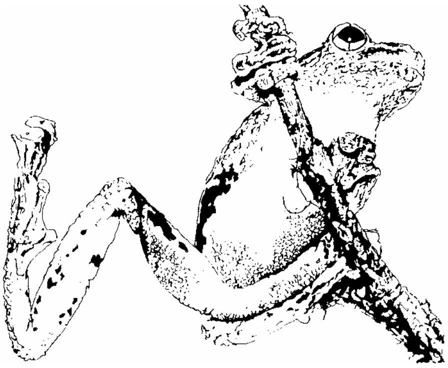

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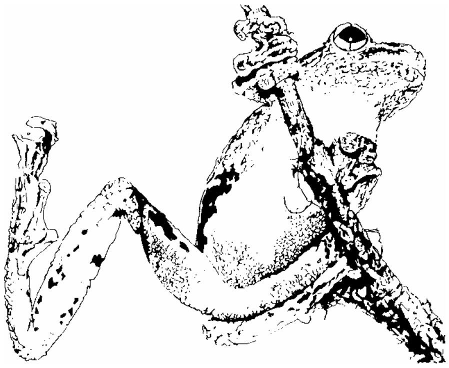

Monitoring Plan for the Pig-nosed Turtle in the Daly River, Northern Territory

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INTERPRETATION OF THE BRIEF

The Applied Ecology Research Group has been commissioned by the Parks and Wildlife Commission of the Northern Territory to prepare a monitoring plan for the Pig-nosed Turtle, *Carettochelys insculpta*, in the Daly River catchment. As a requirement of this brief, we were to

1. Prepare a written review of available information on the life history attributes, habitat requirements, and dispersal, with particular attention paid to how these influence the design of a monitoring program;

2. To collate and analyse existing information relevant to establishing a baseline on the turtle's abundance;

3. To outline a range of options for monitoring turtle absolute abundance or relative abundance, including the use of surrogate measures, and incorporating the sound principles of experimental design; and

4. Provide advice on the potential for community involvement in the monitoring program.

In providing these required elements, we first outline our understanding of the objectives of a monitoring program for the pig-nosed turtle and the rationale for choosing this species as the target of monitoring. We then provide a summary of the biology of the species where relevant to a monitoring program, with broader background on the species and pointers to the literature included as an appendix. We then present estimates of the abundance of pig-nosed turtles obtained from data collected in 1986 (Heaphy, 1990; Georges, unpublished data) and between 1996-99 and an assessment of trends in abundance over that period.

We provide specific monitoring methods and how certain existing knowledge underlies monitoring strategies. Finally, we outline monitoring options, in terms of logistics and personnel, and discuss the strengths and weaknesses of each option. We conclude with a short section on what the outcomes should be, and underscore the importance of consistent data collection and management.

In preparing this plan, we have tried not to be too proscriptive. Options are presented on the understanding that the resources to be allocated to this activity are a matter for the PWCNT to determine, and that resources will largely dictate the final combination of options chosen. To assist in these difficult choices, we have tried to clearly identify the benefits of each option, and the loss of information that will occur if the option is not adopted.

RATIONALE

Carettochelys insculpta is both a flagship species and an umbrella species. It is a flagship species because it is the sole remaining member of its Family, once widespread across the globe, and as such is of considerable interest to scientists and conservationists. It is an umbrella species because it appears to have fairly restricted habitat requirements, and meeting these requirements in conservation planning is likely to afford similar protection to a range of species with less stringent requirements. Monitoring population trends in *Carettochelys insculpta* is therefore regarded to provide a basis for assessing unacceptable degradation of the Daly riverine habitat.

Substantial agricultural development is planned for the Daly River catchment. This will involve development of the local region's water resources, coming into potential conflict with the organisms that depend upon those waters for their survival. Setting environmental flows is contentious, but it has been suggested that up to 50% of the dry season flow of the Daly may be redirected in support of agricultural development. Early plans to derive this water directly from the river, by pumping and the construction of dams and weirs (Anonymous 1993) appear to have been shelved, with the focus shifting to drawing upon groundwater reserves. However, the Daly River during the dry season is largely groundwater fed, and although the connection between groundwater reserves and river flow has not been quantified, off-take from groundwater reserves will have an impact on those flows. This in turn can affect persistence and health of animal populations that have evolved in concert with the existing flow regimes both in terms of the quantity of flow and connectivity of the system, and in terms of the timing and frequency of immediate pre-wet season flood pulses. Alterations in the mix of groundwater to surface water contributions to flow will in turn affect conductivity, the tendency for suspended particles to flocculate, and hence turbidity.

This monitoring plan will provide a means of assessing the effects of human-induced changes by providing baseline information on a flagship species before potentially threatening alterations to flow and habitat, and trends in its relative abundance as the agricultural development proceeds.

GOALS

The monitoring plan for the *Carettochelys insculpta* in the Daly River has the following goals: (1) to provide baseline data on relative abundances that can be used as a foundation for assessing future trends in turtle abundance; (2) to determine long-term trends in relative abundance; and (3) to relate these trends to human-induced change to habitat attributes in the Daly River.

Note that the monitoring plan is concerned with monitoring trends in relative abundances, not absolute abundances, by using surrogate measures of turtle abundance such as nest numbers. The reasons for this are outlined below.

EXISTING KNOWLEDGE

The pig-nosed turtle, *Carettochelys insculpta*, is a large freshwater turtle restricted in distribution to southern New Guinea and Northern Australia (Georges and Rose, 1993). In Australia, substantial breeding populations are known from the Daly, South Alligator and East Alligator drainages. Reliable anecdotal reports have it in the Victoria, Fitsmaurice, and Goomadeer systems (Georges et al., in press). A single specimen is known from the Roper River, though Aboriginal communities of the Roper River region typically have no knowledge of it, and those that do know it only from Timber Creek on the Victoria River. Anecdotal reports of it from the Darwin, Adelaide and McKinlay Rivers of the Northern Territory, and the Wenlock River of Queensland (Webb et al., 1986) have yet to be confirmed. The Wenlock River observation is almost certainly unreliable.

Pig-nosed turtles have diverse habitat requirements, within the constraints of occupying only permanent lentic and lotic habitats. They are common in both the continuous clear waters of the Daly River and the fragmented turbid waters of the Alligator Rivers. During the dry season in the South Alligator River, they achieve highest abundances in the upper reaches below the escarpment, in Barramundi Creek and the South Alligator proper. In the Daly River, they occupy the entire middle reaches of the river, between the escarpment and the saline sections (Fish River). Abundances reach their peak in the Daly River between Bull's Yard and Beeboom Crossing.

During the dry season females occupy home ranges encompassing, on average, 5.7 km of river, compared to 2.6 km for males (Young et al., in prep.). Gravid females move slightly farther (0.5 km) than non-gravid females, and had a greater tendency to undertake exploratory forays outside their home range. Populations appear to comprise resident animals, showing high fidelity to site over years to decades, and transient animals that move considerable distances. Animals marked at Oolloo were subsequently located at the jump up, 23 km upstream of Policeman's (Daly River) Crossing (ca. 100 km downstream of Oolloo Crossing), and 15 km downstream from Claravale Crossing. (ca. 60 km upstream from Oolloo Crossing). One animal marked in Pul Pul Billabong in Kakadu was subsequently captured in Patonga Billabong, many kilometres away.

During the wet season, *Carettochelys* move out of the river channel into the adjacent riparian forest, up creek channels, and into floodplain billabongs (Young et al., in prep.). Contrary to previous speculative reports, they typically stay within a few kilometres of their dry season home ranges (Young et al., in prep.).

Pig-nosed turtles are opportunistic in their dietary habits, consuming aquatic plants, algae, leaves, fruits, flowers, insect larvae, crustaceans, molluscs, fishes, and carrion (Cogger, 1970; Schodde et al., 1972; Legler, 1982; Georges et al., 1989; Georges and Kennett, 1989). In the Daly River, *Carettochelys* feeds mainly on ribbonweed (*Vallisneria* sp.) and snails associated with the *Vallisneria* (*Notopala* sp., *Thiara* sp.) (Heaphy, 1990; Welsh, 1999). Highest aggregations of *Carettochelys* occur in close association with *Vallisneria*, and it is likely that this plant species is an important determinant of the abundance of *Carettochelys* in the Daly River. Impacts on *Vallisneria* are likely to have corresponding impacts on *Carettochelys* populations.

In the Daly River, female *Carettochelys* are about 50 % larger than males (Doody et al., in prep.). Daly River females mature at a mass of 5.9 kg (carapace length 38.0 cm; plastron length 30.5 cm); size at maturity of males is not known, but appears to be at a mass of less than 5 kg (Doody et al., in prep.).

In Australia, *Carettochelys* begins nesting during the winter dry season. The onset of nesting is highly variable (varying by up to 5 weeks), and appears to be related to either or the elevation of water temperatures immediately following the coldest water temperature or the magnitude of the two wet seasons prior to laying (Doody et al., in prep.). Nests are excavated at night (Doody et al., in prep.) in sandy areas along the river that are generally free of vegetation (Georges, 1992). Nest sites are usually in sand, but occasionally in gravel or dirty sand, and are generally 0.5-1.5 m above the water. Higher areas are available and are inspected by gravid turtles, but loose sand precludes nesting at higher elevations in the absence of unseasonal rains (pers. obs.). Distance of nest from the water's edge varies with slope of sandbar (i.e., distance is an artifact of height) (pers. obs.).

In the Daly River population, females reproduce every other year, depositing two clutches in the years in which they reproduce. The inter-nesting interval is estimated to be about 34-46 days (Doody et al., in prep.). Clutches average around 10 spherical eggs (range 3-15), are deposited in flask-shaped nest 10-22 cm deep. Sources of nest mortality during a three-year study were predation by monitor lizards (*Varanus panoptes* and to a lesser extent, *Varanus mertensi*. 15.9 %), flooding (4.8 %), and embryonic failure (5.3 %). Rates of predation by monitor lizards is likely higher than reported here, as nests were often protected with wire cages during the study, and varies considerably from year to year.

Incubation period is 65-100 days depending on temperature, and is difficult to measure due to aestivation of late-term embryos (Webb et al., 1986; Georges and Rose, 1993; Doody et al., in prep.). Embryos hatch in response to one of two environmental triggers, anoxia (Webb et al., 1986) or hatchling movement (Doody et al., in prep.). The anoxia mechanism may be adaptive for synchronous hatching during the onset of early wet season floods (Webb et al., 1986). Emergence from the nest occurs at night, and is associated with rainfall (Doody et al., in prep.).

Carettochelys has temperature-dependent sex determination, whereby egg temperatures during incubation determine sex (Webb et al., 1986). The constant temperature dividing the male producing regimes from female producing regimes is 32 C (Georges et al., in prep.). However, fluctuations in nest temperatures influence sex, greatly complicating the determination of sex ratios based on nest temperatures in nature (Georges 1989; Georges et al., 1994; Georges et al., in prep.).

Very few hatchling, juvenile, or sub-adult *Carettochelys* have been seen during the course of extensive surveys, including diving forays. It is not known whether the lack of young turtles reflects a sampling bias (i.e., young turtles are more cryptic in their behaviour) or is actually a feature of their demography. Major ecological aspects of *Carettochelys* still unknown include juvenile and adult survival, mating behavior, and timing of mating.

BASELINE DATA FOR TURTLE ABUNDANCE

Baseline data on the abundance of the pig-nosed turtle is scant. This reflects the fact that the focus of previous studies has not been on population monitoring, but on reproduction.

A single point Peterson estimate of 12 turtles per km is available for the stretch of the Daly River between Oolloo Crossing and Jinduckin Creek (ca 10 km). It was taken in 1986.

During the 1996 through 1998 field study of *Carettochelys* on the Daly River, 281 adult turtles (186 females, 95 males) were captured and marked with both cattle ear tags and PIT (Passive Identification Transponder) tags. These numbers would have included an unknown number of transient individuals. Of those captured, 122 turtles were recaptured in at least one other year, and 32 of these were captured all three years. Linda Heaphy or Arthur Georges had marked 104 of these turtles during the 1986-1988 study. Their recapture indicates both high fidelity to site and low mortality.

Consequently, we believe that the population has been stable at 12 turtles per km between Oolloo Crossing to Jinduckin Creek between 1986 and 1998, although specific estimates of population size in 1996-8 are not available. This figure can serve as a baseline for absolute abundance at this site.

Table 1 breaks down the nest data (1986-87, 1996-1998) and females capture data (1996-1998) for two specified sections of the Daly River. It gives an indication of the variability that can be expected from year to year under consistent observer conditions. This variability, although not high, is the reason for multiple survey sites (3 – 5 x 2) recommended in the protocols.

Table 1. Total nests and numbers of females captured within designated stretches of the Daly River.

Year	Total Nests	Jinduckin to Oolloo		Oolloo to Cattle Creek	
		Nests	Females caught	Nests	Females caught
1986	*38	17	--	17	--
1996	65	33	67	18	31
1997	49	33	64	12	13
1998	76	22	39	14	13

* 4 nests -- location not recorded

The design for analysis suggested below is a mixed model factorial ANOVA with *Site* as a random factor and *Time* as a fixed factor. The interaction term is the error for a test of significance of the fixed factor *Time*. Significant outcome for the *Time* factor potentially indicates impact. There is no significant trend in the figures presented above (F=5.90; df=1,3; p=0.09).

ISSUES FOR MONITORING

There are several approaches to monitoring animal abundance (Seber, 1973), each differing with respect to accuracy and precision of estimates, the balance between the effort required and the return, the circumstances under which they can be applied (especially open vs closed populations), and various other logistic constraints.

Absolute Measures of Abundance

Absolute abundance is important for assessing the population status of threatened species, but is remarkably difficult to achieve in all but the restricted circumstances of a closed population. Even then, estimators of absolute abundance are only robust to violations of their assumptions when over 75% of the population are marked, and such violations are the norm.

The Daly River is a continuously flowing, spring-fed system, and although water levels vary dramatically with season (up to 20 m), fragmentation of the river during the dry-season so typical of most top end streams does not occur. From the perspective of *Carettochelys,* the system remains essentially connected throughout. Potential break-points such as Oolloo Crossing and numerous other shallow rapids are readily negotiated by the turtles in the dry season, contrary to other reports (Heaphy, 1990). So we are potentially dealing with an open system, whereby the turtle populations comprise a resident component showing great fidelity to site and transient component of animals that have not yet established a home range, are shifting home range, or choose to range more freely. We are dealing with open populations at the scale of any likely monitoring program.

This presents considerable difficulties for estimating absolute abundances of *Carettochelys,* difficulties that can only be overcome by intensive mark-recapture work and the application of Jolly-Seber estimates which take into account immigration and recruitment, emigration and mortality. Even so, it is likely that animals will leave and then return to any selected study site, thus violating the important assumption of equal opportunity for capture.

For these reasons, mark-recapture estimates are regarded as too expensive, and too logistically difficult, to form a regular component of an annual monitoring program. It may be possible however to undertake an intensive mark-recapture exercise once every 5 or 10 years, on a very short time-scale (days to a fortnight) in order to eliminate the effects of recruitment, immigration, mortality and emigration. Such intensive once-up exercises were undertaken in 1986 in the Oolloo region of the Daly and yielded adequate estimates of population abundance of 12 adult turtles per km of river channel. Much higher densities were measured in dry-season refugia in Kadadu National Park (Georges and Kennett, 1989), but these dry-season refugia were not extensive (Pul Pul Billabong, Barramundie Creek).

Relative Measures of Abundance – Direct Sighting

Assessing trends in population size does not require estimates of absolute abundance. It is enough to have a reproducible index to relative abundance and to track that over time. This has been used to great effect in terrestrial work, using spotlight counts, transect counts or indirect measures such as scat counts. Attempts have been made to obtain an index to the abundance of *Carettochelys* using spotlight counts at night and counts of sightings during the day, and these show considerable potential. Counting from a helicopter has been tried, but was not successful.

Using sightings as an index to population abundance does not require that all animals are seen, or even that the majority are seen. All that is required is that the number seen is related in some way to the number present, and preferably that the relationship between the two follows a linear relationship that passes through zero (no animals there, no animals seen). If the number of animal sighted declines over time, then it may be reasonable to assume that the number of animals present has declined.

There are clearly a number of assumptions underlying this approach that must be addressed in formulating a monitoring plan. If observers vary in their ability to see turtles, then trends in relative abundance may be simply a reflection of changing observers from year to year, or increases in the skill with which observers can see the turtles. Protocols are required to minimize this potential confounding effect, and the procedures must not be too complicated or require a great level of skill. This is especially important if community volunteers are to be used. Fortunately, *Carettochelys* is very distinctive, and unlikely to be confused with any of the other species of turtle found in the Daly.

Second, ability to observe turtles may be confounded by environmental conditions. Some of these are recurrent, such as phase of the moon, wind that picks up as the day progresses and greatly impedes visibility, and cloud cover. Every effort must be made to standardize these factors so that sighting estimates of abundance can be compared with confidence.

A third consideration, and one that precludes sole reliance on sighting surveys in any monitoring program, is turbidity. Water clarity greatly influences the ability to see turtles both during the day and when spotlighting at night. Water clarity varies appreciably from year to year, depending upon the severity of the previous wet season and the relative contribution of groundwater and surface water contributions to flow. Judicious choice of the timing of surveys can minimize this effect. However, based on experience elsewhere, increased sediment loads are likely to accompany river degradation in association with agricultural development and associated roads and other infrastructure. If water clarity suffers, so will the submerged macrophytes upon which the turtles depend.

A most likely cause of decline in the turtle populations will also confound our ability to monitor the decline with sighting counts, because the relationship between the number of animals seen and the number present will change as the water becomes less clear. Our experience indicates that relatively small changes in turbidity, compared with the scale of common turbidity values in top end rivers, will greatly affect any sighting index. Thus, relying solely on monitoring turtle abundance through direct counts is not a satisfactory option.

Relative Measures of Abundance – Surrogate Approach

A second approach to estimating relative abundance is to use a surrogate. Two possibilities present themselves. It may be possible to monitor the distribution and abundance of the submerged macrophyte *Vallisneria* sp., which is heavily relied upon by *Carettochelys* for food. Larger aggregations of the turtles are clearly associated with this plant. However, the quantitative link between the two is regarded as too tenuous to provide a basis for indirectly monitoring turtle abundance.

Monitoring nests is an alternative, which has a clearer connection to turtle abundance, and the spatially restricted opportunities for nesting make it a good option logistically. The population structure of *Carettochelys* is well documented and has been stable over the time-scale of decades (1986-1998). Sixty-six percent of the adult population is female, and an estimated 98% of females lay two clutches in a breeding year. For all practical purposes, each female lays two clutches every second year. The clutches are laid on discrete banks of sand adjacent to water (sand in contact with water) in a band ranging from 0.5 to 1.5 m in height above water.

It is possible to survey the number of nests in a discrete stretch of the river, taking advantage of the spatial limitations outlined above, and to use the trends in nest numbers as an index to trends in turtle abundance. These can then be potentially used to correct the index to an estimate of absolute abundance. This latter estimate can be crosschecked against spot mark-recapture estimates of abundance. A correction factor to account for missed nests may be required.

Again, it is necessary to get the protocols right, to ensure comparability of survey personnel across sites and years, and to account for any environmental effect that may confound the detection of trends in abundance. Unseasonal rainfall during the dry season, which would result in a smearing of nest locations across a greater range of heights above water, would be one such confounding effect. It would require adjustment of the survey protocols, for that year, and would add a caveat to any interpretation of trends involving data for that year.

Design Considerations

Statistical design is a key element of any monitoring program. What is to be the sampling unit, and how big should each be? How many sampling units are required to yield adequate precision in the estimates of abundance?

To answer these questions, we need knowledge of the spatial extent of movements of *Carettochelys*, both during their normal activities within single years, and in response to changes in the river environment that span several years. For a given population, stochasticity in the counts of nests will decrease with increasing size of the sampling units to plateau at a value determined by the scale of movements of the turtles. Home range sizes (on average, 5.7 km of river, for females; 2.6 km for males) and the extent of occasional forays to nest, indicate that each survey unit should be at least 10 km in length. Sampling units of at least this size are regarded as necessary to control a substantial component of nuisance variation in nest counts. Over the scale of 10 km, many home ranges would be entirely included, and the effects of individual turtle movements on variation in nest abundances within the transect would be acceptable.

Use of such stretches by turtles changes from year to year, because the river is remodelled each wet season, and the distribution of *Vallisneria* beds and potential nesting banks changes. To capture this variation, it is necessary to replicate the sampling units. Failure to do so would make estimates of turtle abundance vulnerable to shifts in the distribution of the turtles in response to shifts in optimal habitat from year to year. By replicating sampling units on a larger scale (120 km), this effect can captured and accounted for in the analysis.

There are few data to support a decision on how many replicates to use, but three is regarded as a minimum, and five a good compromise between logistics and the risk of unacceptable precision. Ideally, one could estimate the number of replicates required to have a specified probability of detecting a population change of a given magnitude.

This requires an estimate of the error in replicated counts over a single stretch, or counts over replicated stretches of the river, using standardized techniques. Such data are not available. Counts presented in Table 1 were obtained by different teams, working to different ends, and none of them population monitoring. Although the data has been selected to minimize these effects, a substantial component in the error of nest counts can be attributed to these differing techniques and differing search effort. This analysis should be undertaken once some standardized monitoring data becomes available.

If we assume that agricultural development is to be an event, it is possible to assign years to before and after potential impact. Adding a spatial control would allow a BACI design. Unfortunately, owing to the distribution of the major populations of *Carettochelys*, in the main Daly River channel, choice of suitable spatial controls is problematic. Upstream controls in, say, the Flora River are likely influenced by different natural factors, rendering them inappropriate as controls for main channel sites, and populations in the Flora are much less dense and therefore difficult to monitor by nest survey.

Instead, we propose a mixed model factorial ANOVA with *Site* as a random factor and *Time* as a fixed factor as the design most appropriate for this monitoring study. In this design, the differences across time are tested, after taking out variation among replicated sites, which can be expected to differ quite substantially. Linearity of response is not assumed, nor is it precluded by this analysis. The interaction term should be used as error in a test of significance of the fixed factor *Time*. Significant outcome for the *Time* factor indicates a significant change in population, and therefore potentially indicates impact. When applied to the data at hand (Table 1), there is no significant trend (F=5.90; df=1,3; p=0.09).

Table 2. Proposed design for monitoring variation in nest counts across years. Spatial variability is controlled to a degree by replication of sites and to provide an appropriate error term through the interaction of Year and Site.

		YEAR				
		2000	2001	2002	2003	2004
SITE	Oolloo	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
	Bulls Yard	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}
	Clarivale	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}

In the design proposed, good before-development and after-development data should be available for comparison by ANOVA if the development is viewed as an event (mixed model *Site* x *Development* factorial design with *Times* nested within

Development, no replication), or regression techniques if development leads to gradual change in river characteristics.

Limitations of this proposed design derive from the circumstances of the project, beyond the control of the monitoring staff, but need to be acknowledged when interpreting the results. First, owing to the landscape scale of the proposed development, with water drawn from the ground across a diffuse area covering much of the central catchment, it is impossible to obtain a satisfactory spatial control.

Second, some spatial variability in response can be captured by replication of survey stretches, but all survey stretches are impacted by the same development pressures, because the turtles are resident primarily in the single main Daly channel. Hence, true experimental replication of treatments is not possible. This is a common scenario in riverine studies.

Interpretation of the outcome of the monitoring will rest largely upon lack of substantial trends or change in abundance pre-development or early in development, followed by a change in abundance coincident with the development, if indeed that occurs. The stronger result of a change in areas affected by development, but not in true-control areas outside the influence of development, with full treatment replication, will not be possible.

Other statistical considerations will be dealt with when describing the specific activities that comprise the monitoring program.

OVERVIEW OF THE MONITORING PROGRAM

We propose a combination of mark-recapture, sighting surveys and nest surveys as an optimal approach to monitoring *Carettochelys* in the Daly, though we understand that resources may constrain what is actually implemented.

1. Spot mark-recapture exercises conducted initially, then once every five to ten years, or immediately following any obvious alteration to river health.

2. Annual or bi-annual spotlight or daytime surveys of turtle abundance, at each of six to eight paired localities

3. Annual or bi-annual nest surveys at each of six to eight paired localities.

PROGRAM AND GENERAL PROTOCOLS

Mark-Recapture

Mark-recapture estimates provide a reality check. All indications are that *Carettochelys* is exceptionally long-lived and that, in the absence of catastrophic changes to the Daly River environment, a half-decade or a decade is an appropriate interval for a more intensive investigation of numbers. Such investigations in 1986 and 1997-98, conducted incidentally to other studies, have indicated that the abundance of *Carettochelys* has remained stable in the Oolloo Crossing region over that period.

The mark-recapture exercise should involve a brief intensive session of turtle capture and marking. Capture can be effected by pursuing the turtles slowly in a powered boat and maneuvering them into a long-handled dip net. These are commercially available, but the netting will need to be extended to allow for the size of pig-nosed turtles. Handles should be lengthened to near 3 m. With practice, seven out of ten sightings can be captured with the dip net. Diving is an alternative, but a realistic assessment of the risk of crocodiles is required before it can be used to complement capture from the boat. Should the waters become turbid, capture with hoop traps baited with wallaby meat is highly effective, though more labour intensive.

Allflex cattle ear-tags are appropriate for this mark-recapture exercise. Loss of cattle ear-tags occurs over time, therefore PIT (Passive Identification Transponder) tags should also be used to provide for comparisons across mark-recapture exercises. The turtles should be placed on their backs on top of a 4” thick foam pad, with the bottom edge of the carapace extending just beyond the edge of the foam. The ear tags are inserted through a hole drilled in the suture between the first and second peripheral bones of the right side (dorsal view) of the carapace. Medium-sized cattle ear tags with female numbered flange and male stud are appropriate. A specialized applicator is required. The tag can be applied using the tag applicator, ensuring that the numbered side of the tag is placed upright on the carapace side. Cattle ear-tags have the advantage that animals need not be recaptured to be identified, which removes a major contribution to bias of the population estimates.

Peak opportunities for capture are typically brief, and catching should not be curtailed by processing. It is therefore usually necessary to transport the turtles back to a base camp for measuring and marking. The highly aquatic *Carettochelys* are extremely fragile out of water, and will injure themselves if allowed to roam freely in the bottom of the boat. Appropriate bags (hessian sacks are preferred, but plastic feed sacks are sufficient) are necessary to contain the turtles, and allow attachment of a temporary polypaper label to identify the turtle and its point of capture. Numbered steel tags attached permanently to each bag are useful for ease of identification and data taking purposes in the boat. While held in camp, the turtles need to be kept separate, and placed on a foam pad during processing. All turtles should be released as soon as possible at their point of capture.

It is important that the marking exercise is very intensive. The target should be to obtain and mark 75% of the adult animals present. In the clear waters of the Daly, this is achievable at several localities. “Recapture” can be done as part of the sighting surveys outlined below, or as specific exercises. The interval between marking and recapture should be short (3-14 days) to eliminate the potential biases that would result from immigration or emigration. On a small time scale, an open *Carettochelys* population can be regarded as effectively closed.

Peterson estimates of population size should be calculated, with appropriate estimates of precision (Seber, 1984). Other more sophisticated techiques are available for estimating population size of open populations, but none cater for the possibility of individuals temporarily leaving then returning to the survey area. Our approach has been to recommend a snap-shot sample to minimize this effect. Given that such an approach also minimizes departures and arrivals during the sampling period, we are dealing with an effectively closed population. Little is to be gained over the Peterson method by use of more sophisticated approaches.

Ancillary information that should be collected includes sex, carapace length, weight and other selected morphometric measurements.

- Carapace Length (CL) can be measured either by using a measuring tape for an "over the hump" measurement or by using large callipers to measure from the anterior edge to the posterior edge

- Plastron Length (PL) can also be measured using one of the above methods. The method chosen should be consistent for both CL and PL.

- Mass should be measured using a high quality spring balance with a sensitivity of 0.2 kg and a maximum mass of15 kg.

Notes should be taken on injuries and general body condition. Monitoring sex ratios is particularly important if the intention is to correct nest survey data to absolute population densities. *Carettochelys* can be sexed by examination of the tail. Extending the tail results in the cloaca being beyond the carapacial edge in males but not in females.

Sighting Surveys

Sighting surveys, should be conducted at night with the aid of spotlights. Recommended start time is 10.00 pm. Boats need to be constructed such that the person scanning with the spotlight can do so without casting appreciable light on the boat itself, as this will greatly reduce their effectiveness.

Two boats are preferable, each working in parallel to the other on opposite banks, working their way upstream. The boats should try to maintain a fixed distance from the bank overall (5 metres), though they should work the area by moving the boat around logs and aquatic vegetation, and exploring promising habitat. The spotlight should be moved regularly in an arc 5 m on either side of the boat to scan the area while the boat moves forward at about walking- speed. Each sighting should be confirmed as a *Carettochelys* before it is recorded. Marked animals should be identified as such, and if possible, the tag number recorded. However, the survey should not be disrupted by attempts to capture animals.

If daytime surveys are to be conducted, they should be undertaken in the early mornings before wind breaks the surface of the water. Polarised sunglasses are mandatory. As above, two boats should be used, each working one bank. The distance from the bank can be increased to 7 m, with 10 m to the off side. Visibility will be affected by several factors (angle of the sun, level of cloud cover, wind, turbidity). Windy conditions will greatly hinder visibility, and such conditions should be noted. If such conditions do occur, the survey may need to be repeated. Variability in light and wind condition is likely to make daytime surveys nonviable, and so they are not recommended.

Stretches suitable for sighting surveys should correspond exactly to those used for nest surveys, and be drawn from the list:

1. Oolloo Crossing
2. Bull's Yard
3. Lukies Farm

At least three replicate sighting surveys of each bank in each stretch should be conducted to obtain an estimate of the sighting index with sufficient precision. The number of replicates can be refined following initial surveys.

Phase of the moon, Secchi disc turbidity, water temperature and air temperature should be recorded at a fixed station at the time of each survey. These factors are potential confounding influences. For example, in 1996, the water was much clearer compared to 1997 and 1998. In the two latter years, water clarity during the dry season remained low until September, and never reached the clarity of 1996. This had a greater influence on ability to capture the animals than it did on locating them, but water clarity will nevertheless influence sightability. Hence, we recommend that the surveys be conducted between September, when clarity is at its peak, and November, when early season rains risk increasing turbidity. If possible, the phase of the moon should be held constant.

Spot counts of turtles visible at known feeding beds (*Vallisneria* sp.) could supplement the spotlighting counts. These can be done from the bank. Locations should not be published, and are not included here, but are available on request.

Nest surveys

Stereotyped nesting habits open the possibility of using nest surveys to yield an index of turtle abundance. This has the advantage of not being confounded by deterioration in the water clarity of the river as agricultural development and draw-down progress. The turtles nest in discrete sand bars that can be readily identified as potential nesting banks. These nesting areas are sufficiently few and sufficiently small as to make exhaustive surveys possible.

To ensure consistency in nest surveys, it is important to make decisions on what areas will be checked for eggs and what areas will not. Such decisions are pragmatic, in the sense that we sacrifice the possibility of finding a small proportion of nests laid in areas that do not meet our criteria, in order to achieve reproducibility and reduce effort.

Potential nesting banks typically comprise clean fine sand that is immediately adjacent to water. Submerged plant material or silt covering the sand adjacent to the edge dramatically reduces the probability that the sandbank will be used for nesting. Most nests are laid within the range 0.5 to 1.5 m vertical height above water. The turtles require moist sand at a depth of 10 cm or greater in order to construct a nest chamber. We therefore recommend the following restrictions:

1. That banks chosen as part of the survey ***must*** have clean fine sand that is in contact with the water and that extends below the water line free of submerged plant material and not totally obscured by silt.

2. That probing for nests be concentrated within the band of sand parallel to the waterline with ***height above water*** in the range 0.3 to 1.5 m. Nests found outside this range should be recorded, but identified as such.

3. That probing for nests be restricted to the band of sand perpendicular to the waterline that extends back from clean sand at the water's edge, plus lateral wedges to either side defined by 60^{o} angles (see Figure 1). Nests found outside this range should be recorded, but identified as such.

4. That intensive probing for nests be restricted to those areas where it is judged that moist sand was present at chamber depth at the time of nesting. If a chamber can not be made by digging with the hand, because of falling sand, then the sand is unsuitable for nesting. Judgement is required, because the sand may dry as the season progresses, though soil moisture is remarkably constant for most of the dry season.

5. That nest surveys be conducted between 25^{th} of October and 10^{th} of November when all eggs from both clutches of the season are likely to be in the ground and hatching has not yet begun.

Nests can be located by probing the sand with a fine spring steel rod. These rods are 1 m in length and 1.8 mm in diameter, and should be fitted with a handle to avoid tendon fatigue. Eggs are detected by the change in consistency of the sand as the rod enters the egg chamber and the "chink" sound that is made/felt as the rod strikes an egg. Sand typically percolates through the chamber with time, so the change in consistency of the sand is subtle. Use of the rods to locate nests requires practice if eggs are not to be destroyed, so some initial training of survey personnel will be required.

Figure 1. Diagramatic representation of the area to be chosen for intensive probing (stippled). Distances are heights above water. See text for explanation.

Once located, the following data should be collected from each nest:

1. Location – nest bank name and GPS reading.

2. Clutch size.

3. Distance from water, and height above water.

4. Egg dimensions and weight (time consuming, so optional, but measurements from one typical egg would be a compromise).

5. Nest age (requires candling of eggs, optional), to verify that two clutches have been laid for the season.

6. Number of infertile/non-starter eggs.

When handling eggs, it is essential that their up-down orientation be maintained, and that they not be dropped, rapidly rotated or jarred to avoid movement induced mortality. Their initial orientation can be indicated by numbering the eggs at their uppermost point with a pencil before they are removed from the nest. After processing, the eggs should be returned to the nest with their initial orientation in their original chamber. Loose sand should be removed from the chamber to ensure the eggs are returned to roughly their initial depths.

Nest survey sites should be chosen from the following list of sites, subject to resource constraints: two replicates, one at least 10 km upstream and one at least 10 km downstream from

1. Oolloo Crossing

2. Bull's Yard

3. Lukies Farm

4. Claravale Crossing

5. Beeboom Crossing

6. Daly River Crossing (20 km upstream only).

These sites are ranked in priority order, from the most suitable (1) to the least suitable (6). It is important to extend the survey stretches beyond 10 km to the first substantial impediment to turtle movement, usually a short stretch of riffle or rapids. Corrections can later be made for actual distances if necessary. Surveys should endeavour to be exhaustive, within the chosen stretches, and subject to the area selection criteria above.

Corrections can be made to nest counts on the basis that the adult population comprises 66% females, and that for all practical purposes, each female nests twice every second year. An additional correction factor may be required to account for a systematic bias owing to missed nests, and can be determined in those years when mark-recapture exercises are undertaken. We emphasise that rarely are absolute abundances necessary in detecting trends in abundance, as trends in indirect indices will suffice.

Table 3. An indication of the contribution made by some of the specific options described in the text, as a guide to selecting the final study design.

OPTION	*CONTRIBUTION/LOSS*
Mark-Recapture	
Not undertaken	No estimates of absolute abundance. Not able to correct relative abundance to absolute abundances. One independent cross-check of trends in abundance lost.
Not Spatially Replicated (i.e. one site only)	Study more vulnerable to local shifts in population, which will be erroneously interpreted as population decline or rise. Vulnerability will depend on size of single area chosen for survey (smaller = more vulnerable).
Turtles not sexed or measured	Changes in population structure (size distribution, sex ratios) likely to influence nest abundance index or other indicies to abundance will go undetected.
Spot-light Surveys	
Not undertaken	One independent cross-check of trends in abundance lost. Considered most effective index to abundance if water clarity is unaffected by development.
Not Spatially Replicated	Study vulnerable to local shifts in population, which will be erroneously interpreted as population decline or rise.
No sample replication (replicate surveys at a single site-time)	Loss of power, therefore reduced ability to detect change or trends.
Nest surveys	
Not Undertaken	Monitoring extremely vulnerable to changes in water clarity. Unacceptable confounding of the monitoring program. Regarded as fatal.
No Spatial Replication	Study vulnerable to local shifts in population, which will be erroneously interpreted as population decline or rise. Unable to adequately control for spatial variability in assessing the change over time. No satisfactory error term for testing. Fatal.
Inadequate Spatial Replication	Loss of power for detecting change. Requires optimization after collection of first few year's data to avoid over or under allocation of resources.

Nest data not collected (heights, distances, etc)	Alteration in the pattern of nesting likely to influence the nest abundance index (e.g. change in average nesting height) will go undetected. Unseasonal rainfall may affect average nesting height, and force a change in protocols.
Eggs not examined	Early indications of decline, such as decreased fertility rate, reduced clutch sizes, reduced average egg size, will go undetected.
Eggs not aged	No independent check that there is a balanced double nesting season. Nesting index will be very sensitive to changes in this parameter.

SURVEY PERSONNEL AND RESOURCES

We see three personnel options for implementation of the pig-nosed monitoring plan. These options will reflect tradeoffs in time, money and expertise. The first option is that external consultants be contracted to conduct the surveys, drawing from the research team that conducted the 1996-99 research program. Advantages would include (1) knowledge of the protocols and study area, and (2) expertise in data collection. Disadvantages might be (1) expenses of consultants, and (2) potential unavailability. A second option is that surveys be conducted by personnel of the Parks and Wildlife Commission. This option would include advantages such as (1) a potential line of training within the Commission, reducing (2) timetable constraints possibly imposed by external consultants, and (3) lower cost. Disadvantages might be (1) inconsistency among surveys due to different personnel conducting surveys, and (2) erosion of expertise in methods and techniques over time. A third option would include both Commission personnel and external consultants, with a recurrent on-site training component. Whatever option is chosen, clearly defined protocols and overlap of personnel from year to year is essential.

For turtle spotlight counts, we recommend the following equipment:

- 2 x 12’ boats, each fitted with 8-15 hp motors, and sufficient room aft to allow a single person to stand and shine light into the water without light falling upon the boat itself. A blackened standing platform is optimal.
- 4 x 12 volt spotlights (2 per boat) and 12 volt car batteries.
- 3 persons per boat, one driving, one spotting, and one recording.
- Waterproof data sheets, pencils, timepiece.
- Appropriate emergency and safety gear.

For nest surveys we recommend the following equipment:

- 2 x 12’ boats, each fitted with 8-15 hp motors.

- 3 persons per boat, of which two search for suitable nesting beaches, and one drives at a moderate speed (~ 20 km/hr).
- middle person records GPS location of nesting beach on map with waterproof marking pen
- 2 nest probes per person (1.8 mm spring steel, 1 m lengths).
- Tape measures, metre rule, GPS, balance, callipers, pencils, candling lamp, 12 volt power source, waterproof data pad.
- Appropriate emergency and safety gear.

For mark-recapture we recommend the following equipment:

- 2 x 12’ boats, each fitted with 8-15 hp motors, 2-3 persons per boat.
- Long-handled dip nets (two per boat).
- Hessian sacks
- GPS and waterproof notebooks. Timepiece.
- 4” thick foam pad.
- 12 volt hand drill, ¾” bit, numbered Allflex cattle ear tags, and applicator.
- 1 m measuring tape, spring balance to 15 kg, callipers.
- PIT (Passive identification transponder) tag, applicator, and reader.

DATA MANAGEMENT

The results of this monitoring program should provide data to determine long-term changes in the abundance of *Carettochelys insculpta* in selected areas of the Daly River. However, a critical component of the success of any monitoring program is appropriate data management. Since monitoring may be carried out by different personnel over time, we recommend that strict adherence to formal data sheets. Such data sheets will be provided by the authors upon acceptance of this plan. We also recommend data be entered promptly into a contemporary spreadsheet such as Microsoft EXCEL, which contains some measure of autoanalysis and graphing to provide immediate and positive feedback on data entry.

COMMUNITY PARTICPATION

Community involvement is valuable for successful implementation of any program for conserving native organisms and systems, and there is an inevitable human dimension to the success of such activities. The protocol for this monitoring program requires a minimum of 6 people. With the monetary, logistical and time limitations which are inevitable for Parks and Wildlife Commission staff, a program for briefing, training and involving volunteers will be desirable. In particular, indigenous owners with an active interest in the Daly River and/or the Pig-nosed Turtle should be involved in monitoring and offered the opportunity to incorporate their knowledge and skills into the process. Effort should be made to incorporate into the monitoring plan any methods for monitoring already in place in the Aboriginal communities. An agreement to record number of turtles and number of eggs taken should be made between the Northern Territory Government and those traditional owners who utilise *Carettochelys* and its eggs as a resource.

To foster community participation, an education program could be mounted to highlight issues and potential impacts for the pig-nosed turtle in the Daly River region. Emphasis should be made on the importance of monitoring Pig-nosed Turtles to ensure their survival as well as linking the benefits to the other species within the biotic community. Public participation in the monitoring program can be seen as part of this education process.

With sufficient interest, opportunity for involving the public exists in the mar-recapture activities and in the spotlight surveys. The monitoring program requires minimally 6 people to implement. We suggest, at least two individuals should be experienced Parks and Wildlife Commission staff, supplemented with up to four volunteers. Only Parks and Wildlife Commission staff should man the spotlight during spotlight surveys, to maintain consistency in counts. Mark-recapture activities are amenable to public involvement, provided there is some initial training in the marking and capture procedures and equipment, and in the general handling of animals. The training process should occur prior to the actual monitoring session, and should include providing all volunteers with notes on the basic life history attributes of the turtles and a copy of this monitoring plan.

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APPENDIX 1.

Biology of the Pig-nosed Turtle, *Carettochelys insculpta* Ramsay 1886.

The following account provides additional background on the species, and should be circulated to all personnel involved in the monitoring exercise.

SUMMARY

Carettochelys insculpta is the sole surviving member of the Carettochelydidae, a family of turtles widely distributed during the Tertiary. It is restricted to the southern rivers of New Guinea and the major rivers of the Northern Territory in Australia. *Carettochelys* is therefore a distinctive geographic and taxonomic relict and, although locally abundant, it is rare in the sense of being geographically restricted.

Populations in New Guinea are thought to be declining because of increased exploitation for meat and eggs. This exploitation has been exacerbated in recent times by the introduction of modern technology, principally outboard motors. In addition, clan warfare has ceased, and people have moved from the hinterland to more convenient positions along riverbanks. Moreover, levels of industrial activity such as mining and exploration for oil, gold and copper, logging and fishing have increased in recent times. The activities of any one of these has the potential to impact on wildlife populations including those of the pig-nosed turtle.

In Australia, feral water buffalo pose a major threat through trampling of nesting banks and widespread destruction of the riparian vegetation upon which the turtles depend. Other potential pressures include aggressive pastoral and agricultural practices that push the land in the important catchments beyond land capability. This can result in erosion, destruction of riparian vegetation, siltation of watercourses and reduction of environmental flows below that required to sustain natural riverine ecosystems. Mining activity in sensitive areas, such Kakadu National Park of Australia or the Fly river of New Guinea, may also pose a threat unless strict controls are applied on containment of mine waste, fishing activities of the mine staff, draw down of the water table and routes taken in the transport of chemicals used for extraction of minerals.

Urgent research is required to determine trends in population numbers and levels of exploitation in New Guinea. Additional research should be undertaken to determine whether management leading to sustainable exploitation of *Carettochelys* is necessary and attainable, and to make recommendations on how such sustainable utilization might be brought about. Associated research should be directed at integrating into local economies the measures designed to ensure a sustainable harvest.

In Australia, research is required to determine the distribution of *Carettochelys* so that the value of the two known major populations can be adequately assessed. Wet-season habitat requirements, extent of seasonal movements and requirements of juveniles are unknown, yet this information is needed to gauge the possible impact of

proposed or potential development within catchments and to gauge the adequacy of existing reserves for protecting the species.

TAXONOMY

Carettochelys insculpta was first described as a new genus and species in 1886 by Dr E.P. Ramsay from an incomplete specimen collected in the Strickland River, a tributary of the Fly River in Papua New Guinea. The circumstances of its collection, by Walter Froggatt and Jas H. Shaw while on an expedition with the Geographical Society of Australasia, are described by Waite (1905). The genus is monotypic and no subspecies are recognized.

Soon after its description, Boulenger (1887) placed *Carettochelys insculpta* in its own family, the Carettochelydidae, and included it among the sub-order of side-necked turtles, the Pleurodira. He made this latter decision with some reference to morphological characters, but primarily because at the time, only side-necked turtles were known from Australia and New Guinea. Baur (1891a,b) was vehemently opposed to grouping *Carettochelys* with the side-necked turtles, and called upon Ramsay to release details of the articulation of the cervical vertebrae "to show at once the affinities of this peculiar genus". Unfortunately, the specimen lacked key anatomical elements, the cervical vertebrae, so the matter remained one of considerable debate (Strauch, 1890; Vaillant, 1894; Boulenger, 1898; Gadow, 1901; Ogilby, 1907; Hay, 1908) until the work of Waite (1905) became widely known. He described a more complete specimen from the island of Kiwai at the mouth of the Fly River, and examination of the cervical vertebrae established that *Carettochelys insculpta* properly belongs in the sub-order Cryptodira, not the side-necked Pleurodira.

The debate on the affinities of *Carettochelys* continued sporadically, as summarized by Walther (1922:609-610), Frair (1985) and Meylan (1988). Current wisdom has it that *Carettochelys insculpta* is the sole surviving member of a family that was widespread in the late Tertiary (Pritchard, 1979a), with closest living relatives among the soft-shelled turtles (Trionychidae) (Chen et al., 1980; Frair, 1983, 1985; Meylan, 1988; Shaffer et al., 1997). However it is sufficiently distinct to warrant retention of the family Carettochelydidae and some would argue that it should be separated from the Trionychids at the level of superfamily at least (Williams, 1950; Frair, 1985). Time of divergence is estimated from the molecular clock to be of the order of 40 million years (Chen et al., 1980).

DESCRIPTION

Original detailed descriptions of the morphology of *Carettochelys insculpta* are provided by Ramsay (1886), Waite (1905) and Walther (1922) and are summarized by Pritchard (1979a) and Georges and Wombey (1993). *Carettochelys insculpta* is a heavy-bodied turtle, up to 22.5 kg in weight and 56.3 cm in length (Rose, unpublished data). Coloration is rich grey, olive-grey or grey-brown above and white, cream or yellowish below. The jaws are cream and there is a pale streak behind the eye. The species is cryptodirous, that is, the vertebral column in its neck flexes in the vertical plane when the head is withdrawn. There are no epidermal scutes overlying the shell, which is covered instead with a continuous skin. The carapace is relatively deep, with a median keel toward the rear. The peripheral bones are complete and well developed, so there is no flexible shell margin. The plastron, although small, forms a continuous plate without even a median fontanelle. Several of the plastron elements are not rigidly ossified together, but rather have cartilaginous connections that allow a certain amount of flexibility. The limbs are paddle-shaped, like those of sea turtles, each with two claws. The dorsal surface of the tail is covered with a single line of crescent-shaped scales that decrease in size from the base to the tip. Prominent folds of skin extend laterally on each side from the undersurface of the tail across the thigh region and down the hind limbs. The nostrils are at the end of a prominent fleshy proboscis. Mature males can be distinguished from females of the same size by the tail, which is larger in males to enable successful copulation.

On emergence, hatchlings have well-formed, strong limbs but an extremely soft plastron and carapace. The plastron has a deep crease where folding of the body has occurred during incubation. The periphery of the shell comprises loose flaps of skin, which become firm after about one week to form a serrated margin. Hatchlings also have a tuberculate median keel; a poorly defined and transient polygonal outline around each of these tubercules may be homologous to the scute seams of other turtles (Pritchard, 1979a). The tubercules are lost as the turtle grows and the median keel is present only on the posterior quarter of the carapace by the time the turtle matures.

Hatchlings from New Guinea weigh 29.6 $\pm$ 0.32 g on average and have an average carapace length of 53 $\pm$ 0.25 mm (Rose, unpublished data), whereas the equivalent data for the South Alligator River are 24.7 $\pm$ 0.84g and 56.1 $\pm$ 0.91 mm (Georges and Kennett, 1989) and for the Daly River are 20.5g and 41.1 $\pm$ 1.22 mm (Webb et al., 1986). They exhibit the full range of shell colour variation shown in the adults, even within single clutches, and the pale streak behind the eye is present. There may be small light patches on the carapace radiating to the peripherals, and these are more prominent toward the rear of the carapace.

DISTRIBUTION

The discovery and description of this peculiar species (Ramsay, 1886) generated great interest in Europe (Walther, 1922), and the species was often specifically sought by explorers and travellers visiting Papua New Guinea and Irian Jaya (Boulenger, 1914; de Rooij, 1915, 1922; Wermuth, 1963; Schultze-Westrum, 1963; Cann, 1974). The species was soon recorded from the Strickland (Ramsay, 1886; Waite, 1905), Fly (Boulenger, 1898; Waite, 1905), Morehead (Longman, 1913), Aramia, Omati (Slater, 1961), Binaturi (Rhodin and Rhodin, 1977), Purari (Pernetta and Burgin, 1980) and Kikori Rivers (Rose, 1981) of Papua New Guinea. It is known in Irian Jaya from the Setekwa (Boulenger, 1914), Heron (de Rooy, 1922) and other southern flowing rivers (Cann, 1974, 1978, 1980). It was also reported from Lake Jamur (de Rooij, 1915), but the specimen consisted of fragments of shell and may have been carried there by natives (de Rooy, 1922). Brongersma (1958) reports that *Carettochelys* is relatively common in the southern flowing rivers of New Guinea and Lake Jamur. It seems likely that *Carettochelys insculpta* occurs in all of the major and some of the smaller southern-flowing rivers of Papua New Guinea and Irian Jaya, but the exact boundaries to its distribution are unknown. No published records of the species exist for rivers east of the Purari, but local native information (Rose, unpublished) indicates that its range extends to the Vailala River in the east.

The existence of *Carettochelys insculpta* in northern Australia was not widely known until a specimen from the Daly River was reported in the scientific literature (Cogger, 1970; Peters, 1970). Evidence of breeding in Australia dates back to 1918 when eggs from the East Alligator River were lodged with the Victorian Museum (Georges et al., 1989) and the presence of Aboriginal rock paintings of *Carettochelys* (Cann, 1980; Dupe, 1980; Georges, 1987), some dating back more than 7000 years (Chaloupka et al., 1985; George Chaloupka, pers. comm.) suggest that the species has been a long term resident of northern Australia. Nevertheless, Cogger and Heatwole (1981) have argued that the restricted range of *Carettochelys* (New Guinea and scattered coastal localities in the Northern Territory), the lack of even sub-specific differentiation between the two areas, and the highly aquatic nature and estuarine tendencies of this species, suggests that it is a relatively recent immigrant from New Guinea to Australia.

In northern Australia, *Carettochelys insculpta* occurs in the Daly (Cogger, 1970; Cann, 1972; Webb et al., 1986; Georges, 1987), South Alligator (Schodde et al., 1972; Legler, 1980, 1982; Press, 1986), East Alligator (Georges et al., 1989) and Victoria drainages (Cogger, 1975; Jessie Roberts, pers. comm.) There have also been anecdotal reports of the species from the Darwin, Adelaide, McKinlay and Roper Rivers of the Northern Territory (Cann, 1972; John Bywater, pers, comm.), but these reports need to be substantiated. Aboriginal people report *Carettochelys* from the Fitzmaurice River, between the Daly and Victoria rivers, and from the Goomadeer at the eastern extent of the species range in Australia. The report of *Carettochelys* from the Wenlock River on the west coast of Cape York (Keith Day in pers. comm. with Webb et al., 1986) cannot be substantiated, and may have resulted from a misidentification. The distribution of *Carettochelys* in Australia clearly requires further investigation.

POPULATION STATUS

Carettochelys insculpta was long considered one of the rarest turtles in the world (Groombridge, 1982) but it is not certain whether this reputation reflects its remote distribution or also low population densities (Pritchard, 1979a). In fact many consider it to be fairly common where it occurs in both Australia and New Guinea (Brongersma, 1958; Slater, 1961; Cann, 1974, 1980; Press, 1986; Shelley Burgin, pers. comm.), but there are few precise estimates of population sizes. Georges and Kennett (1989) found *Carettochelys* to be widespread between the tidal reaches and the head-waters of the South Alligator River in Australia, and that high densities may be present in the upper reaches during the dry season (33.8 $\pm$ 11.3 turtles per ha in small discrete ponds on the main channel). Over 250 specimens have been captured in a 20 km stretch of the Daly River over a 3 year period (Sean Doody, unpubl. data). Populations of *Carettochelys* in the Kikori River District of Papua New Guinea (Gulf Province) are reported to have been severely depleted in the last 20 years, and the populations in the Western Province appear to be declining (Rose, 1981; Groombridge, 1982). It is reported as rare in Irian Jaya, with a sparse and limited distribution (Anon., 1978), but this conflicts with the observations of Cann (1974, 1978, 1980). Regardless of high densities in some areas within its range, *Carettochelys* is both a geographic and a taxonomic relict species (sensu Simpson, 1944) and is rare in the sense of being geographically restricted. Locally abundant species with restricted ranges are possibly more vulnerable than scarce but widely distributed species.

HABITAT AND ECOLOGY

In Papua New Guinea, *Carettochelys insculpta* inhabits rivers (including estuarine reaches and river deltas), grassy lagoons, swamps, lakes and water-holes of the southern lowlands (Leim and Haines, 1977; Groombridge, 1982). Locals of the Purari region claim that the hatchling turtles congregate in the lower delta and feed on vegetation and fruits of mangroves. In Australia, there are no substantiated reports of *Carettochelys insculpta* occurring in estuarine areas (Press, 1986; Georges and Kennett, 1989) but it is known from the clear, shallow, continuously-flowing waters of the Daly drainage (Cogger, 1970; Cann, 1972; Webb et al., 1986) and from lowland billabongs, upland billabongs and plunge pools of the Alligator Rivers region (Legler, 1980, 1982; Press, 1986; Georges and Kennett, 1989). The preferred dry season habitat in the Alligator Rivers region is typified by Barramundi Creek (Legler, 1982) and Pul Pul Billabong (Georges and Kennett, 1989). Average depth was approximately 2 m but there were holes between 3 and 7 m deep. The substratum was sand and gravel covered with a thin layer of fine silt and litter. Fallen trees and branches, undercut banks, exposed tree roots, and local accumulations of litter provided a diverse range of underwater cover for turtles. The banks of the billabongs were covered in a dense broadleaved forest, including the important turtle food *Ficus racemosa*. The many small sandbanks adjacent to the water were more than adequate in number and size for nesting. Water flows through the billabongs in all months of most years.

Carettochelys is omnivorous, but tends more toward herbivory than omnivory (Groombridge, 1982). In the Gulf Province of Papua New Guinea, it feeds principally on the unripe fruits of the mangrove species *Sonneratia* spp., possibly by cropping the fruits from the vegetation at high tide (Rose, unpublished data). Fruits from *Xylocarpus* sp., *Nypa fructicous*, *Canorium indicum*, *Antrocarpus incisor*, the wild pit pit *Sachhorum robistum* are also eaten. Animal foods included the molluscs *Batissa violocea*, *Nerita* sp. and *Centhidea* sp., and the crustacean *Siyellu serrata*. In the Alligator River system of Australia, *Carettochelys* feeds on the leaves, fruits and flowers of riparian vegetation, especially the Fig *Ficus racemosa*, the bush apple *Syzygium forte*, and *Pandanus aquaticus* (Schodde et al., 1972; Legler, 1982; Georges and Kennett, 1989). Other foods include aquatic insect larvae, crustacea, mollusca, fishes and mammals (possibly eaten as carrion), and aquatic plants such as algae, *Vallisneria* sp. and *Najas tenuifolia* (Cogger, 1970; Schodde et al., 1972; Legler, 1982; Georges et al., 1989; Georges and Kennett, 1989).). In the Daly River, *Carettochelys* eats mainly ribbonweed (*Vallisnaria* sp.), but also eats green algae, snails, and figs (Heaphy, 1990; Michael Welsh, unpublished data). The wide range of foods eaten provides great scope for opportunism, and the diet varies greatly with the foods available from locality to locality.

Preliminary analyses of dry season movements in the Daly River suggest that linear home ranges of adult females (mean = 5.7 km) are larger than those of adult males (mean = 2.6 km) (Young et al., in prep.). Gravid females (mean = 6.2 km) had longer home ranges than non-gravid females (mean = 4.9 km), but this difference was not statistically significant (Young et al., in prep.). Radiotelemetry during the wet season revealed that turtles did not migrate great distances as previously suspected, but remained in billabongs and flooded riparian areas near their dry season home ranges (Young et al., in prep.).

Female *Carettochelys* from the Daly River mature at around 82% of maximum size (smallest gravid turtle, CL=38.0, PL=30.5, mass=5.9 kg, Doody and Georges, in prep.). There are no data on the minimum size at maturity of males, or the age at maturity of either sex. In New Guinea, *Carettochelys insculpta* nests in the late dry season between September and December (Cogger, 1975; Cann, 1978; Pernetta and Burgin, 1980), but as eggs appear in the Kikori markets as late as February (Groombridge, 1982), the nesting season may extend to the end of January. Nesting in the Kikori District spanned 19 weeks in 1981/82 (Rose, unpublished data). *Carettochelys* also nests in the late dry season in Australia. The nesting season extends between mid-July and late-October on the Daly River (Georges and Kennett, 1989; Doody and Georges, in prep.) and from mid July to early November in the Alligator Rivers region (Georges and Kennett, 1989). Bimodal distributions of nesting dates both in the Kikori District of Papua New Guinea and the Daly River of Australia provides strong evidence of multiple clutching (see also Legler, 1980), a conclusion supported by examination of reproductive tracts of three specimens dissected during the nesting season at Kikori (Mark Rose, unpublished data). More recently, monitoring of reproductive condition using radiography revealed that *Carettochelys* deposits two clutches every other year on the Daly River (Doody and Georges, in prep.), a pattern is unique among freshwater turtles.

Carettochelys typically chooses clean fine sand adjacent to water in which to nest (Cann, 1978, Pernetta and Burgin, 1980; Legler, 1982; Webb et al., 1986; Rose, pers. obs.), but also nests in mud, loams, and fine gravel at some localities (Slater, 1961; Cogger, 1975: Plate 59 and pers. comm.; Groombridge, 1982; Rob Elvish, pers. comm.; Rose, pers. obs.; Doody, pers. obs.) In Australia, it nests on sand banks adjacent to rivers and billabongs (Webb et al., 1986; Georges and Kennett, 1989); in New Guinea it nests also adjacent to water in the middle reaches and mouths of river, on sandy shores of islands in river deltas, and on coastal beaches (Rhodin and Rhodin, 1977; Groombridge 1982). Nesting activity has been reported from the Strickland, Setekwa, Purari, Kikori, Turama, Era, Pai and Fly Rivers of Papua New Guinea (Waite, 1905; Boulenger, 1914; Pernetta and Burgin, 1980; Rose, unpublished data), the southern rivers of Irian Jaya (Cann, 1978, 1980), and the Daly, South Alligator and East Alligator Rivers of northern Australia (Schodde et al., 1986; Georges et al., 1989; Georges and Kennett, 1989).

Nesting occurs at night between dusk and 5 am, peaking at around midnight (Doody et al., in prep). In the Daly River, gravid females form groups during the nesting season, moving from beach to beach at night in search of a nest site. Although these groups may contain as many as 12 turtles, usually less than 6 individuals emerge on a given night, and only 1 to 3 actually nest (Doody et al., in prep.).

The eggs are white, hard-shelled and almost quite round (Ramsay, 1886) with a mean diameter of 38.7 $\pm$ 1.3 mm and a mean weight of 33.7 $\pm$ 3.5 g for eggs from the Daly River of northern Australia (Webb et al., 1986). Eggs from the East Alligator River were somewhat larger (42.0-44.8 mm, n=15) (Georges et al., 1989), more in keeping with the size of eggs in New Guinea (Purari River: 38-46 mm, mean 42.9

mm, n=108, Pernetta and Burgin, 1980; Kikori River: means 42.8 $\pm$ 2.3 mm, 45.7 $\pm$ 0.7 g, Rose, unpublished data). Both the ultrastructure (Erben, 1970) and the gross morphology of the eggshell (Webb et al., 1986) have been described, and Webb et al. provide details on egg constituents. Beggs et al. (1999) describes their embryonic development.

Clutch sizes range from 7 to 19 (mean=10, atypically as few as three eggs may be laid) in the Daly River of northern Australia (Webb et al., 1986; Georges, 1987) and from 8 to 39 in New Guinea (De Rooij, 1915, Cann, 1978; Pernetta and Burgin, 1980; Groombridge, 1982; Rose, unpublished). Some of the largest New Guinea clutches may have been laid by more than one female, in areas where there was intense nesting activity (Cann, 1978). Those that survive require 64 to 74 days (at 30^{o}C) to develop to a point where hatching is possible (i.e. until yolk internalization) after which they enter an embryonic aestivation within the egg (Webb et al., 1986). At onset of aestivation, metabolic rate decreases precipitously and embryonic growth ceases. Yolk is used during diapause at a rate that yielded an estimate of 59 days to yolk exhaustion at 28^{o}C to 30^{o}C Webb et al., 1986). Hatching can be stimulated by reducing oxygen availability, either by submerging eggs in water or replacing the atmosphere that surrounds them with nitrogen, suggesting that in the field, hatching is either stimulated by early season rains or flooding (Webb et al., 1986). Incubation period for 30 natural nests from the Kikori River of Papua New Guinea was between 86 and 102 days (average nest temperature 31.6^{o}C) (Rose, unpublished data). This presumably included a substantial period of aestivation, which would account for the discrepancy between these findings and those of Webb et al. (1986).

Emergence occurs at night (Doody et al., in prep.). Within a nest, hatchlings generally emerge one at a time and all in one night, usually within a few hours. As with nesting, emergence begins at dusk and ends before 5 am, with a peak at around midnight.

The hatchling sex ratio of *Carettochelys insculpta* is influenced by the temperature that prevails during incubation, both under constant conditions in the laboratory (Webb et al., 1986) and under fluctuating conditions in field nests (Georges, 1992). The laboratory threshold for sex determination is 32.0^{o}C, with half a degree shift in either direction sufficient to yield 100% of one sex (Young et al., 1999). In the field, first clutches of the season usually yield males, whereas second clutches of the season usually produced females, with some mixed nests in each. Thus, a strong temporal effect determines hatchling sex of early and late nests, while spatial effects (i.e. nest site choice) has the potential to affect the sex of hatchlings to emerge from nests with intermediate laying dates (Doody and Georges, in prep.).

Nests of *Carettochelys insculpta* are taken by monitor lizards (Pernetta and Burgin, 1980; Legler, 1982; Georges and Kennett, 1989; Doody and Georges, unpubl. data) and man (Cann, 1974; Pernetta and Burgin, 1980; Groombridge, 1982; Press, 1986; Georges and Kennett, 1988). In a three year study on the Daly River, predation by monitors (chiefly *Varanus panoptes*) was common (1996 – 25 %, 1997 – 12 %, 1998 – 11 %, Doody and Georges, unpubl. data). However, because protective cages were employed on most of the nests within 2 days of laying, the estimates are conservative. Flooding caused mortality in 14 % nests in one of three years, primarily due to cool winter temperatures, which shifted the nesting season forward in time, thus exposing some developing embryos to wet season floods (Doody and Georges, in prep.). There is little information on natural levels of survivorship elsewhere (83.2% from 30 nests, Rose unpublished data) and none on rates of recruitment to the parent population.

THREATS TO SURVIVAL

Carettochelys insculpta is highly prized as a food item by the indigenous peoples within its range both in Australia and New Guinea (Schultze-Westrum, 1963; Cann, 1980; Press, 1986) and it is important to the subsistence economies of several Papuan communities (Pernetta and Burgin, 1980). Both the adults and their eggs are collected, consumed and sold throughout its range in Papua New Guinea. In Kikori Market alone, over 5000 eggs were sold between October 1980 and February 1981 (Groombridge, 1982). In the following year, over 20,000 eggs were collected and consumed in Kikori and three surrounding villages (Rose, unpublished data). In the breeding season, villagers collect female turtles and their eggs when they come to shore to nest, or they locate nests by systematically prodding sand banks with a stick or spear. In some areas, pit-traps are checked each day for nesting turtles that have fallen in to them on the previous night (Groombridge, 1982). Out of season, the turtles are caught by hand from boats in shallow water and swamps, or are caught on lines baited with crab or de-shelled mussels (Groombridge, 1982) and in basket traps (Schultze-Westrum, 1963).

In northern Australia, turtles are regularly eaten by Aborigines, and *Carettochelys insculpta* are favoured by some for their size and flavour (Cann, 1980; Press, 1986). Traditionally, men used to climb trees on the banks of billabongs and spear the turtles when they came near to the surface (Georges, 1987). Alternatively, *Carettochelys* could be hunted by diving on top of them from the bank or by waiting quietly in the water while others herded the turtles in. Today, however, they are more often caught on hand lines baited with wallaby or buffalo meat (Cann, 1972; Georges, 1987). There are no reports of Australian Aborigines harvesting the eggs of *Carettochelys* in Kakadu National Park, but they are occasionally collected as food by Aboriginal people of the Daly River Mission.

Groombridge (1982) considers that traditional hunting of turtles and harvesting of eggs in southern New Guinea is the principal threat to the species. Stereotyped nesting habits render *Carettochelys insculpta* (like sea turtles) extremely susceptible to over-exploitation. Levels of exploitation in the Gulf and Western Provinces have been exacerbated in recent times by the introduction of modern technology, principally outboard motors, and because since clan warfare has ceased, people have moved from the hinterland to more convenient positions along the riverbanks. Populations in New Guinea have been reported to have declined sharply in the past 20 years (Groombridge, 1982). There are few data on levels of exploitation in Australia. Georges & Kennett (1988) report an annual offtake of 19 turtles by two Aboriginal families at Nourlangie Camp, but without adequate data on population numbers and recruitment, it is not known whether this exceeds a sustainable yield.

Feral water buffalo once posed a major threat to pig-nosed turtles and their habitat in the Alligator Rivers region of Northern Australia. The sandbanks used for nesting by *Carettochelys* were also used as easy access to water and as resting places at night by water buffalo. This led Archie Carr to comment in a letter to Pritchard

(1979b) that *Carettochelys* may have become much more restricted in its Australian distribution since the introduction of water buffalo. In 1987, buffalo densities in Goodparla Station (now part of Kakadu National Park) were so high that all potential nesting banks were heavily trampled. Such trampling is known to destroy nests (Georges & Kennett, 1989).Water Buffalo also destroy the riparian vegetation, upon which the turtles depend in the dry season for food, by foraging on young plants and by structurally destroying the banks of billabongs. While this may initially benefit *Carettochelys* by increasing underwater cover afforded by fallen trees, branches and litter, it can only have long-term deleterious effects on the turtle populations.

Fortunately, buffalo numbers have been drastically reduced within the park, as part of on-going management for nature conservation and disease control. *Carettochelys* presumably will be a beneficiary of this action, but without monitoring, it will be difficult to quantify the benefits.

Agricultural and pastoral activities in the catchments of the Daly drainage have the potential to seriously impact *Carettochelys* populations where stocking rates are high, the riparian vegetation is cleared, or the land is pushed beyond its capability, with subsequent erosion and siltation of water courses. Plans currently under development include the possibility of drawing up to 50% of the dry-season river-flow, via surface and ground-water offtake, in support of agriculture. The resultant fragmentation of what is now a year-round flowing system, and alteration of water temperatures, could have a major impact on *Carettochelys insculpta*. A relatively minor shift in nesting date in response to water temperatures could have a major impact on offspring sex ratios, which respond to soil temperatures, or on timing of hatching in relation to the onset of the wet.

Mining activity in sensitive areas such as Kakadu National Park in Australia or the Fly River in New Guinea, may pose a potential threat to the environment and the fauna that depends upon it (Dames and Moore, 1987; Georges and Kennett, 1988). Exploration and Mining for gold by chemical extraction was once planned for the head-waters of the South Alligator River, in the region identified as providing important refuge ponds for *Carettochelys* in the dry season (Georges and Kennett, 1988, 1989). Contaminated rainwater run-off, accidental discharges from the tailings dam or treatment plant, or accidental spillage of hazardous industrial chemicals at stream or tributary crossings during transport to the mill site are all potential sources of destructive pollution of the South Alligator River. Demands on water for mining operations may deplete the water table and reduce water levels in the shallow billabongs used by *Carettochelys* as dry-season refuges. Upgrading river crossings and causeways may restrict the free movement of turtles during the early dry-season *Carettochelys* is easily caught on baited lines (Cogger, 1970; Georges and Kennett, 1988). Populations may be decimated by increased fishing activity in the dry-season refuges by mine workers and others allowed into the mining area. Although fishing may be prohibited for non-aboriginal employees of the mine, any restrictions will be difficult to apply to Aboriginal employees (to be a substantial proportion) and those who accompany them, as the Aboriginal community remains the traditional owner of the head-waters of the South Alligator River.

The issue of allowing mining and extensive exploration within Kakadu National Park has not been resolved at the time of writing, and the atmosphere of confrontation is not conducive to finding a compromise that serves both the long-term interests of the unique biota of the region and the interests of a sustainable Australian economy (Georges, 1990a,b). Mining in the headwaters of the South Alligator River is off the government's agenda, but significant deposits of gold and other minerals reside there, and successive governments vary in their commitment to this world heritage area. Kakadu National Park should not be seen as fully sufficient to cater for the conservation needs of *Carettochelys* in northern Australia.

Similar concerns are felt for New Guinea populations. Gold and copper are being mined on the Fly River System at Ok Tedi and standards for the protection of the environment there have been questioned. Quite apart from the risk of environmental contamination, mining and other commercial operations organised by expatrial interests will increase river traffic which will in turn increase the number of turtles and eggs taken.

CAPTIVE HUSBANDRY

Procedures for egg collection, transportation and artificial incubation have been established and can be incorporated into management programs with the option of accurately predicting and controlling hatchling sizes, sexes, amounts of internalised yolk and incubation times (Webb et al., 1986). Techniques for accurately aging embryos and for non-destructively assessing the progress of incubation have been developed also (Beggs et al., 1999)

Carettochelys can be readily kept in aquaria in clean water maintained at a temperature between 28 and 33^{o}C. A spacious tank with a diversity of underwater cover is required, as even small individuals can become aggressive and will habitually inflict damage to others of their species if confined together. In captivity, they will accept and thrive on a diverse diet of figs, apple, other fruits, eel weed (*Vallisneria* sp.), whitebait (Pisces) and shrimp. A high pH (7.5-8.5) seems essential for maintaining healthy animals in captivity.

Hatchling and sub-adult specimens are particularly susceptible to fungal white spot (*Sphagnalium* sp.) which if not treated promptly, kills young animals within a week (Mike Palmer-Allen, pers. comm.). It can be effectively treated externally by removing all loose skin and scabs and treating liberally with 1% Mercurichrome (Windholtz et al., 1983: 5698) or Acriflavine Solution (Windhotlz et al., 1983: 116), which is allowed to dry on the skin before the animals are returned to the tank. Addition of marine salt seems to be effective in preventing fungal infection.

Captive specimens are held in Australia at the Territory Wildlife Park (Darwin), Taronga Park Zoo (Sydney), Sydney Aquarium, the National Aquarium (Canberra), Hartley Creek Crocodile Farm (Cairns), Australia Zoo (near Nambour) and the University of Canberra. Only the first two organisations are in a position to mount a captive-breeding program. Specimens at Territory Wildlife Park mated in 1989 after having been transferred from an outdoor enclosure earlier in the year, and the female subsequently laid eggs on the bottom of the aquarium. Unfortunately, the turtles were removed from this aquarium following damage to the viewing tunnel attributed to their activities, so the possibility of successful breeding in captivity at this facility is now remote.

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