Flatbacks and foxes: Using cameras to capture sea turtle nest predation

by

Joanne King
Bachelor of Science (Environmental)

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Author’s Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

[Signature]
Abstract

Flatback turtles (*Natator depressus*) are marine turtle species endemic to Australia. There is currently insufficient data to allocate a conservation status for this species by the International Union for Conservation of Nature (IUCN). Predation upon turtle nests is recognised as a key threatening process to marine turtle species (Commonwealth of Australia, 2003) along with a number of other key anthropogenic threats. The Pilbara region in north-west Western Australia has a number of regionally significant rookeries including the Mundabullangana (Munda) Rookery located on the mainland. Fox predation is known to occur at the Munda rookery however the predation rate and impact of predators disturbing nests is unknown.

Physically observing turtle nests daily for signs of predation is time consuming and requires extensive resources to access remote locations. Camera and non-camera sites were installed at the time of oviposition by flatback turtles to monitor the entire incubation period. Daily observations were undertaken and $\chi^2$ tests were applied to determine effectiveness of camera monitoring as opposed to physical observation and impacts upon nests.

Foxes were found to be the primary predator of turtle nests at Munda rookery. The predation rate by foxes was found to be 26% at Munda rookery with 42% of predated nests predated more than once. Foxes were found to be a late term nest predators with 11 out of 19 nests predated in the period of time between post-hatching and pre-emergence. Cameras were found to be significantly better than physically observing turtle nests for incidents of predation. Cameras were also able to provide behavioural data on target species as well as identify avian and other native faunal predators of hatchlings.

Predation of nests at Munda were significant and warrant the implementation of fox mitigation strategies and actions to protect nests. Cameras are a useful tool for monitoring turtle nesting beaches for predators, however, the research location, weather conditions and ease of accessibility are factors which need to be considered, as cameras do require more frequent cleaning in beach
environments than when located in less exposed sites and removal may be necessary during extreme weather events.
Acknowledgements

Firstly I would like to thank my supervisors Dr Peter Adams, Professor Trish Fleming, Dr Bill Bateman and Dr Scott Whiting. The guidance and support has been invaluable. In particular thank you to Trish for your time, effort and patience in walking me through statistics, and to Scott for coming out in the field and camping in the north-west November heat.

I would like to thank Michael Thompson, owner of Mundabullangana station, for permission to access the rookery through your property. As well as station staff Meado, Phil and Gail for all your assistance and information provided throughout the project.

I would like to thank the Department of Parks and Wildlife for providing the opportunity to undertake this project as an honours degree. In particular thank you to my work supervisor Rachael Marshall for your support and encouragement, of without which this study would never have happened. I would also like to acknowledge the North West Shelf Flatback Turtle Conservation Program for providing the funding to purchase the cameras used in this project.

To volunteers Mick Davies and Clem Whittles a huge thank you. The camping conditions; the heat, flies, working during the nights and trying to sleep during the days were extremely challenging. Yet both of you met these challenges with good humour and came back for more. To Phil and Jenelle Paxman your enthusiasm and assistance in the field was fantastic, as were the treats, thank you Jenelle. To Pendoley staff and volunteers, especially Anna Vitenbergs, Anna and Tyrone, it was a pleasure to work alongside of all of you. A special thank-you to the two Anna’s, without your help components of this study would not have been achieved. Thank you to Margie Mohring and Jo Kuiper for providing feedback on my thesis.

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Chapter 1  General introduction

The predation upon turtle nests is recognised as a key threatening process to marine turtle species (Commonwealth of Australia, 2003). Mortality rates of young are high with the period of vulnerability extending from when the egg is laid to when the hatchling reaches the open ocean. Predation is experienced from a range of animals which includes crustaceans, birds, fish, reptiles and mammals. Nest predation by introduced terrestrial vertebrate predators can destroy eggs and hatchlings and places additional pressure upon recruitment rates of a species already under threat from anthropogenic impacts. In Australia the introduced red fox (Vulpes vulpes) has become one such predator impacting upon sea turtle nesting (Limpus, 1971, Limpus, 2007, Butcher and Hattingh, 2013).

1.1  Background

Foxes are known to be a predator of marine turtle nests and hatchlings (Kurz et al., 2012, Baskale and Kaska, 2005, Longo et al., 2009, Mroziak, 1997, Welicky et al., 2012, Limpus, 2007). Foxes excavate turtle chambers removing eggs or hatchlings and in the process can damage the remaining eggs, or leave chambers exposed which results in embryonic mortality through changed temperatures. Foxes are known to raid flatback turtle nests, eating eggs and hatchlings at all phases of the incubation period often damaging more eggs than they ate (Limpus, 1971). Similarly, loggerhead turtle (Caretta caretta) nests were raided by foxes at Dalyan beach in Turkey where the chambers were left fully exposed (MacDonald et al., 1994). At some rookeries sand will fall back into the chamber following disturbance re-covering the eggs which may mitigate some of the impacts of excavation (Limpus, 1971). In semi-arid areas, such as Onslow in the Pilbara, foxes have been observed to predate upon every nest at a low-density nesting rookery after rain events (pers. comms. David Waayers, Imbricata). It is presumed that the wet sand makes excavation easier.
Further south at Ningaloo station, 70% of loggerhead nests were predated by foxes prior to lethal control (Butcher and Hattingh, 2013). At Wreck Rock in Queensland, an estimated 90-95% of turtle clutches were lost to fox predation during 1976-82; following control the predation rate on flatback eggs was reduced to near zero (Limpus, 2007). However this report did not mention what the effects of predation were upon hatchling rates.

The excavation of the egg chamber by foxes can attract other predators, leaving remaining eggs or hatchlings vulnerable to further predation by other species (Welicky et al., 2012). Foxes will also predate upon hatchlings as they travel from the nest to the water’s edge (Brown and Macdonald, 1995, Limpus, 1971). Compounding the effect of fox predation on turtle nests and hatchlings is the fox’s propensity for the caching of food including turtle eggs (MacDonald et al., 1994, Limpus, 1971). This caching behaviour often results in a higher number of eggs or hatchlings being taken than if predation were only to satiation.

There is a lack of published material relating to the impact foxes may have when digging into a nest of hatchlings when a number of hatchlings are killed but not recovered by the fox. A potential issue may be an increase in subsurface mortality, where deceased hatchlings become an obstruction to hatchlings below, preventing them from digging their way out of the chamber to the surface. Subsequently these trapped hatchlings may die after energy resources were expended or by being caught in high temperature sand through daytime.

Turtle research often includes human-mediated disturbance related to removing, counting eggs and recovering the nest (Miller, 1999). This activity may have the effect of attracting foxes to a newly laid nest or may deter fox predation by changing scents and visual look of the finished covered nest. While sensory cues used by foxes during foraging has been researched (Spencer, 2002, Dawson et al., 2014), the potential role of people covering nests acting as a visual or olfactory cue is unexplored.
Placement of objects on beaches has had a mixed result for predator attraction globally. Flags have been utilised to successfully deter the crab-eating fox (*Cerdocyon thous*) from nests in Brazil (Longo et al., 2009), yet have been found to cue to racoons to nest locations (Mroziak et al., 2000).

### 1.2 Overall aim of this thesis

This study aims to provide information for management agencies on the predation level upon flatback nests at Munda rookery, variation in the impacts sustained by nests due to predation and to provide data on predator species and behaviour. Remote cameras are utilised to compare their effectiveness as a monitoring tool in sea turtle nest predation against current practices as well as provide data on predation and predator behaviour. It is anticipated the information provided will be used to develop strategic management actions to conserve this and other nesting population of turtles.

Key questions include:

**Hypothesis 1:** Red foxes are a significant source of mortality of eggs and hatchlings at the flatback rookery at Mundabullangana station

1) What is the predation rate of flatback turtle nests at Munda Rookery?

2) Does human and predator mediated disturbance impact on remaining eggs and hatchlings within the nest?

**Hypothesis 2:** Remote cameras are more effective than direct observation for recording introduced predator activity at sea turtle nests.

3) Are remote cameras more effective than direct observation to confirm predation events on monitored turtle nests?
4) Are cameras a useful tool for capturing predator activities?

1.3 Thesis structure

Chapter 2 begins with a description of flatback turtle biology and pressures impacting upon the survival of the species. The red foxes’ introduction into Australia and biology is outlined. The chapter finishes with an outline of monitoring techniques for turtle nest predation.

Chapter 3 outlines the study site, experimental design and methods used. The results are presented and discussed.

Chapter 4 contains the conclusion, future study options and recommendations are presented.
Chapter 2  Flatback turtle biology

Flatback turtles (*Natator depressus*) are listed as ‘Vulnerable’ under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999 and as ‘data deficient’ under the IUCN red list. Flatbacks are a large marine turtle considered endemic to Australia. Although known to forage in the waters off the Australian continental shelf, Papua New Guinea gulf and Indonesia waters, the only known nesting occurs on Australian beaches (Limpus et al., 1988, Limpus, 2007). Nesting occurs on islands and the mainland from the North West shelf in Western Australia, across northern Australia including the Kimberley region, Northern Territory, and Northern Queensland and South to Bundaberg in Queensland (Figure 2.1) (Pendoley et al., 2014, Limpus, 2007, Whiting et al., 2009, Hamann et al., 2009, Limpus et al., 1989).

![Figure 2.1](image_url)-Distribution of flatback nesting beaches: sourced from Limpus (2007)
The life span of flatbacks is currently unknown; however Parmenter and Limpus (1995) calculated a minimal female adult lifespan of 30.5 years, with sexual maturation occurring at approximately 20 years (Limpus, 2007). The majority of the flatback life cycle occurs within the ocean but, being oviparous, they emerge onto beaches to lay their eggs. For nesting flatbacks exhibit strong migratory behaviour with some travelling over a thousand kilometres between foraging grounds to breeding sites (Limpus et al., 1983, Limpus, 2007). Flatback females show a high fidelity to their chosen nesting beaches, returning to the same, or nearby beaches to lay clutches during a season and in successive seasons (Limpus et al., 1984, Pendoley et al., 2014, Limpus, 2007, Schäuble et al., 2006).

There is an average gap of 2-3 years between breeding cycles for females; however, this gap can range from 1 - 5 years (Limpus, 2007, Limpus et al., 1984, Parmenter and Limpus, 1995, Schäuble et al., 2006, Pendoley et al., 2014). Throughout a nesting season the female will lay up to 4 clutches of eggs with an average inter-nesting interval of approximately 14 days. The nesting activity of a season demonstrates a bell curve, with activity beginning slowly with the early season nesters, rising to a peak when all females are nesting, then declining as the early nesters finish and leave. Hatchling emergence shadows the same bell curve as incubation takes approximately 6-7 weeks (Limpus, 2007).

Flatbacks nest by using all four flippers to create a large depression in the sand, known as body pitting. They use their back flippers alternately to dig a chamber where the eggs will be deposited. After oviposition, females cover the chamber with sand using their back flippers, and will then use all four flippers to camouflage the clutch by flicking sand backwards while gradually moving forwards, creating a long ‘fluffed’ mound of sand under which the chamber and surrounding area is covered (Fig.2.2). This covering results in the clutch depth at the top of the eggs ranging between 28 cm to 41 cm from the surface (Limpus, 2007, Whiting et al., 2009).
Figure 2.2-Photo of a female flatback turtle flicking sand behind her as she covers and camouflages the egg chamber creating the nest.

Mean clutch size range varies from 46.6 eggs (Pendoley et al., 2014), to 57.0 (Sutherland and Sutherland, 2003) with most rookeries averaging approximately 50 per clutch (Parmenter and Limpus, 1995, Limpus, 1971). Eggs are spherical and an average of 5cm in diameter, with some variations in size between rookeries (Limpus, 2007). The eggs will successfully incubate in sand temperatures ranging from 25.5°C – 35.5°C (Hewavisenthi and Parmenter, 2002). Successful nests need to be in a well ventilated substrate that is not subjected to flooding and is of low salinity and high humidity (Limpus, 1971, Hewavisenthi and Parmenter, 2001, Hewavisenthi and Parmenter, 2002).
Eggs in a single clutch can hatch over a number of days with emergence usually occurring at night (Limpus, 1971, Koch et al., 2008). Hatchlings are vocal, making a ‘chirping’ sound in the egg and nest (Guinea et al., 2015), and are known to demonstrate synchronous emergence, the act of waiting below the surface and emerge to the surface in a group (Koch et al., 2008). Upon emergence hatchlings make their way down the beach to the water guided by low elevation light horizons, typically created by moon reflection on the ocean (Limpus, 2007). They will then swim offshore for a number of days using energy stores in the internalised yolk sac before beginning to feed. Upon commencement of foraging the hatchling phase is considered over (Limpus, 2007). Unlike other sea turtles, flatback hatchlings do not have an oceanic dispersal phase in its life cycle, but remain primarily within the Australian continental shelf (Walker and Parmenter, 1990, Limpus, 2007).

2.1  Population pressures and impacts on flatback turtles

The Recovery Plan for Marine Turtles in Australia recognises a number of key threats to marine turtle conservation in Australia. These include both global and local influences that directly and indirectly impact on adult turtles, hatchlings and eggs and are summarised in the following sections.

2.1.1  Climate change/increasing temperatures

Increased temperatures associated with human-induced climate change will potentially have significant impacts on the sex ratio of flatback turtle hatchlings. As with other sea turtles, flatbacks possess pivotal temperature sex determination (Hewavisenth and Parmenter, 2000). This is the temperature which will produce an even ratio of female to male offspring. Lower than this temperature will increase the male ratio whilst a higher temperature will favour more females (Wibbels, 2003). A sustained increase in temperatures would continually skew the ratio towards females thus having a negative effect upon future populations (Hawkes et al., 2007). Limpus (2007) found the pivotal sex-determining temperature at the south east Queensland rookery ‘Mon Repo’ to be 29.3°C. In a laboratory setting flatback eggs incubated at a constant 29°C produced all male
hatchlings and eggs incubated at 32°C produced all females (Hewavisenthi and Parmenter, 2000). In tropical northern Australia, flatbacks were found to be more adaptable to higher sand temperatures and dry sand conditions; however, nests’ still produced a high female ratio of hatchlings (Hewavisenthi and Parmenter, 2002, Howard et al., 2015). One study identified flatback populations as having a low to medium (eastern half of Australia) and medium (western half) level of resilience to increasing temperatures (Fuentes et al., 2013). As temperatures increase, flatbacks may adapt by moving further south over time, or differences in seasonal breeding habits and locations may mitigate some of the impacts predicted under different climate change models; however, there is a high likelihood of skewing male to female recruitment at some rookeries (Poloczanska et al., 2009). The flatbacks’ long term survival will depend upon how quickly the species can adapt to rising temperatures before skewed hatchling sex ratios cause major population impacts.

### 2.1.2 Commercial fishing

Commercial fishing is a global and local threat which has had significant impacts upon turtle populations. Being migratory, flatback turtles cover long distances at all ages thus encountering commercial fishing operations in Indonesian and Papua gulf waters. Longline fishing, trawling, gill nets and discarded or lost fishing nets have all contributed to turtle mortality (Poiner et al., 1990, Guinea and Chatto, 1992). Longline fishing for pelagic fish species includes the use of a main line, set with floats, many kilometres in length with multiple branching lines running from it. Thousands of baited hooks are attached to the branching lines. Feeding turtles ingest the baited hooks or the hooks get caught on their bodies subsequently leading to drowning when the line is hauled in (Lewison and Crowder, 2007). While attempts to design hook types to prevent turtle by-catch have been implemented, deaths still occur (Stokes et al., 2012). The use of trawl nets and gill nets has also contributed to flatback mortalities (Guinea and Chatto, 1992, Limpus, 2007, Lewison and Crowder, 2007). Both these types of nets frequently cause entrapment or entanglement of turtles and result in drowning. The development and implementation of strategies including Turtle Exclusion Devices
(TEDs) fitted into trawling nets providing the turtles an escape hatch when caught, and net attendance rules, there have been a reduction in turtle mortality in these industries (Flint et al., 2015, Brewer et al., 2006).

### 2.1.3 Marine debris

Marine debris is defined as any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment and is a major environmental concern (UN Environment Program, 2009). Ocean currents cause transportation of debris away from entry point into neighbouring territorial waters. Plastics are recognised as the most hazardous to sea life with a significant amount of research recording their detrimental impacts on marine turtles (Schuyler et al., 2014a, Wedemeyer-Strombel et al., 2015, Chaloupka et al., 2008, Katsanevakis, 2008). Lost and discarded fishing nets have been reported as a major source of turtle mortalities. Floating through the oceans, turtles become tangled within the ropes and lines often resulting in death (Kiessling, 2003). Degrading nets break apart and result in small particles which can be mistakenly ingested by turtles. Turtles are known to ingest soft plastics which are thought to be mistaken for jellyfish, a common food source for many species (Schuyler et al., 2014b). As plastics degrade into smaller particles these are also ingested by juvenile turtles mistakenly thought to be small jellyfish or plankton (Schuyler et al., 2012). The plastic builds up in their gut causing blockages and results in disease and potentially death (Katsanevakis, 2008). Discarded tyres, cloth straps, string, plastic and burlap are other items which have been found to cause entrapment or entanglement resulting in drownings or disease (Schuyler et al., 2014a, Wilcox et al., 2015, Katsanevakis, 2008, Laist, 1997).

### 2.1.4 Habitat loss

Coastal development along beach foreshores has the potential to change or remove nesting habitats completely. Construction of rock or concrete walls, groynes and jetties have altered natural sand
movement on some nesting beaches resulting in loss of nesting beaches over time (Fletcher et al., 1997). Foreshore development along the dunal systems prevents the landward migration of beaches in the event of sea level rises or erosion through intense storm activity and can raise sand temperatures through removal of coastal vegetation (Fish et al., 2008). This loss of nesting beaches may require turtles to move to potentially less productive beaches where the sand composition, hydric and gas exchange environment is sub-optimal for successful incubation and hatching.

2.1.5 Industrial activities

A component of coastal development may be the use of dredging. Dredging is the excavation of the sea bed and its deposition elsewhere, typically using vacuum pumps and/or diggers. Often utilised to keep channels navigable for shipping it is also used for port expansion, beach nourishment (the act of replenishing sand lost from currents or erosion) or contaminant removal. Flatbacks are vulnerable to dredging as they rest on soft bottom sea beds that can be in excess of 40 meters deep staying under for up to an hour and a half at a time (Sperling et al., 2010). Flatbacks unable to get out of the way of the suction nozzle are susceptible to entrainment, being drawn into the suction nozzle and hose resulting in injury or death as has been found in research by Goldberg et al. (2015). Chain and ridged deflectors on drag heads have been used to mitigate this issue and can reduce the numbers of turtles entrained but do not completely prevent entrainment (Banks and Alexander, 1994, Goldberg et al., 2015).

2.1.6 Lighting

Development often introduces artificial lighting into an area. Turtle hatchlings are sensitive to light and rely on natural low horizon light, which is often the moon’s reflection upon the ocean, to guide them to the water’s edge (Limpus, 2007). Even if development does not result in direct loss of habitat, increased lighting can have detrimental impacts on hatchlings ability to make it to the ocean. Artificial lighting attracts hatchlings as they emerge from the sand and try to make their way to the
water. They can become mis-orientated, moving in the wrong direction or disorientated, walking in circles (Witherington and Martin, 2000). This causes them to spend more time on land using energy reserves and elevating the risk of predation. Increases in lighting from sources on the ocean such as ship lighting also have potential impacts on hatchlings. Hatchlings can be attracted to this light and potentially cause a higher risk of ocean predators from being in artificially lit waters (Thums et al., 2016).

2.1.7 Anthropogenic impacts

Recreational activities such as vehicle use, camping and fishing on nesting beaches can have direct and indirect impacts to nesting. Vehicle use on beaches may result in direct mortality through running over emerged hatchlings as well as the compaction of sand from the weight of vehicles. The compaction of sand can prevent the hatchlings digging upwards to the surface resulting in increased subsurface mortality (Hosier et al., 1981). Vehicles driving over nests can completely destroy nests (Brown and Macdonald, 1995). Ruts from tyre tracks become difficult obstacles for hatchlings to climb over increasing the time hatchlings remain on the beach creating a higher risk of terrestrial predation (Brown and Macdonald, 1995). Increased night time activities such as camping and fishing usually includes lighting which, as discussed above, influences the hatchlings ability to find the sea, increasing energy expenditure and their exposure to predation. Repeated disturbances to a nesting female turtle will result in nesting multiple attempts, which wastes energy and may even result in her attempting to nest at a different, potentially less productive beach.

2.1.8 Predation

Increased human habitation near nesting beaches can also result in an increase in predators of nests and hatchlings. Frequently, an increase in human habitations correlates to an increase in domestic dog and cat presence. In addition to domestic animals, the presence of humans also correlates with an increase in native and introduced wildlife associated with human habitation such as Silver Gulls
(Chroicocephalus novaehollandiae), corvid species, varanid species, dingoes (Canis lupus dingo), feral cats (Felis catus), pigs (Sus scrofa), wild dogs (Canis lupus familiaris) and red foxes (Vulpes vulpes) in response to increased resources such as food and shelter (Welicky et al., 2012). The presence of these species, and frequently the increase of these species in relation to human habitation, can lead to an increase predation on nests and hatchlings (MacDonald et al., 1994). Predation by introduced terrestrial vertebrate predators upon nests, destroying eggs and hatchlings, places additional pressure upon recruitment rates of a species already under threat from anthropogenic impacts (Table 2.1.). In Australia, the red fox has proven to be a nest predator of turtle nests (Limpus, 1971, Limpus, 2007, Butcher and Hattingh, 2013). In response to the impacts of foxes the Recovery Plan for Marine Turtles in Australia recognises foxes as a key threat to turtle nesting in Australia (Environment Australia, 2003).
Table 2.1-Example of vertebrate turtle nest predators and impacts.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Species</th>
<th>Location</th>
<th>Predator</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longo et al. (2009)</td>
<td><em>Caretta caretta</em>, <em>Eretmochelys imbricata</em>, <em>Lepidochelys olivacea</em></td>
<td>Brazil</td>
<td>Crab eating fox</td>
<td>22.8% nests predated</td>
</tr>
<tr>
<td>MacDonald et al. (1994)</td>
<td><em>Caretta caretta</em></td>
<td>Turkey</td>
<td>Red fox</td>
<td>89% nests predated</td>
</tr>
<tr>
<td>Welicky et al. (2012)</td>
<td><em>Caretta caretta</em>, <em>Chelonia mydas</em></td>
<td>Florida</td>
<td>Racoon</td>
<td>22% nests predated from 20 years of survey data</td>
</tr>
<tr>
<td>Yerli et al. (1997)</td>
<td><em>Caretta caretta</em></td>
<td>Turkey</td>
<td>Red fox</td>
<td>62.5% predation of unprotected nests</td>
</tr>
<tr>
<td>Whytlaw et al. (2013)</td>
<td><em>Natator depressus</em>, <em>Eretmochelys imbricata</em>, <em>Lepidochelys olivacea</em></td>
<td>Australia</td>
<td>Pig (introduced)</td>
<td>33.5% nests predated</td>
</tr>
<tr>
<td>Whiting et al. (2009)</td>
<td><em>Natator depressus</em></td>
<td>Australia</td>
<td>Dingo</td>
<td>Minimum 1 clutch per night</td>
</tr>
<tr>
<td>Mroziak (1997)</td>
<td><em>Caretta caretta</em>, <em>Florida Racoon</em>, <em>gray fox</em></td>
<td>Florida</td>
<td>Racoon, gray fox</td>
<td>26% nest predated</td>
</tr>
<tr>
<td>Leighton et al. (2011)</td>
<td><em>Eretmochelys imbricata</em></td>
<td>Barbados</td>
<td>Mongoose (introduced)</td>
<td>27% nests predated over 5 year survey period 22 of 66 nests in CTA and screen experimental study</td>
</tr>
<tr>
<td>Lamarre-Dejesus and Griffin (2013)</td>
<td><em>Caretta caretta</em></td>
<td>South Carolina</td>
<td>Coyote</td>
<td>95% nests predated</td>
</tr>
<tr>
<td>Bain et al (1997)</td>
<td><em>Caretta caretta</em>, <em>Chelonia mydas</em>, <em>Dermochelys coriacea</em></td>
<td>Florida</td>
<td>Racoon, armadillo (introduced)</td>
<td>70% nests predated</td>
</tr>
<tr>
<td>Butcher and Hattingh (2013)</td>
<td><em>Caretta caretta</em></td>
<td>Australia</td>
<td>Red fox (introduced)</td>
<td></td>
</tr>
<tr>
<td>Fowler (1979)</td>
<td><em>Chelonia mydas</em></td>
<td>Costa Rica</td>
<td>Dog, coatis, turkey vulture</td>
<td>39.7% nests predated</td>
</tr>
</tbody>
</table>

2.2 The red fox in Australia

The red fox is a member of the Canidae family, a small omnivorous species between 3 and 8kg.

Foxes are primarily nocturnal but can also be crepuscular and use dens or refuge sites such as hollow logs, thick growth, rabbit burrows or caves during the day (Saunders et al., 1995).
Foxes are opportunistic hunters and scavengers and are known to eat hunted prey, carrion, plants and insects (Macdonald, 1987). They forage using sight, smell and hearing cues and can exhibit surplus killing traits and cache food either by burying it or hiding it under leaf litter or debris (MacDonald et al., 1994, Kay et al., 1999). Foxes may rely upon these caches as a food source during times of limited resources or to feed young (Kay et al., 1999, MacDonald et al., 1994, Thomson and Kok, 2002, Short et al., 2002).

The red fox in Australia breeds once a year, usually mating in winter with pups born predominately through August and September. A male and female will pair for a season or more. The female will bear pups and may have subordinate daughters to help with rearing. They can have litters of up to 10 pups, though the usual average is around 4 (Saunders et al., 1995). Sub adults reach sexual maturity at 1 year and begin dispersal during late summer continuing through to winter and the onset of mating. Foxes generally live up to 6 years in the wild, living in pairs or small family groups that occupy defined home ranges (Macdonald, 1983, Saunders et al., 1995). The size of the home range depends upon the resources available and climatic variability and foxes are known to show flexibility in changing home range boundaries (Lucherini and Lovari, 1996, Meek and Saunders, 2000).

The red fox was released in Australia in the mid-1800s for recreational hunting and became established in southern Victoria during the 1870s (Saunders et al., 2010, Saunders et al., 1995). Their impact upon livestock was recognised early and they were first given pest status in 1894 in Victoria and declared a noxious animal in parts of NSW in 1903 (Saunders et al., 2010). A combination of the foxes generalist diet, high fecundity and climatic adaptability, allowed them to spread rapidly throughout Australia (Saunders et al., 1995). Foxes are known to inhabit a variety of habitats including lightly wooded modified landscapes associated with farming and arid, alpine and urban areas (Saunders et al., 1995, Saunders et al., 2010). Foxes now occupy 76% of Australia and are a declared pest in all states and territories (Figure 2.3).
In addition to being an agricultural pest, foxes also have had a devastating effect on Australia’s native fauna. Native species with a weight range between 35gm and 5500gm are most at risk (Saunders et al., 1995, Short and Smith, 1994, Mcleod, 2004). Since European settlement of Australia 30 terrestrial mammal species have become extinct and foxes are considered to have been a factor for 13 of these species (Woinarski et al., 2015). Another 76 threatened species listed under the EPBC Act 1999 are considered at risk from foxes (Department of Environment Water Heritage and Arts, 2008). The economic cost of foxes to Australian agriculture and environment in 2004 was estimated to be $227.5 million (Mcleod, 2004).

### 2.2.1 Predation monitoring of turtle nests

Typically predation events are established through directly monitoring the nests for activity, identifying predators by the tracks left imprinted at the nest site, scats and egg or hatchling remains.
left at the site (Brown and Macdonald, 1995). A nesting beach may be monitored daily, every second day, weekly or intermittently dependent upon the location, availability of people and other resources. Typically beach monitoring is done in early morning walks when tracks are still fresh and before the sun heats the sand causing it to lose form. In addition, sand plot monitoring on beaches and tracks adjacent or leading to the beaches can be used to identify species and activity using a passive activity index (Engeman et al., 2003, Engeman et al., 2005). Increasingly remote camera traps are being used in place of traditional research techniques, such as sand plot monitoring, to provide the data of abundance, occupancy and activity for target species (Towerton et al., 2011, Sarmento et al., 2009, Bengsen et al., 2011, Ballard et al., 2014).

Camera trapping is a growing field which has facilitated the gathering of new biological data (Fleming et al., 2014). By using an infra-red sensor to trigger the camera, animals can be photographed or filmed without the need for people to be in the vicinity. New animal species have been discovered, rediscovered, and behavioural activity recorded including cryptic or trap wary species (Swann and Perkins, 2014). This information has increased knowledge about wildlife by image capture and video recordings which are reported through a number of mediums including scientific papers and websites. Although the technology is continually evolving and advancing, a number of issues occur in the use of cameras which introduce questions about their reliability. Functionality varies across makes and models and includes differences in accurate detection of target species, quality of images, capture speed, weather proofing and robustness of device, which, combined with user error in the set-up, can result in missed detections (Meek and Pittet, 2014). Cameras are an effective, labour efficient tool for detecting foxes and that sites could be monitored for months at a time (Vine et al., 2009). However, there were limitations for cameras when trialled against other fox detection methods in terms of the incidence of false negatives, waning camera efficiency and disparity between models (Vine et al., 2009). While many of these limitations are improved through the constant advancement of technology, there remain limitations such as the lack of a heat signature triggering a response when animal and ambient backgrounds are similar (Swann and Perkins, 2014).
Additionally, game cameras are primarily designed to target larger game species such as deer and restricts monitoring for smaller, cryptic species e.g. reptiles (Swann and Perkins, 2014).

Many species, including foxes have been shown to be able to detect the infra and ultra sounds emitted by camera traps as well as detect the infra-red flash which may result in avoidance of cameras by some species and bias study results (Meek et al., 2014). Additionally, the potential for a large number of photo or video material requires a significant amount of time and effort for the user to analyse which may not have been factored into during planning. Despite these concerns, researchers are continually testing the suitability of camera trapping against established monitoring and survey methods and improving the collection of wildlife data (Glen and Dickman, 2003, Vine et al., 2009). Daily monitoring can become logistically difficult and expensive if undertaken in remote areas over a given length of time. Yet with camera traps a site can be monitored continuously for months at a time without requiring people to be on site (Vine et al., 2009).

Utilising camera traps for monitoring of turtle nest and hatchling predators is an area of increasing interest. Avian predators of flatback hatchlings were identified on Bare Sand Island using video and still images (Giuliano et al., 2014). Coyotes (*Canis latrans*) have also been captured on camera predating hatchlings which had emerged from the nest and were making their way to the water Eskew (2012). Remote camera traps are utilised in Parks and Wildlife nest and predation monitoring at 80 Mile beach and Ningaloo, Western Australia (*unpublished Dept. Parks and Wildlife*). To date, there is a minimal amount of published literature relating to the use of camera traps in the beach environment for turtle nesting, however preliminary studies indicate this monitoring technique could be applicable.
Chapter 3  Impacts of fox predation upon sea turtle nests using remote cameras as a monitoring tool

Munda is well known as a regionally significant flatback population, with nesting female tagging studies first initiated in the 1980’s. Foxes, a known primary nest predator, were identified to be active in the area and predate upon nests in the late 1990s (unpublished Dept. Parks and Wildlife). Intermittent fox monitoring and control was conducted, however, in recent years, monitoring of fox activity has not been undertaken and the current rate of predation upon flatback nests is unknown. It is also unknown what level of impact predation is having upon the eggs and hatchlings remaining in predated nests.

Munda is a remote rookery, adjacent to Mundabullangana, a pastoral property over an hour’s drive from the nearest town, and three hours from the nearest state conservation agency office, Department of Parks and Wildlife. The resources required to undertake daily beach surveys to establish predation activities are considerable. Factors including labour, travel, camping or accommodation hire contributes to high costs of surveys aimed at establishing predation rates and impacts, which requires implementation over several consecutive weeks as a minimum. The use of remote cameras to monitor sites and fauna activity has become an established tool in wildlife management and has particular advantage in remote sites. The camera, once installed, will capture activity for up to months at a time, requiring battery, card and other functioning checks as determined by the environmental conditions it is operating in. Of particular interest is the cameras success to monitor cryptic wildlife, such as the red fox, which has been well documented in scientific research (Vine et al., 2009, Towerton et al., 2011, Dawson et al., 2014). Remote cameras have the potential to improve efficacy in turtle nest predation monitoring, providing information on the rate and impacts of predation as well as behavioural activity of predators, however, camera performance in a beach environment needs to be evaluated.
3.1 Materials and Methods

3.1.1 Study site

This study was conducted at Munda rookery, located over three beaches adjacent to Mundabullangana pastoral station in the Pilbara region, north-west Western Australia (Fig.3.1). The Pilbara is a remote area of Western Australia covering over 500,000 square kilometres with a population of 67,503 people in 2014 (Australian Bureau of Statistics, 2015). Two main coastal town centres, Karratha and Port Hedland are more than 1500 km by road from the capital Perth. The closest town to the Munda rookery is Port Hedland; approximately 70km by road to the pastoral station turn off. Access to the rookery is via Mundabullangana station, along a further 50km of dirt tracks. The area has a semi-arid climate with summer maximum temperatures averaging 36 °C with highs often >40°C. Mean rainfall is 317 mm per year, often associated with summer storm events (Bureau of Meteorology climate statistics, Port Hedland Airport). The region is subject to cyclonic activity which can lead to significant beach erosion. The three beaches of the Munda rookery are Cowrie beach (approximately 3km in length), Victory beach (approximately 500m in length) and Munda beach (approximately 11km in length of which nesting occurs on the eastern 6km). The rookery is flanked by river systems at the northeast end of Cowrie beach and the south west end of Munda beach. The river systems are minimally-branched mangrove-lined estuaries of seasonal flow with some permanent and semi-permanent waterholes along their lengths. The coastal zone is characterised by low energy sandy beaches with predominately high secondary dunes interspersed with rocky platform shelves and has a wide intertidal zone consisting of a sand and rocky platform substrate.
Munda is a flatback turtle nesting area with a summer breeding season there is an estimated 1,861 nesting females per year making the rookery a regionally-significant nesting population and the largest on the Pilbara mainland (Pendoley et al., 2014). Cowrie beach has been divided into two sections for the purpose of this study, the western end of Cowrie having high density nesting and the eastern end low density nesting. Victory beach has high density nesting and Munda beach is low density nesting on the eastern end with no nesting seen to occur on the western half over the two seasons of the study.

### 3.1.1.1 Management history

The turtles at the Munda rookery have been studied for a number of years. Turtle tagging was carried out by Department of Parks and Wildlife (formerly Conservation and Land Management, CALM) from 1986/87 to 2004/05 nesting season. From the 2005/06 nesting season to present Pendoley Environmental Pty Ltd have undertaken monitoring programs at this site (Pendoley et al., 2014).
The threat of fox predation on flatback nests was recognised at Munda in the late 1990s’ and 1080 baiting by the Department of Parks and Wildlife was undertaken on an *ad hoc* basis from 2002 onwards. The significance of the Munda rookery was subsequently recognised and the area was included as a site under the Western Shield Fauna Recovery Programme which commenced in 2007. Western Shield was implemented by the Department of Parks and Wildlife and consisted of targeted and regular 1080 baiting of foxes in areas of high conservation value. Targeted monitoring and baiting for foxes occurred along the fore dunes on a strip of unallocated crown land (UCL) adjacent to the pastoral property under this programme (Speirs, 2008).

The Western Shield baiting program was suspended at the end of the 2009-2010 turtle season at the request of the adjacent Landholder. The Landholder requested further information relating to nest predation such as extent and spatial distribution before control strategies are re-instated.

Currently management of foxes on the Munda Rookery is limited. Mundabullangana staffs undertake opportunistic control of foxes on the pastoral lease through ground shooting and 1080 baiting around water points for wild dogs over summer was carried out up to the 2013/14 season (*pers. comm.* Meado, Station Manager). Wild dog 1080 baiting by the Department of Agriculture and Food occurs on adjacent pastoral properties to Mundabullangana. Poison baiting is targeted at wild dogs but foxes may also take baits, however the rate of incidental bait take by foxes is unknown.

### 3.1.2 Experimental approach

Two camera trap surveys were undertaken in 2013 and 2014 at the Munda Rookery. The 2013 survey was a pilot study (year 1) to identify predator species, predation levels and if camera monitoring in a beach environment would be feasible. The 2014 survey (year 2) expanded on year 1 and included modifications to camera set up and experimental design.
3.1.2.1 Year 1 (2013)

The year 1 survey was a pilot study examining the predation impacts upon flatback nests using remote cameras focused over the nests. Remote cameras were deployed at 34 nests at one camera per nest along Cowrie, Victory and Munda beaches covering approximately 11 kilometres of coastline. Sites above the highest tide mark were chosen at random. Cameras were attached to upright metal star pickets situated 3m from the centre of the egg chamber. Metal star pickets were chosen due to their sturdiness in comparison to plastic star pickets and helped to prevent blurred images from wind force vibration. They were also less likely to be disturbed by a turtle forcing their way past it. It is acknowledged that the choice of metal star pickets may cause some magnetic interference with hatchlings (Irwin et al. 2004). Sites were accessed using a quad bike to move equipment and cover distances effectively; the bike was driven below the high tide mark and not used during highest tide peaks.

![Figure 3.2](image)

*Figure 3.2*- Year 1 camera site set-up to monitor flatback turtle nest. Camera is attached to an upright star picket approximately 40cm above the surface.
This projected utilised Reconyx Hyperfire 600 remote cameras with either Delkin 32GB or SanDisk 16GB cards with a bank of 12 lithium batteries. The Reconyx HC600 uses a Passive Infrared (PIR) motion sensor to activate the trigger, relying on a difference in ambient and animal’s temperatures and movement across more than two detection zones (Figure 3.4b)Cameras were set to take three consecutive photos per trigger event with no delay between triggers i.e. rapidfire. This allowed sufficient images to assist species identification and determine behaviour. Cameras were set to record 24 hours for the entire length of deployment with date, time and site number records stored for each photo.

Photos were manually viewed as jpeg files and observations of all species were recorded using Microsoft Excel 2010. A capture event was defined as a series of images with a time interval of 30 min between the previous and next group of images of the same species (Dinata et al., 2008). Fox behaviour was categorised as walking through, sniffing, predation (i.e. digging at nest site and/or consuming eggs and hatchlings) and scent marking. Predation was defined as an attempt to enter the nest regardless of the attempt being successful or not.

Cameras were attached using thick cable ties at approximately 40cm high, adjusted for slope. Cameras were angled horizontal to the surface and orientated in a southerly direction to avoid sunrise and sunset glare which can cause false triggers (Fig.3.2). This arrangement was considered best to capture fox, cat, dingo and dog activity, the primary targets for this study. A northerly aspect was avoided to prevent waves activating the trigger. Vegetation was removed to prevent false triggers when required. Cameras were inspected every two weeks where screens were cleaned, batteries and SD cards were checked and replaced if necessary.

Egg counts were completed on 15 of the 34 nests. This involved moving the nesting female off the nest once she begun to fill in the chamber after laying. The clutch was uncovered, eggs removed, counted and returned to the chamber with a small piece of flagging tape at the bottom of the chamber, to confirm nest presence at exhumation. The nest was then re-covered. The area above the
clutch was marked to assist with orientation of camera installation, and then removed. The date; time and GPS location of each nest was also recorded.

Sand plot monitoring was initiated to evaluate fox activity on the beaches and the property, yet discarded due to human traffic interfering with tracks. A cyclone towards the end of the season meant the cameras were retrieved prematurely and the study was incomplete; data from year 1 has only been used where comparable. Unless year 1 (2013) is mentioned, then results and discussion refer to data collected during 2014 (year 2).

A separate turtle tagging study was in progress during the same period as the cameras were deployed in year 1. Researchers were on the Cowrie and Victory beaches overnight for at least 2-3 hours each side of the high tide. Cowrie beach had five researchers, split into three groups consisting of two pairs and a single person. The beach was split into three sections and each group worked a section on foot. Victory beach had two researchers working the entire beach on foot.

### 3.1.2.2 Year 2 (2014)

Year 2 was undertaken in the 2014 nesting season. A total of 31 camera sites and 38 non camera sites were installed with 69 sites in total. Non-camera sites were introduced to test whether the presence of camera traps affected predation rates and to compare camera trapping with physical observation for capturing predation events at nesting sites. The rate of nest predation is presented as the percentage of nests where predator activity was evident.

Sites were established along the Cowrie, Victory and Munda beaches. Monitored beaches were classified into two nesting area densities; high (>2 nests per 10 m) and two low (≤2 nests per 10 m). The density classification for each beach was assigned based on counts carried out at the start of the project when monitoring equipment was being installed. Cowrie west and Victory beaches were classified as high density nesting areas and Munda and Cowrie east beaches were classified as low density nesting areas (Fig. 3.3)
All camera sites were marked with a steel picket located 3m from the egg chamber (Fig. 3.4a). In year 2, the camera setup was altered based on issues identified during the first year. Cameras were attached near the top of a steel picket using thick cable ties, approximately 1.3m above the surface and angled with the camera focused downwards (Fig. 3.4a). The specified detection zone of the remote camera was aimed directly at the surface above the chamber (Fig. 3.4b). The result was that in most frames the sky was not in view, which eliminated sunrise and sunset triggers so orientation of cameras could be more easterly or westerly if that suited the site. Less vegetation was captured in frames so very little vegetation needed to be removed. Cameras were orientated from south easterly, to southern to south westerly direction; northern orientation was avoided to prevent false triggers from tidal movement. Non-camera sites were marked with a wooden stake located 1m from the egg chamber orientated in a direct line from ocean to nest, stake and dune.
Figure 3.4-a) Year 2 camera trap set up. Camera is approximately 1.3m above the surface, focused downwards with sensor trained on the surface above the egg chamber. b) Camera trap showing temporary marker placed over the egg chamber on a monitored site with an approximation of a Reconyx Hyperfire600 detection zone overlayed upon picture.

All stakes and pickets had a specified site number recorded on them using paint pens. Cameras and stakes were installed either immediately after nesting or before the nights nesting session finished. If there was a delay between laying and site installation then the area was checked for predator activity and recorded.
Two techniques were used to count eggs at each of the 69 sites. The first technique had egg counts where the clutch was uncovered, eggs removed, counted and returned to the chamber with a small piece of flagging tape at the bottom of the chamber, to confirm nest at exhumation after incubation completed, and re-covered. The second technique involved filming actual egg drop at oviposition. This was achieved by lying behind the nesting female and using a Panasonic Lumix camera to record actual egg drop into the nest. When the turtle began to cover the nest, a person would stay in situ holding a marker above the chamber, placing it into the sand once the turtle had moved far enough forward that she would no longer disturb the marker. The person could then move away from the area and return to finish site set-up after the turtle had left. The count by video could then be re-checked for accuracy at a later time. The two techniques were undertaken to test predation across naturally turtle covered and human covered nests.

The Cowrie west beach had 17 non-camera and 14 cameras sites. The Cowrie east beach had four non-camera and four camera sites. Victory beach had 15 non-camera and 11 camera sites. Munda beach had two non-camera and two camera sites. Eggs counts at 21 of the 69 sites were conducted using video recording. Of the videoed sites, ten had remote cameras while 11 were non camera sites (Table 3.1).
Table 3.1 – Overview of numbers of nests monitored throughout this study.

<table>
<thead>
<tr>
<th>Beach ID</th>
<th>Tagging activities</th>
<th>Beach nesting density</th>
<th>Total monitored sites</th>
<th>Monitored with camera</th>
<th>Monitored with no camera</th>
<th>Egg count via video (natural nest cover)</th>
<th>Egg count via exhumation (human nest cover)</th>
<th>Daily observations</th>
<th>Weekly observations</th>
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<tr>
<td><strong>Year 1 (2013)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cowrie</td>
<td>To 23 Dec</td>
<td></td>
<td>11</td>
<td>11</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Victory</td>
<td>To 23 Dec</td>
<td></td>
<td>14</td>
<td>14</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Munda</td>
<td>N</td>
<td></td>
<td>9</td>
<td>9</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Total treatments</strong></td>
<td></td>
<td></td>
<td><strong>34</strong></td>
<td><strong>34</strong></td>
<td><strong>0</strong></td>
<td></td>
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<tr>
<td><strong>Year 2 (2014)</strong></td>
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<td></td>
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<tr>
<td>Cowrie east</td>
<td>To 17 Nov</td>
<td>Low</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>8</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Munda</td>
<td>Nil</td>
<td>Low</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Cowrie west</td>
<td>To 17 Nov</td>
<td>High</td>
<td>31</td>
<td>14</td>
<td>5</td>
<td>9</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td>Victory</td>
<td>To 17 Nov</td>
<td>High</td>
<td>26</td>
<td>11</td>
<td>5</td>
<td>10</td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
<td><strong>Y</strong></td>
</tr>
<tr>
<td><strong>Total treatments</strong></td>
<td></td>
<td></td>
<td><strong>69</strong></td>
<td><strong>31</strong></td>
<td><strong>38</strong></td>
<td><strong>21</strong></td>
<td><strong>48</strong></td>
<td></td>
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</tr>
</tbody>
</table>
Measurements of clutch depth were taken with a fiberglass measuring tape before the clutch was covered over. The top of clutch depth was measured from the top of eggs in the chamber to the beach surface. Bottom clutch depth was measured after the eggs were removed from the chamber and was from the bottom of the chamber to beach surface.

Daily physical observations for predation were carried out during early morning walks from when first installed until the 23rd of December on Cowrie east, Cowrie west and Victory beaches. Munda beach was not included in the daily observations. Additional physical checks for predation and tracks were completed on all sites, including Munda beach, every 7-10 days when cameras were cleaned, batteries and cards checked.

Incubation age was calculated for each of the predated nests. Day 39 was determined as the earliest possible hatchling date from images of foxes digging up hatchlings. At the conclusion of the incubation period, nests were exhumed and the contents of the nest were sorted and classified as empty shells >50% intact, live hatchlings in nest, dead hatchlings in nest, undeveloped egg, early stage embryo, mid stage embryo and full term embryo (Miller, 1999).

Turtle tagging in a separate research study was undertaken on Cowrie east, Cowrie west and Victory beaches up until the 17th November in year 2. The presence of a crocodile on Cowrie west beach resulted in the two respective studies were halted for safety reasons and no night time activities were undertaken after this date.

3.1.3 Statistical analyses

Statistical significance was accepted at $\alpha <0.05$. Statistica 12 (StatSoft Inc. 2007) was used for multiple regression analysis.
A $\chi^2$ test was used for analysis to determine if cameras are a better tool for detecting incidents of predation over direct observation, assuming an even proportion of predation events were detected by both methods. A total of 26 sites were included in the analysis where direct observation and camera monitoring occurred concurrently.

The $\chi^2$ test was used for analysis to determine if cameras increased nest predation by assuming that there was an even proportion of observed predation events across both camera and non-camera sites. A total of 62 sites were included in the analysis where direct observation and camera monitoring occurred concurrently.

Multiple regression was used to analyse the relationship between fox activity with the day of the season, the year of study and the number of people on the beach during nights. Daily camera trap rate was calculated from the number of foxes captured on camera per 24 hour period over the same period of time for each year. Camera trap rate is the independent value, the day of the season, the year and people on the beach were used as dependant values.

A $\chi^2$ test was used for analysis to determine if there were increased numbers of expired eggs in a predated nest, assuming that the presence of dead eggs in each nest is even across predated and non-predated nests.

A Mann-Whitney $U$ test was used to determine if the number of expired hatchlings was greater in a nest which had been predated (n=17) than in nests which had not been predated (n=48).

A $\chi^2$ test was used for analysis to determine if there is a difference in predation rates between high and low density nesting beaches by assuming there would be an even proportion of nests predated across high and low nesting density beaches.

A $\chi^2$ test was used for analysis to determine if foxes were attracted to nests re-covered by people as a cue to predate nests, assuming there would be an even proportion of nests predated across human covered and turtle covered nests.
3.2 Results

3.2.1 What is the predation rate of flatback turtle nests at Munda Rookery?

Predation rates were calculated using data from non-camera and camera sites. A total of 19 out of 69 monitored nests were predated. Foxes were responsible for predation on 18 nests, while goannas were responsible for predation of one nest. This resulted in a predation rate by foxes of 26% and total predation rate of 27.5%. Of these predated nests, two were completely destroyed and one nest had one viable egg shell remaining (>50% intact). Four nests were observed to be intact when exhumed for the egg counts, despite images of foxes digging into the nest and eating hatchlings at two of these nests.

There was no significant difference between predation rates on high (14 predation events out of 57 sites; 24%) and low (five predation events out of 12 sites; 41%) density nesting beaches ($\chi^2 = 1.45$, $p = 0.228$).

3.2.2 Does human and predator mediated disturbance impact on remaining eggs and hatchlings within the nest?

There was no significant difference in the number of expired eggs present in predated or non-predated nests ($\chi^2 = 0.24$, $p = 0.621$). The overall average of expired eggs present within nests was $4.54 \pm 5.09$, range $0 - 25$. 
There was no significant difference in the number of expired hatchlings present in predated (n=17, mean 3.47 ± 6.80, range 0-22) or non-predated (n=48, mean 5.54 ± 10.59 range 0 - 42) nests ($U = 334, p = 0.239$). The overall average of expired hatchlings present within nests was $5.00 ± 9.73$, range 0 - 42.

There was no significant difference ($\chi^2_1 = 2.66, p = 0.103$) in predation rates between human covered (16 predated out of 48 monitored sites; 33%) and turtle covered (3 predated of 21 monitored nests; 14%) sites.

Multiple predation events were observed throughout the study. Out of 19 nests predated, eight were re-visited by predators (42%). A total of 17 nests were initially predated by foxes; two were initially predated by goannas (Table 3.2). There were two revisits by goannas on sites which were initially predated by foxes. A fox revisited one site that was initially attacked by a goanna. Multiple predation events were not recorded for the non-camera sites.

<table>
<thead>
<tr>
<th>Species</th>
<th>Predation attempt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox</td>
<td>Initial</td>
</tr>
<tr>
<td>Fox</td>
<td>17</td>
</tr>
<tr>
<td>Goanna</td>
<td>2</td>
</tr>
</tbody>
</table>

The first predation event was by a fox and occurred on day 12 of incubation. The last initial predation event on a nest was also by a fox and occurred on day 47 of incubation. There was an overall preference by foxes to predate nests in the hatchling phase, when the hatchlings have begun to emerge from the eggs but are still within the chamber. Seven predation attempts by foxes occurred while chambers still contained eggs, and 11 from the period of time when hatchlings would have begun to emerge from their shells. Three of the goanna predations occurred during egg phase, and one attempt at predation occurred post fox predation during hatching phase (Fig. 3.5).
3.2.3 Are remote cameras more effective than direct observation to confirm predation events on monitored turtle nests?

There was a significant difference between technique (remote cameras and direct observation) (n=26) for identifying incidents of predation ($\chi^2 = 8.86, p = 0.003$). Predation events were recorded by both remote cameras and direct observation on 4 occasions with remote cameras recording a further 3 predation events which were not detected by direct observation (Table 3.3).

Table 3.3-Predation events by monitoring technique over 26 camera monitored sites.

<table>
<thead>
<tr>
<th>Predation Event Description</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct observation and camera captures</td>
<td>4</td>
</tr>
<tr>
<td>Camera (no observation capture)</td>
<td>3</td>
</tr>
<tr>
<td>Direct observation (no camera capture)</td>
<td>0</td>
</tr>
<tr>
<td>Total predation events</td>
<td>7</td>
</tr>
</tbody>
</table>
There was no significant difference between the number of predation events observed for nests monitored with remote cameras (n=26) and those nests without a camera (non-camera) (n=36) ($\chi^2_{1} = 0.07, p = 0.794$). In comparing predation events between camera and stake (non-camera) sites using direct observation data only, five observed nest predation events occurred at camera nests and six observed predation events occurred on non-camera nests (Table 3.4).

**Table 3.4** Predation events across camera and non-camera sites (stake) as recorded by daily observation.

<table>
<thead>
<tr>
<th></th>
<th>Number of sites</th>
<th>Predation events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>Non-camera</td>
<td>36</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>11</td>
</tr>
</tbody>
</table>

3.2.4 Are cameras a useful tool for capturing predator activities?

Fourteen identifiable mammal and bird species were recorded from 13,306 photo images over 1437 trap nights for year 1 and ten identifiable species were recorded from 13,433 photo images over 1594 trap nights for year 2 (Table 3.5).
Table 3.5—Species captured on camera at turtle nests over years 1 and 2. An independent capture event is defined as a capture with a minimum 30 minute interval between the previous and next group of images for the same species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>Year 1 2013 Capture events</th>
<th>Number of cameras locations (nests)</th>
<th>Year 2 2014 Capture events</th>
<th>Number of cameras locations (nests)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Vulpes vulpes</em></td>
<td>Red Fox</td>
<td>94</td>
<td>24</td>
<td>235</td>
<td>31</td>
</tr>
<tr>
<td><em>Canis lupus dingo</em></td>
<td>Dingo</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Felis catus</em></td>
<td>Cat</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Varanus gouldii</em></td>
<td>Goanna</td>
<td>6</td>
<td>5</td>
<td>41</td>
<td>13</td>
</tr>
<tr>
<td><em>Natator depressus</em></td>
<td>Flatback Turtle adult</td>
<td>37</td>
<td>17</td>
<td>99</td>
<td>26</td>
</tr>
<tr>
<td><em>Macropus sp.</em></td>
<td>Kangaroo</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td><em>Haliastur sphenurus</em></td>
<td>Whistling Kite</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td><em>Chroicocephalus novaehollandiae</em></td>
<td>Silver Gull</td>
<td>4</td>
<td>1</td>
<td>40</td>
<td>17</td>
</tr>
<tr>
<td><em>Corvus sp.</em></td>
<td>Crow</td>
<td>12</td>
<td>9</td>
<td>23</td>
<td>12</td>
</tr>
<tr>
<td><em>Nycticorax caledonicus</em></td>
<td>Nankeen Night Heron</td>
<td>9</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td><em>Aquila audax</em></td>
<td>Wedge-tailed Eagle</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Haliaeetus leucogaster</em></td>
<td>White-bellied Sea Eagle</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Anthus novaeseelandiae</em></td>
<td>Richards Pipit</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Two species of vertebrate nest predators were identified on camera in year 2, the native *Varanus gouldii* and the introduced red fox. Other species captured on remote camera were adult flatback turtles, kangaroos (*Macropus sp.*), Silver gulls (*Chroicocephalus novaehollandiae*), Nankeen Night Herons (*Nycticorax caledonicus*), crows (*Corvus sp.*), White-bellied Sea Eagle (*Haliaeetus leucogaster*), Richard’s Pipit (*Anthus novaeseelandiae*) and Whistling Kites (*Haliastur sphenurus*). In year 1, one dingo and four cats were seen on camera, yet neither species were observed in year 2. In both years Nankeen Night Herons, Silver Gulls, Crows and Kites were captured predating on hatchlings once they emerged onto the surface and making their way to the water and as they were emerging (Figure 3.6a &b). Hermit crabs and seagulls were captured on camera coming in and cleaning up any remains after a nest was predated. The red fox was the most common introduced vertebrate predator caught on camera in year 1 and 2(Fig.3.6c).
There were 235 capture events of foxes recorded on cameras in year 2. Foxes were more active in the first half of the night, with peak active times from 8pm to 10pm and again between 11pm and midnight (Fig. 3.7). Activity decreased briefly between the hours from midnight to 2am, with a brief surge in activity and sharp decline from 5am. There were only two out of a total 235 capture events where foxes were captured on camera out during the day. Foxes were still active on the beach for close to an hour and a half after sunrise yet no capture events occurred until an hour after sunset (Fig. 3.7).

There was a significant relationship between fox activity on the beaches and the date of the field season (p=0.030). An upward trend shows the increase in frequency of foxes being captured on
cameras as the season progresses (Fig. 3.8). There was no significant difference in fox activity and the year of study, and no significant difference for fox activity when people were present or absent on the beaches at night.

Figure 3.8-Scatterplot of camera trap rate against day of the field season.

The longest hatchling emergence, including subsurface to last known emergence time period, was 6 days. This was captured on camera from when a fox dug up hatchlings, taken as day 1, to when hatchlings were emerging from the same nest 6 days later and were predated by Kites, which triggered the camera.

Surplus killing by foxes was observed on camera on four occasions. Foxes were observed digging up multiple hatchlings in a nest, killing them as they were dug up and consuming some but also
gathering as many as four in their mouths and departing (Fig. 3.9). Foxes did not return to collect dead hatchlings left lying on the surface around the nest (Fig. 3.10). Images were captured on two occasions of foxes with mouths full of eggs as they walked through the frame.

**Figure 3.9**-Image of fox about to collect the fourth and last hatchling before departing area.

**Figure 3.10**-Dead hatchlings left at a predated nest.
Remote cameras failed to record fox activity on ten occasions (fox prints were observed at the nest site but with no corresponding images of the fox). No predation events were missed due to a no-trigger event as recorded by either observation or later image capture.

3.3 Discussion

3.3.1 What is the predation rate of flatback turtle nests at Munda Rookery?

The predation rate upon flatback turtle nests at the Munda rookery was found to be 26% of nests. The results of this study were not as high as experienced in rookeries in other regions of Australia and the world where, for example 70% of nests were predated along the Ningaloo coastline, or 89% of nests predated in Turkey (Butcher and Hattingh, 2013, MacDonald et al., 1994). Careful consideration needs to be taken when assessing the predation rates at Munda especially when deciding whether the predation rates are of a significant amount to warrant management intervention.

There was no significant difference in the predation rate across high and low density nesting areas. This result infers the ease of which a fox can find turtle nests irrespective of the nesting density. This result is similar to those found in Costa Rica where dogs were the primary predator of nests (Fowler, 1979). At Munda where low density nesting beaches neighbour high density nesting beaches a similar predation rate across different density beaches has little overall impact as the beaches are considered one population in management of the rookery. However, the finding that foxes can easily locate nests on low density beaches does have implications for recruitment and longevity of the nesting population at other rookeries where the nesting population is low.
3.3.2 What impacts occur to predated nest?

Egg mortality in predated nests was not significantly different to mortality in non-predated nests. This finding is not consistent with the results of Limpus (1971) where it was observed that often more eggs are destroyed in the act of predation by foxes damaging additional eggs, than are consumed or taken. Sand composition and moisture content at the Munda rookery may assist eggs in a predated nest to remain viable. As the study site is in a semi-arid climate it is possible that the eggs suffered little disturbance due to the sand being dry and falling back into the nest as foxes are excavating. This process is described in Limpus (1971) where sand would fall back into the nest as predators are digging, re-covering eggs which were not damaged resulting in them remaining viable.

There were no significant differences in the number of expired hatchlings found in a predated nest as opposed to a non-predated nest. The results did not support the premise that the action of digging into a nest could kill hatchlings below the surface, block hatchlings below from emerging and resulting in higher sub surface mortality rates.

With no significant difference found between the two nest covering practices it indicates that neither the visual and olfactory cues of newly laid nor human covered nests affected predation behaviour of foxes. This finding is strengthened by the lack of predation on nests prior to day 12 of incubation. It is possible that the fox’s inhabiting the study area have not learnt cues to dig up newly laid nests, instead relying on the scent or sound of eggs or hatchlings in the later stages of incubation. Many studies of hatching success utilise methods which requires the filling in of nest chambers by humans and for statistical robustness these studies can continue for multiple years. The result in this study suggests that this monitoring technique does not increase the risk of predation on these nests. This is an important result as attracting predators to nests due to human interference would be an unwanted consequence of research. Caution is needed with this result and future monitoring techniques as foxes are curious and intelligent. It is possible they could learn to identify research activity with a new nest ready for predation.
With 42% of predated nests being re-visited a second time it shows the vulnerability to remaining eggs or hatchlings within. Once breached, the nest is likely an easy target with visual or scent cues attracting the same, or different, foxes to investigate the nests contents. This is consistent with other research, for example Yerli et al. (1997) found 33% of nests were attacked on a second occasion by foxes at Dalyan beach. A 20 year analysis of predation activities in Florida found that once a nest had been predated it had increased the probability of it being predated a second time compared to other nests on the beach (Welicky et al., 2012). This suggests that future management techniques may include re-covering any predated nests found as a way to increase the viability of eggs remaining. If hatchlings are present they could be removed prior to recovering the nest.

### 3.3.3 Are remote cameras a useful tool for monitoring turtle nests for vertebrate predators?

More predation events were captured with camera traps compared to direct observation. The recording of predation events requires the ability of the observer to accurately interpret the signs of a predator including tracks, disturbance of the ground and remains. Environmental factors such as high winds can obscure most if not all of the signs left behind by predators through sand movement thus producing a false negative result for a predator event. The nesting actions of sea turtles in digging and shifting of sand can cover any predator signs also leading the observer to record a false negative. The interpretation of nest predation is further confounded by the removal of eggs or hatchling remains by birds or crabs, as seen in this study, resulting in minimal evidence of the disturbance of nests. The potential recording of false negatives in observation alone can underestimate the predation rate within a rookery. The advantage of cameras in this study was the consistent capture of predation activity, irrespective of weather conditions or scavenger activity.

Camera and observation sites were marked with a star picket and camera or wooden stake. While cameras are demonstrated to make a significant difference in picking up the incidents of predation, importantly, there was no significant difference in predation events for camera and non-camera
sites. This can be interpreted that cameras did not attract foxes to the nests they were focused on. Cameras sites had more sensory cues which did not attract or deter predator species to the site. These cues include visual through infrared flash and olfactory through the ongoing handling when cleaning and checking batteries and cards. Wooden stakes were handled only once when installed and not handled again for the life of the project. The alternate can also be implied that the non-camera sites, placed at 1m distance from the nest, did not attract a higher level of predation. This is not dissimilar with findings from Longo et al. (2009) where flags were used to successfully deter predators. However, Mroziak et al. (2000) found that marking a nest resulted in significant increased predation attempts on nests. It should be noted however that nests in Mroziak (2000) were marked with wire cages which it can be assumed had higher visual and potentially olfactory cues than presented in this study and the predators were raccoons (*Procyon lotor*) (88%) and the gray fox (*Urocyon cinereoargenteus*) (11%). This study found no difference in predation events between sites marked in different ways however the predation rates between marked and completely unmarked sites was not tested here and is an area requiring more research to attain a more comprehensive understanding of foxes predatory behaviour towards turtle nests.

### 3.3.4 Are cameras a useful tool for capturing predator activities?

Results in year 1 and year 2 showed a significant relationship between fox activity on the beaches and date of season. This indicates that fox presence on beaches increases as the season progresses, presumably due to increased hatchling activity. Similar results have been recorded in other studies where nest predations were found to be at the highest in the middle of the nesting season (Welicky et al., 2012). This result is supported by the preference of foxes to predate late term nests as discussed below. Additionally, there is the potential that foxes migrate to the area during nesting season to take advantage of the additional food resources available thus increasing the level of activity on the beaches. Seasonal migration is an area worth further study and would provide information for planning of fox mitigation activities.
There was no significant difference in fox activity between year 1 and year 2 indicating that the water point baiting undertaken by station staff in year 1, and opportunistic shooting of foxes over both years has little effect of fox activity at the rookery. This *ad hoc* approach to pest animal control has been found to be ineffective in studies comparing techniques of fox control in New South Wales where the fox rapidly re-colonised areas after a once-off shooting program (Newsome et al., 2014). It was recommended that an integrated control and monitoring program would be the most successful approach to fox control. This aligns with research by Engeman et al. (2003) where control activities were initiated as required based upon strategic monitoring results and achieved the highest number of loggerhead nests being protected as opposed to preventative damage reduction measures.

Foxes at Munda showed a preference for predating upon late term nests. For foxes, seven predation events occurred while the nest contained eggs, while 11 predation events occurred from the time when hatchlings would have begun emerging from their shells (*Fig.3.2*). The earliest nest predation in year 2 occurred on day 12 which is contrary to other studies where 90% of green turtle (*Chelonia mydas*) nests were attacked by foxes in the first 3 days at Akyatan beach in Turkey (Brown and Macdonald, 1995) and loggerhead nests raided by foxes within the first 48 hours at Dalyan beach in turkey (MacDonald et al., 1994). The results of this study are more consistent with those found by Limpus (1971) that found predation by foxes of flatback turtle nest occur at all stages of incubation, however the study does not indicate whether predation rates increase in relation to incubation period. This result of late term nest predation in this study infers that synchronous hatching, while having benefits in conserving energy (Rusli et al., 2016), combined with flatback hatchling vocalisation (Guinea et al., 2015) may assist predators with locate the nest as the hatchlings wait to emerge below the surface. The earliest incubation period of 39 days in year 2 was consistent with that found by Pendoley et al. (2014) with a range of 39 to 48 days reported.

No-trigger events occurred across different cameras sites indicating that it wasn’t related to fault from a single camera, but likely a result of the camera performance in detecting heat signatures in this particular environment where temperature range was between 25°C and 44°C. In some
instances fox footprints were noticed when another trigger source, such as sand movement from a
female turtle off camera flicking sand in front of the sensor. In other images it may have been a late
trigger as no other sensor source could be discerned. Failures in the sensor activating a trigger means
that care needs to be taken when analysing photos, it is easy to miss tracks, or misinterpret why
there is a false trigger.

Although this study was targeted at recording nest predation using cameras it is worth noting that
hatchling images were only taken incidentally if the camera was triggered by another larger mammal
or bird. This is consistent with research from Bare Sand Island in the Northern Territory investigating
avian predation of flatback hatchlings where cameras were only triggered by the avian predator
(Giuliano et al., 2014). Other unpublished monitoring has shown some cameras are successful in
picking up hatchlings emerging from the sand without the need for a third party trigger (Unpublished
data, E. Young). The Uovision black ops 565 camera was more successful in capturing emerging
hatchlings in comparison to the Reconyx Hyperfire 600 where both cameras were set 1 meter distant
from the nest (pers. comms. E. Young). This is in line with (Meek and Pittet, 2014) research in
effectiveness of different remote camera models. The Reconyx has been a successful model for
inland mammal trapping yet has varying degrees of success for beach environments suggesting
further trials into the effectiveness of different cameras sensors for this environment would be
beneficial.

Foxes were seen to predate a nest, feed and depart with egg in mouth not to return, and feed upon
hatchlings before departing with as many as possible. This may indicate caching activity for both eggs
and hatchlings. This is consistent with results reported by (MacDonald et al., 1994) where foxes
cached eggs of loggerhead turtles at beaches in Turkey. In addition to possible caching activities,
cameras also captured surplus killing behaviour by foxes where dead hatchlings were left lying
around the predated nest. Fox activity mapped over 24 hour time period indicate that night time and
early morning activity of foxes shows the ideal times for planning fox removal activities such as
trapping or spotlight shooting. The ability of cameras to capture behavioural data makes cameras a very useful tool for monitoring.

### 3.4 Limitations of the study

In year 1 sand-plots for establishing an index of fox activity was soon discarded due to high human foot traffic on Cowrie and Victory beaches and the nightly vehicle movements along tracks which were obscuring relevant sand-plot data.

This study in year 1 was suspended early due to tropical cyclone Christine, category 3 at landfall, impacting the coastline nearby on 31st December. Cameras were removed on the 28th December with the nest sites first installed at day 39 of incubation. Although site markers were left in place, upon return only 7 out of 34 site markers remained due to substantial beach erosion. Of these only three of seven nests were found, and only one of these had the eggs counted at time of being laid. Due to the long period of time between the cyclone and revisiting the beaches, the remaining hatchlings in the nest had deteriorated badly and the count is not considered accurate.

In year 2 the original experimental site design was unable to be completed due to health and safety considerations after a crocodile was seen on the beach at dusk. This resulted in all personnel being removed from the beach effectively ending the field work. This resulted with the two low densities nesting sites not having their planned quota of sites.

The camera set up in year 2 was a more successful way to monitor a nest for predation. With the higher aspect of the camera, mounds of sand did not prevent the fox being completely in view when active around the nest. It was easier to see if the fox was successful in predating the nest and what nest contents, if any, were being taken. Birds and other animals were equally clearer to see when in frame. The camera lenses did not get as covered in sand in year 2. This is attributed to the height and angle of the camera as being out of the main range of nesting turtles flicking sand about and being
above and angled which prevented direct impact from windblown sand movement across the surface of the beach.

**Chapter 4  General discussion**

**4.1  Conclusion**

There was not a catastrophic predation rate upon the nesting at Munda, as seen in other regions in Australia and the world, and nests which were predated had varying levels of impacts, only a few were completely destroyed. However, the study only provides a snapshot in time of predation activities. A few considerations should be taken into account when deciding if 26% predation is a significant amount and the level of control and monitoring required.

The Munda rookery is situated in an area that is particularly prone to cyclonic activity. This cyclonic activity needs to be taken into consideration when evaluating the potential effects of a predation rate of 26% on nesting. It is possibly that all nests within the rookery will be lost due to cyclonic activities in certain years. Therefore a predation rate of 26% in non-cyclonic years has a much greater impact upon overall recruitment rates over consecutive seasons.

Flatback turtles are considered data deficient by the IUCN and listed as Vulnerable under the EPBC Act (1999). Monitoring of flatback turtles is most commonly focused on nesting females as a large percentage of the population that congregates to a rookery can be captured and the ease of monitoring in the terrestrial phase of the species life cycle. The ability to collect robust population data between hatchling to reproductive phase is difficult due to the spatial distribution and efficacy of capture methods while animals are at sea. For these reasons, it is difficult to measure the impacts of nest and hatchling loss on population dynamics. Using the current monitoring techniques, the effects of a fox predation rate of 26% at the Munda rookery cannot be assessed in terms of population changes for a minimum of 20 years, when new adults commence nesting at Munda. A
A cautionary approach to mitigating predation pressure should therefore be adopted and management techniques implemented to reduce predation especially from introduced vertebrate pests such as the fox.

Cameras traps successfully recorded incidents of predation and provided information regarding predator activities which may have been missed during direct observations. Predation did not increase when compared against general nest marking techniques of a stake 1m distance from the chamber, though is yet to be tested against controls with no nest marking. While capturing the act of predation, additional data can be gathered to observe predator behaviour which contributes to the knowledge gained about the site or highlighting alternate issues. Once installed, there is no requirement for personnel to be present at the site on a daily basis, unlike direct observations of nest predation. The beach environment is harsh, with wind born sand and salt covering the lenses and requiring frequent cleaning, more so than what may be required in inland locations. Moreover, extreme storm events require the cameras to be removed from the site to prevent inundation and loss. This requires a work force to be located within a reasonable distance enabling the cameras to be serviced regularly and removed at short notice if required. Therefore, cameras have a limited use in remote locations where there is no accessibility by vehicle. Moreover the temperature range experienced on this beach, which would be similar for many locations in northern Australia, can have impacts on the infra-red sensor detection capability resulting in no-trigger events, as experienced in this study. As technology advances this issue may be addressed, until then trials of different makes and models of cameras to find the most responsive for the location would be required.

### 4.2 Future study

Two nest marking practices (stake and camera) were tested against each other in this study. Confounding these results is the lack of controls. Future studies testing marked (camera and stake)
and unmarked nests with eggs counted in the same way on all nests should be undertaken to
determine if human activities are having an impact upon predation rates when undertaking research.

This study used only the Reconyx Hyperfire 600 camera installed using different methods in year 1
and year 2. As the range of cameras on the market are increasing and continually improving
alternative camera types may function better in the harsh beach environment. Cameras with
different sensor sensitivity and noise output may also increase or decrease the number of predators
captured on camera and is an area requiring more investigation.

It is noted throughout this study that camera traps are a useful tool in collecting data relating to the
predation of turtle nest at the Munda Rookery. Further research should aim at developing a fox
activity or predation index using data from cameras on beaches. Research that utilises a defined
number of cameras to develop an index relating to fox activity and predation of nest would be a
useful extension to this study. The development of a predation index utilising camera could greatly
improve management decisions regarding whether or not mitigation activities aimed at the red fox
should be implemented.

There is limited published data about fox populations in the arid coastal area of North West Western
Australia. Research into fox populations, home range, dispersal and seasonal migration in response
to food resources (if any) area need to be undertaken to gain understanding of fox dynamics in
relation to turtle nesting beaches. This research could greatly improve the efficacy of control
programs potentially implemented to conserve turtle rookeries in the area.

4.3 Recommendations

This study found significant predation on Flatback turtle nests at the Munda Rookery however it is
unclear what impact this predation has on the overall population dynamics of the Flatback turtle.
Despite this uncertainty a precautionary approach should be undertaken to mitigate the current
predation levels. It is recommended that fox mitigation activities should be implemented at Munda
rookery to exert consistent downward pressure on the population of foxes in the area. Control activities should be combined with a strategic monitoring program to provide robust data on levels of predation and efficacy of control activities.

It is noted throughout this study that camera traps are a useful tool for collecting data regarding predation of turtle nests by the red fox. Continued development of methodologies using cameras should be undertaken to assist land managers in making decisions regarding management intervention.
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