

## ABSTRACT

The life cycle of sea turtles is complex and is not yet fully understood. For most species, it involves at least three habitats: the pelagic, the demersal foraging and the nesting habitats. This study investigated the ecology of green and hawksbill sea turtles foraging on two dissimilar reefs in north-western Australia. Aspects of this study included: species, size and sex composition, population size, growth rates, health assessment, available food resources, diet, short-term movements, foraging behaviour and the analysis of blood chemistry. It focused on an assemblage of green and hawksbill turtles on an inshore terrigenous reef (Fog Bay) and a population of green turtles on a shelf-edge platform reef (Ashmore Reef) in north-western Australia. The two reefs were approximately 800 km apart. Turtles were captured by hand, individually tagged, measured and examined before release. The significant contributions to our knowledge of sea turtle biology are presented for each locality as well as those of a more universal application.

### Fog Bay

- 1048 captures were made of 891 individuals
- Fog Bay contained 62% green and 38% hawksbill turtles
- Size structure was dominated by immature turtles: mean size of greens 48.1 cm ccl, mean size of hawksbills 48.7 cm ccl. At least 99.4 % of greens and 86.1% of hawksbills were under adult size
- Species and size composition varied over temporal and spatial scales
- Sex ratios of both species were biased toward females
- Both species occurred in high densities: 200 green/km<sup>2</sup> and 60 hawksbills/km<sup>2</sup>
- Green turtles grew at approximately 1.5 cm ccl/year while hawksbills grew at 2.5 cm ccl/year
- Natural and anthropogenic factors impacted on the health of these turtles
- The foraging area was dominated by algae and sponges
- The diet of the green turtles was dominated by algae
- The diet of the hawksbill turtles comprised algae and sponge
- Both turtle species showed diet selection
- Overlap occurred between foraging niches
- Both species demonstrated short and long term fidelity to feeding sites
- Fog Bay is a critical developmental habitat for green and hawksbill turtles

### Ashmore Reef

- 371 captures were made of 335 individuals

- Ashmore Reef contained 95% green, 3.5% loggerhead turtles and 1.5% hawksbill turtles
- Size structure was dominated by immature greens: Mean size 54.9 cm ccl. At least 93 % were under adult size
- Species and size composition showed temporal and spatial variability
- Green turtles occurred in a high density: 40 green/km<sup>2</sup>
- Green turtles grew over more than twice as fast (4 cm ccl/year) as green turtles in Fog Bay
- Natural and anthropogenic factors impact on the health of these turtles
- The foraging area and the diet of green turtles was dominated by seagrass
- Green turtles showed both short and long term fidelity to feeding sites
- Ashmore Reef is a critical developmental habitat for green turtles

#### General

- The concept of developmental migration has been expanded to include oceanic islands, smaller scale movements into overlapping habitat, and habitats of mixed sized individuals
- Current methods of population estimates are insufficient to cope with large population sizes in homogenous habitat with high turnover rates
- Comparative study areas are useful to examine processes within foraging areas
- More than one capture technique is recommend to remove capture bias
- Blood chemistry has the potential for use in health and nutritional studies in sea turtles when the diet is known

Further studies in more geographically and ecologically diverse habitats are required to better understand the spatial and temporal variability of processes operating within developmental habitats. Such studies would provide valuable comparisons and would assist in population modelling and management of sea turtles.

# CONTENTS

ABSTRACT.....	II
CONTENTS.....	VI
<b>CHAPTER 1. ....</b>	<b>1</b>
<b>GENERAL INTRODUCTION &amp; BACKGROUND LITERATURE .....</b>	<b>1</b>
GENERAL INTRODUCTION.....	1
BACKGROUND SEA TURTLE LITERATURE .....	3
<i>Taxonomy</i> .....	3
<i>Life History</i> .....	4
<i>Global Distribution and Abundance</i> .....	7
Hawksbill Turtles .....	7
Green Turtles .....	7
<i>Distribution of Sea Turtles in the Northern Territory - A Regional Perspective</i> .....	7
Green Turtle.....	9
Hawksbill turtle.....	9
<i>Conservation Status</i> .....	10
<i>Biological Status</i> .....	11
Green Turtle.....	12
Hawksbill Turtle.....	12
<b>CHAPTER 2. ....</b>	<b>16</b>
<b>STUDY AREA AND GENERAL METHODS .....</b>	<b>16</b>
STUDY AREA.....	16
<i>Fog Bay - Primary Study Site</i> .....	16
Geographic Location and Physical Features.....	16
History .....	17
Climate.....	18
Tides .....	18
Marine Plants.....	18
Sea Turtles.....	19
<i>Ashmore Reef - Comparative Study Site</i> .....	19
Physical Features.....	19
History .....	20
Climate.....	21
Tides .....	21
Marine Plants.....	21
Sea Turtles.....	22
GENERAL METHODS.....	22
<i>Sampling Period</i> .....	22
Fog Bay .....	22
Ashmore Reef.....	22
<i>Catch Sectors and Areas and Seasons</i> .....	23
Fog Bay .....	23
Ashmore Reef.....	25
<i>Season</i> .....	26
<i>Capture of Turtles</i> .....	26
Fog Bay .....	26
Ashmore Reef.....	27
<i>Tags and Tagging</i> .....	28
<i>General Measurements</i> .....	28
<i>Gender</i> .....	29

<i>Data Management and Analyses</i> .....	30
<b>CHAPTER 3.</b> .....	<b>36</b>
<b>DEVELOPMENTAL HABITATS &amp; DEVELOPMENTAL POPULATIONS</b> .....	<b>36</b>
INTRODUCTION.....	36
<i>A Review of the Concept of Developmental Migration</i> .....	36
<i>Definitions of Developmental Habitat and Developmental Migration</i> .....	37
Developmental Habitat.....	37
Developmental Migration .....	39
<i>Current Knowledge and Evidence for Developmental Migration</i> .....	41
METHODS.....	43
<i>Species Composition</i> .....	43
<i>Size Class Composition</i> .....	43
Analysis .....	43
<i>Maturity</i> .....	44
<i>Gender</i> .....	44
<i>Recruitment</i> .....	44
<i>Morphometric Measurements</i> .....	44
RESULTS.....	45
<i>Species Composition</i> .....	45
Fog Bay .....	45
Ashmore Reef.....	47
<i>Size Structure</i> .....	47
Fog Bay - Green Turtles.....	48
Fog Bay - Hawksbill turtles.....	50
Ashmore Reef – Green and Hawksbill Turtles .....	51
Comparisons of Populations .....	52
<i>Maturity</i> .....	53
Fog Bay .....	53
Ashmore Reef.....	53
<i>Recruitment Size</i> .....	54
<i>Indication of Emigration Size</i> .....	55
<i>Gender</i> .....	55
Fog Bay .....	55
Ashmore Reef.....	56
<i>Morphology</i> .....	56
DISCUSSION.....	57
<i>Species Composition</i> .....	57
Size Structure .....	59
Recruitment Size .....	61
Emigration Size .....	62
Gender .....	62
Morphology.....	63
<i>The Concept of Developmental Habitat and Developmental Migration</i> .....	64
Origin of Recruits.....	65
Destination of Emigrants.....	67
Mechanisms that Drive Developmental Migration.....	68
<i>Problems in Defining Developmental Migration and Developmental Habitats</i> .....	70
<i>A Problem of Scale in Defining Migration and Habitat</i> .....	72
<i>Implementing Foraging Studies</i> .....	74
<i>The Importance of Studies in Developmental Habitat</i> .....	75
CONCLUSION .....	76
<b>CHAPTER 4</b> .....	<b>102</b>
<b>POPULATION ESTIMATES</b> .....	<b>102</b>
INTRODUCTION .....	102
<i>Relative Estimates</i> .....	103

<i>Absolute Estimates</i> .....	103
Strip-Transect Surveys .....	103
Mark Recapture Studies .....	104
<i>Predictive Models using Existing Frequency of Catch Data</i> .....	105
Recapture rates and length of study .....	105
METHODS .....	107
<i>Mark-Recapture</i> .....	107
<i>Strip -Transects</i> .....	108
<i>Biomass</i> .....	109
<i>Assessment of Population Estimates for Each of the Populations</i> .....	109
<i>Predictive Models Using Existing Frequency of Catch Data</i> .....	110
RESULTS.....	110
<i>Population Estimates</i> .....	111
Hawksbill Turtles Fog Bay.....	111
Green Turtles Fog Bay .....	111
Green Turtles Ashmore Reef.....	112
Hawksbill Turtles at Ashmore Reef.....	112
<i>Predictive Models Using Frequency of Catch Data</i> .....	113
Recapture Rates and Length of Study.....	113
DISCUSSION.....	114
<i>Hawksbill Turtles Fog Bay</i> .....	114
<i>Green Turtles</i> .....	115
<i>Assessment of Methods</i> .....	117
Frequency of Capture.....	117
Jolly-Seber - mark-recapture.....	117
Boat Strip-Transects.....	119
<i>Proportion of Recaptures to Captures - Implications for Foraging Studies</i> .....	119
CONCLUSION .....	120
<b>FIGURE 30 GRAPH TO PREDICT PROGRESSIVE RECAPTURES AT GIVEN CUMULATIVE CAPTURES</b> .....	<b>125</b>
<b>CHAPTER 5</b> .....	<b>126</b>
<b>GROWTH RATES</b> .....	<b>126</b>
INTRODUCTION .....	126
<i>Importance of Growth Studies</i> .....	126
<i>Growth Factors</i> .....	127
<i>Aims</i> .....	128
METHODS .....	129
Growth Models.....	130
<i>Comparisons between populations</i> .....	131
RESULTS.....	131
<i>Growth Rates - Curved Carapace</i> .....	131
Hawksbill Turtles - Fog Bay .....	131
Green Turtles - Fog Bay .....	132
Green Turtles - Ashmore Reef .....	132
<i>Between Species Comparison - Hawksbills and Greens in Fog Bay</i> .....	132
<i>Within Species Comparison - Greens at Fog Bay and Ashmore Reef</i> .....	133
DISCUSSION .....	133
<i>Comparisons between Green Turtles from Fog Bay and Ashmore Reef</i> .....	133
<i>Hawksbill and Green Turtles from Fog Bay</i> .....	135
<i>Growth Rates Compared with Other Studies</i> .....	136
Green Turtles.....	136
Hawksbill Turtles .....	137
CONCLUSION .....	137
<b>CHAPTER 6</b> .....	<b>144</b>

<b>HEALTH, CONDITION AND MORTALITY .....</b>	<b>144</b>
INTRODUCTION .....	144
METHODS .....	145
RESULTS .....	146
<i>Fog Bay</i> .....	146
Cachectic Myopathy .....	146
Parasites .....	147
Fibropapillomatosis .....	149
Boat Strike .....	149
Traditional Hunting .....	149
Commercial Fishing .....	149
Marine Debris .....	150
Predation .....	150
Unknown .....	151
<i>Ashmore Reef</i> .....	151
Cachectic Myopathy .....	151
Fibropapillomatosis .....	152
Harvest .....	152
Marine Debris .....	152
Predation .....	152
Unknown .....	153
Deformities .....	153
DISCUSSION .....	153
CONCLUSION .....	159
<b>CHAPTER 7 .....</b>	<b>165</b>
<b>AVAILABLE FOOD RESOURCES .....</b>	<b>165</b>
INTRODUCTION .....	165
Fog Bay .....	165
Ashmore Reef .....	166
<i>Food Availability and Diet Selection</i> .....	166
METHODS .....	167
Terminology .....	167
Identification .....	168
General Description of Habitat and Food Resources .....	168
<i>Food Resources Study - Fog Bay: Temporal and Spatial Variation (Part 1 Diet Selectivity Study)</i> .....	169
RESULTS .....	171
Description of Habitat .....	171
Fog Bay .....	171
Ashmore Reef .....	172
<i>Food Resources Study - Fog Bay: Temporal and Spatial Variation (Part 1 Diet Selectivity Study)</i> .....	173
Algae .....	173
Sponges .....	174
Seagrass .....	175
DISCUSSION .....	175
Fog Bay .....	175
Algae and Seagrasses .....	175
Sponges .....	176
Ashmore Reef .....	176
<i>Food Resources Study - Fog Bay: Temporal and Spatial Variation (Part 1 Diet Selectivity Study)</i> .....	177
Algae .....	177
Sponges .....	178
Importance of Algal and Seagrass Ecosystems .....	179
Conclusion .....	180
<b>CHAPTER 8 .....</b>	<b>202</b>
<b>DIET : BREADTH, NICHE OVERLAP AND SELECTION .....</b>	<b>202</b>

INTRODUCTION.....	202
<i>Diet of Sea Turtles</i> .....	202
Green turtle.....	202
Hawksbill.....	203
<i>Breadth of diet</i> .....	204
<i>Interspecific Competition and Niche Overlap</i> .....	204
<i>Diet Selection</i> .....	205
<i>Sampling Techniques Available</i> .....	207
<i>Aims</i> .....	208
METHODS.....	209
<i>Diet</i> .....	209
Techniques Used in This Study.....	209
Preservation and Analysis.....	209
<i>Breadth of Diet</i> .....	210
<i>Niche Overlap Between Hawksbill and Green Turtles</i> .....	210
<i>Diet Selection</i> .....	210
RESULTS.....	211
<i>Diet</i> .....	211
Green Turtles - Ashmore Reef.....	211
Green Turtles - Fog Bay.....	211
Hawksbill Turtles - Fog Bay.....	211
<i>Dietary Breadth</i> .....	212
<i>Niche Overlap</i> .....	212
<i>Diet Selectivity - Fog Bay</i> .....	212
Green Turtles.....	213
Hawksbill Turtles.....	213
DISCUSSION.....	213
<i>Green Turtles</i> .....	213
<i>Hawksbill Turtles</i> .....	215
<i>Dietary Breadth</i> .....	216
<i>Niche Overlap</i> .....	216
<i>Diet Selection</i> .....	217
Food Availability.....	218
Physical Limitations.....	218
Nutrient Composition.....	219
Secondary Compounds.....	219
General.....	220
CONCLUSION.....	220
<b>CHAPTER 9.....</b>	<b>226</b>
<b>FORAGING BEHAVIOUR AND MOVEMENT.....</b>	<b>226</b>
INTRODUCTION.....	226
METHODS.....	228
<i>General Foraging Behaviour</i> .....	228
<i>Short and Long Term Fidelity</i> .....	228
<i>Homing Ability</i> .....	229
Homing Ability Detected by VHF Tracking.....	229
<i>Detailed Foraging Movements</i> .....	230
RESULTS.....	231
<i>General Behaviour</i> .....	231
Foraging Behaviour.....	232
Activity.....	233
Foraging Habitat.....	233
<i>Fidelity</i> .....	234
Tag and Release at Same Location.....	234
<i>Homing Ability</i> .....	237
Translocation Experiment - Mark-Recapture.....	237
Translocation Experiment - VHF tracking.....	239

<i>Detailed Foraging Movements</i> .....	241
DISCUSSION .....	243
<i>Feeding Behaviour</i> .....	243
<i>Fidelity</i> .....	245
<i>Homing</i> .....	248
<i>Detailed Movements and Tracking Success</i> .....	249
CONCLUSION .....	249
<b>CHAPTER 10</b> .....	<b>259</b>
<b>ANALYSIS OF BLOOD CHEMISTRY - A RESEARCH TOOL FOR FORAGING TURTLES?259</b>	
INTRODUCTION .....	259
<i>Blood Chemistry and Reference Values</i> .....	260
<i>Uses of Blood Chemistry for Wild Animals - Background</i> .....	260
Diseased, Sick and Malnourished Animals .....	261
Nutritional Studies and Growth .....	262
Reference Values and General Investigation .....	263
Nutritional Assessment.....	264
Health Assessment.....	264
METHODS.....	264
<i>General</i> .....	264
Reference Values.....	265
Correlations .....	266
Gender .....	266
New recruits and resident turtles.....	266
Use of Discriminant Analysis to determine similarity between populations.....	266
<i>Health Assessment</i> .....	267
Comparison Between Healthy and Clinically Sick Turtles .....	267
Comparison of Healthy Turtles With and Without Internal Cysts .....	267
<i>Nutritional Assessment</i> .....	267
Comparison Between Green Turtles from Ashmore Reef and Fog Bay .....	267
Comparison Between Hawksbill and Green Turtles in Fog Bay.....	268
RESULTS.....	268
<i>General</i> .....	268
Reference Values.....	268
Correlations .....	268
Gender .....	269
Comparison Between New Recruits and Resident Turtles.....	269
Overall Comparisons Between Foraging Populations.....	269
<i>Health Assessment</i> .....	270
Comparison Between Healthy and Clinically Sick Turtles .....	270
Comparison Between Healthy Turtles With Internal Cysts and Without Internal Cysts.....	271
<i>Nutritional Assessment</i> .....	271
Comparison Between Green Turtles from Ashmore Reef and Fog Bay .....	271
Comparison Between Hawksbill and Green Turtles in Fog Bay.....	272
DISCUSSION .....	272
<i>General</i> .....	272
Reference Values.....	272
Overall Comparisons Between Foraging Populations.....	274
Correlations .....	275
Gender .....	275
New Recruits .....	276
<i>Health Assessment</i> .....	276
Comparison Between Healthy and Clinically Sick Turtles .....	276
Comparison Between Clinically Healthy Turtles With and Without Internal Cysts.....	278
<i>Nutrition</i> .....	279
Comparison between green turtles from Ashmore Reef and Fog Bay .....	279
Comparison between hawksbill and green turtles in Fog Bay .....	281
<i>Assessment of Blood Chemistry as a Research Tool</i> .....	281
CONCLUSION .....	284



<b>CHAPTER 11 .....</b>	<b>309</b>
<b>GENERAL DISCUSSION .....</b>	<b>309</b>
<i>The Complexity of Foraging Ecology.....</i>	<i>309</i>
<i>Goals, Techniques and Logistics of Conducting Foraging Studies .....</i>	<i>309</i>
<i>Implications for Management of Sea Turtles in North-Western Australia .....</i>	<i>312</i>
CONCLUSION .....	314
<b>REFERENCES.....</b>	<b>315</b>
<b>APPENDIX 1.....</b>	<b>362</b>
<b>WATER TEMPERATURE .....</b>	<b>362</b>
METHODS.....	362
<i>Fog Bay .....</i>	<i>362</i>
Subtidal.....	362
Intertidal .....	362
<i>Ashmore Reef.....</i>	<i>362</i>
RESULTS.....	363
<i>Fog Bay .....</i>	<i>363</i>
Subtidal.....	363
Intertidal .....	363
<i>Ashmore Reef.....</i>	<i>363</i>
DISCUSSION.....	363
<b>APPENDIX 2.....</b>	<b>367</b>
<b>ANNOTATED REFERENCES TO OTHER BLOOD CHEMISTRY STUDIES.....</b>	<b>367</b>
<i>Analysis of Blood Chemistry of Other Wild Species.....</i>	<i>367</i>
<i>Blood Chemistry Analysis Used on Different Species of Sea Turtles.....</i>	<i>368</i>
<b>APPENDIX 3.....</b>	<b>369</b>
<b>DESCRIPTION OF BLOOD PARAMETERS.....</b>	<b>369</b>
BLOOD PARAMETERS.....	369
<i>Elements - Electrolytes and Metals.....</i>	<i>369</i>
<i>Enzymes.....</i>	<i>370</i>
<i>Nutrients or Metabolites.....</i>	<i>370</i>