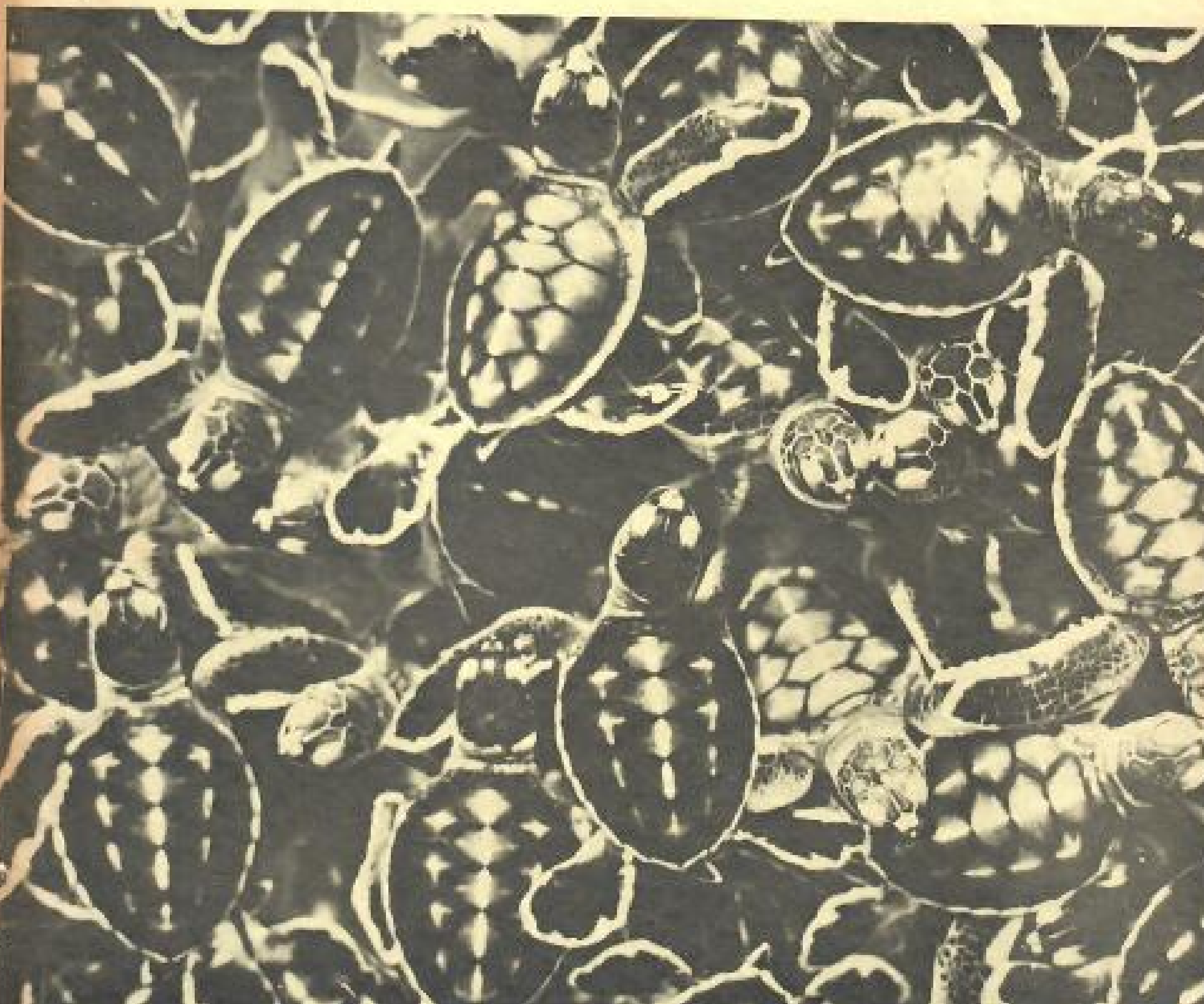
APPLIED ECOLOGY

MANAGEMENT OF TURTLE RESOURCES

Research Monograph 1



JAMES COOK UNIVERSITY OF NORTH QUEENSLAND

MANAGEMENT OF TURTLE RESOURCES.

Proceedings of a Seminar held jointly by Applied Ecology Pty Ltd and the Department of Tropical Veterinary Science

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JAMES COOK UNIVERSITY OF NORTH QUEENSLAND

First published 1980

ISBN 0 86443 010 8

Wholly set up and printed
within the University

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MANAGEMENT OF TURTLE RESOURCES

Contents

THE GREEN TURTLE, *CHELONIA MYDAS*(L) IN EASTERN AUSTRALIA

Colin J. Limpus
Research & Planning Branch, Queensland Natural Parks & Wildlife Service

The early navigators in eastern Australia hunted the green turtle *Chelonia mydas* at every opportunity. Captain Cook's crew landed 21 large turtles in 27 days from the reefs offshore from the Endeavour River while the boat was beached for repairs. This was their first major supply of fresh meat in eleven months. Cook in summarising his Australian experiences commented that there occurred ". . . . . . upon the shoals and reefs great numbers of the finest green turtle in the world . . . ." (Reed, 1969). Sweatman (Allen and Corris, 1977) in describing the return of HMS Bramble to Sydney in 1845 noted "we entered the heads of Port Jackson just as the last pound of bread was being served out, there being only 3 days salt meat left in the ship. Had it not been for the turtle caught at Raine's Is. and the fish caught on the reefs we should have been destitute of food three weeks before".

While initially the green turtle was sought for the sailors' own needs, in later years the emphasis changed. Early this century the serious attempts to commercialise the green turtle resources of the Great Barrier Reef saw the establishment of turtle soup factories on North West Island and Heron Island. Lack of permanent water, bad weather, life on remote islands and the economic depression of the late 1920's caused the closure of these factories.

As the Heron Island turtle soup factory ceased operation in 1929 a Queensland Government fisheries biologist, F. Moorehouse, arrived to study the green turtle nesting biology. His pioneering study provided the basis for drafting protective legislation for green turtles in Queensland. The work of Moorehouse provided the foundation for the more recent long term green turtle research (Table 1) which commenced on Heron Island 34 years later under the supervision of Dr H.R. Bustard. There were continuing sporadic harvests of green turtles from throughout the region for local and overseas markets but the industry never gained much momentum. The industry effectively ceased in 1968 (Table 2) when all turtles in Queensland waters were totally protected by an Order in Council introduced by the Queensland Fisheries Service. This however did not preclude the right of the indigenous peoples living in reserves to take turtles for their own use. They have traditionally done this, almost certainly in significant numbers, since long before European settlement. In recent years through the efforts of Applied Ecology Pty Ltd in the Torres Straits, farming methods are being investigated whereby these indigenous people might exploit the green turtle as a cash crop.

With all the taking of green turtles over the past two centuries since European colonisation there has been no record of the loss of a green turtle population in eastern Australia. Indeed, with the possible exception of Bramble Cay, there has been no instance of even a major decline in nesting populations on any of the rockeries here. This contrasts markedly with the pattern observed in areas such as the Caribbean islands where many colonies disappeared through over-harvesting. Captain Cook's assessment of "great numbers of the finest green turtles in the world" can still be applied to the Great Barrier Reef today.

Table 1: Summary of green turtle research in eastern Australia. Asterisk (*) indicates much of the data gathered is unpublished.

Principal researcher	Period of research	Main study areas and type of research	References to green turtle biology
F.W. Moorehouse	1929-1930	Heron Is: Reproductive biology	Moorehouse (1933)
O.L. and D. Tanis*	1962-1973	Brisbane: Captive rearing	(This study was incorporated into Dr Bustard's general studies. See Bustard, 1972a)
H.R. Bustard*	1964-1973	Heron Is and the Capricorn Group: Reproductive biology	Bustard (1966, 1967, 1969a, b, 1970, 1971a, b, 1974, 1976), Bustard and Greenham (1968, (1969)
		Queensland: General rookery surveys	Bustard, Simkiss and Jenkins (1969), Bustard and Tognetti (1969)
		Torres Straits: commenced Applied Ecology turtle farms	Carr and Main (1973), Smart (1973)
J. Booth*	1960s-1977	Fairfax and Wreck Is: and general underwater and courtship studies	Booth and Peters (1972)
C.J. Limpus*	1968-continuing	Bundaberg coast and Capricorn and Bunker Groups, Heron Is (since 1974) Raine Island: Reproductive biology	Limpus (1975a, b, 1978a, b, c, 1979, in press) Munroe and Limpus (in press)
		Queensland: General rookery surveys	
		Capricorn and Bunker Reefs, Cairns area reefs: feeding ground biology	
Applied Ecology P/L* (currently Dr C.J. Parmenter)	1973-continuing	Torres Straits: Farming, general rookery surveys	Kowarsky (1977, 1978) Parmenter (1977)
		Bramble Cay and Raine Is: Reproductive biology	
		Torres Straits: Feeding ground biology	

Generalised green turtle life cycle:

The following interpretation (Figure 1) is a synthesis of views expressed in the literature and the results, largely unpublished, of the author's own research on green turtle populations throughout eastern Australia. Much remains to be learned of the underwater life of sea turtles.

Research on green turtles in Australia has been summarised (Table 1). Reviews of green turtle research in other countries can be found in Carr (1968), Frazier (1971), Hendrickson (1958), Hirth (1971), Hirth and Carr (1970), Hughes (1974a, b), Parsons (1962), Schultz (1975). See also Gilboa and Dowling (1973).

Table 2: Milestones in the conservation of green turtles in Queensland

Fisheries Acts			
Order in Council	15 Dec 1932	Green turtle: closed season for turtle and egg harvest during months October and November	south of 17°S
Order in Council	7 Sept 1950	Green turtle: year round closed season for turtle and egg harvest	all of Queensland
Order in Council	4 Sept 1958	Green turtle: (i) year round closed season for turtle harvest	south of 15°S
		(ii) year round closed season for egg harvest	all of Queensland
Order in Council	18 July 1968	all turtle species year round closed season for turtle and egg harvest	all of Queensland
Forestry Acts			
Order in Council	22 April 1971	all turtle species (being part of indigenous animal life): total protection of the animal and its habitat	State Forest, Timber Reserve, National Park

Green turtles utilise feeding grounds often far removed from the nesting beaches. With the onset of the breeding season adult males and females migrate to the vicinity of the nesting area where most mating occurs. There is no pair bond between individuals and copulation with a number of different partners during the mating period is probably normal. At the completion of mating the males depart, presumably returning to the distant feeding grounds, while the females come ashore to nest. Most nesting activity is nocturnal. For those beaches fronted by reef flats nesting coincides with the higher tidal levels. Within the one nesting season each female typically lays several clutches at about fortnightly intervals.

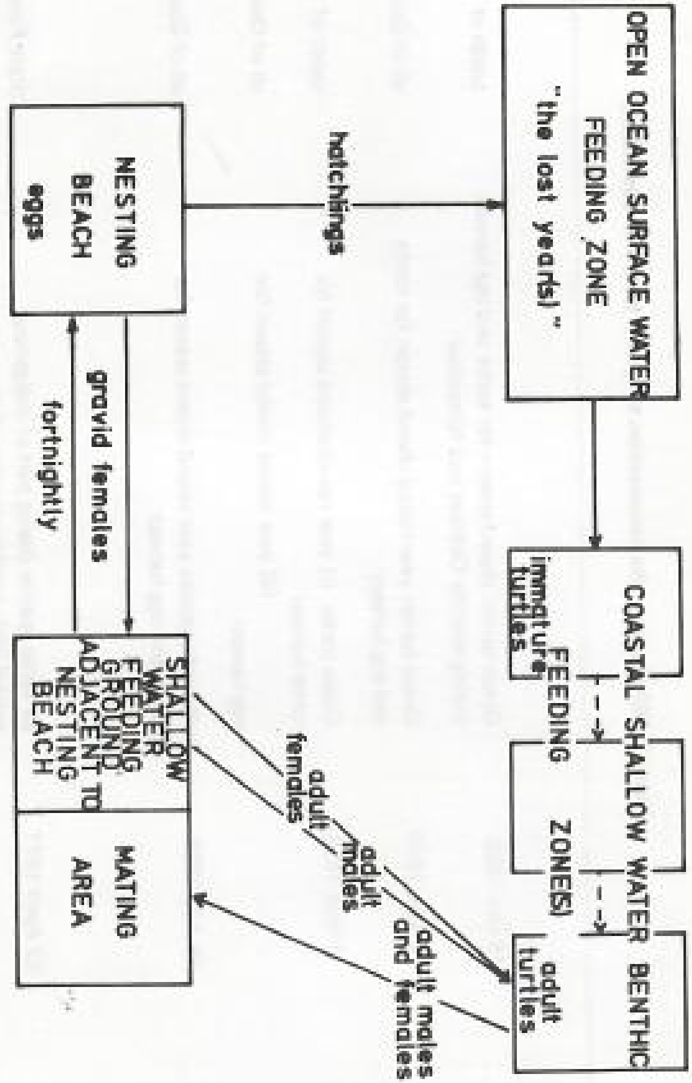

Figure 1. Schematic representation of the life cycle of the green turtle. (after Limpus, 1978b).

Each female usually chooses to return to the same beach or island for the repeated nestings within the one nesting season. However several percent of the females can be expected to lay on more than one beach within less than 100km of their initial nesting site. At the completion of the nesting season the females do not use the adjacent reefs or sea grass pastures as year round feeding grounds but return to their respective distant feeding grounds, presumably to the same area that each left at the start of her nesting migration. After three or more years a small percentage of these females will again breed, each generally returning to nest on the same beach. This behaviour and the annual use of traditional nesting beaches has led to the assumption that a sea turtle returns to nest on the beach of its birth. This behavioural trait is yet to be demonstrated.

Females lay their eggs high up on the beach usually within the vegetated strand. No parental care is exercised. The eggs hatch about 7 to 12 weeks after laying, the incubation period being a function of the temperature of the surrounding sound. The hatchling turtles dig their way unaided and as a group through the 50cm or more of sand to the surface. On surfacing they immediately cross the beach to the sea. This hatchling emergency is almost entirely nocturnal. For most eastern Australian green turtle rookeries only a small percentage of hatchlings is lost to terrestrial predators during the beach crossing. Immediately the hatchlings reach water they begin oriented swimming which takes them away from the beach and into deep water. In coral reef areas when the hatchlings are crossing the reef flat they are probably exposed to their greatest predator pressure. This is a period of substantial transfer to predatory fish of nutrients derived from adult turtles via the eggs and hatchlings. On reaching the deep water areas the hatchlings continue to swim away from the beach and this activity presumably brings them under the effect of the open ocean currents where they drift for the first few years of their life. The newly hatched turtles do not take up residence on the reefs adjacent to where they were born.

When the hatchlings disperse from the nesting beach they are virtually lost to study for the next few years. Archie Carr refers to this as the "lost year of the sea turtle". While in this oceanic phase the turtles presumably feed on the macroplanktonic algae and animals at the surface. The young turtles "reappear" at about the size of a large dinner plate (curved carapace length 35-40cm, age undetermined). At this size and larger they take up residence in the shallow water habitats of the continental shelf, feeding principally on benthic plants such as green, brown and red algae and sea grasses. Animals especially the macroplanktonic forms such as jellyfish are also taken during these later life phases. These immature turtles may remain in the one feeding ground for extended periods, perhaps years, before moving to another major area. At least several such shifts occur in the life of the turtle in this coastal shallow water benthic-feeding phase.

The age at maturity is almost traditionally given as 4-13 years (based on captive studies). Present studies of wild turtles suggest that more than 30 years will be a closer estimate of their age at maturity.

At no stage in their life are green turtles free of predation, the immature to adult turtles are potential prey to large cod, gropers, sharks, crocodiles and killer whales. In many countries however man continues to be the most significant predator.

Eastern Australian breeding populations:

It is not the function of this discussion to provide a detailed comparison of the mostly unpublished data collected from the various east Australian green turtle populations in recent years. It is to be hoped that the data will be published elsewhere. In broad terms it can be noted that while there are variations between populations nesting at the one rookery in different seasons and between populations from different rookeries, the green turtles of eastern Australia are a relatively uniform group. Thus data from a southern Great Barrier Reef population are used to illustrate green turtle biology and general comparisons made between this and other populations as required.

Most of the eastern Australian coast line and islands have now been surveyed to determine the distribution of turtle nesting. Figure 2 shows the distribution of the significant green turtle rookeries of eastern Australia. The two most important rookery areas are Raine Island together with the associated cays and North West Island in conjunction with the associated islands of the Capricorn and Bunker Groups. In an average nesting season each of these areas can be expected to support a nesting population of several thousand. Smaller rookeries each involving only a few hundred females occur at Bell Cay, No. 7 and No. 8 Sand Banks and Bramble Cay. A substantial rookery but of undetermined size occurs in the southern Gulf of Carpentaria at Bountiful Island and nearby areas. Numerous vague reports of turtle nesting on islands of the Coral Sea have been received. Green turtles appear to be the dominant nesting species on Wreck Reef Cays, Lihou Cays, Diamond Islets, Magdeline Cays, and Willis Islets. Diamond Islets appear to support the most significant nesting population of these latter unsurveyed rookeries.

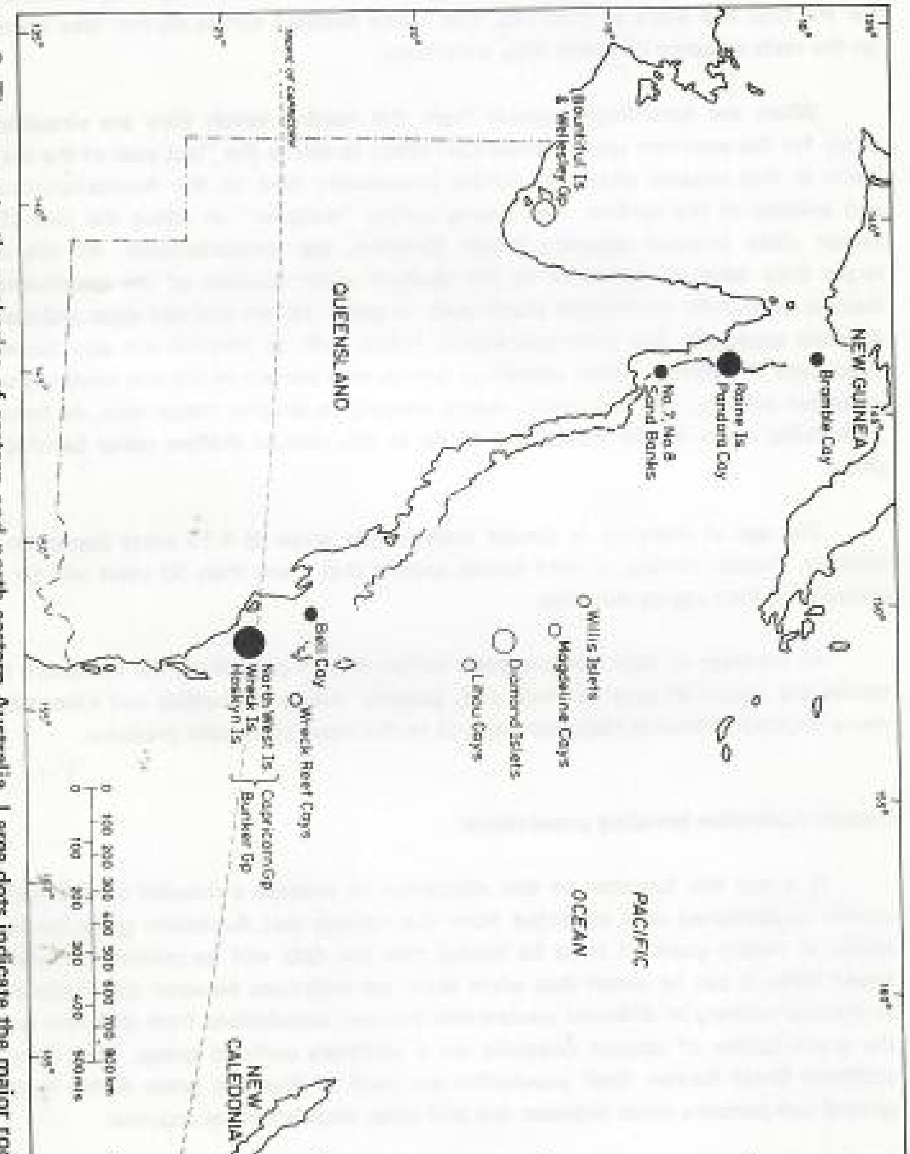

Figure 2. The green turtle rookeries of eastern and north eastern Australia. Large dots indicate the major rookery areas where several thousand turtles nest in an average season. The smaller dots indicate rookery areas where several hundred turtles nest each summer. Green turtle rookeries of undetermined size are indicated by open circles.

The following sequence of turtle activity can be expected in the southern Great Barrier Reef (Figure 3). Courting turtles first appear over these reefs in late August to early September and mating activity reaches a peak in October. After late November mating rarely occurs. Nesting begins in late October, reaches a peak in December to January and ceases in late March to early April. In the northern Great Barrier Reef the breeding season follows a similar though more expanded pattern, each activity beginning earlier and ending later. At Raine Island isolated nestings can be expected in any month outside the main summer nesting season. In the southern Gulf of Carpentaria nesting appears to occur year round with at least a mid-year peak of activity.

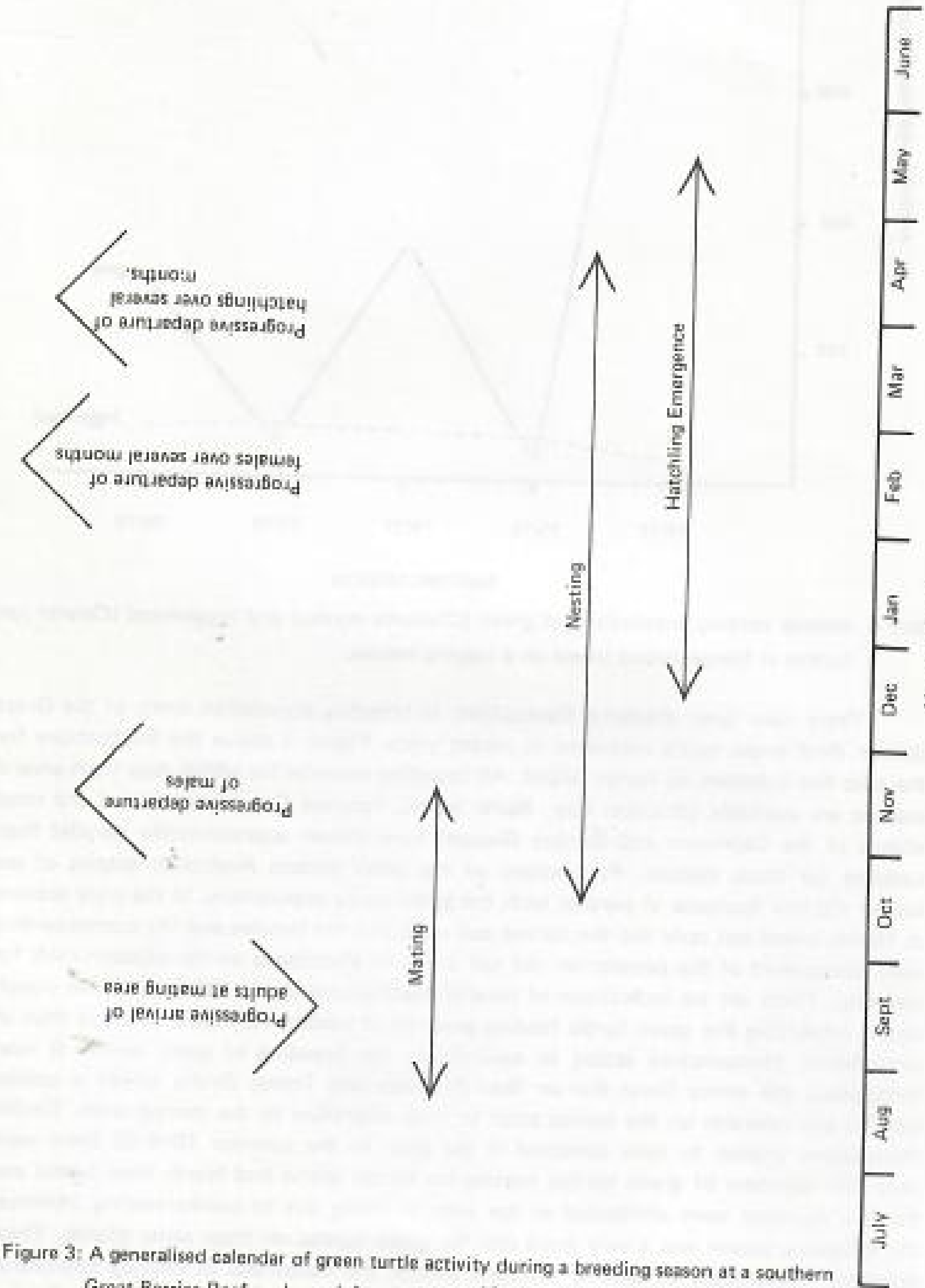

Figure 3: A generalised calendar of green turtle activity during a breeding season at a southern Great Barrier Reef rookery. (after Limpus, 1978b)

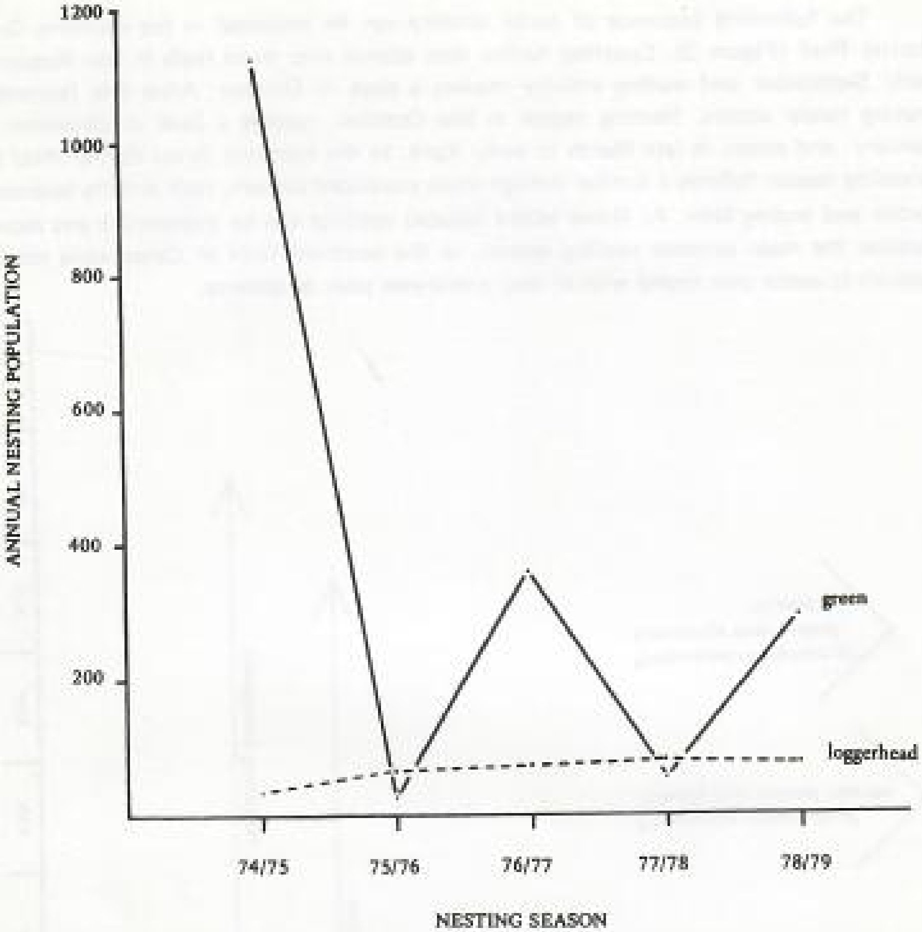

Figure 4. Annual nesting populations of green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles at Heron Island based on a tagging census.

There have been dramatic fluctuations in breeding population levels of the Great Barrier Reef green turtle rookeries in recent years. Figure 4 shows the fluctuations for the past five summers at Heron Island. All breeding colonies for which data from several seasons are available (Bramble Cay, Raine Island, Pandora Cay, Heron Island and most islands of the Capricorn and Bunker Groups) have shown approximately parallel fluctuations for these seasons. Populations of the other eastern Australian species of sea turtles did not fluctuate in parallel with the green turtle populations. In the poor seasons at Heron Island not only did the turtles not nest, but the females and the corresponding male component of the population did not arrive in abundance on the adjacent reefs for courting. There are no indications of parallel fluctuations in the densities of the populations inhabiting the green turtle feeding grounds of eastern Australia. There is thus an unexplained phenomenon acting to co-ordinate the breeding of green turtles at least throughout the entire Great Barrier Reef Province and Torres Straits which is species specific and operates on the turtles prior to their migration to the mating areas. Similar fluctuations appear to have occurred in the past. In the summer 1949-50 there were only low numbers of green turtles nesting on Heron Island and North West Island and the low numbers were attributed at the time as being due to overharvesting. However the following season was a very good one for green turtles on these same islands. These dramatic fluctuations in nesting numbers reduce the usefulness of nesting population levels as a measure of the actual feeding ground populations. Although the feeding ground populations appear to be stable there is an urgent need to continue monitoring the eastern Australian populations and to attempt to define the parameters controlling the nesting population levels.

Table 3: Biometric data from a sample of the Heron Island nesting population of green turtles *Chelonia mydas*, 1974-1975 nesting season

	$\bar{x}$	S.D.	range	n
Adult ♀:				
curved carapace length (cm)	107.0	5.25	91.0-124.0	451
clutch size	112.0	21.56	62-153	35
egg diameter (cm)	4.46	0.18	3.89-4.69	22 clutches, 10 eggs/clutch
egg weight (g)	50.02	7.31	33.5-58.3	11 clutches, 10 eggs/clutch
renesting interval (days)	13.52	0.11	10-21	253
Hatchling:				
straight carapace length (cm)	4.97	0.19	4.02-5.19	11 clutches, 10 hatchlings/clutch
weight (g)	24.83	1.84	19.8-28.4	11 clutches, 10 hatchlings/clutch

Table 3 summarises some of the data collected annually from the Heron Island green turtle rookery. The nesting females from the northern Great Barrier Reef appear to be slightly larger, laying more often in the one season but fewer eggs per clutch than those in the south. Within any one season a green turtle at Heron Island can lay up to eight, but usually 5 or 6, successive clutches. Very few turtles will be recorded nesting again in later seasons. When the author commenced monitoring the Heron Island rookery in October 1974 it was expected that an appreciable proportion of the nesting population would already be tagged from Dr H.R. Bustard's research from 1964 to 1973. No tagging was carried out in the 1973/1974 summer. Only 3.6% of the nesting green turtles examined in the 1974/1975 summer on Heron Island had been previously tagged. The author's own research has involved approximately a total tagging of all nesting green turtles on Heron Island in the five summers 1974 to 1979. In this time there has been a decline in the proportion of recoveries of turtles tagged by Dr Bustard and in the 1978/1979 season after a four year absence the first recoveries of green turtles tagged by the author were made. In this 1978/1979 nesting season only 3.2% of the Heron Island nesting green turtles had been previously tagged. Of 1121 green turtles tagged in 1974/1975 on Heron Island less than 1% have now been recaptured nesting in later seasons. The low recovery rate of remigrant green turtles contrasts with the higher recovery rates the author obtains from similar programs with loggerhead and flatback turtles. This apparent high rate of recruitment of neonate turtles into the nesting populations needs further investigation.

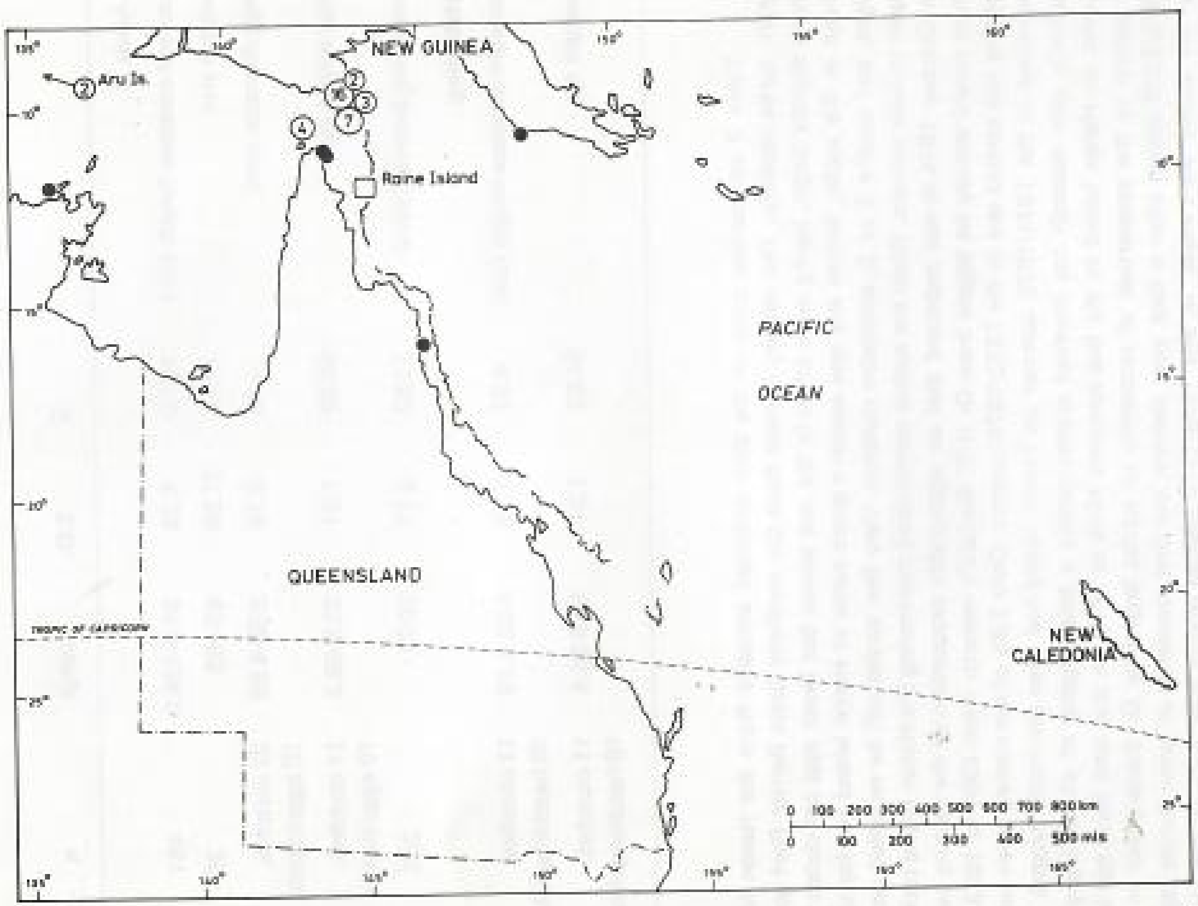

Figure 5. Distribution of recapture sites (39 recaptures) of green turtles previously tagged while nesting at Raine Island or nearby Pandora Cay.

Adult Dispersal

It has been generally assumed in sea turtle research that the female turtle returns to her particular feeding grounds at the completion of a nesting season. Although the author has been able to demonstrate this behaviour for loggerhead turtles it has yet to be demonstrated for the green turtle. If such behaviour holds for the green turtle then it can be assumed that a turtle recovered after it has left the rookery (or outside of the breeding season) is either on its way to or at its particular feeding grounds. Thus recoveries of tagged turtles away from the nesting beach are used to determine the feeding grounds supplying turtles to a particular rookery.

Examination of the distribution of tag recoveries from green turtles tagged nesting at Raine Island (Figure 5) and Heron Island and other islands of the Capricorn and Bunker Groups (Figure 6) show two quite different distributions. These suggest that while there is some overlap in the northern Great Barrier Reef these two rookery areas receive turtles from essentially different feeding grounds. (Care must be exercised at this point since there has not been uniform sampling of the Coral Sea region. Figures 5 and 6 are essentially plots of where people are encountering green turtle, not necessarily a plot of the total green turtle dispersal.) The tag recoveries from north Queensland of south Queensland nesters indicate that the turtle does not necessarily nest in the closest rookery area to its feeding ground. However these data suggest that migrations of more than 1000km from feeding grounds to nesting beaches are not the normal behaviour. Most recaptures have been made within a few hundred kilometres of the respective nesting area.

Hatchling Dispersal

The most outstanding gap in the understanding of eastern Australian sea turtles results from the almost total lack of sightings of turtles between hatchling size and those with curved carapace length of about 35cm in our waters.

In the Australian Museum collection are four post hatchling green turtles having a carapace length approximately 1.5 to 3.0cm longer than the carapace length of newly emerged hatchlings. These were collected from Sydney beaches between 1913 and 1964. No other wild caught post-hatchling green turtles from eastern Australia are known to the author. The occurrence of these few green turtles downstream from the southern Great Barrier Reef rookeries along the East Australian Current is consistent with the hypothesis that hatchlings are dispersed via currents through open oceans. This post-hatchling phase of the sea turtle life cycle is in urgent need of investigation. Until better data are gathered, any further discussion is only conjecture.

Feeding Ground Populations

The coral reefs and shallow coastal areas of tropical and sub-tropical Queensland support very large populations of immature and adult green turtles. Sporadic sightings have occurred as far south as Tasmania and New Zealand (Green, 1971; McCann, 1966). Unfortunately, as with most aspects of the underwater life of turtles, the biology of this benthic-feeding phase is poorly understood and very little studied.

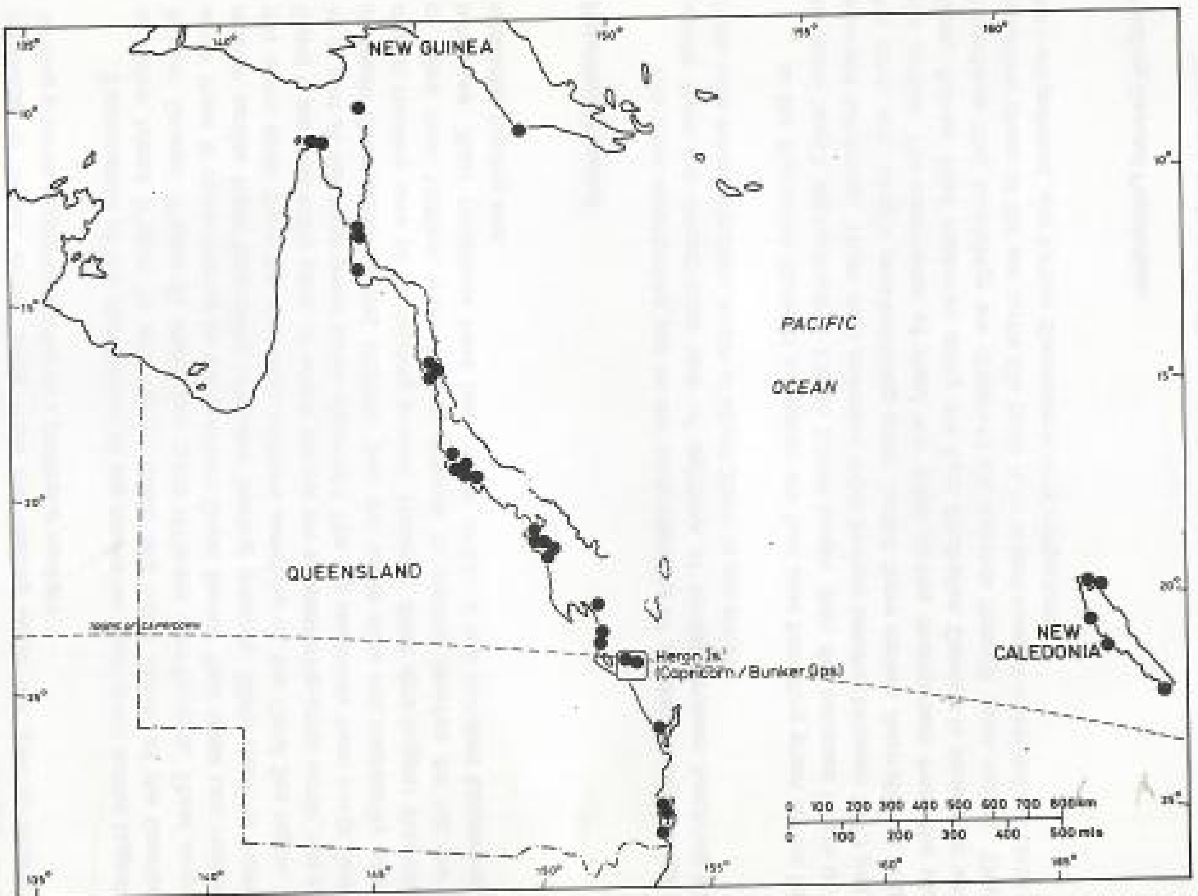

Figure 6. Distribution of recapture sites (34 recaptures) of green turtles previously tagged while nesting at Heron Island or one of the other islands of the Capricorn and Bunker Groups.

Table 4: Growth rates of wild green turtle

	CCL(cm)	Growth rate (cm/yr) $\bar{x}$	SD	range	n	Reference
Immature:						
Southern Great Barrier Reef (23°27'S)	40-50	–	–	0 - 1.54	4	Limpus (1979)
	50-60	–	–	0.95	1	"
	60-70	1.432	1.957	0 - 3.24	14	"
	70-80	1.42	0.653	0.6 - 2.25	15	"
	80-90	1.098	0.993	-0.6 - 2.86	11	"
Hawaiian Archipelago (19°10'N)	48-55	5.28	–	4.56 - 6.24	4	Balazs (1979)
" " (23°45'N)	37-55	0.96	–	0.12 - 1.56	17	"
" " 28°13' - 28°25'	40-59	1.2	–	0.36 - 2.52	9	"
Adult males:						
Southern Great Barrier Reef (23°27'S)	90-102	0.14	0.1132	-0.3 - 0.26	12	Limpus (1979)
Adult (nesting) females:						
Heron Island (24°S)	adult	<1 cm in 4 to 5 yr	–	–	–	Bustard (1974)
Tortuguero, Costa Rica (10°N)	adult	0.4	–	–	–	Carr and Goodman (1970)

In the feeding grounds sea turtles live essentially solitary lives with feeding, sleeping and basking being their principal activities. Small grazing and browsing fish appear to play an important role in reducing the growth of fouling organisms on the carapace and skin. Off the coast of Florida there has been some indication that the immature turtles follow at least seasonal migratory patterns through feeding pastures. This type of behaviour has not been recorded with the eastern Australian studies. The pattern that is emerging from recapture data obtained from southern Great Barrier Reef green turtles is one of immature and adult green turtles occupying a home range within a particular habitat type. The extent of the home range is yet to be determined.

There has been no comprehensive survey of the population structure (by age or size class) of the green turtle populations in different habitats of eastern Australia. On the reef at Heron Island where a localised survey is in progress immature green turtles (40-90cm curved carapace length) constitute more than 80% of all turtles using the reef front and reef crest feeding zones. The remainder of the turtles in these same feeding zones are adult green turtles with a small percentage of loggerhead and hawksbill turtles. In the lagoon feeding zones of Heron Reef, green turtles represent about 50% of the turtles present, of these 50 – 80% are adults. The remaining immature green turtles are mostly in the 65 – 90cm curved carapace length size class with very few in the 40 – 50cm class. That different size class turtles occupy different habitats suggest that there must be one or more shifts in habitat during the immature to adult life of the turtle. Near Cairns, green turtles are plentiful in a variety of habitats ranging from estuarine to coral reefs. On these coral reefs (reef crest, reef front sightings) the majority of green turtles are immature. The relative importance of different habitat types for the species is undetermined.

There is no reliable method for determining the sex of immature sea turtles from external characters. Males can be recognised once they reach maturity and the secondary sexual characters of the long tail and more recurved claws have differentiated. Since the males appear to grow to approximately adult size before differentiating there is the possibility that a large turtle which resembles a female could be an undifferentiated male. Thus the sex ratio of a sea turtle population is not readily determined. The applicability to field study of the method for sex determination using blood hormonal levels described by Owens et. al. (1978) warrants investigation.

Growth and Age

Growth rates and projected ages at maturity for green turtles have until recently been almost entirely based on data from captive reared turtles. Recently it has become apparent that growth of wild green turtles can be very slow and that the age at sexual maturity may be in the range of 10-50 years, possibly being a function of latitude.

Table 4 summarises some of the now extensive growth data available from immature green turtles in southern Great Barrier Reef and Hawaiian feeding grounds. These data while indicating that immature green turtles grow slowly show growth of mature male and female turtles to be even slower, averaging only a few millimetres per year. The projected age at maturity for green turtles inhabiting southern Great Barrier Reef feeding grounds based on an extrapolation of available growth data is in excess of 30 years.

Exploitation

Sea turtles in eastern Australia are protected and managed by several Queensland and Australian Government agencies (Queensland Fisheries Service, Queensland National Parks and Wildlife Service and the Australian National Parks and Wildlife Service). The indigenous peoples living in reserves in Queensland are able to take turtles for their own use. Of the important green turtle rookeries Raine Island, Bramble Cay and islands of the Wellesley Group (including Bountiful Island) are administered by the Queensland Department of Aboriginal and Islander Advancement. None of the extremely large nesting colonies occurs in National Parks although several of the smaller green turtle rookeries (Hoskyn, Lady Musgrave, Heron and Fairfax Islands) are National Parks.

Several potential problems are being highlighted by the continuing recovery of tagged migrant green turtles from the eastern Australian rookeries. From about Cooktown south the tag recoveries are mostly the result of incidental captures of green turtle in trawl nets, shark nets and fish traps. The majority of these turtles have been released alive. Currently there is no evidence of a substantial drain on our green turtle stocks through this type of accidental capture. North of Cooktown almost all of green turtle recaptures have resulted from captures by indigenous people taking the turtles for food. The highest concentration of tag recoveries is from the Torres Strait region where there is the additional harvest by Papua-New Guineans from Daru. An estimated (order of magnitude estimate only) 10,000 green turtles per year are being taken throughout the Torres Straits and the adjacent Papua New Guinea communities. There is little historical data to compare with to know if this harvest rate is on the increase as the author suspects it to be. There is a strong possibility that shifts from traditional methods of hunting turtle have significantly increased the catching efficiency, and consequently the size of the catch, of these people. While some of the turtles taken are immatures and males there is a selection for females resulting in perhaps 40% of the harvest being adult females. An annual female harvest of this magnitude is equivalent to a major portion of the total average nesting population of the entire Great Barrier Reef for the past four summers. If there is no major contribution to the Torres Strait feeding grounds from the Gulf of Carpentaria, Coral Sea or other more remote rookeries then a potentially critical situation has developed for this turtle fishery. The situation is perhaps even more alarming when it is realised that no turtle fishery is officially recognised for the area by the Australian and Queensland fisheries services. The New Guinea fisheries service is investigating the harvest at Daru. There is need for immediate in-depth investigation of the fishery. Though it may not be a cash crop for the people concerned it is a major source of red meat for them and, should the fishery fail, finding an alternative meat source would be expensive. Recruitment of turtles into a feeding ground population is almost certainly very slow and a long interval would probably need to be allowed for recovery of any depleted population.

Management of eastern Australian green turtle populations will be complicated by the dispersal of our turtles across international borders. Cooperative international management of our green turtles stocks may be required.

Conclusion

Eastern Australia supports one of the few remaining large populations of green turtles. A considerable body of knowledge exists for the nesting biology of the species but there has been insufficient research carried out to determine the more important management-wise aspects such as life tables and population dynamics. Many of the blanks in understanding are associated with the paucity of research effort that has been directed towards the life of green turtles away from the nesting beach. Long term studies are needed to bridge these gaps in knowledge before effective conservation of sea turtles can be achieved.

In the short term there is an urgent need for detailed monitoring of the Torres Strait green turtle harvest and subsequent implementation of management action found necessary.

Acknowledgements:

This research has been funded in part by the Australian National Parks and Wildlife Service. Numerous students, teachers and Queensland National Parks and Wildlife Staff have participated in the field research. Their assistance is gratefully acknowledged.

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ENVIRONMENTAL FACTORS IN TURTLE FARMING

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Chelonians are an ancient reptilian group with fossil records from 100 million years ago showing sea turtles morphologically identical to those of today. Although some species have restricted ranges others are cosmopolitan, inhabiting warm, usually shallow waters all over the world (e.g. the green turtle *Chelonia mydas*, hawksbill turtle *Eretmochelys imbricata*, loggerhead turtle *Caretta caretta* and leatherback turtle *Dermochelys coriacea*).

When European explorers "discovered" the Caribbean there were green turtles in abundance. They were initially used as fresh meat by the ships operating in these waters but their hardiness was soon used to commercial advantage. Turtles readily survived shipment to Europe if they were wet down periodically, thus a large commercial enterprise developed. Exploitation developed without thought of the carrying capacity of the population — the numbers of turtle were initially so great that it was considered to be an unlimited resource. It was not. Today the green turtle populations in the Caribbean are still under severe pressure despite numerous conservation efforts including the ban on international trade in wild turtle products imposed by many nations (including Australia).

The over-exploitation of turtles has not been restricted to the Caribbean, but it is the best known example. The international restrictions on trade in wild turtle products are not confined to specific geographical regions although the ratings of population status do vary by species and locality. The products from turtle farming ventures may be granted exemptions to these trade restrictions if it can be demonstrated that the farming operation does not have detrimental effects on the wild stocks.

The investigations conducted by Applied Ecology Pty Ltd are necessary to compile an Environmental Impact Statement and are essential for the formulation of efficient farm management practices. Studies have been approached on a two-pronged basis:

i) within the farms

ii) on the natural population

i) Farm Studies

Some factors have demonstrable direct effects on the performance of farm stock, e.g. diet and water quality. Others have more subtle effects (or may be totally ineffectual), e.g. insolation, temperature cycles, social interactions and the repression of migratory instincts. Some of these factors are being studied in farm turtles allowing comparison of the efficacy of various farming procedures. Comparisons are also being attempted between farm and wild turtles.

Operations are restricted in scale due to logistical limitations. An example is the determination of turtle nutritional requirements by examination of gut contents and alimentary absorption in wild turtles. Samples are limited to those that can be collected during slaughters carried out by Torres Strait Islanders. There appear to be substantial differences in the food composition taken at different localities within the Torres Strait. In order to adequately census these differences long term sampling is needed at several localities. Trained personnel and support facilities are not available for such intensive sampling.

Another problem hindering the determination of green turtle nutritional needs is that adult turtles are herbivorous while hatchlings are believed to be carnivorous. However the natural food of hatchling turtles is not documented because their whereabouts and habits are not known till they settle on feeding reefs (as herbivores) at a size of about 35-40 cm carapace length. This disappearance of hatchlings when they leave the rookery is often termed "the missing year" or "the great turtle mystery". The age of turtles when they settle is not known although they are often termed "yearlings".

This "missing year" is a problem that beleaguers almost all turtle research. It prevents study of wild hatchlings for determination of growth rates, survivorship, age, dispersions, natural diseases etc. Since these studies have not been made one cannot compare the performance of farm-reared turtles. This increases the difficulty of making judgements as to "satisfactory base lines" of growth and survivorship in farm reared stock.

Most turtle research biologists believe that hatchlings go through a pelagic phase, drifting with the currents and feeding in the surface layers of the ocean. The counter-colouring exhibited by green turtle hatchlings (i.e. dark dorsum, light venter) supports this theory as it would make them less conspicuous to both marine and aerial predators. However the theory has not be substantiated by actual observation. In fact the location of a turtle smaller than 35 cm curved carapace length is quite a rare occurrence.

Current experiments and progress reports of farm studies are presented in detail in the papers on "Nutritional Problems" and "Diseases of Farmed Turtles" presented elsewhere.

ii) **Natural Population Studies**

Studies of rookeries and feeding reef turtles are in progress to ascertain various population parameters (for example, nesting interval of females, fecundity, hatch success as affected by both physical and biological factors, population size, growth rate of wild turtles etc).

The main study site is Bramble Cay (9°9'S, 143°52'E), a small, isolated coral cay in the far north east of the Torres Strait. Several other rookeries are visited for short periods during each nesting season including Raine Island (11°36'S, 144°3'E) which is one of the largest green turtle rookeries in the world.

Tagging of nesting females over the last three seasons has provided tag recoveries from Papua New Guinean and Indonesian waters, though the majority have been from the Torres Strait. It is normally assumed that at the end of a nesting season females return to the site from which they came. If this is so, then some of the green turtles nesting at Bramble Cay are drawn from the waters of other nations, and the hatchlings produced at Bramble Cay could be presumed to be (at least partially) stocking those waters. Tag returns of females nesting at Raine Island indicate almost total overlap with those from Bramble Cay (unpublished data and C.J. Limpus pers. comm.). Investigations are in progress to find whether these two rookeries represent separate populations.

A number of factors have been found to influence hatch rate and incubation time of turtle eggs at Bramble Cay. These are not independent in their action. For example the site of a nest will often be partially determined by the sea conditions, the moisture content of the sand (i.e. rainfall) and the instantaneous conditions of the forebeach caused by erosion. This final site will affect nest depth which then partially determines nest temperature and moisture available to the eggs.

A preliminary model of some of these interactions is presented in Figure 1.

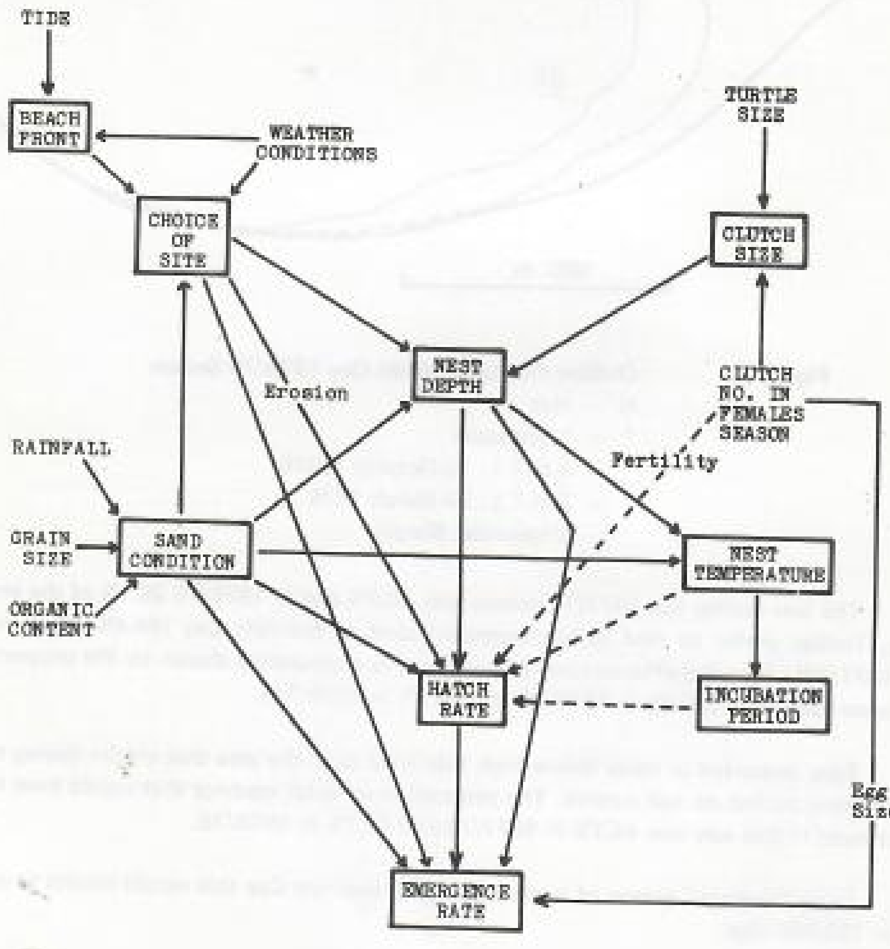

Figure 1: Preliminary model of factors affecting the hatch and emergence of *Chelonia mydas* nests at Bramble Cay.
Dependent factors shown in boxes.
Dotted lines indicate possible influences not yet demonstrated.
Length of lines does not represent magnitude of effect.

Perhaps the most spectacular effect on the numbers of hatchlings produced is the annual erosion and deposition of sand. During the SE (= dry) season sand is deposited on the NW portion of the cay. When the NW season (= wet) begins (usually in December) substantial erosion of the NW portion occurs (e.g. see Figure 2).

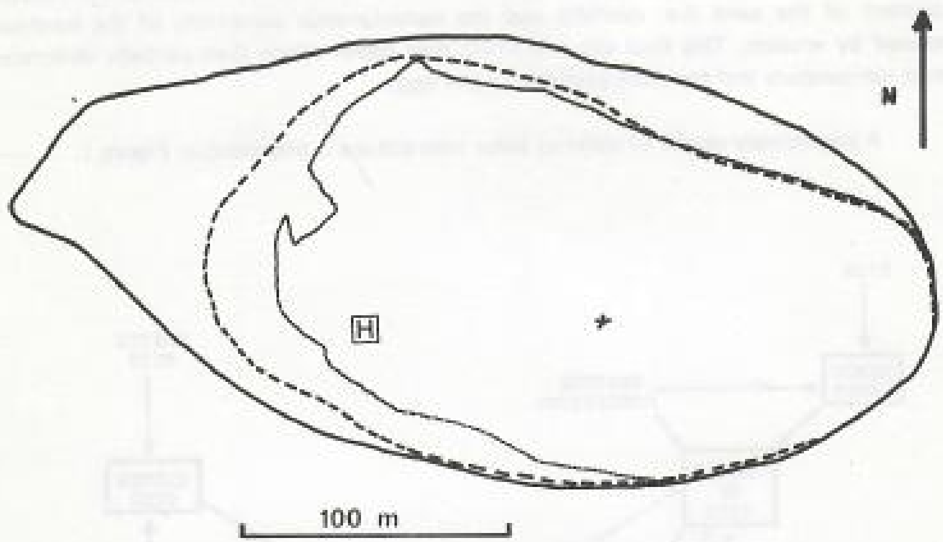

Figure 2: Outline map of Bramble Cay 1978/79 Season
H – Hut
* – Lighthouse
– S.H.T.L. 15 October 1978
– S.H.T.L. 29 March 1979
– Vegetation Margin

The loss during the 1977/78 season was 30.2% and in 1978/79 25.1% of the entire cay. Turtles prefer to nest in non-vegetated sand at Bramble Cay (84.4% of all nests in 1977/78). Thus the effective loss of beach is more accurately shown by the proportion of open beach loss (65.9% in 1977/78 and 66.5% in 1978/79).

Eggs deposited in nests below high tide level or in the area that erodes during their incubation period do not survive. The proportion of total nestings that would have been destroyed in this way was 44.1% in 1977/78 and 42.7% in 1978/79.

In an "average" season of turtle nestings at Bramble Cay this would equate to more than 100,000 eggs.

During the past five seasons there have been massive fluctuations in the numbers of nesting female green turtles in eastern Queensland waters (unpublished data; C.J. Limpus pers. comm.). For example, in December 1974 a James Cook University of North Queensland/Australian Institute of Marine Science research group made an instantaneous count of over 11,000 female green turtles nesting on Raine Island (A. Birtles, pers. comm.). In December 1977 the average total number of emergent females over five nights was 23. These fluctuations have not been reflected in counts of green turtles on the feeding reefs nor have other species' nesting numbers varied in this manner (C.J. Limpus pers. comm.).

The factor(s) causing the fluctuations of annual green turtle nesting numbers must be equally operative over a huge geographic range, since all of the eastern Queensland rookeries monitored are fluctuating in synchrony and the magnitudes of the changes are of the same order.

The energetic load of reproduction must be very high for females (average weight of eggs produced at Bramble Cay in 1978/79 was 28% of their initial weight). It would therefore be reasonable to suggest that females have to reach a critical level of energy storage (as fat) before they would migrate to a rookery in any particular season. If this was so then the sample of females at the rookeries would represent the "fittest" at that time. The most obvious criticism of such an "energetic" hypothesis is that any factor(s) affecting fat storage by females would have to be simultaneously operating over a huge area.

Two observations partially support the "energetic" hypothesis:

i) adult green turtles are herbivorous while adults of other species are either omnivorous or carnivorous.

ii) three years data from Bramble Cay suggest that in poor years only larger females breed. Perhaps large animals are "fitter" (i.e. better able to cope with whatever conditions prevent sufficient fat deposition in smaller females).

At this time no direct testing of this hypothesis has been formulated.

Another environmental factor that must be considered is that of human exploitation of turtles. Many opinions have been stated as to the impact of European settlement in the Torres Strait on the rate at which indigenous Islanders subsequently slaughtered turtle. The usual view is that hunting pressure has been dramatically reduced by the availability of canned meats through the Government stores (e.g. Bustard 1972). In conflict with this however is the greater mobility that has been imparted with the advent of the outboard motor.

In the early 1960's purchase of large outboard motors began in the relatively affluent Thursday Island vicinity. A large increase in turtle harvest (especially eggs) quickly resulted but a plateau was soon reached followed by a gradual decrease to present levels (J. Scott pers. comm.).

It was not until 1972 (when large scale government social programs raised affluence levels) that large outboard motors and aluminium dinghies became common in the outer Reserve Islands. Today almost all families own, or are purchasing, an aluminium dinghy (at least 12' long) with an outboard in the 20-40 hp range.

Unfortunately there has been no regular recording of the turtle harvest by the islander peoples so most of the opinions stated are without a data base. Since it is difficult to envisage a more efficient vehicle for catching turtles (or gathering eggs) than a 14' aluminium dinghy with a 40 hp outboard motor; and since it will be some considerable time before transportation and storage facilities (commercial and private) are adequate to guarantee regular supplies of fresh or frozen meats on the outer islands, I cannot see that there will be any major increase or decrease in the present levels of harvesting in the immediate future.

From 22 October 1976 till 30 June 1977 a record was made of the capture and slaughter of turtles by the people of Yorke Island. Some slaughters were not included in the following estimates because they were not reported till several weeks after the event. This means that the estimate given below will be less than the actual rate — the non-reported turtles probably amount to 10-15% of the catch.

During the 252 days of recording 88 green turtles were recorded as slaughtered at Yorke Island. This rate corresponds to approximately 127 per annum.

An estimate of slaughter can be calculated for the total Islander population of Torres Strait if the following assumptions are made:

i) that the ratio of population on Yorke Island to that of the Torres Strait, during the recording period, was similar to that of the two separate population census figures used.

ii) that the slaughter at Yorke Island during the recording period was typical of the total slaughter rate. This may not be so, as the dugong is frequently hunted in the western islands of the Torres Strait which may decrease the per capita per annum slaughter of turtles.

Based on these assumptions, estimates of the annual turtle slaughter by Torres Strait Islanders were calculated using the two census figures available (Table 1). Although the census data were taken 7 years apart, the ratio of Yorke Island population to that of the total Torres Strait was remarkably constant. The turtle slaughter by Torres Strait Islanders is thus about 4150 per annum (approximately one turtle/person/year). When the indigenous populations of the far northern Cape York Peninsula communities and those of the Papuan coast are considered then the annual turtle slaughter in the Torres Strait is probably of the order of 10000.

Table 1

Estimated annual turtle slaughter by Torres Strait Islanders

	Estimate 1	Estimate 2
Year of Census	1971	1978
Source	Duncan (1974) Caldwell (1975)	Community Profile compiled by the Torres Strait Office of the D.A.A.
Estimated Slaughter	4136	4170

Figure 3 shows the size distribution of the Yorke Island turtle slaughter while Figure 4 shows the size distribution of the tagging programme catch at the same group of reefs over the same time period. The research captures were made by the same basic methods (with the exception of spearing) as those for slaughter but unbiased capturing was attempted.

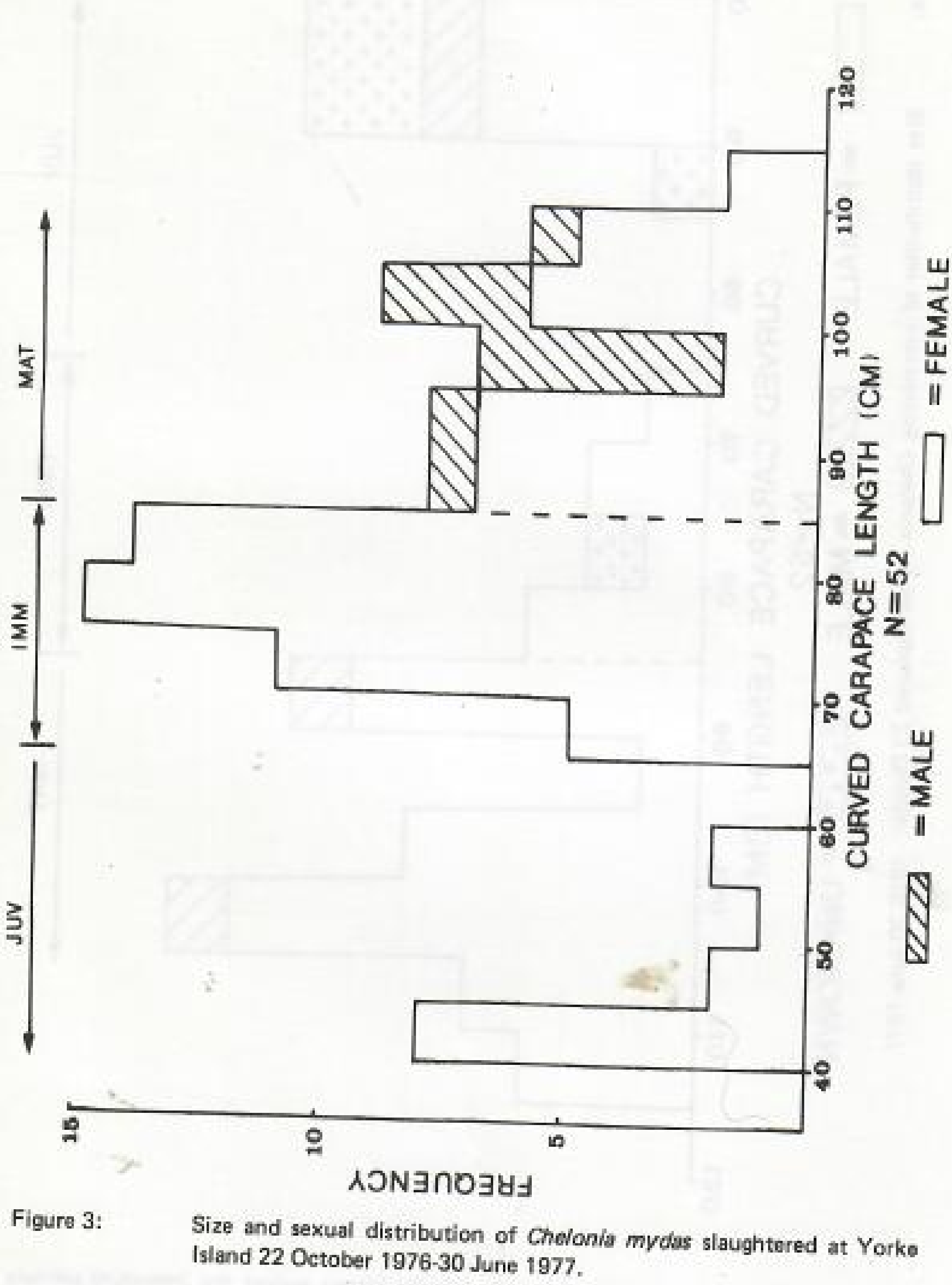

Figure 3: Size and sexual distribution of *Chelonia mydas* slaughtered at Yorke Island 22 October 1976-30 June 1977.

The two distributions were very significantly different:

$\overline{X}$ = 59.4 df = 14 $P \ll 0.001$ (two-tailed).

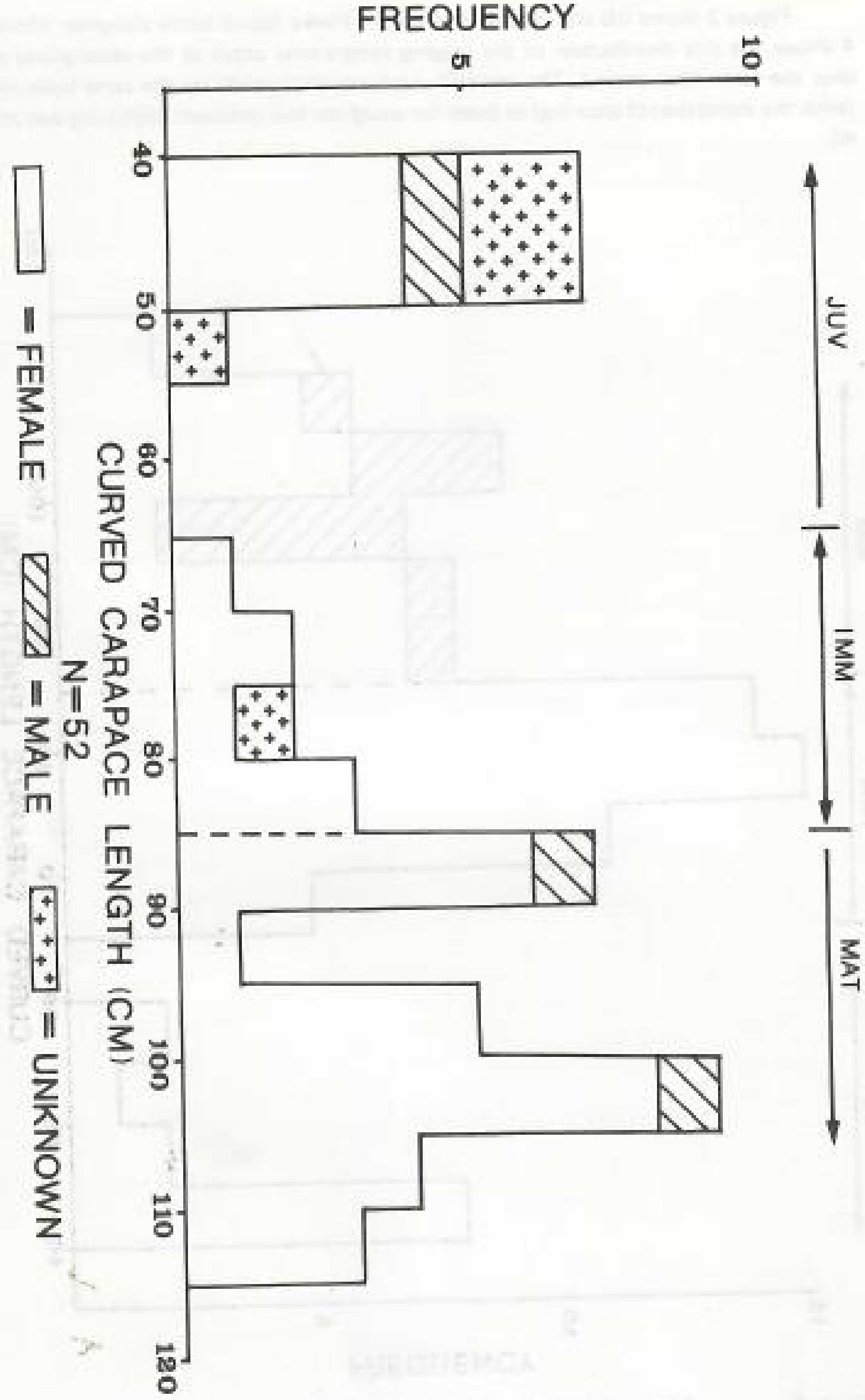

Figure 4: Size distribution of non-nesting *Chelonia mydas* captured 22 October 1976-30 June 1977.

The capture for slaughter was heavily biased against the immature animals that were the mode of the research capture distribution. It is also apparent that when adult turtles are hunted, there is a strong preference for females. This practise means that the impact of the slaughter is higher than the gross numbers suggest since the reproductive portion of the population is being selectively hunted.

Green turtle rookeries are normally in very isolated locations so the collection of eggs necessitates travel across large distances of open ocean. As a result, the harvest rate is low. The major rookeries of the hawksbill turtle (*Eretmochelys imbricata*) and the flatback turtle (*Chelonia depressa*) are quite close to centres of habitation and are heavily harvested but no records of the actual harvest rate are available.

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MANAGEMENT OF TURTLE RESOURCES

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In contrast to many of the world's historical turtle areas Queensland waters still have large populations of several species of sea turtles. This has been partly due to the pattern of European settlement and more recently to the protective legislation enacted by the Government of the State of Queensland.

European shipping was rare in the northern reaches of the Great Barrier Reef until the late nineteenth century and even then was only sporadic. The extreme distance from the major turtle markets of Europe prevented large scale commercial exploitation (and consequent decline in turtle population levels) as had occurred in the Caribbean and other areas.

Nevertheless several relatively small green turtle soup canneries operated in the Capricorn-Bunker group (at about 23½°S) during the 1920's and 1930's. These enterprises relied on the taking of female turtles from the nesting beaches. Following the investigations of Moorehouse (1933) the Queensland Government enacted legislation that prevented the taking of green turtles (*Chelonia mydas*) south of latitude 17°S between 30 September and 30 November annually. The aim of this legislation was to ensure that females had the opportunity to deposit a proportion of their clutches before being slaughtered. Green turtle nesting in the Capricorn-Bunker group usually begins toward the end of October and reaches its "full level" by the end of November (Bustard, 1974). The initial legislation was such that most females would be able to deposit 1 or 2 clutches prior to their being taken for slaughter.

In 1950 the legislation was altered to afford total protection to the green turtle in southern Queensland.

This total protection was expanded to all Queensland waters for all sea turtle species in July 1968, a situation that exists at the present time.

This protection is not limited to the killing of turtles – it also precludes "interfering with" sea turtles at any time. This aspect is quite important as some major southern Queensland rookeries are tourist resorts. Female turtles are usually very easily disturbed during nesting emergences prior to the actual beginning of oviposition. Unlimited beach front activity by tourists, especially the use of lights, could seriously upset the nesting cycles of a rookery.

Aboriginal peoples who live on reserves have automatic exemption from the present protective legislation regarding turtles. This exemption allows them to take turtles and/or eggs for their own use but they may not take them for commercial purposes.

Green Turtle Exploitation

There are a number of different ways in which green turtle resources could be exploited in the future including various styles of turtle farming.

i) **No Exploitation** – it has been shown by tag recoveries from turtles nesting on far northern Queensland rookeries that at least some of the females disperse to (and presumably drew from) foreign national waters to the north (Papua New Guinea) and north west (Indonesia). It is therefore likely that the hatchling production of these rookeries stock those waters to some degree.

If future findings indicate that a significant proportion of these rookeries are drawing from foreign waters, then it could be argued that an affluent country such as Australia can well afford to absolutely protect turtle stocks to ensure a continuing supply of turtles (for subsistence purposes) to our less developed northern neighbours.

ii) **Limited Subsistence Exploitation** – this is the situation that currently exists whereby aboriginal peoples may harvest from turtle stocks for subsistence purposes. No data are yet available to gauge the effect on turtle harvest of the increasing affluence that is occurring in the remote areas where most of the reserves are located.

For that matter, there are no data available on the relative level of historic harvesting compared to that of the present time. Thus the impact of human population changes and the advent of modern technology (particularly the aluminium dinghy and outboard motor) on the turtle stocks cannot be judged.

Continuing, long term, monitoring of turtle population levels (both at the rookeries and feeding reefs) will be necessary to answer these questions.

iii) **Commercial Turtle Farming** – the experimental turtle farms operated by Applied Ecology Pty. Ltd. in the Torres Strait have been investigating the feasibility of turtle farming as a commercial industry for Torres Strait Islanders. The basis upon which all development alternatives are being considered is that commercial farming must not be deleterious to wild turtle stocks.

A number of variations of farming procedure are being investigated:

a) **Closed Farm System** – this would be the ideal turtle farm where all stock would be produced from eggs laid by a captive breeding stock. The imminent completion of a large beach enclosure at Badu Island will allow investigations of this farming practice. It will be necessary to take a small number of adult turtles from the wild for initial experiments of captive breeding.

The major obvious obstacle to a closed farm system is the economic strain that would be engendered by the maintenance of captive adult stocks. Wildlife studies in various parts of the world have demonstrated that females do not nest annually. The average observed return interval is about 3 years, but only a small proportion (10% or less) ever return.

At Bramble Cay the average egg production per female in the 1978/79 season was 767. If farm adults produced eggs at this rate then the costs of maintaining a captive breeding stock would undoubtedly be prohibitive. However, there are reports of some females nesting annually in the wild (a very small proportion of the total) and at large rookeries such as Raine Island there is sporadic nesting year round. This suggests the possibility that the fecundity of females may be maximised by the intensive husbandry of which farms would be capable (e.g. regular and intensive feeding regimes, hormonal manipulation).

b) **Reaping of Wild Eggs** – the most commonly proposed procedure whereby a commercial farming enterprise collects eggs from natural rookeries is often termed "ranching". Eggs are taken from rookeries, artificially incubated (to achieve higher hatch rates than natural nests), grown in culture to a pre-determined size and then released to the wild. The theory is that such "head started" juvenile turtles are too large to be killed by the majority of their natural predators, thus the number of adults produced from a given number of eggs is substantially greater than those eggs would have produced in the wild. If this were correct then the difference between the natural production and that by "head starting" could be harvested from the wild without harming the population.

This theory has not as yet been verified. The survivorship, growth etc. of "head started" turtles is not known. In fact, the relevant parameters for wild turtles are not known (the "missing year" previously discussed in Environmental Factors).

Investigatory head-starting is being conducted by Applied Ecology Pty. Ltd. Tagged juveniles are being released to study dispersion, growth etc. The data base is as yet far too small to make conclusions but one factor has become apparent – juveniles smaller than "yearlings" (i.e. about 40 cm carapace length) are not settling on local feeding reefs but are undertaking long distance dispersion (one tag has been returned from the Gilbert Islands).

Recent studies at Heron Island have indicated that green turtles may take in excess of 30 years to reach maturity in the wild (C.J. Limpus pers. comm.). Heron Island is towards the southern end of the green turtles' range so it is possible that there may be a latitudinal effect whereby animals in the Torres Strait grow more rapidly. This is being investigated but results to date are too limited to quote.

Even if Torres Strait turtles grow significantly faster than those at Heron Island, a substantial lead time would be necessary in any "ranching" project (to allow "head-started" juveniles to reach maturity before wild captured adults could be slaughtered).

A second variation of wild egg reap is such that a proportion of the juveniles reared are released, so as to repay the value of the eggs taken from the wild. The remainder are husbanded in farms for commercial purposes. With our present lack of knowledge of the survivorship of young turtles in the wild (both natural hatchlings and "head-started" juveniles) it is virtually impossible to determine what ratio of eggs/released juveniles would be necessary.

A third wild egg collection farming method has possibilities (at least in the Torres Strait). The annual erosion/deposition cycle of cays in the Torres Strait results in turtle nest losses by erosion in excess of 40% annually at Bramble Cay. Short term observations at other cays suggest similar erosion rates.

In an average year in excess of 100,000 eggs are lost at Bramble Cay. These eggs are of zero value to the population and thus could be legitimately taken to stock a farming operation. The major problem associated with such a management plan would be the uncertainty of supply – massive annual fluctuations in the numbers of nesting turtles would create a surfeit of eggs in good years and a deficit in poor years.

iv) **Direct Slaughter of Wild Turtle** – experience in other parts of the world has shown that uncontrolled commercial harvest of green turtles has invariably resulted in population collapse.

Many fisheries operate on a critical level of cropping that the population can sustain indefinitely. The paucity of knowledge of sea turtle growth, survivorship etc. in the wild makes the calculation of such a cropping rate impossible at the present time and for a considerable time in the future.

The currently available indications of very slow growth and extremely high juvenile mortality suggest that any such cropping would have to be at a very low level.

Exploitation of Other Species

In the Torres Strait the hawksbill turtle (*Eretmochelys imbricata*) and flatback turtle (*Chelonia depressa*) have major rookeries. All of the known major rookeries are readily accessible to population centres and are consequently harvested for eggs. The actual harvest rates are not known but are high relative to the green turtle rookeries.

Crab Island (11°S 142°6'E) is the largest known rookery of the flatback (a species believed to be endemic to Australian waters). It is also the major egg gathering site for peoples of the Thursday Island and Bamaga regions. On occasion nesting females are also taken from Crab Island for slaughter.

Since the flatback turtle seems to have a relatively limited distribution and its major nesting sites appear to be in the Cape York-Thursday Island area, special investigation of the population status (re: egg reap and nesting female slaughter) is warranted.

The hawksbill turtle nests sporadically on many islands throughout the Torres Strait. The majority of these islands are relatively easily accessible. Egg harvest is intense in some areas. Adults are not usually slaughtered because of the apparent toxicity of their flesh.

Since hawksbill nestings are spread over large numbers of islands in the Torres Strait (and on at least some of the cays of the northern sector of the Great Barrier Reef) and adults are seldom slaughtered, existing management practices are probably adequate.

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A PRELIMINARY REPORT ON THE NUTRITION AND MANAGEMENT OF TURTLE HATCHLINGS ON BADU ISLAND

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SUMMARY

It must be stressed that these are only preliminary experimental results. Eventually it will be necessary to elucidate not only a better diet and system of hatchling management but also the characteristics of freshly emerged turtles most likely to survive rearing in a farm situation. It appears that heavier animals and clutches are favoured.

Introduction

As with other aspects of turtle husbandry, the knowledge of nutrition outside the Cayman Islands is elementary. It is based on assumptions as much as facts. Green turtles over the age of one year are certainly herbivorous in the wild, eating a mixture of algae and sea grasses in the Torres Strait, but under that age virtually nothing is known of their diet. Hirth, in his review of turtle literature up to 1971, says "the feeding habits of juveniles are not well known, although it is commonly believed that they are carnivorous in the first few months of life. It is assumed that after the turtle passes one year of age . . . it becomes mostly herbivorous". Although the assumption is soundly based on the knowledge of the pelagic environment for which the young turtle is adapted it is a significant gap in our knowledge. It is one assumption that my experiments are designed to investigate.

The experiments, which have been running but a few months, test three aspects of hatchling nutrition and management. These are the food which produces the highest growth rate, the water change frequency that results in the lowest mortality and the stocking rate that gives the greatest increase in biomass.

Materials and Methods

The work is being conducted at the Badu Turtle Farm on six clutches of hatchlings collected as eggs that were laid below the high tide mark on Bramble Cay (so would otherwise have perished). Each type of experiment is duplicated three times, where possible on three different clutches. The animals are kept in 50 litre plastic tubs with a maximum depth of 25 cm. For feeding the ratio of water depth (cm) to weight (gm) is kept at 12 which gives the 20 small turtles 5 cm of water and the largest turtles so far about 15 cm. When they are small the hatchlings are extremely buoyant and can collect food from the bottom of only the shallowest water. Their capacity to dive and remain submerged increases with age. At night, when they do not feed, the water to weight ratio is increased to 25 so the concentration of organic pollution is kept to a minimum. Before their first feed, at the age of about a week from the time of hatching, each animal was individually marked with a unique combination of holes pierced with a sterile needle, in four of the twelve rear lateral scutes. These marks are still visible so it has been possible to follow the fate of each animal. All animals are weighed and inspected weekly.

Food: Five diets have been tested: diced filleted fish, ground turtle pellets (35% protein), grated fresh coconut, algae collected from the beach and sea surface, mostly *Sargassum* sp. with some red epiphytes, and a combination of fish and algae. All foods were given in quantities that left a surplus at the next water change.

Frequency of Water Change: Others who have worked with hatchlings have had a continuous flow of new water, either recycled through filters or fresh from the sea. In the straits water can be pumped only when the tides are suitable and, on Badu in particular, the water pumped is often turbid and usually at a temperature that differs from that in the tubs. To change the water the hatchlings are transferred by hand from the old water to tubs prefilled with the cleanest available seawater. When tides have allowed, the new water has been left standing for some time to let it reach the same temperature as the old water. Any temperature change is recorded. The effects of these processes are being tested on 12 groups of 20 hatchlings.

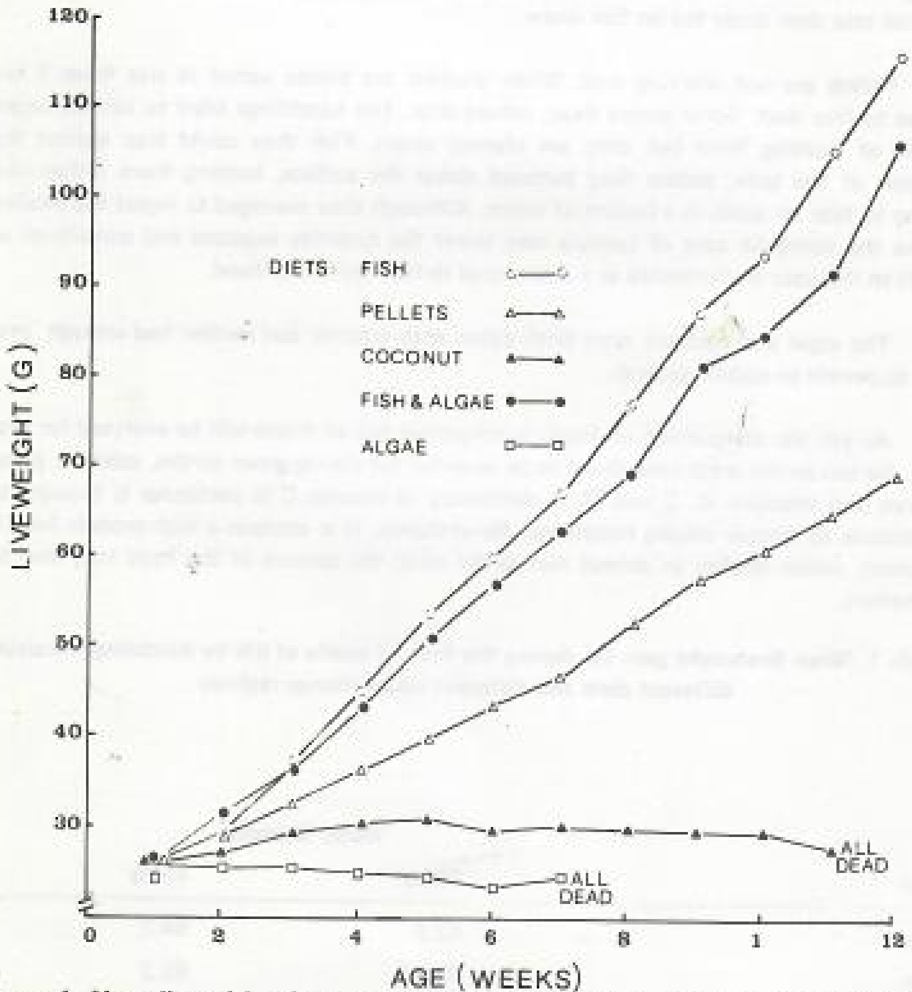

Figure 1. Mean liveweight change during the first 12 weeks of life for hatchlings given different diets. Hatchlings from 3 clutches (20 per clutch) were observed per treatment.

Six groups, three fed pellets and three fed fish, have clean water and fresh feed four times a day and once in the evening. A duplicate set of six is changed only twice in the day.

Results

The comparative growth rates on the different diets are shown in Figure 1.

The best diet was the filleted fish. Caught locally the fillets of some thirty species have been used although the bulk of it has been garfish, whiting and mullet. The fish was cut into blocks of about one cubic centimetre and dispersed through the water by hand. It was collected from the bottom by the hatchlings and dismembered using the claw on the leading edge of the front flipper, a behavioural pattern used by hatchlings as soon as they began to feed. The same technique was used on algae and pellets but with little effect.

The fish and algae diet was the next most successful. It may be less successful than fish in terms of weight gain because the algae increases the passage rate of food through the gut. It is still too early to tell whether these animals on a mixed diet have a greater survival rate than those fed on fish alone.

Pellets are not working well. When crushed the pieces varied in size from 1 cm across to fine dust. Some pieces float, others sink. The hatchlings tried to eat the larger pieces of floating food but they are clumsy eaters. Fish they could trap against the bottom of the tank; pellets they pursued about the surface, butting them rather like trying to bite an apple in a bucket of water. Although they managed to ingest the smaller pieces the energetic cost of capture may lower the quantity ingested and contribute as much to the poor performance as a nutritional deficiency in the food.

The algae and coconut were both eaten with alacrity but neither had enough protein to permit or sustain growth.

As yet the comparison of foods is subjective but all foods will be analysed for protein, the ten amino acids considered to be essential for young green turtles, calcium, phosphorus and vitamins A, C and D. A deficiency of vitamin C in particular is thought to contribute to disease among hatchlings. Nevertheless, it is obvious a high protein food is required, which implies an animal diet in the wild; the texture of the food may also be important.

Table 1. Mean liveweight gain (g) during the first 12 weeks of life by hatchlings receiving different diets and different water change regimes

	Water Changes	
Diet	**2/day**	**4/day**
Pellet	42.9	54.2
Fish	90.9	92.2

The weight gains are shown in Table 1 but the more revealing mortality rates are shown in Figure 2.

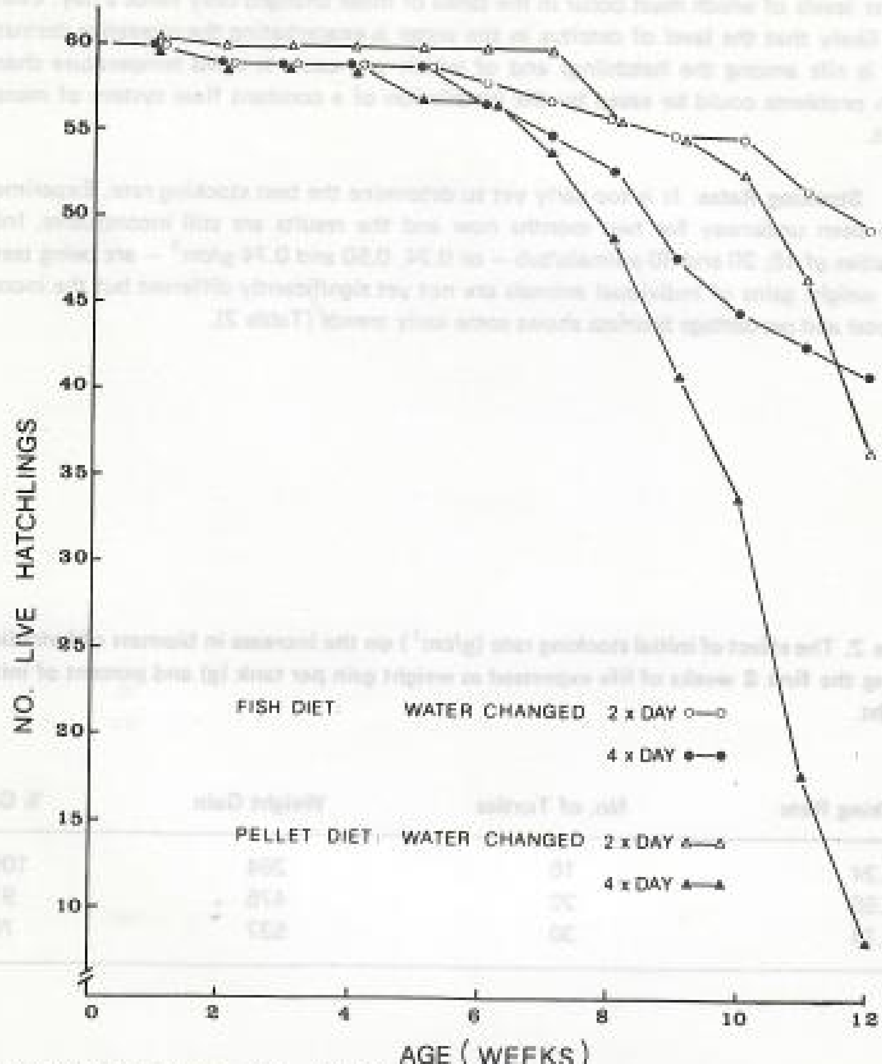

Figure 2. Mortality rates during the first 12 weeks of life among hatchlings receiving two different diets.

It can be seen that although the weight gains are comparable or greater among those fed on pellets 4 times daily, the mortality is much higher among those groups changed more frequently. There are two possible reasons for this. Witham and Futch (1977) weighed their hatchlings only once a fortnight because "previous difficulties in rearing Leatherback turtles suggested that they be handled infrequently". It is possible that the stress of extra handling contributed to the higher mortality. It is more likely, however, that it resulted from cumulative thermal shock. On the Cayman Islands, Haines and Kleese (1977) found that disease occurred both earlier and more severely on hatchlings subjected to only two temperature changes of 5°C in eight weeks compared to those that suffered only gradual temperature alteration. Although the maximum temperature change recorded in this experiment so far has been 2.8°C, changes exceeding 1.5°C have occurred 34 times among those moved twice a day and 55 times for those changed four times a day. The effect of this temperature stress appears to be cumulative because the mortality curves are similar for both diets except that those changed less frequently died later.

In this experiment as it currently stands it would seem that the combined effects of extra handling and thermal shock are more important than the level of organic pollution, higher levels of which must occur in the tanks of those changed only twice a day. Even so it is likely that the level of detritus in the water is exacerbating the ulcerative dermatitis that is rife among the hatchlings and of which one cause is rapid temperature change. Both problems could be eased by the installation of a constant flow system of management.

Stocking Rates: It is too early yet to determine the best stocking rate. Experiments have been underway for two months now and the results are still inconclusive. Initial densities of 10, 20 and 30 animals/tub – or 0.24, 0.50 and 0.74 g/cm^3 – are being tested. The weight gains of individual animals are not yet significantly different but the increase in total and percentage biomass shows some early trends (Table 2).

Table 2. The effect of initial stocking rate (g/cm^3) on the increase in biomass of hatchlings during the first 8 weeks of life expressed as weight gain per tank (g) and percent of initial weight.

Stocking Rate	No. of Turtles	Weight Gain	% Gain
0.24	10	264	105
0.50	20	475	91
0.74	30	537	70

It will be interesting to see whether the total biomass of the high density turtles remains heavier than those at lower densities despite heavy losses.

One aspect of stocking rate that is showing more significant differences is that of disease. Each week, as they are weighed, all lesions are recorded. The incidence of infected patches of ulcerative dermatitis is shown in Figure 3.

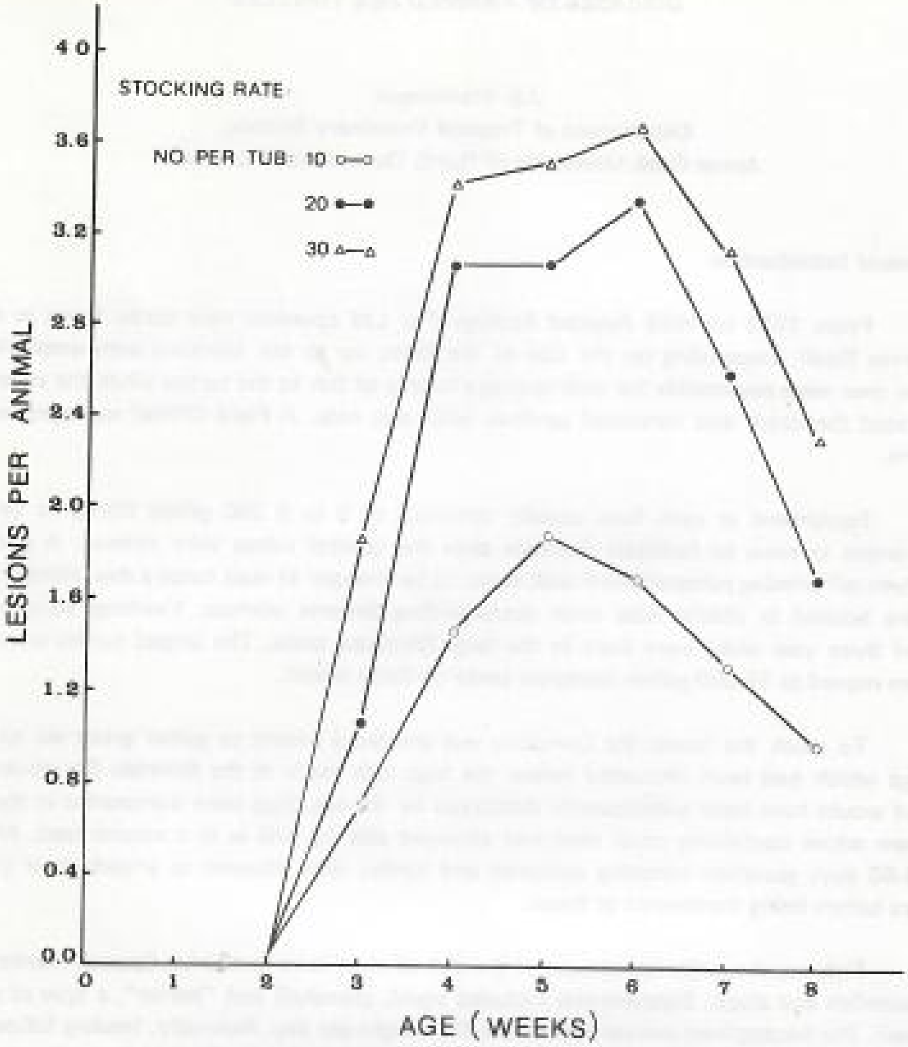

Figure 3. Mean number of lesions developing per hatchling for animals kept at 3 different stocking rates during the first 8 weeks of life. Stocking rates of 0.24, 0.50 and 0.74g/cm^3 were achieved with 10, 20 and 30 turtles per tank.

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DISEASES OF FARMED SEA TURTLES

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General Introduction

From 1973 to 1979 Applied Ecology Pty Ltd operated nine turtle farms in the Torres Strait. Depending on the size of the farm, up to ten Islanders were employed. The men were responsible for maintaining a supply of fish to the turtles while the women filleted the catch and harvested sardines with cast nets. A Field Officer managed each farm.

Equipment at each farm usually consisted of 6 to 8 250 gallon fibreglass tanks arranged in rows to facilitate drainage once the control valves were opened. A petrol driven self priming pump allowed tank water to be changed at least twice a day. Hatchlings were housed in plastic tubs until overcrowding became obvious. Yearlings (one, two and three year olds) were kept in the large fibreglass tanks. The largest turtles were in turn moved to 15,000 gallon fibreglass tanks on Badu Island.

To stock the farms, the Company was granted a permit to gather green sea turtle eggs which had been deposited below the high tide mark at the Bramble Cay rookery and would have been subsequently destroyed by the sea. Eggs were transported in styrofoam eskies containing coral sand and arranged side by side as in a natural nest. After 55-60 days gestation hatching occurred and turtles were allowed to absorb their yolk sacs before being transferred to basins.

Fish was the major constituent of the diet of most farm turtles i.e. Spanish mackerel, queenfish and shark. Supplements included squid, clamshell and "parter", a type of pigweed. The feeding level averaged 2% of the live weight per day. Normally, feeding followed after each water change during which the remaining food was flushed from the tanks.

Green sea turtles *Chelonia mydas* (L) were farmed to the exclusion of other species in the Torres Strait because of the known marketability of their flesh which is akin to veal in taste and palatability.

During the past three years the Department of Tropical Veterinary Science at the James Cook University of North Queensland has conducted research into the husbandry and diseases of farm turtles. Investigations were carried out at all farms but especially on Yorke and Badu Islands. Only four of the diseases will be considered here:

i) focal ulcerative dermatitis
ii) ulcerative stomatitis-pneumonia complex
iii) anisakiasis (parasitic gastritis — serositis syndrome)
iv) osteodystrophy

Table 1 indicates the number of turtles examined with each condition.

Table 1

	Ulcerative dermatitis	Ulcerative stomatitis-pneumonia	Anisakiasis	Osteodystrophy
Number of turtles *(C. mydas)*	35	24	7	2

i) Focal Ulcerative Dermatitis

Reports of skin lesions in captive sea turtles have appeared intermittently throughout the literature. At the Mariculture Farm on Grand Cayman Island in the West Indies a herpes-type virus was shown to initiate flipper and neck lesions in green turtle hatchlings 55-60 days old (Rebell *et al.* 1975). Characteristic intranuclear viral inclusion bodies were present within the epithelium. The lesions first appeared as papules and progressed to gray patches with an advancing border. Witham (1973) described lesions which developed around the eyes and on the dorsal surface of the neck of green turtle hatchlings. These lesions later ulcerated sometimes with the loss of an eye. No aetiological agent was isolated. Both Rebell and Witham used 1% potassium permanganate topically to treat the cutaneous lesions. A deficiency of Vitamin A has also been shown to promote the shedding of large irregular patches of skin in tortoises (Burke 1970).

Field Observations

Many of the farm turtles examined during field trips to the Torres Strait from April 1977 to October 1979 showed multiple skin lesions on the front and rear flippers and around the eyes and neck. These greatly disfigured both hatchlings and juveniles. Severely affected hatchlings lost their appetite and died in an emaciated state. Juvenile turtles did not seem to be adversely affected by these lesions. Curiously, the lesions did not appear on hawksbill turtles *E. imbricata* (L) reared under the same conditions.

Clinical Signs

Moribund hatchlings often floated motionless on the surface of the water with their flippers drooping beneath them. Their eyes were sunken bilaterally and in some cases large flipper segments were missing. More general signs included inappetance and cachexia. In the extreme cases, juvenile turtles had lost part of an entire limb making efficient feeding very difficult.

Gross Pathology

In hatchlings lesions were concentrated on the flippers as craters <1 mmd and yellow papules 1-3 mmd which later developed into ulcers 3-6 mm in diameter. The more severe ulcerative lesions (up to 5 cms in diameter) occurred on the dorsum of the neck and axillary regions of juveniles. These chronic lesions sometimes extended through the dermis to underlying muscle but were also capable of healing completely.

Histopathology

Microscopically early lesions were characterised by an inflammatory dermal infiltrate and localised vasculitis but in advanced lesions the epithelium showed hydropic degeneration and later became eroded and ulcerated. Secondary marine bacteria invaded the host tissues following ulceration. Viral inclusion bodies could not be detected in the epithelium at any stage of the disease.

Microbiology

Cultures of swabs taken from lesions of several farm turtles revealed the presence of *Aeromonas hydrophila, Pseudomonas fluorescens, Flavobacterium* spp. and *Proteus* spp. The first two organisms are recognised fish pathogens and produce potent toxins.

Attempts to isolate a virus from lesion material inoculated onto green turtle skin and kidney cells have so far been unsuccessful. The lesions do not appear to be causally related to a herpes virus, although they showed similar gross and microscopic features.

Pathogenesis

A series of controlled laboratory experiments were set up to study the development of the disease. The findings may be summarised as follows:

i) lesions showed a regular anatomical pattern of development and distribution was limited to certain areas;

ii) characteristic lesions first appeared in hatchlings 14-17 days old and by day 30 100% were affected;

iii) viral inclusion bodies were not present within the epithelium;

iv) the mortality peak occurred when hatchlings were 35-40 days old immediately following the lesion peak;

v) mortalities were significantly higher in hatchlings fed only on fish compared to those receiving a mixed diet of fish and algae. Hatchlings reared on a pure fish diet showed significantly greater weight gains over a 10 week period;

vi) sixty hatchlings fed sterile fish/pellets or raw fish in separate containers *failed* to develop skin lesions during an 8 week trial;

vii) Vitamin A deficiency did not appear to be a contributing factor.

Therapy

Chronic ulcerative lesions healed successfully when turtles were injected intramuscularly with chlortetracycline and chloromycetin ointment was applied topically to skin lesions. Individual treatment of animals would be difficult and possibly expensive under farm conditions. Research should therefore be directed towards a greater understanding of the aetiology and pathogenesis of the disease so that new prophylactic methods can be developed.

ii) Ulcerative Stomatitis — Pneumonia Complex

Ulcerative stomatitis has been recorded in many species of captive reptiles throughout the world including the African rock python in Kenya (Cooper 1973), gaboon viper in North America (Kuehn 1974), South American boa constrictor in the United States (Stull and Anderson 1976), the reticulated python in the United States and the Greek tortoise in England (Holt and Cooper 1976; Keymer 1978).

In snakes the first sign was the appearance of a bubbly exudate around the lips. The animal then refused to eat and did not attack its prey. In the acute lesion the gingiva adjacent to the upper and lower dental arcades were inflamed and swollen (Wallach 1969). As the infection progressed copious amounts of yellow to grey exudate accumulated between the lips and the palate. The exudate was invariably aspirated into the respiratory system or swallowed and pneumonia or gastroenteritis followed. *Pseudomonas fluorescens, Ps. aeruginosa, Aeromonas hydrophila* and *Proteus* spp. were frequently isolated from the caseous exudate.

The treatment of ulcerative stomatitis was complicated and practical only when valuable reptiles were involved. The exudate was removed by gentle debridement, the mouth flushed with hydrogen peroxide and streptomycin solution applied topically. Multivitamins and a broad spectrum antibiotic were injected intramuscularly or subcutaneously for 7-10 days (Cooper 1973; Stull and Anderson 1976).

Present indications are that poor cage hygiene, overcrowding and excessive competition for food may predispose reptiles to ulcerative stomatitis. The disease has not previously been reported in the green sea turtle.

Field Observations

During the summer of 1977 to 1978 both conditions occurred on the farms supplied with new hatchlings. At the time it was not possible to determine the seriousness of the situation because hatchlings were not separated on the basis of their age, diet and disease status.

Clinical Signs

The appearance of a plug of yellow caseous material within the external nares of hatchlings five to seven weeks old was usually the first overt sign of the ulcerative stomatitis-pneumonia complex. On closer examination the oral cavity was blocked by an accumulation of yellow pus surrounding the glottis and extending back to the pharynx. Severe ulceration of the mucosa sometimes resulted in haemorrhage, circulatory failure and death. Grossly the level of tissue oedema was difficult to estimate. Debridement of caseous material caused only slight bleeding indicating the presence of membranes beneath the areas of necrosis. When the hatchling attempted to feed and breathe superficial layers of caseous exudate were dislodged and became fixed within the nasal passages and trachea. Hatchlings in the advanced stages of the disease showed open mouths and dyspnoea (or "air hunger").

Pneumonia was a frequent complication of ulcerative stomatitis in hatchlings and juveniles aged between two and eight months. Affected animals showed a loss of equilibrium in the water and their respiration became laboured. They refused to eat and lost weight up to the time of death.

Gross Pathology

The initial lesions of ulcerative stomatitis usually appeared on the side of the tongue or adjacent to the glottis and took the form of yellow plaques 1-2mm in diameter surrounded by a zone of inflammation. In more advanced cases lesions also occurred on the floor and roof of the pharynx and extended back towards the crop. Typically, advanced lesions consisted of a gross accumulation of yellow caseous material which when debrided left a distinct depression within the oral mucosa. These depressions ranged in size from 2 to 4 mm and were subject to bleeding. Pus dislodged during the process of swallowing occasionally blocked the nasal passages and a mucopurulent rhinitis resulted.

Turtles with clinical respiratory signs were in most cases found to be suffering from a purulent form of bronchopneumonia. Most were aged between three and five months and had survived a previous ulcerative stomatitis outbreak.

Histopathology

Microscopic sections of early lesions, when stained by haematoxylin and eosin, showed hydropic degeneration of the stratified squamous epithelium lining the oral cavity and a lymphocytic infiltrate in the submucosa. As the epithelium continued to degenerate it was replaced by a layer of eosinophilic necrotic material containing pyknotic nuclei and clouds of basophilic staining bacteria. With subsequent ulceration, macrophages became an additional feature of the infiltrate and the endothelial cells of adjacent vessels were swollen. Lymphocytes could be seen passing through the walls of capillaries and into the submucosa which was oedematous. The epithelium bordering the ulcer was frequently hyperplastic.

Bronchopneumonia in green turtles was characterised by the accumulation of necrotic material, bacteria and mucus within the bronchi and alveoli and the presence of infiltrating lymphocytes and focal granulomas in the interstitium. Caseous material often blocked air passages completely, causing collapse of affected alveoli and a degree of compensatory emphysema in adjacent air sacs. At the same time, epithelial cells lining the alveoli began to desquamate. Focal granulomas consisted of a central necrotic core containing bacteria or fungi, accompanied by macrophages together with heterophils and surrounded by a ring of multinucleated giant cells. A heavy infiltrate of lymphocytes was associated with each granuloma and interstitial oedema was marked.

Microbiology

Attempts to isolate bacteria and fungi from cases of ulcerative stomatitis and pneumonia yielded the variety of organisms listed in Table 2.

The oral flora of hatchlings with "canker" usually consisted of three or four types of marine bacteria and occasionally a saprophytic fungus. All were capable of growing on media containing 3.5% sodium chloride. *A. hydrophila* and *Flavobacterium* spp. predominated and were isolated from caseous material in 70% (7 out of 10) of the hatchlings examined. The other organisms were detected in only one or two turtles. *Aeromonas hydrophila* and *Flavobacterium* spp. were also cultured from plugs of caseous material in the bronchi of 75% (6 out of 8) hatchlings with bronchopneumonia. Saprophytic fungi were isolated intermittently.

Table 2

	Ulcerative stomatitis	Pneumonia
Bacteria	*Aeromonas hydrophila*	*A. hydrophila*
	Flavobacterium spp.	*Flavobacterium* spp.
	Pseudomonads (non-oxidative)	*Pseudomonads* (non-oxidative)
	Ps. aeruginosa	*Ps. fluorescens*
	Ps. fluorescens	*Proteus* spp.
	Ps. putrefaciens	
	Micrococcus spp.	
	Vibrio alginolyticus	
	Klebsiella spp.	
	Proteus spp.	
Fungi, yeasts	*Alternaria* spp.	*Penicillium* spp.
		Paecilomyces spp.
		Fusarium spp.
		Rhodotorula

Antibiotic sensitivities performed on four strains of *A. hydrophila* and two strains of *Flavobacterium* spp. showed them to be susceptible to chloramphenicol and the tetracyclines but resistant to penicillin and streptomycin.

Experimental Studies

In the 1978-79 season controlled experiments were set up on Badu and Yorke Islands to obtain further information on the epidemiology of the condition. Methods of treatment were also investigated.

a) Badu Island: From mid January to early February 1979 five clutches of green turtle eggs were hatched and the hatchlings subsequently housed in a single 250 gallon fibreglass tank. All hatchlings first developed cutaneous flipper lesions but most mortalities occurred in the acute stage of ulcerative stomatitis at 5-7 weeks (Table 3).

Table 3: Mortality in turtles (single tank)

Days	No. in Group	Progressive Mortality Rate (%)
0	451	
28	415	7.9
42	258	42.7
49	165	63.4
51	150	66.7
58	115	74.5

b) Yorke Island: In an improved experiment four turtles were reared in basins (2 clutches with 6 basins per clutch) or tanks (2 clutches in separate tanks) according to their diet. Half received a pure fish ration at the rate of 5% of their live weight per day and the other half were given fish and algae at the same rate. Again, most of the deaths occurred in hatchlings 5-7 weeks old. Mortalities ceased at the age of 8 weeks when the clinical disease had eventually disappeared (Table 4).

Table 4: Mortalities in segregated turtles

Diet	Housing	No. hatched	Stocking rate (gm/litre)	Survivors (5 wks)	Mortality rate (%)
Fish	basin	88	16.6	28	62.8
Fish	tank	68	3.8	9	86.9
Fish and algae	basin	84	15.9	73	13.0
Fish and algae	tank	58	3.2	36	38.9

All groups developed ulcerative dermatitis and ulcerative stomatitis as seen on Badu Island. Mortalities were significantly higher in turtles reared on a pure fish diet compared to those on a fish and algae ($p<.01$). Both groups were subjected to the same feeding and water change schedule. This survival pattern has persisted although the hatchlings are now five months old. In addition, hatchlings reared in basins had a better chance of survival than those reared in tanks ($p<.01$).

c) Therapy: Forty-two affected hatchlings aged 7-8 weeks from Badu Island were treated for ulcerative stomatitis according to the regime of Burton (1978). The exudate was gently debrided, the oral cavity flushed with hydrogen peroxide and streptomycin sulphate applied topically each day. Vitamin C was also administered orally at the rate of 50 mg per day and chlortetracycline was injected intramuscularly (3 mg/100 g) every 2-3 days. They were initially divided into 3 groups of fourteen, an untreated (control) group and two test groups (Table 5). In the control group and test group I, hatchlings were kept 14 to a basin and in test group II they were housed individually in 2.5 litre ice cream containers. The turtles were not fed during 10 consecutive days of treatment.

Table 5: Treatment of ulcerative stomatitis (after Burton 1978)

Group	Housing	Morbidity % Day 0	Morbidity % Day 10	Mortality % Day 10
Control	Basin	100 14/14	0 0/4	71.4 10/14
Test 1	Basin	100 14/14	12.5 1/8	42.8 6/14
Test 2	Ice cream container	100 14/14	40 4/10	28.6 4/14

In the control group, only 4 hatchlings were able to survive the 10 day experimental period without treatment and it appeared that their oral lesions had healed spontaneously. The survival rate of hatchlings in Groups II (71.4%) was significantly higher than the controls 28.6% ($p<.01$), but was not significantly higher than Group I, 57.2% ($p<.05$). In test group I, a definite improvement was noted in the overall condition of the 6 surviving turtles. As the oral lesions regressed they became stronger and more active so that pacing activity against the side of the basin resumed. In test group II the practice of separating hatchlings during treatment permitted the survival of weaker individuals still suffering from the disease.

In general, therapeutic measures were effective but needed to be applied for longer than 10 days when hatchlings had lost weight and condition following the onset of disease. Feeding could recommence with the successful healing of oral lesions.

iii) Parasitic Gastritis and Serositis (Anisakiasis)

A parasitic disease of man, "herring worm disease" was first reported in the Netherlands by Van Thiel *et al*. (1960). Larval nematodes of the genus *Anisakis* from undercooked fish were shown to cause gastric ulcers in a small percentage of the Dutch population. The disease has since been recorded in Japan and Scandanavia where third stage larvae have been found in marketed fish (Cheng 1973).

In Australia adults of the same genus have been found in the stomach and small intestine of marine mammals (Arundel 1978) and Cannon (1977) identified third stage larvae in nine species of fish including sardines and mackerel. The bottlenosed (*Tursiops* spp.) and common dolphins (*Delphinus* spp.) which host the adult form, feed mainly on school fish including sardines and mackerel which in turn carry the infective larvae (Needham 1978). During a visit to the Torres Strait, Carr and Main (1973) realised that whole, ungutted sardines represented a source of infective parasitic larvae to farm turtles. Sprent (1973) subsequently recommended that the sardines be boiled or frozen before being fed to the turtles. A proposed life cycle has been summarized in Figure 1.

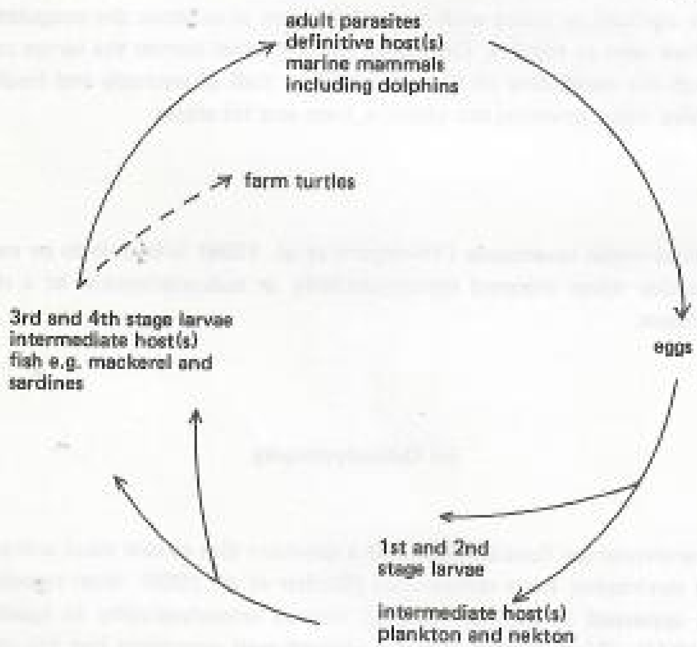

Figure 1: Proposed life cycle for nematodes of the genus *Anisakis* in the Torres Strait after Cannon (1977)

Field Observations

Seven farm turtles examined from Darnley and Murray Islands were infested with *Anisakis* larvae. The number of parasites in each animal varied greatly as did their pathogenic effect. The disease was evidently transferred from the eastern islands to Badu Island in 1978 where the largest turtles were re-established in a new 15,000 gallon fibreglass tank.

Clinical Signs

Turtles infested with larval nematodes rarely showed acute clinical signs but many appeared to be weak and emaciated and fed infrequently. Some seemed unable to dive while others maintained a persistent list to one side. Turtles with buoyancy problems attempted to correct them using their front swimming flippers.

Gross Pathology

When the pleuroperitoneal cavity was first opened encysted larvae were immediately apparent in the mesentery of the stomach and small intestine and within the liver capsule. Closer examination revealed more larvae in the parietal peritoneum covering the kidneys and close to peripheral fat stores. Parasitic cysts consisted of collections of tightly coiled larvae surrounded by a wall of fibrous tissue. In several cases the stomach wall was adhering to the adjacent peritoneum. Gastric and intestinal ulcers were a consistent pathological feature of the seven turtles examined and took the form of hard caseous nodules up to 3 cm in diameter. Migrating larvae often protruded from the centre of these nodules into the gastric and intestinal lumen.

Histopathology

Microscopically, gastric and intestinal lesions consisted of a central necrotic core surrounded by an infiltrate of eosinophils and mononuclear cells. Marine bacteria had penetrated the epithelium along with migrating larvae to produce the coagulative form of necrosis so often seen in reptiles. Once past the intestinal barrier the larvae continued to migrate through the mesentery of the gut leaving a trail of necrosis and finally encysted in the connective tissue covering the kidneys, liver and fat stores.

Therapy

The antihelmintic levamisole (Thienpont *et al.* 1966) is known to be very effective against nematodes when injected intramuscularly or subcutaneously at a dose rate of 5 mg/kg soft tissue.

iv) Osteodystrophy

Large carnivores e.g. lions and tigers on a constant diet of raw meat while in captivity may develop dystrophic bone deformities (Slusher *et al.* 1965). With regard to reptiles, reports have appeared in the literature of fibrous osteodystrophy in iguanas (Wallach 1968; Frye 1973). Clinically the animals seemed well nourished but the mandible was misshapen. Land tortoises with a similar disease suffer from fractures of the appendicular skeleton because of the enormous weights these bones have to bear (Murphy 1973).

Field Observations

Osteodystrophy was a comparatively rare disease in farm turtles observed only in juvenile turtles. In 1978 two advanced cases were recorded on Badu and Yorke Islands in juveniles approximately 8 months old.

Clinical Signs

Green turtles in a state of calcium-phosphorus imbalance showed obvious skeletal changes. Although the patient appeared well nourished, the carapace was soft and sensitive to digital pressure. The shell "curled" as the growth of epithelial tissue exceeded that of skeletal tissue and stress lines were apparent in many of the dorsal scutes. Carapace dimensions were reduced compared to a turtle of the same age receiving adequate dietary calcium. The mandible or lower jaw was misshapen and the skull featured lateral prominences in the occipital regions. Turtles with severe calcium deficiency became inactive and lost their appetite.

Gross Pathology

In osteodystrophic conditions, although many of the important lesions were obvious externally, additional internal changes did occur. The long bone dimensions were consistently greater in the control animal. The humeri and femora were soft and spongy and could be twisted laterally. Cortical regions of the bones appeared to be poorly calcified. Urinary calculi were another feature of the disease; one stone of 1.5 cm diameter was removed from the bladder of a Yorke Island turtle.

Histopathology

When microscopic sections of the long bones of the two cases were examined, very little ossification or bone formation had occurred at the epiphyseal plate. The small amount of bone present was concentrated at the periphery rather than at the plate itself. Although provisional calcification of cartilage was apparent in some areas, resorbed bone had not been replaced by fibrous tissue as in scurvy. Further, the cartilaginous arms did not show microfractures as in rickets.

Radiography

Perhaps the most important aid in the clinical diagnosis of bone deformities was radiography. The more heavily calcified the skeleton the more radio-opaque it will be.

In the case of the turtle with osteodystrophy calcification was not evenly distributed throughout the appendicular skeleton but concentrated as rings near the epiphyseal junctions which were widened. The long bones also showed poor calcification along their longitudinal axes. In addition, very little calcium had been incorporated into the skull and carapace.

A turtle of the same age receiving adequate dietary calcium showed marked calcification throughout the entire skeleton.

Therapy

In the farm situation bone deformities can usually be recognised purely on morphological grounds and treatment can start immediately. Frye (1973) recommended injections of calcium gluconate two or three times weekly, oral administration of calcium and Vitamin D and a change to a more natural diet. Nutritional diseases can be prevented by a thorough investigation into the dietary preferences of wild turtles and the subsequent analysis of this food.

GENERAL DISCUSSION

Sea turtles reared in captivity in the Torres Strait for periods up to 6 years experienced a range of diseases indicative of their farm environment. The diseases appeared to be the direct result of poor husbandry and management.

The possibility that a herpes-type virus (Rebell *et al.* 1975) was responsible for the initial lesions of ulcerative dermatitis was discounted on the basis of our inability to isolate a virus from lesion material or transmit the disease by scratch inoculation. Affected turtles did not shed their skin in irregular patches, a sign of Vitamin A deficiency in chelonians (Burke 1970). Further, palpebral oedema was not observed. The isolation of *A. hydrophila* and *Ps. fluorescens* from skin lesions in farm turtles was not unexpected as these organisms are often associated with aquaculture (Reichelt 1979, pers. comm.). The key to this condition may lie in the failure of individually reared hatchlings to develop characteristic flipper lesions over an 8 week experimental period. Physical separation of hatchlings prevented an outbreak of the disease which may mean that it is in some way related to hatchling behaviour or captive stress.

Although Holt and Cooper (1976) and Keymer (1978) described cases of ulcerative stomatitis in the Greek tortoise *Testudo graeca*, this condition has not been reported in sea turtles. In the farm situation the disease occurred as an epizootic in hatchlings 5-9 weeks old in contrast to isolated cases seen in adult and juvenile snakes (Cooper 1973; Kuehn 1974; Stull and Anderson 1976). Green turtle hatchlings with ulcerative stomatitis were listless and weak as were the snakes of Stull and Anderson (1976) and the tortoises of Holt and Cooper (1976). However, with green turtles, oedema of the oral mucosa was not marked and in some cases plugs of exudate had formed in the nasal passages, trachea and major bronchi. Microscopically, pathological changes were similar to those reported in the Greek tortoise. *A. hydrophila* and *Flavobacterium* spp. were repeatedly isolated from lesion material and it seems likely that these organisms acted as opportunistic pathogens. The mortality rate with ulcerative stomatitis was in the vicinity of 60%. No comparative figures exist in the literature for reptiles housed so intensively as on the Torres Strait turtle farms.

The results of the experiment carried out on Yorke Island indicate the importance of husbandry and management factors viz. diet and housing, for the successful rearing of wild animals in captivity. The comparatively low mortality rates recorded for 8 weeks old hatchlings on a diet of fish and algae (13.0 and 38.9% cf. 62.8 and 86.9% for a pure fish diet), may be due to the presence of essential nutritional factors in fresh algae e.g. Vitamin A and/or C. Frye (1973) had recommended doses of Vitamin C as adjunctive therapy for reptiles suffering from ulcerative stomatitis. Further, intermittent water changes had allowed rapid multiplication of organisms potentially pathogenic to turtles.

A continuous flow system would remove organic material e.g. small particles of fish remaining in the water after feeding. Regardless of their diet, hatchlings had a better chance of surviving their first 8 weeks housed in basins rather than the larger tanks. Kowarsky (1977) also obtained evidence that overcrowding did not adversely affect the culture of green turtle hatchlings.

Bronchopneumonia in farm turtles resulted from the inspiration of necrotic material present in the oral cavity of hatchlings with "canker". Several of the turtles in this survey were suffering from ulcerative stomatitis and bronchopneumonia concurrently. Susceptible turtles were aged between 2 and 8 months compared with 4 to 7 months for the Cayman Island farm turtles examined by Jacobson *et al.* (1979). In addition to the loss of equilibrium seen by these authors, farm turtles in the Torres Strait were listless and weak and showed a laboured respiration with dyspnoea. At autopsy consolidation was evident in areas adjacent to the major bronchi, where plugs of caseous exudate had become lodged. Nodules similar to those described by Jacobson and his co-workers were rarely seen. Histologically, the most important change was the host's response to the organisms invading the alveoli and interstitium. Interstitial focal granulomas were few and in all but two cases, staining by Ziehl Neelsen and the periodic acid-Schiff reaction failed to reveal the presence of acid fast bacilli or fungal hyphae. These findings contrasted with the multifocal granulomas containing branching septate hyphae seen by Jacobson *et al.* (1979) in mariculture reared turtles. Although both bacteria (*A. hydrophila, Ps. fluorescens, Flavobacterium* spp.) and fungi (*Penicillium, Paecilomyces* and *Fusarium* spp.) were recovered from caseous material found in the trachea and primary bronchi of turtles from the Torres Strait farms, the bacterium *A. hydrophila* was isolated consistently and thought to be the aetiologic agent responsible for the disease. Frye (1977) and Burton (1978) also reported an association between *A. hydrophila* and pneumonia in reptiles. Various fungi, including *Paecilomyces* spp., have previously been implicated (Austwick 1974; Jacobson *et al.* 1979) in cases of mycotic pneumonia in sea turtles and may have played a secondary role here. The observation that ulcerative stomatitis in farm turtles immediately precedes the development of bronchopneumonia lends support to the argument that these two diseases are closely related.

Larval nematodes of the genus *Anisakis* were introduced into the Torres Strait farms by the feeding of whole, ungutted sardines to juvenile turtles on Murray and Darnley Islands. The farm turtles acted as paratenic hosts for the third stage larvae which were unable to complete their life cycle when confined to the tissues of a cold blooded animal. The incidence of the disease was 100% in the seven cases examined but the extent of gastric and intestinal ulceration varied in each case as did the number of migrating and encysted larvae. Mortalities due to anisakiasis were infrequent and seemed to result from secondary bacteria invading the host tissues e.g. intestinal wall and peritoneum and not from tissue damage directly associated with larval migration. Parasites were concentrated in the mesentery of the gut and capsule of the liver as recorded by Ruitenberg *et al.* (1971) when they experimentally infected rabbits with *Anisakis* larvae from herrings. At the microscopic level, the pathological changes that resulted from the migration of larvae through reptilian tissues were similar to those seen in marine mammals (Young and Lowe 1969) except where lymphocytes, eosinophils and heterophils replaced neutrophils in areas of necrosis.

The diet of farm turtles consisted mostly of Spanish mackerel for the greater part of the year but was replaced by rubbish fish from trawlers during the off season.

Supplements included clam muscle and algae. As a staple diet mackerel represented a good source of protein but in other respects it was seriously deficient e.g. calcium and Vitamin A. The calcium-phosphorus ratio for filleted mackerel is in the order of 1:44 (Wallach 1970). To correct the imbalance Collins (1971) suggested the addition of 1-1/3 teaspoons of calcium carbonate to 1 lb of mackerel diet.

CONCLUSION

Preliminary investigations led to the identification of four new diseases of farm turtles in the Torres Strait. These diseases have not been reported elsewhere. The successful farming of green turtles will require the development of a new technology based on a continuing research effort.

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COMMERCIAL PROSPECTS FOR TURTLE FARMING IN THE TORRES STRAITS, AUSTRALIA

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Introduction

1. The culture or farming of marine turtles for commercial purposes is a controversial topic and the prospects for any such venture are difficult to assess as adequate background and information is not available for proper analysis or appraisal. This paper only addresses itself to the position of the green sea turtle, *Chelonia mydas*, the species prized for its meat and as the essential ingredient for turtle soup.

2. As a result of excessive exploitation in many populations and the need for conservation measures, the green turtle is on Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), commonly known as the Washington Convention, except for the Australian population of green turtles which is on Appendix II of the Convention. CITES in effect prohibits all trade in green turtle products except from fully farmed sources. In the Australian context, green turtles are fully protected from exploitation excepting their taking and use by Aborigines and Torres Strait Islanders for subsistence in a reserve or a traditional situation.

3. For much of the world, even with conservation measures and trade restrictions, the demand for turtle products for subsistence and international commerce continues unabated. To meet at least in part these demands several countries have put forward ideas and plans to farm green turtles. To date only Mariculture, now called Cayman Island Turtle Farms, on Grand Cayman Island in the West Indies have taken such a venture to the commercial sales stage. The husbandry, management and economic viability of such a venture is not known.

4. Historically the Applied Ecology Unit of the Australian National University's involvement with turtles and turtle farming in the Torres Strait was motivated by a desire to conserve the turtle population of the area and provide employment for Torres Strait Islanders. At present as Applied Ecology Pty. Ltd. the emphasis is on green turtle population studies, biology and natural history for a wide ranging Environmental Impact Assessment and Statement on the project. In addition the investigation of turtle husbandry, nutrition and disease in various farm situations is being undertaken.

Background

(a) **Turtle Farm**, the term 'Turtle Farm' has been used to described a variety of establishments in which the only common feature is the holding of turtles in captivity. Apart from small research and display facilities, turtle farming or raising facilities might be categorised as follows:

(i) *Turtle Farm*, or closed turtle farm is the ideal, a fully self-contained facility breeding and raising turtles from its own captive produced eggs. Any such operation is independent of wild turtle populations once established and should thus be able to operate and trade within the terms and conditions of Appendix I of CITES.

(ii) *Turtle Raising Farm* is a facility raising turtles from eggs taken from the wild. Any such operation normally operates under some licence arrangement on the premise that the eggs can be off-set at little cost to the wild population due to the very high egg and hatchling losses in the wild. A percentage may be returned to the wild at the hatchling or older stage to offset any loss to the population.

(iii) *Turtle Ranching* or Head Start Farms – these are facilities hatching and rearing large numbers of turtle for return to the wild to 'enhance' the wild population and off-set the effects of taking turtles and turtle eggs from the wild for commercial purposes. While it is known that numbers of captive raised turtles do survive in the wild (Whitham and Fuch 1977; Kowarsky and Capelle 1979) such practices have not demonstrated that it enhances resident breeding turtle populations.

(b) **Turtle Products**

A 60 lb green turtle may be broadly broken down by percentage of weight as follows:

Soup and Meat	54%	Steak pieces, Calipee Calipash, flipper meat and some fat.
Leather	6%	Set of flipper skins
Shell	16%	Whole shell or jewellery pieces
Rest	24%	Fat, oil, offal, waste etc.

It is doubtful if a 60 lb green turtle would be large enough for most markets.

(c) **Markets for Turtle Products**

In a market survey Major (1976) states "It would appear to be correct in surmising that the world wide market for turtle products must be enormous in its untapped potential. Enhanced further by the end products of delicious clear soup, tasty veal-like turtle steak, renowned absorbent qualities of the oil and the undisputed attractiveness of turtle leather or shell jewellery, one senses that turtle farming should have a bright future. Unfortunately, for the Torres Strait turtle farmers it presently remains an untapped market with actual sales considerably lower than the expected natural markets. The traditional markets for turtle soup and leather are currently being saturated from wild and farm sources". It is not known if that situation has changed substantially since 1976.

Brown (1977) estimated a yearly market in Australia for 100,000 pieces of turtle shell souvenirs, 5,000 whole shells, 304,000 lb turtle meat with 5,000 sets of flipper skins for export in addition.

More recent information is that there is a stable market for flipper skins overseas and good prospects for gelatinous turtle meat at $US7.00 per lb F.O.B. West Germany, whose present sources are the Cayman Island Turtle Farm and Mexico.

Turtle Farming Research Project, Torres Strait, Queensland

The turtle project was started in 1970 to conserve the Australian green turtle resource, to produce and market turtle meat, shell, oil, leather, etc. and provide an economic base for Torres Strait Islanders on their own islands with least disruption to their culture and way of life. The project has five experimental turtle farms, some two thousand turtles (1-5 years old) and seven thousand hatchlings located on four of the thirteen island reserves of the group and employs some sixty Islanders as turtle farmers or to service the project. The project (even at this experimental stage) has a significant economic impact on the reserve islands' population of 2,100 where employment opportunities are extremely limited.

The 5 experimental Islander turtle farms are organised on a cooperative, cottage-industry basis, raising turtles to one year old (2 farms), to one year and two years old (1 farm), two and three years old (2 farms), in fibreglass tanks, using locally available fish with marine and terrestrial grasses as feed. A central farm on Badu Island (with larger tanks and an experimental sea enclosure 100m x 100m) has been developed to evaluate pelleted compound turtle feed formulae, the sea enclosure structure itself and, in the future, captive turtle breeding.

Major research effort is being devoted to green turtle population studies in the area, to produce a wide-ranging Environmental Impact Statement (E.I.S.) required by the Australian Government before any commercial turtle farming development is approved. In addition, comprehensive data is being collected on turtle biology, natural history, husbandry and a head-start programme initiated. The turtle husbandry, diseases and nutrition studies are being conducted in liaison with James Cook University of North Queensland, with compound pellet feeds, tanks, pumping systems and turtle enclosures etc. also being evaluated as part of the project.

Results

Turtle farming or husbandry research has been of a limited nature, mainly due to primary emphasis on the turtle population studies necessary for the Environmental Impact Statement and restrictions on the employment of additional professional biologists for the project. As a result of these limitations the project has had to rely largely on limited husbandry experiments, farm performance records and on postgraduate student research studies in specific areas i.e. turtle disease and nutrition, rather than an overall integrated turtle husbandry research programme.

All the turtle farming operations are geared to train the Islanders in turtle husbandry and assess their capability and capacity as turtle farmers for future economic evaluation of turtle farming as a sustained and viable proposition for Torres Strait Islanders.

Results to date indicate that the Torres Strait green turtle resource is shared with Papua New Guinea and Indonesia and that significant numbers of turtle eggs can be taken from certain nesting beaches with little or no loss to the natural population, as these eggs would normally be lost to beach erosion (Parmenter 1978). On the husbandry side there are nutritional, disease and growth rate problems.

Compared with Mariculture performance data given to us by Major (1976) which showed their turtles to weigh 2400 gm, with 42% mortality at 12 months of age, by comparison Islander turtle farm mortality has been up to and in some cases over 60% in the first year with corresponding weight gains at a year old 30% below those achieved by Mariculture. In these circumstances, even with farmer training and improved turtle husbandry and nutrition, it is still doubtful if the required production, estimated in 1976 at 600 kg of turtle per farmer per annum can be achieved in the island farm situation, to make turtle raising for meat an economic proportion.

Whether slower growth rates of Torres Strait green turtles is due to genetic factors or inadequate husbandry, particularly nutrition, is not certain. One indicator on this matter came from a small batch of turtles on Murray Island where they consistently exceeded the Mariculture performance figures, in fact reaching an average of 2400 gm at 10 months of age with only 37% mortality, this would indicate husbandry and nutrition as the major problems rather than genetic factors. It is hoped that Garnett's nutrition research programme on Badu Island will provide more critical information in this important area.

Discussion

From the present limited research base it is difficult to draw many positive conclusions, the turtle husbandry research conducted so far in the Torres Strait having pinpointed the many problems to be faced, but as yet, provided few answers.

On the economic side alone efforts to find a breakeven situation based on a fully closed farm development is difficult to see, in the light of so many unknown factors in the areas of turtle husbandry and turtle breeding in captivity. The high value of products overseas and markets in Australia for limited quantities are more than off-set by the following:

(i) Wages and productivity, the payment of award wages, currently $7000-8000 p.a. per turtle farm employee is unlikely to be off-set by the volume or value of turtle product likely to be produced under the present system. It was estimated in 1976 before award wages that each farmer would have to turn-off some 600 kg of turtle product p.a. for the project to be viable.

(ii) Turtle feed costs; compound feed was estimated in 1976 at $265 tonne, 1978 pellet formulations ranging from $332-600 tonne, plus freight, which brought the cost of feed landed in the Torres Strait to $812-1140 tonne. Even at the lower cost and a conversion rate of 3:1 feed to turtle, it would cost $2.44 per kg turtle produced for food alone. Allowing for the multiplier effects of mortality and percentage meat in the turtle, the feed alone would work out at $6.00 per kilogram of turtle meat produced.

(iii) The administration and servicing necessary to adequately manage any project in the Torres Strait area is expensive, particularly for communications in the form of ships. The provision of such services in 'Catch 22 fashion' while necessary for the project's existence, will tend to raise costs to make the venture an uneconomic proposition.

At present there are good markets for turtle products, but what are the prospects for turtle farming or some form of turtle utilisation for benefit of Torres Strait Islanders? A full or a closed turtle farming system is most unlikely to prove an economic or viable proposition. Other options for turtle development and utilisation are:

(a) Commercial turtle raising from eggs taken from the wild; and

(b) Limited commercial exploitation of the turtle resource on a straight, put-back or headstart basis. It is known the quantities of turtle eggs are available from rookeries such as Bramble Cay at little or no loss to the wild population, so turtle raising could prove a valid option for the future.

A programme of limited commercial turtle exploitation, in addition to the present subsistence utilisation of some 4100 turtles p.a. by the reserve Torres Strait Islanders would have the immediate attraction of generating cash flow within the project. This in turn would help justify a long term head-start research and turtle population monitoring programme necessary to safely manage the Torres Strait green turtle resource.

In contrast to what has been stated on the economics of turtle farming the special social and economic situation of the Torres Strait Islanders in the reserve island situation must be considered, as is the need to provide valid development options and opportunities for the Islanders to meet their needs in a manner compatible with their culture and status as Australian citizens. The project even at the present experimental stage has had a significant economic impact on the reserve islands' population where employment opportunities are extremely limited.

Conclusion

There are many problems in the areas of husbandry, conservation and economics of turtle farm development, turtle utilisation or management, yet for those who can see it through and can develop an acceptable economic resource management system, the rewards will be considerable. In the Torres Strait situation turtles should be considered in the context of other resources available and not as a one-off development to satisfy what is the complex socio-economic and resource development problem of the whole area.

"Behold the turtle, he makes progress only when he sticks his neck out"
— James B. Conant.

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THE RAINE ISLAND AREA – A PROSPECTIVE NATURE REFERENCE SITE IN QUEENSLAND

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INTRODUCTION

Raine Island, at 11°36'S, 144°01'E, is a small vegetated sand cay located on the outer Great Barrier Reef approximately 100 km ENE of Cape Grenville, Cape York Peninsula. It is situated on the northern side of the 15 km-wide Raine Island Entrance, formerly the most usually employed passage in the Great Barrier Reef from Coral Sea 200 km direct through Torres Strait (Moseley 1879)*. To the south of the Entrance lies Great Detached Reef. North from Raine Island about 15 km lies Pandora Cay (11°27'S, 144°00'E), a smaller island on the southern side of Pandora Entrance. The only other vegetated cay in the vicinity is found 22 km to the north-west at 11°22'S, 143°48'E; this is presently unnamed, though Queensland Place Names Board has been asked to ratify this as McLennan Cay (Limpus *in prep*).

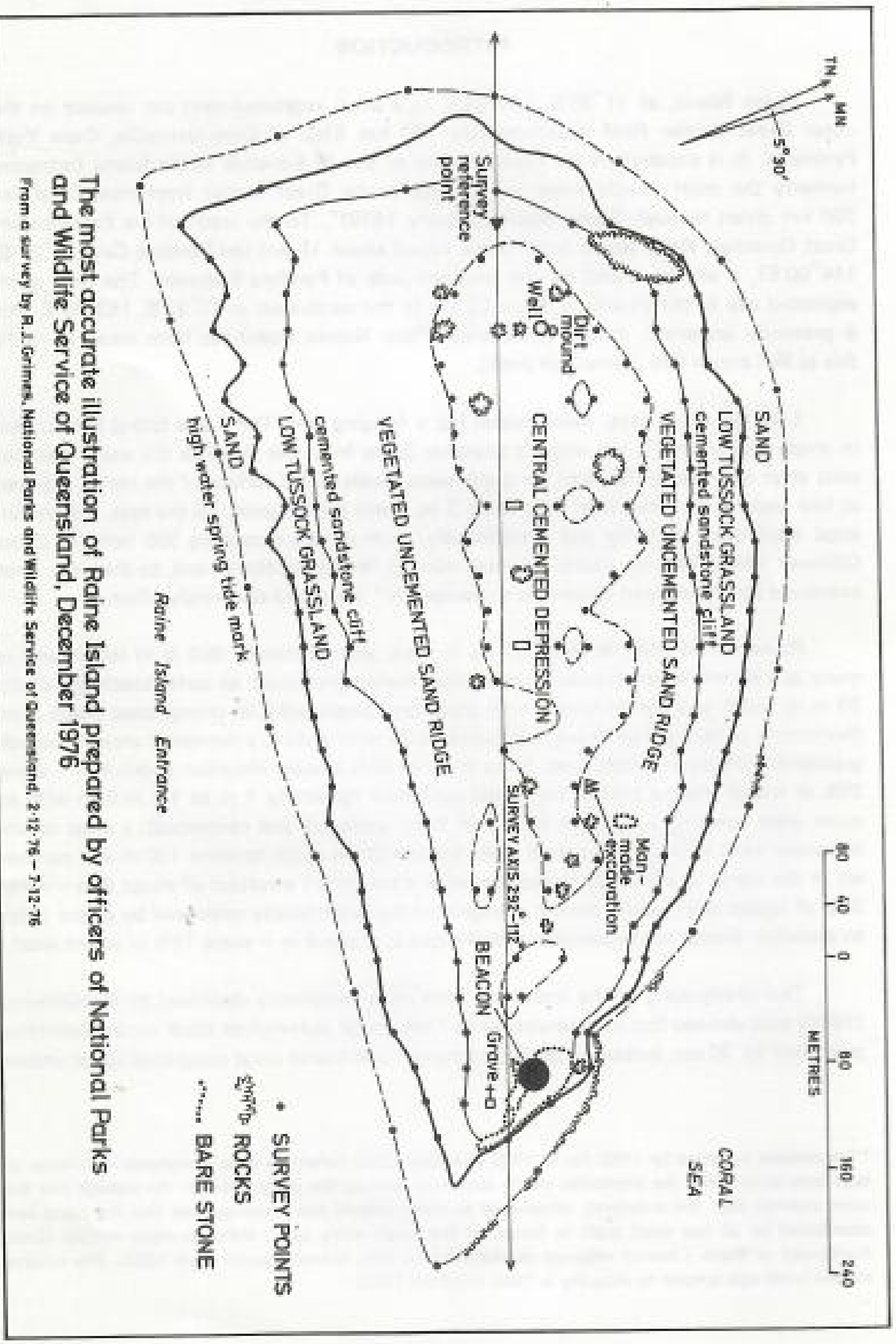
Like the other cays, Raine Island has a fringing reef. The Raine Island Reef is oval in shape and nearly 2 km wide; it stretches 3 km from the shore to the south-east but ends after only some 150 m to the north-west. Much of the surface of the reef is exposed at low water tides when level falls some 3 m. There is no lagoon. To the east, the continental shelf stops abruptly and precipitously, with depths exceeding 350 fathoms (MacGillivray 1846). Nearby, charts are most marked "heavy breakers" and, to the west, "not examined but considered dangerous to navigation" is marked alarmingly often.

Raine Island itself is some 30 ha in area, approximately 850 m in length and as many as 430 m in width. It consists of distinct concentric zones: an outer beach (generally 20 m in width and 5 m in height, with occasional beachrock); an unvegetated beach crest (horizontal or falling slightly landwards and 20-25 m in width); a depressed area of tussock grassland (varying in width from 10 m to 80 m with average elevation about 4 m – some 25% of island area); a cliff of cemented sandstone (generally 1 m to 1.5 m high with an outer edge reaching a uniform height of 6 m, undercut and cavernous); a ridge of uncemented sand with grass and herb cover (widest in the south to some 100 m and narrowest in the north at about 35 m average, with a maximum elevation of about 9 m – some 35% of island area); and a central unvegetated flat superficially cemented by guano (with an elevation similar to the peripheral cliff edges at about 6 m – some 15% of island area).

The stratigraphy of the island has been most completely described by MacGillivray (1846) who showed fine coral sandstone to 7 cm, moist pulverulent black earth resembling peat then to 30 cm, successive deposits ranging from coarse coral conglomerate to uncon-

*The passage surveyed by HMS Fly in 1843 was abandoned before its crew completed the Raine Island beacon in 1844; the intricacies of the navigation among the reefs, between the passage and the open channel near the mainland, occasioned so many wrecks and misadventures that the route was abandoned by all but small craft in favour of the much more open, although more remote, Great North-east or Blyth Channel adjacent to the coast of New Guinea (Saville-Kent 1893). The present coastal route was opened to shipping in 1865 (Warham 1961).

creted calcareous sand then to 4 m, and masses and large fragments of coral of species still living on the reef loosely embedded in coarse sand then to 4.27 m when inflow of salt-water took place. (There is no permanent surface freshwater on Raine Island and, despite an inscription to the contrary, none likely to be below ground.) Jukes (1847), Rattray (1869), Fairbridge (1950, 1967), Bennett (1971) and others have variously interpreted the geology of the island.



The most accurate illustration of Raine Island prepared by officers of National Parks and Wildlife Service of Queensland, December 1976

From a survey by R.J. Grimes, National Parks and Wildlife Service of Queensland, 2-12-76 – 7-12-76

HISTORY

Raine Island was first recorded in 1815 by Thomas Raine aboard "HMS Surry". With three exceptions, all subsequent reports on the island have been the result of short, almost opportunistic visits that have offered interesting descriptive comments but little data that are repetitive, comparable or cumulative. Of the three more prolonged periods of visitation, the most comprehensive information, by Jukes (1847, 1871) and MacGillivray (1846), was gathered in May-September 1844 when a beacon was constructed. The other visits involved beche-de-mer fishing in the 1870s (Ellis 1936), and guano collecting in 1890-1892 (Ellis 1936, Hutchinson 1950, and in the diary of John Arundel of the J.T. Arundel Company that dug these deposits). Again, these records are of uncertain accuracy. Thus the beche-de-mer fishery conducted most regularly by two Europeans and 2 or 3 natives in 1873 was concluded to "hardly have been on a very large scale" because of the absence of fuel for boiling and smoking the animals. Guano production likewise is uncertain, with any figures often inseparable from those for other Great Barrier Reef islands. In the main period of digging, when A.F. (later Sir Albert) Ellis was in charge of 9-10 Europeans and some 100 Asian labourers, it is reported that "tens of thousands of tons" of guano were exported; the quality of the phosphate remains unknown, though lacking in the ammonia of Peruvian deposits.

The result of all these visits is thus more noteworthy for the materials they gathered rather than the data they recorded. The changes occasioned by them remain evident in the man-made structures and quarries strewn over the island; thankfully little remains to be seen of the tramways, locomotive, jetty, vegetable gardens (of pumpkin, coconuts, Cape gooseberry, maize, tomato, capsicum, water melon), huts, tents, observatory, flagstaff, graves, at least 4 shipwrecks (Lack 1953), and goats [innumerable in the 1930s according to Patterson (1936)] that have deliberately or otherwise been introduced to convert this isolated landscape.

TERRESTRIAL BIOLOGY

It is this isolation, or at least partly this attribute, that has produced the two most obvious natural features of Raine Island as it is presently known.

The island is "probably the most important breeding station for tropical sea-birds in Australian seas" (Warham 1961), and "the largest and densest green turtle rookery ever recorded anywhere in the world" (C.J. Limpus and R.A. Birtles, unpub. report, 18 April 1977).

These qualities have been recognized, and exploited, from the outset. Thus Jukes (1847) recounts: "The whole surface of the island was covered with old and young birds . . . There were young of all ages — some able to fly, others just hatched, and covered with yellowish down . . . The boobies and gannets each formed separate flocks, but few of them had either eggs or young ones. All the rest of the island was covered with the eggs and young ones of the terns and noddies. . . The whole island stank like a foul hen-roost, and we were covered with bird-lice and ticks after sleeping in the sand. We dined upon young boobies and frigate-birds and terns' eggs — the latter were excellent, and the former very good, especially when cooked with a little curry powder. As night closed in, it was curious to see the long lines and flocks of birds streaming from all quarters of the horizon towards the island. The noise was incessant and tiresome. On walking rapidly into the centre of the island, countless myriads of birds rose shrieking on every side, so that the clangour was absolutely deafening, like the roar of some great cataract". Or as Mosëley (1879) concludes even more romantically, "Birds . . . are in such numbers as to darken the air beneath as they fly overhead. . ." Or again, in the words of John MacGillivray (1846): ". . . we found not less than eighteen species of birds, several of which were new to science, inhabiting this mere speck of land, and to me they constituted the most interesting feature of the place. Upon nearing the shore on my first visit in May, 1844, an immense cloud of sea-fowl was observed hovering over the place, and their cries were distinctly heard at the distance of a mile. Crossing the reef, we landed on a steep sandy beach, and a few yards further brought us upon one of those vast breeding-places of birds, of which none but an eye-witness can form an adequate idea. The ground was so thickly strewed with eggs, that we could not walk about without occasionally crushing them under foot; myriads of terns, noddies and boobies darkened the air around; the mingling of loud, harsh, discordant cries was absolutely deafening, and caused even a painful sensation, which, with the stench from numbers of putrefying carcasses and other sources, was almost insufferable. . . A large flock of gannets and boobies covered a bare spot in the centre of the island, chequered black and white with their dense masses. The eggs and newly-fledged young of the tern and noddy were turned to good account by the party established upon the island. . . I amused myself one day with making a calculation of the consumption of young birds and eggs during the month of June, and found it to amount, at the lowest possible estimate, to 3,000 of the former, and 1,410 dozen of the latter." Reference to this exploitation of the island takes another turn with John Sweatman's nonchalent, "Our first act of landing was, of course, to break every egg on the island so that all we collected afterwards were sure to be fresh" (Allan and Corris 1977).

The second outstanding feature of the island has been less prosaically described, less usefully documented, and less grossly exploited. These are the turtles, about which John MacGillivray noted: "A visitor to Raine's Islet, is apt to be surprised at the number of dead turtles scattered about the margin of the island, the remains probably of such as have fallen on their backs while endeavouring to climb the low rocky border. . . These are all of the green species, which resorts to this and the other sand-banks and islets of the N.E. coast of New Holland, in considerable numbers. . ." or, as his namesake Dr William MacGillivray reported, in 1910, "Great numbers of turtles are on the beach and in the shallow water round the boat". Accounts of exploitation, for example by Mackenzie (1845) where the crew of HMS Heroine "obtained fourteen large turtles, each averaging four cwt" no doubt reflect a constant, low-level of food gathering that must have proceeded endlessly. That turtles have thrived there over time is evident from the subfossil eggs located there (MacGillivray 1846).

The absence of the more spectacular records of turtles subsequently reported by Limpus may be explained by the seasonal and annual variations in numbers of the green turtle along the reef. The infrequent, short visits, amounting to some 18 reports over 160 years, during seasons when cyclonic and other adverse weather conditions are minimal, together with a bewildering confusion of animal life over, under and around Raine Island make it remarkable, perhaps, that any worthwhile data at all are available. Of a biological nature, sufficient for the moment to propose that a situation exists where an island and its surroundings support a food chain of an unprecedented magnitude on the Great Barrier Reef. Hindwood *et al*. (1963) have concluded that an inevitable conclusion must be drawn that large sea-bird populations reflect a plentiful food supply in the form of fish and other marine organisms. The turtle numbers endorse this further still. John MacGillivray (1846) has long since noted that "Raine's Islet abounds with marine productions, especially Radiata and Mollusca".

SYSTEMATIC STUDY

As recently as 1925 W.B. Alexander has claimed, "It is clear that a visit to an island for a few hours or a few days is of little value for this purpose. . . . Systematic observations undertaken at several islands on different parts of the coast and carried on for several seasons, if correlated with physical and meteorological data, might well yield results of great interest to biologists. . ." It is this approach, together with the same opportunistic visits that have gone before but which have now explored a more definite role, that is the basis for the following proposal:

That Raine Island and its adjacent seas and reefs constitute the principal site in the Great Barrier Reef Province at which to institute long-term monitoring of the total environment by means of selected indices.

Its verification is made somewhat easier by present circumstances: no study site has yet been nominated in unquestionably the richest region of the Province; the study area is selected for its natural features rather than its accessibility to man; the study area, by the same token, is likely to remain free from intrusion other than for mainly scientific purposes; and a wide range of scientific disciplines is now available to initiate comprehensive, integrated projects.

LOGISTICS

No such programme could, or should, be contemplated without careful attention to the detail that was the disadvantage of earlier work and the necessity of the above approach.

The Study Area

Though the influence of the Raine Island is, by corollary, far-reaching, it is impractical to spread (or dilute) attention too far afield. Thus while Warham (1961) proposed Ashmore Banks (11°53'S, 143°39'E) to be an "offshoot of the main rookery on Raine Island", and Limpus (unpub. data) has found movement of turtles from Raine Island through Torres Strait, it would seem desirable to contain immediate study within an area surrounding Raine Island, Pandora Cay (also mentioned by Warham *loc cit.*) and McLennan Cay, and part of Great Detached Reef. All elements of the outer reef would seem to be included; while intrusive mainland effects such as by Sir Charles Hardy Islands on Ashmore Banks appear to have been avoided. The area is now the subject of detailed photography and mapping by the Australian Survey Office on behalf of the Great Barrier Reef Marine Park Authority.

Statutory authorities and land tenure

Within the study area four Government instrumentalities would appear to hold legislative responsibility: Raine Island is a Reserve (R 4) for Departmental and Official purposes under the trusteeship of the Department of Aboriginal and Islanders Advancement. That small part of the island on which the beacon and the grave of Mrs A.F. Ellis are situated, and Pandora Cay and McLennan Cay presently Vacant Crown Land, have now been sought as reserves under the Queensland National Parks and Wildlife Service which has responsibility for the fauna of the region. The beacon, the oldest lighthouse in Australian seas (Patterson 1936), is now listed by the National Trust of Queensland on behalf of the National Parks and Wildlife Service. The area surrounding Raine Island has been proposed to be a Marine Park under the jurisdiction of the Queensland Fisheries Service as are, of course, all marine products. The Great Barrier Reef Marine Park Authority has a responsibility for the environment throughout. For the purpose of this exercise, a nominee from each authority comprises a Co-ordinating Committee whose collective role is to co-ordinate and integrate the necessarily individual objectives and opportunities.

Facilities

It is not timely to propose those facilities that may soon be available to counteract the harsh and isolated conditions prevailing in the area. Sufficient to suggest that the beacon will be reconstituted along acceptable National Trust lines as fully furnished and maintained laboratory accommodation for the use of those visitors whose work would contribute to the knowledge of the area. This matter is presently being resolved in all its legal, structural and financial aspects.

NATURE REFERENCE SITES

The matter of retention of natural environmental quality is, of course, more general than that represented by national parks. It is evidenced in the way all land is used, and that is the responsibility of many, if not all, sections of the community. The paramount need is always to retain that viable segment upon which the remainder of the environment may depend in adverse moments of time. This is a responsibility that a National Parks and Wildlife Service should be expected to accept. The recognition of these segments, and the way they behave over time, are critical elements of this management responsibility.

Locations that have been the centre of concentrations of endeavours to monitor environment and the dynamic changes in this are well known outside the biological field. Trigonometrical and meteorological stations are obvious examples; in Queensland, given the notoriety of our beaches, the formal benchmarks of the Beach Projection Authority are well known.

Given also Western man's familiarity with some of the world's wildlife, various zoological monitoring sites have become key global stations in relatively short periods of time. It is no coincidence that these mostly are islands; problems are more discrete and recognizable, and disturbance is more readily able to be controlled. Thus in the eastern Pacific Ocean the Galapagos Islands with the Charles Darwin Research Station have become famous; other islands in every ocean are equally noteworthy for their contributions to science.

In the United States, the need for areas available for scientific research to monitor the environment and changes in this was recognised early on. Federal land management agencies have been actively developing a national system of Research Natural Areas since 1927. From the inception there have been two primary purposes for developing a comprehensive system: Firstly, to preserve a representative array of all significant natural ecosystems and their inherent processes as baseline areas, and secondly, to obtain through scientific education and research, information about natural system components, inherent processes, and comparisons with representative manipulated systems. Most recently in Australia, the Victorian Legislative Assembly has passed, without opposition, a "Reference Areas Bill".

In 1978, Queensland instituted a Nature Reference Site concept, whereby a Nature Reference Site is a defined area of significant ecological interest at which facilities are provided allowing the intensive, long-term monitoring of the total ecosystem, or some part of it, to be undertaken by those best suited for the purpose (Lavery 1979).

It is fortuitous, we believe, for a country to be in a position to contemplate the prospect of securing scientific monitoring areas that could reasonably be held to represent the natural countryside. Our definition of "natural" here envisages an environmental system not perceptibly influenced by man, either directly or indirectly.

The inverse relationship existing between increasing ecological understanding and diminishing ecological opportunity could be proposed to intersect in such a situation as Queensland. The argument is that the United Kingdom, for example, now has the skills but no longer has the natural lands, while the tropical Americas, for example, have the lands but lack the technical sophistication and standing to argue successfully for their retention in the face of western-style development. Perhaps Australia in general, and Queensland in particular, is at the "point of balance", and so it may be that the establishment of viable, representative, scientific monitoring sites is a real prospect.

In Queensland the first area of land has been set aside towards this end. It is a 27,400 ha tract of more or less natural mulga land between Charleville and Adavale, with its environment protected on the one hand by its situation at the headwaters of the Warrego, Paroo and Bulloo Rivers and on the other by its relative inaccessibility to man and his agencies through the surrounding escarpments. A detailed descriptive phase of work is now in progress. All results point up the relevance of a Site such as the Raine Island area.

At this juncture there appears to be no nature conservation legislation in Queensland suitable to meet the land tenure requirements, whatever these are, of a Nature Reference Site concept. The final solution needs to be evolved; new forms of land tenure may need to be erected. These presumably may need to account for zones within the Sites — sacrosanct core regions, experimental regions, and surrounding buffers. It is for this reason that one must consider the inclusion of Pandora Cay and McLennan Cay.

The Nature Reference Sites programme was instituted within the Queensland National Parks and Wildlife Service through funds made available for the purpose by the Director to his Research and Planning Branch in July 1978. The Service currently has before it some 800 proposals for land to be reserved for conservation purposes; the Branch has gathered an early experience in evaluating land, with some 350 reports now completed, as well as the more systematic land evaluation that is in progress in the long-term Regional Resource Maps series. For practical reasons, Nature Reference Sites will necessarily comprise a limited number of areas.

The subject of ecological benchmarks is clearly one of the scientific community at large; it is not one that can be handled by a small group of scientists within one institution, however dedicated. The tasks of the National Parks and Wildlife Service must therefore include the provision, as a public service if you like, of the where-with-all that a nature conservation authority has at its disposal. We welcome the interest of the scientific community in these Sites, and we shall encourage it as best we can. Already at the mulga Site, the Department of Primary Industries has had officers inspect the area for the provision of "control plots".

The programme is not one-sided. National parks are widely held as a major means of conserving nature. It seems likely in Queensland that Nature Reference Sites, in practice, will provide the information whereby national parks can be scientifically managed. There is no prospect that each park can be scientifically studied; representative sites for investigation must be selected carefully, and results judiciously extrapolated. Thus not only could the collective results of scientific endeavour at Raine Island, for example, be used to manage other reef situations, indeed these may also be used to select national parks in a region where now there is none.

PARTICULAR PROJECTS

It would be premature to propose the style of individual research projects that might be designed for the Raine Island area. By the same token, it would be fruitless to approach the island without a prepared plan of action, including the materials with which to conduct this.

In the first instance the projects would seem to need to be descriptive, if only to establish base lines from which change may be identified and measured. This descriptive work would presumably be in three fields — that concerned with the physical features; that related to the vegetation; and that concerned with the fauna.

Because the outstanding features are zoological and are the subject of the initial studies, it is likely, and desirable, that the measurements of flora and landform are of those characters apparently related to the behaviour of the fauna. Thus, cays are notable for their rapid land accretion and erosion (see, for example, Limpus and Lyon *in prep.*); a fixed grid system from the outset would provide the means of measuring these, if only to establish the relationship between them and the fauna that so obviously requires the presence of land surface for reproductive purposes. It will, of course, require careful reconciliation with national mapping grids to confirm the absolute position of the island in space, though this task can wait on broader mapping plans. As with subsequent, or concurrent, studies of the vegetation, physical studies may be most conveniently conducted on a randomized grid basis, though line transects and belt transects may also be necessary for complete coverage. Some 12 species of grasses, herbs and forbs have been recorded within zones of the island; the seasonal and annual behaviour of these have not been described there, yet their effects on the physical and zoological stability of the island could be profound.

Much work has been done along the Great Barrier Reef to study the reproductive behaviour of sea turtles; Raine Island is within the framework of this project, and relevant data on the relationship of the Raine Island area to elsewhere are forthcoming. Perhaps greatest other progress at this juncture can be provided by the sea-birds in two respects. Firstly, like tagged turtles the banded birds could indicate the relationship of the area to elsewhere on the reef; perhaps even more importantly, recoveries would reveal the role of the area itself in the life of the birds. And secondly, a study of diet, so easily undertaken, could readily provide some indication of the reason why Raine Island has been selected as a principal breeding site. No doubt the food source is itself part of a food chain, in turn linking with the foods of the turtles, indeed, with the abundant "marine productions" of MacGillivray (1846). Again, a link with measurements of the physical ocean currents seems worth investigating.

Much of the biology of the cosmopolitan sea-birds has been studied elsewhere and it would be wasteful of time to repeat these at least initially. At best, comparisons with foods and with productivity might reveal particular aspects of the area. In this latter instance, it should be recalled that the area is given to vast fluctuations in numbers of breeding turtles, and the phenomenon may be broadly based.

It is evident that such a key area on the Great Barrier Reef must be approached with circumspection. The fundamental questions are clear — why is the faunistically rich Raine Island where it is? And, how stable is this situation, geologically and biologically, in the face of those reasons for its location?

COMMENTS

Under the auspices of I.U.C.N. the World Wildlife Fund must select topics of international significance. Under the auspices of the Australian Government, the Great Barrier Reef Marine Park Authority and the Australian National Parks and Wildlife Service must choose to study items of national concern. And under the auspices of the Queensland Government, the Department of Aboriginal and Islanders Advancement, the Queensland Fisheries Service and the National Parks and Wildlife Service, like other State departments, must allocate top priority to the major issues.

The Great Barrier Reef deserves such a rating, and Raine Island is the Province's most productive single location. No ongoing study has previously been considered; any serious approach will necessarily be multidisciplinary in the long run and beyond the immediate responsibilities and resources of any one statutory agency. The voluntary establishment of a co-ordinating body of all of these, the provision of funds, by or through or with them, and the fitting of activities within a scientific concept that is both sound and workable, signals a major initiative towards the conservation of one of the world's best signalled but least known natural resources.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge information gathered during visits to the Raine Island area by a number of officers of Queensland National Parks and Wildlife Service, notably Messrs C.J. Limpus and R.J. Grimes, Research and Planning Branch. Some photographs used in the Seminar were by Mr Steve Parish, also of National Parks and Wildlife Service.

SUMMARY

Raine Island (11°36'S, 144°01'E) is a small vegetated sand cay towards the northern end of the Great Barrier Reef off Cape York Peninsula. It is possibly the largest green turtle rookery in the world, the principal sea-bird breeding island of north-eastern Australia, and the most obviously productive island (in biological terms) of the Great Barrier Reef. Although remarked on as outstanding since its discovery in the first half of the nineteenth century, it has remained the subject only of occasional and unsystematic studies. Because it is a highly dynamic system, because its resources are the subject of exploitation (sometimes massive), and because it is a reserve for aboriginal purposes and protected only by fauna sanctuary status, its future is presently uncertain. This should be unacceptable to society at all levels.

A Co-ordinating Committee of the four statutory authorities involved in the area — comprising Raine Island, Pandora Cay, an unnamed cay proposed to be McLennan Cay, and the surrounding and intervening waters over some 1300 km^2 — has therefore been formed. Funds for particular projects — specifically designed to determine why Raine Island is where it is, and how stable the system is in the face of this — have now been received from such eminent sources as World Wildlife Fund. And the area is proposed as a Nature Reference Site to secure its purpose as an ecological monitoring point henceforth.

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MANAGEMENT OF TURTLE RESOURCES

RESEARCH MONOGRAPH 1

ERRATA

Please amend as follows:

. *On title page, after "Department of Tropical Veterinary Science" add "at Townsville, Qld., Australia, 28 June 1979".*

. *"Dr J. Parmenter" on page 3 to "Dr C.J. Parmenter".*

. *"J. Parmenter" on pages 4 and 23 to "C.J. Parmenter".*

. *In Figure 2 on page 26 the legend should appear as:*

H - Hut

** - Lighthouse*

—— - S.H.T.L. 15 October 1978

---- - S.H.T.L. 29 March 1979

...... - Vegetation Margin

. *Interchange Figure number "3" and caption ("Size and sexual distribution of Chelonia mydas slaughtered at Yorke Island 22 October 1976-30 June 1977") on page 29 with Figure number "4" and caption ("Size distribution of non-nesting Chelonia mydas captured 22 October 1976-30 June 1977") on page 30.*

. *"J. Parmenter" on page 32 to "C.J. Parmenter".*