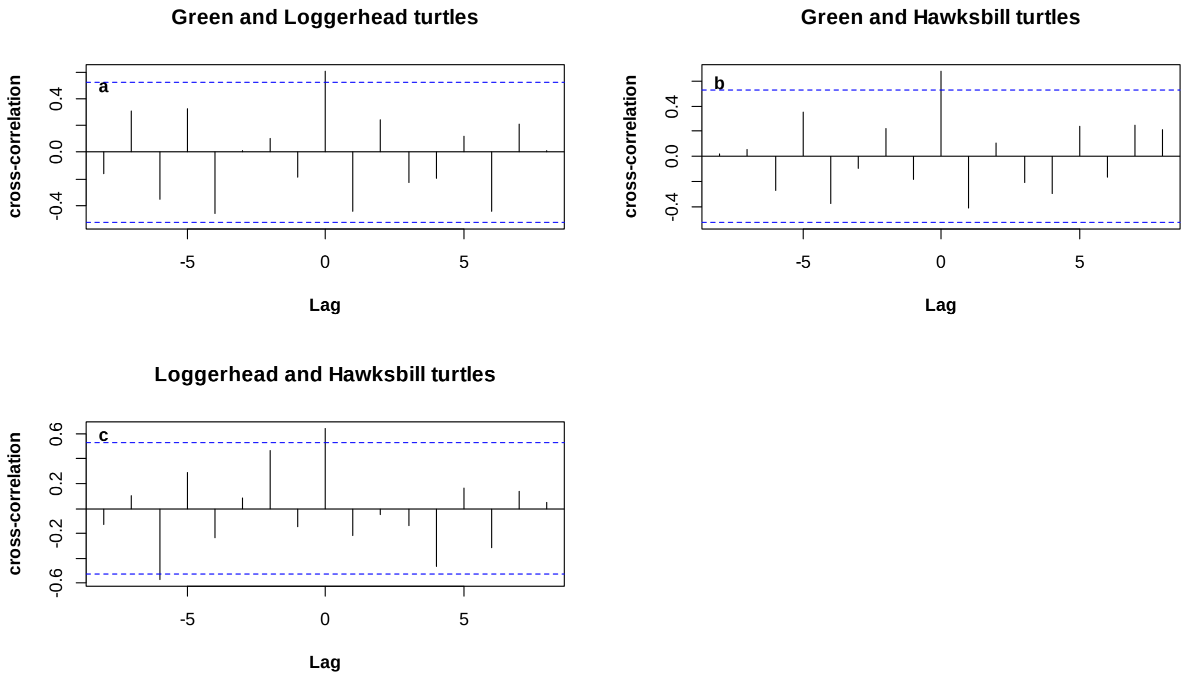


Figure 10. Cross-correlation function analysis for nesting success between green, loggerhead and hawksbill turtles for nesting occurring between 2002-03 and 2015-16 seasons.

Species identification

There was approximately 40% variation in the ratio of loggerhead to hawksbill turtle nesting between years and there was no significant linear trend (P>0.1, Figure 11). This indicates that even if there is a misidentification of species, it is unlikely to impact on trends assuming that hawksbill turtles and loggerhead turtles are nesting in reasonable synchrony. The highest proportion of hawksbill turtles (shown in 2008-09, 2009-10, 2010-11 and 2012-13; Figure 11), correspond with the highest four years of nesting of hawksbill turtles at Cape Range, and within the highest five years of hawksbill turtle nesting at North West Cape (see Figure 4 and Figure 5).

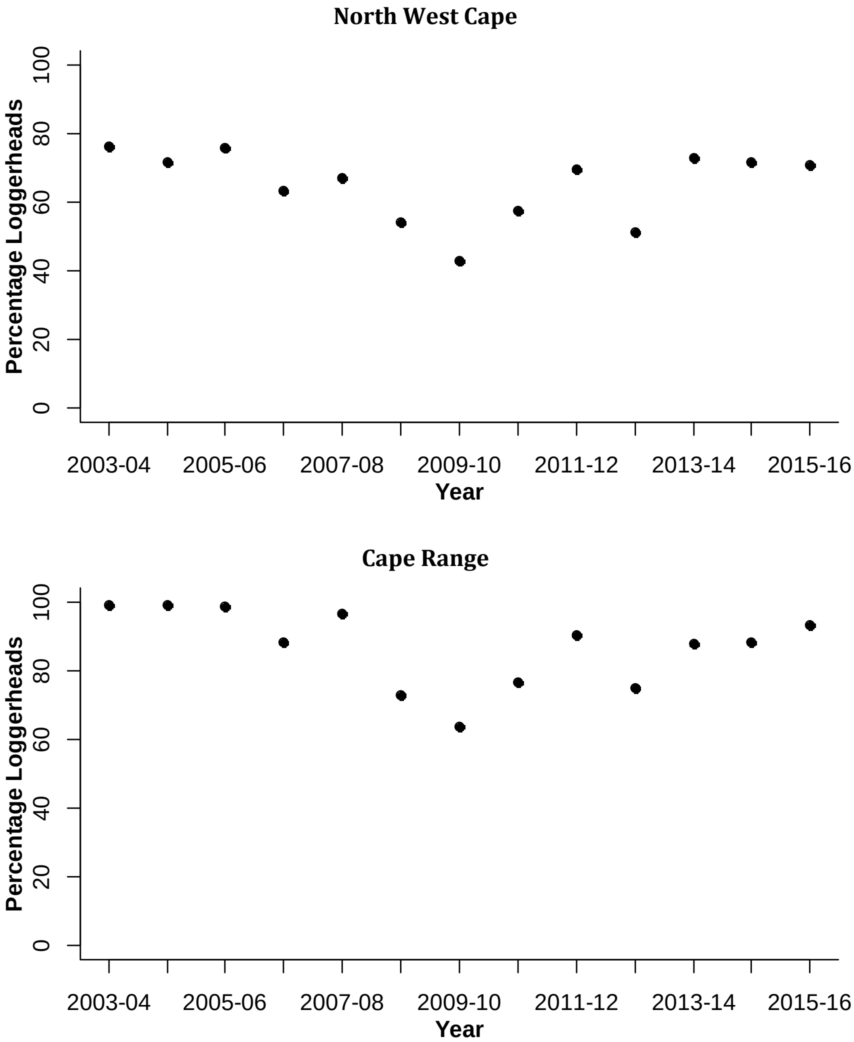


Figure 11. The percentage of loggerhead turtles of all alternative gait turtle species nesting at Ningaloo (hawksbill turtles and loggerhead turtles) for North West Cape and Cape Range divisions.

Variation in spatial distribution of nesting

There was little variation in spatial distribution of annual nesting abundance between sections for green turtles and loggerhead turtles between the 2005-06 and 2015-16 seasons (

Table 8), using a minimum of 24 days of sampling (Table 9). Variation for hawksbill turtles was much higher, and also had a much lower number of nests used to calculate this. The coefficient of variation (as a measure of spread of data, calculated as the standard deviation divided by the mean) was 0.23 for variation between sections for green turtles and 0.37 for variation between sub-sections for green turtles; 0.59 and 0.65 for variation between sections and sub-sections respectively for hawksbill turtles; and 0.28 and 0.38 for variation between sections and sub-sections respectively for loggerhead turtles.

Table 8. Spatial distribution of nesting abundance shown as a percentage of total nesting for suspected nests and all tracks (suspected nests and false crawls combined) .

Species	Factor monitored	Spatial distribution (%)				
		Bungelup	Graveyards	Hunters	Lighthouse Bay	Tandabiddi
Green	Suspected nests	1.3 (s.d.= 0.5)	41.3 (s.d.= 3.3)	34.0 (s.d.= 3.3)	9.4 (s.d.= 1.5)	13.9 (s.d.= 1.7)
	All tracks	1.2 (s.d.= 0.5)	41.2 (s.d.= 3.7)	35.4 (s.d.= 4.6)	11.1 (s.d.= 2.3)	11.1 (s.d.= 3.1)
Hawksbill	Suspected nests	41.3 (s.d.= 17.2)	16.2 (s.d.= 7.7)	25.6 (s.d.= 10.4)	15.8 (s.d.= 7.3)	1.0 (s.d.= 1.8)
	All tracks	20.5 (s.d.= 17.5)	25.5 (s.d.= 10.3)	32.0 (s.d.= 10.0)	18.2 (s.d.= 6.5)	3.8 (s.d.= 3.9)
Loggerhead	Suspected nests	74.9 (s.d.= 4.0)	7.0 (s.d.= 1.4)	12.9 (s.d.= 3.0)	4.6 (s.d.= 1.2)	0.6 (s.d.= 0.3)
	All tracks	72.1 (s.d.= 4.1)	7.9 (s.d.= 2.1)	13.9 (s.d.= 2.5)	5.4 (s.d.= 1.5)	0.6 (s.d.= 0.4)
Unidentified	Suspected nests	33.6 (s.d.= 29.5)	15.1 (s.d.= 16.0)	25.5 (s.d.= 14.5)	15.0 (s.d.= 12.3)	10.8 (s.d.= 13.4)
	All tracks	50.0 (s.d.= 28.4)	14.0 (s.d.= 11.2)	20.0 (s.d.= 11.4)	11.8 (s.d.= 8.6)	4.2 (s.d.= 7.1)

Table 9. Sample sizes for the number of nests used to calculate spatial variation in nesting abundance across Cape Range and North West Cape Divisions.

Season	Number of Nests				Number of days
	Green	Hawksbill	Loggerhead	Unidentified	
2005-06	2133	63	732	24	35
2006-07	2252	99	406	19	37
2007-08	3221	90	678	39	46
2008-09	4360	235	467	26	38
2009-10	354	165	263	8	24
2010-11	1940	145	330	11	24
2011-12	5678	60	368	3	28
2012-13	392	114	281	6	25
2013-14	1691	50	371	16	26
2014-15	459	73	398	19	28
2015-16	504	46	441	4	26

Discussion

Annual nesting abundance

Estimated annual nest abundance for green, loggerhead and hawksbill turtles was relatively consistent over the last three years, and all fell within one standard deviation of the mean nest abundance over the last 12 years.

In those cases where data needed to be interpolated, results need to be used with caution. Interpolating data where not all sections were monitored is likely to have some error due to the nightly variability in distribution of nesting between sectors. Whiting (2008) found at least four subsequent nights needed to be grouped to gain a significant correlation in nesting abundance between sections for green turtles and between 7 and 14 nights for loggerhead and hawksbill turtles.

Trends in annual nesting abundance

Over the last 13 years, green, loggerhead and hawksbill nesting activity appears to have remained stable with no significant positive or negative trends in nesting abundance for any species. Prior to the last three years, nesting abundance of hawksbill turtles showed a significant linear increase (Coote *et al*. 2013). This positive trend has not continued in the last three years. The apparent trend was probably due to a relatively short monitoring period and cyclic changes in nesting abundance caused by the non-annual nesting behaviour or the reasonably high error in abundance estimates for hawksbill turtles of ca. 35%. Species identification may also be a factor if hawksbill turtle tracks were being misidentified or if unidentified tracks were biased towards hawksbill turtles. The number of unidentified tracks is unlikely to impact on green or loggerhead turtle trends given their low relative abundance, but may impact on hawksbill turtle tracks due to the lower abundance of nesting hawksbill turtles.

Population size

Estimates of abundance in the nesting female population give a broad estimate of population size and have a considerable range in estimates due to unknown clutches per female per season and intervals between breeding seasons for turtles nesting at Ningaloo. The estimates also assume that immigration, emigration, births or deaths are not significantly impacting the population size, which may not hold true if it is a recovering or decreasing population or if turtles are shifting nesting to or from adjacent beaches.

The sections of beach monitored over the last three years are estimated to encompass 98%, 71.2% and 50.7% of quantified green, loggerhead and hawksbill turtle nesting respectively within the Cape Range, Bundera/Ningaloo and North West Cape Divisions (Whiting 2008). The remainder of quantified nesting occurs on the sections Boat Harbour, Carbaddaman, Janes Bay and Navy Pier. Navy Pier is thought to host 45.5% of all hawksbill turtle nesting (Whiting 2008), calculated from 27 days of monitoring during the 2003-04 nesting season. If the relative abundance of nesting at Navy Pier is actually this high, then adding monitoring at Navy Pier would substantially reduce error estimates in annual nesting abundances for hawksbill turtles. There is also turtle nesting nearby at Coral Bay, Serrurier Island, Muiron Islands, Waroora Station and other sections of the Cape Range coastline including Bloodwood, South Mandu and Turquoise Bay sections, but the relative abundance on these beaches has not been quantified. Over the last 8 nesting seasons, nesting abundance of loggerhead turtles at Gnaraloo is approximately 38% the size of nesting loggerhead abundance in the monitored North West Cape and Cape Range divisions (Data source= Hattingh *et al.* 2016). Nesting green and hawksbill turtle abundance at Gnaraloo is very low in comparison to Ningaloo (Hattingh *et al.* 2016).

The estimates of population size indicate that the Ningaloo region supports regionally significant numbers of green turtles, with nesting abundance appearing to be approximately five times higher than nearby nesting at each of Barrow Island and the Montebello Islands (Pendoley 2005) and approximately five times lower than nesting green turtle abundance at the Lacepede Islands (RPS 2010). These comparisons were only made for the same seasons and are only broad estimates due to the limited survey coverage. Comparing with longer term data from more distant populations, green turtle abundance at Ningaloo is approximately equal to nesting abundance on Heron Island in Queensland (Limpus 2007), substantially lower than green turtle nesting abundance on Raine Island (Limpus 2007) or the Sabah Turtles Islands (Chan 2006; Whiting 2010), and substantially higher than green turtle nesting on the Sarawak Turtle Islands (Chan 2006), and at Terrenganu Malaysia (Chan and Liew 1999, Chan 2006).

The abundance of hawksbill turtles nesting within the Ningaloo region indicate it is a fairly substantial population, with possibly similar abundance to Barrow Island and the Montebello Islands (Pendoley 2005), but considerably lower nesting abundance than Rosemary Island (Parks and Wildlife 2015), which may host one of the largest hawksbill turtle populations in the world (Limpus 2009).

Loggerhead turtle nesting abundance at Ningaloo is relatively low compared to nesting at Dirk Hartog Island, which had 1853 loggerhead tracks during 13 days in the 2010-11 season and supports a globally significant nesting population (Reinhold and Whiting 2014) but is within the same genetic stock as the Dirk Hartog Island nesting aggregation. Loggerhead turtles nest regularly at the Muiron Islands (Prince 1994; CALM 2005), but nesting abundance is unknown. Loggerhead nesting abundance is approximately three times the magnitude of that on the Woongarra coast in Queensland during 1988-2003 (Limpus 2008), but may be an overestimate since the Queensland population appears to be increasing and data from Ningaloo are more recent.

Temporal distribution of nesting

The apparent peak in nesting abundance between late December and early January is consistent with nesting surveys from 2003-04 to 2007-08 where nightly surveys were conducted for three months (Whiting 2008). The peak nesting period identified during these years was centred on 7 January for green and loggerhead turtles and 9 January for hawksbill turtles (Whiting 2008). Data from 2008-09 seasons through to 2015-16 show no indication of a shift in temporal distribution of nesting. A small shift in temporal nesting distribution or change in kurtosis would be difficult to identify given the survey methods used during the last eight years due to the substantial nightly variation in nesting abundance and the one-month long survey period. Data outside the intensive survey period are limited in use due to the sporadic frequency and often partial spatial coverage of nesting beaches. To gain a more accurate indication of changes in temporal distribution of nesting, monitoring would be needed throughout the nesting season. A better understanding resulting in similar level of expected error could be obtained using an additional two days of monitoring per week throughout the season giving a total of 18 extra survey days (Whiting 2008). This equates to an estimated error (mean + SD) in calculating annual nesting abundance of ca. 7%, 14% and 35% for green, loggerhead and hawksbill turtles respectively. Given the significantly higher nesting recorded on the first nights of surveys for green turtles, I would also recommend walking the beach prior to these two days and crossing all tracks without counting them to ensure the survey nights are only counting tracks from the previous night. Although there was no significant difference between the first and subsequent night's counts outside of the intensive monitoring period for loggerhead and hawksbill turtles, this may have been a result of the dominance in data for the North West Cape, where green turtle nesting dominates with only sporadic loggerhead and hawksbill turtle nesting. Given this, I would also recommend crossing all tracks for all divisions to increase accuracy of counts.

Counts outside the intensive monitoring period indicate that turtles may start nesting in reasonable numbers prior to the presumed start of the nesting season of mid-November. Prior to the 2013-14 season, there were few counts in early November and nesting was estimated to begin in mid-November (Whiting 2008). During the 2013-14, 2014-15 and 2015-16 seasons, counts in early November indicate that green turtle nesting may begin in reasonable numbers before the presumed start of the nesting season of mid-November, but all divisions and sub-sections were not monitored so further monitoring would be required to accurately define the start and ends of the nesting season. Although interpolated nesting abundance indicates reasonably high counts, this may be overestimated by counting tracks that weren't from the previous night's nesting. There may also be substantial error from extrapolating using the expected spatial distribution, as significant correlation between sections was only shown for between four and 14 consecutive days of monitoring (Whiting 2008). To gain a better estimate of the start and end of the nesting season, monitoring could occur two days per week in late October to early November through to late March for one season.

Potential changes between seasons in the peak or shape of the nesting season could also be investigated using the two days per week sampling regime, although this would not be required regularly especially if shifts in nesting peaks are not indicated by the intensive sampling data. Long-term studies of green and loggerhead turtles have shown no significant trends in phylogeny of nesting turtles (Hawkes *et al.* 2007; Dalleau *et al.* 2012), but both studies have demonstrated that sea surface temperature is correlated with the distribution and shape of the nesting season. Dalleau *et al.* (2012) showed warmer sea surface temperatures were correlated with later nesting peaks for green turtles, whereas Hawkes *et al.* (2007) found warmer sea surface temperatures were correlated with earlier nesting and longer nesting seasons. If there are significant changes in sea surface temperatures near Ningaloo, such as from global warming, further investigation of temporal changes would be advantageous.

Nesting success

Since the turtle track monitoring began, nesting success has been estimating using the visual identification of the track and nesting site and whether the track resulted in a suspected nest or false crawl is assessed. To do this takes substantial time as it requires following the track up the beach to the nesting site and assessing the marks in the sand.

If resources are limited in a year or if time is required to monitor other beach sections, an alternative approach could be adopted for these times, where every track is counted and identified to species (without looking at the nesting site) and then a metric is used to estimate the number of suspected nests from the total number of nests. This metric could be obtained either using the overall mean nesting success per species over the last 14 years, or a sampling technique could be developed, with an acceptable level of error, to gain an indication of nesting success. This could potentially leave resources available for monitoring other sections of beach or extend the temporal coverage of monitoring. As nightly variation in nesting success was quite substantial and nesting success was not always uniform throughout the season, a representative sampling technique would need to be developed.

The reasonably low annual variation in nesting success over the last 14 years, with most annual nesting success within 10% of the overall mean, indicates that it would be possible to count only tracks within the nesting season and still obtain relatively accurate estimates of clutches laid. This may be useful if resources are limited in a particular season, or in order to spread resources to focus on other monitoring objectives – such as looking at greater temporal or spatial spread in monitoring to see if there are shifts in abundance and also determine relative abundance at sites that have not been extensively monitored previously.

Species identification

There is likely to be some error in distinguishing between loggerhead and hawksbill turtle tracks due to the similar appearance of the track specifically caused by their alternate gait and overlapping range in track width. Tail drag marks are useful to distinguish between the species, but is not always present or absent for either species. Without verifying species identification by seeing the turtles, there is no way to know the magnitude of the error.

If, however, abundance of loggerhead turtles and hawksbill turtles is cross-correlated as is indicated between hawksbill turtle nesting on Milman Island and loggerhead turtle nesting on the Woongarra coast (Limpus 2008 and Limpus 2009), then we can estimate whether species identification is changing with time and biasing population estimates. Data from the ratio of loggerhead to hawksbill turtles nesting at Ningaloo showed no linear trend, so unlikely to significantly impact on trend detection. There was up to 40% variation in the ratio of loggerhead to hawksbill turtles which indicates either the annual abundance of loggerhead and hawksbill turtles is not always fluctuating in synchrony, or there may be year-specific error in track identification. For example, few hawksbill turtles were recorded relative to loggerhead turtles during the first five years of monitoring. This may have been real or may have been due to observer error and misidentifying turtles based on characteristics used to identify species from tracks. To verify the accuracy of track identification, turtles would need to be observed when they come ashore at night.

The relatively low density of nesting hawksbill turtles, imply that it would be quite labour intensive to verify species identification from tracks and visual observations with sufficient accuracy. From a cost-effective perspective, this is probably not going to give you much greater accuracy given that there is already reasonable inherent error in annual nesting abundance estimates from the current monitoring regime (within ca. 35% for hawksbill turtles and ca. 14% for loggerhead turtles, Whiting 2008). Alternatively, track identification could be assessed using areas thought to have higher density nesting of hawksbill turtles such as at Navy Pier or the ratio of loggerhead turtle to hawksbill turtle tracks should be monitored to look at any trends that may significantly bias any potential trends in the time-series.

Spatial distribution of nesting

Within the core nesting areas monitored regularly, there was no significant shift in nesting distribution between the sections over the last 11 years. The relative distribution on areas outside the core monitored beaches is unknown, with the exception of several years monitoring at Coral Bay and Janes Bay and one year of monitoring at Navy Pier, Carbaddaman and Boat Harbour sections (Whiting 2008).

The sections monitored within the core sampling period are thought to cover approximately 98% of known green turtle nesting with ca. 7% error; 71.2% of loggerhead turtle nesting with ca. 14% error and 50.7% of hawksbill turtle nesting with ca. 35% error. Given the lower density nesting and higher survey error for hawksbill turtles, the spatial correlation was weaker with greater annual variation between nesting sections.

To assess potential shifts in nesting abundance between nesting sites or identification of new nesting areas, areas other than the core monitoring areas could be assessed on a sporadic basis. Given the relatively low annual variability in nesting distribution between the studied areas for green and loggerhead turtles, relative abundance and potential spatial shifts in nesting would be optimally assessed using sporadic surveys conducted every few years as resources allow with relatively high temporal survey coverage. This would give the most accurate assessments as there is greater error in estimating nesting abundance from few counts than there is difference in relative abundance between areas monitored. Temporal survey coverage for areas outside of the core monitoring areas would optimally match the expected error of the current intensive surveys, with either intensive daily monitoring at the peak of the nesting season or monitoring throughout the nesting season. Similar accuracy in estimates could be obtained monitoring two days per week throughout the nesting season (Whiting 2008), which would also identify potential temporal shifts in nesting distribution.

Less survey effort could be used to gain a broader indication of relative nesting abundance on nearby beaches (with higher estimated error), but would require a minimum of four consecutive days of monitoring for green turtles and between 7 and 14 consecutive days of monitoring for loggerhead and hawksbill turtles, as these were the minimum numbers of days required to get significant correlations in nesting abundance between sections (Whiting 2008). This would optimally be done as close to the peak of the nesting season as possible, where the most turtles will be encountered.

Conclusion

The 2013-14 to 2015-16 seasons continued to provide abundance estimates for long-term population monitoring of green, loggerhead and hawksbill turtles nesting within the Cape Range and North West Cape Division.

Nesting abundances for all species are globally significant with population abundance among the highest globally for all species.

Population estimates could be further refined by:

- increasing temporal coverage within the monitored sections to target hawksbill turtle nesting, with monitoring occurring more frequently outside of the core monitoring period between early November through to the end of March
- increasing spatial coverage to include Navy Pier to target hawksbill turtle nesting
- increasing temporal coverage within Cape Range to target loggerhead turtle nesting, with monitoring occurring more frequently outside of the core monitoring period between early November through to the end of March
- increasing spatial coverage to include Janes Bay, Carbaddaman and Boat Harbour sections to target loggerhead turtle nesting
- increasing spatial coverage on previously unmonitored beaches to determine relative abundance and potential shifts in nesting distribution
- increasing temporal coverage within a season to refine the start and ends of the nesting seasons and identify potential temporal changes in nesting abundance

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.

CALM (2005). ‘Management Plan for the Ningaloo Marine Park and Muiron Islands Marine Management Area 2005-2015.’ Conservation and Land Management: Management Plan Number 52.

Casale, P. & Tucker, A.D. (2015). *Caretta caretta*. The IUCN Red List of Threatened Species 2015: e.T3897A83157651. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T3897A83157651.en

Chan, E. H. (2006). Marine turtles in Malaysia: On the verge of extinction? *Aquatic Ecosystem Health & Management*, **9**, 175-184.

Chan, E. H. and Liew, H. C. (1999). Hawksbill turtles, *Eretmochelys imbricata*, nesting on Redang Island, Terengganu, Malaysia, from 1993 to 1997. *Chelonian Conservation and Biology,* **3**, 326-329.

Coote, C., Markovina, K., Prophet, M., Smallwood, C. and Whiting, A. (2013). ‘Ningaloo Turtle Program Annual Report 2012-2013’. Department of Environment and Conservation and the Ningaloo Turtle Program, Exmouth, Western Australia.

Dalleau, M., Ciccione, S., Mortimer, J. A., Garnier, J., Benhamou, S., and Bourjea, J. (2012). Nesting Phenology of Marine Turtles: Insights from a Regional Comparative Analysis on Green Turtle (*Chelonia mydas*). *PLoS One* 7(10): e46920.

Hastie, T. J. and Tibshirani, R. J. (1990). ‘Generalized Additive Models’. Chapman and Hall/ CRC Press, Boca Raton, Florida..

Hattingh, K., Thomson, J., Goldsmith, N., Nielsen, K., Green, A. & Do, M. (2016). Gnaraloo Turtle Conservation Program (GTCP). ‘Gnaraloo Bay Rookery and Gnaraloo Cape Farquhar Rookery, Report 2015/16’. Gnaraloo Wilderness Foundation, Western Australia, www.gnaraloo.org

Hawkes, L. A., Broderick, A. C., Godfrey, M. H. and Godley, B. J. (2007). Investigating the potential impacts of climate change on a marine turtle population. *Global Change Biology* 13, 1–10.

Limpus, C.J. (1985). ‘A study of the loggerhead turtle, *Caretta caretta*, in Queensland’. PhD thesis, University of Queensland, Brisbane.

Limpus, C. (2007). ‘A biological review of Australian marine turtles. 2. Green turtle, *Chelonia mydas* (Linnaeus)’. Queensland Government Environmental Protection Agency, Brisbane.

Limpus, C. (2008). ‘A biological review of Australian marine turtles. 1. Loggerhead turtle, *Caretta caretta* (Linnaeus)’. Queensland Government Environmental Protection Agency, Brisbane.

Limpus, C. (2009). ‘A biological review of Australian marine turtles. 3. Hawksbill turtle, *Eretmochelys imbricata* (Linnaeus)’. Queensland Government Environmental Protection Agency, Brisbane.

Limpus, C.J., Eggler, P. and Miller, J.D. (1994). Long interval remigration in eastern Australian *Chelonia. National Oceanic and Atmospheric Administration Technical Memorandum National Marine Fisheries Service Southeast Fisheries Center* **341:** 85-88.

Limpus, C. J., Carter, D. and Hamann, M. (2001). The green turtle, *Chelonia mydas*, in Queensland: the Bramble Cay rookery in the 1979-80 breeding season. *Chelonian Conservation and Biology* **4(1):** 34-46.

Limpus, C.J., Miller, J.D., Parmenter, C.J. and Limpus, D.J. (2003). The green turtle, *Chelonia mydas*, population of Raine Island and the northern Great Barrier Reef: 1843-2001. *Memoirs of the Queensland Museum* **49(1):** 349-440.

Mortimer, J.A & Donnelly, M. (2008). *Eretmochelys imbricata*. The IUCN Red List of Threatened Species 2008: e.T8005A12881238. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T8005A12881238.en

Parks and Wildlife (2015). 'Another successful year for Rosemary Island hawksbill turtle tagging'. Published: Monday, 07 December 2015. Available online: https://www.dpaw.wa.gov.au/news/item/2191-another-successful-year-for-rosemary-island-hawksbill-turtle-tagging

Pendoley, K. L. (2005). Sea turtles and the environmental management of industrial activities in North West Western Australia. PhD thesis, Murdoch University, Perth.

Prince, R. I. T. (1994). 'Status of the Western Australian Marine Turtle Populations: The Western Australian Marine Turtle Project 1986-1990.' In: Proceedings of the Australian Marine Turtle Conservation Workshop, (James, R. compiler), Sea World Nara Resort, 14-17 November 1990, Australian National Parks and Wildlife Service, Canberra.

Reinhold, L. and Whiting, A. (2014). High-density Loggerhead Sea Turtle Nesting on Dirk Hartog Island, Western Australia *Marine Turtle Newsletter* 141:7-10.

RPS (2010). 'Woodside Browse Turtle Technical Report: Ecology of Marine Turtles of the Dampier Peninsula and the Lacepede Island Group, 2009–2010.' Prepared for Woodside Browse Pty Ltd, Perth, WA. Available online: http://www.woodside.com.au/Our-Business/Developing/Browse/Documents/Environmental%20Impact%20Statement/F33.PDF

Seminoff, J.A. (2004). *Chelonia mydas*. The IUCN Red List of Threatened Species 2004: e.T4615A11037468. http://dx.doi.org/10.2305/IUCN.UK.2004.RLTS.T4615A11037468.en

Vargas, S. M., Jensen, M. P., Ho, S. Y. W, Mobaraki, A., Broderick, D., Mortimer, J. A., Whiting, S. D., Miller, J., Prince, R. I. T., Bell, I. P., Hoenner, X., Limpus, C. J., Santos F. R. and FitzSimmons, N. N. (2016). Phylogeography, genetic diversity, and management units of hawksbill turtles in the Indo-Pacific. *Journal of Heredity* 107(3): 199-213.

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, Exmouth WA.

Whiting, A. U. (2010). Sampling efficiency for monitoring nesting sea turtle populations, PhD Thesis, Charles Darwin University, NT.

Whiting, A., Valentine, C., Spry, C., Waters, M., Bedford, S. and Whiting, S. (2013). 'Nesting attempts and egg deposition for loggerhead turtles at Bungelup, Ningaloo in 2012-13: pilot study.' Report to the Department of Parks and Wildlife, Exmouth district, Exmouth WA.

Whiting, A.U., Chaloupka, M., Pilcher, N., Basintal, P and Limpus, C.J. (2014). Comparison and review of models describing sea turtle nesting abundance. Marine Ecology Progress Series 508: 233-246.

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