6. FEEDING RESPONSES

6.1 ABSTRACT

Living hosts, namely a cow, goats and bushpig, were placed within an incomplete ring of electric nets, within forest vegetation. Observations were made of the numbers of *Glossina brevipalpis* and *G. austeni* attracted to the hosts as well as the feeding responses of tsetse. The cow attracted significantly more *G. brevipalpis* and *G. austeni* than did goats or bushpig. Significantly more flies also fed on the cow with less than *c.* 10 % feeding on either goats or bushpig. Comparisons were also made on the attraction and feeding responses of tsetse during different periods of day as well as at night at two sites, the first being inside their preferred habitat, namely forest vegetation, and the second at about 750 m away from the forest. Both *G. brevipalpis* and *G. austeni* were attracted to the cow inside the forest at all times of day, even at night, while the largest percentage of flies feeding occurred after dark. *G. brevipalpis* was also attracted to the cow outside the forest area during the daytime until dark and significantly fewer after dark, while very few flies fed during all occasions. Only a few individual *G. austeni* were occasionally attracted to the cow at the latter site during the day, while virtually no flies fed.

6.2 INTRODUCTION

The use of pour-ons to control tsetse flies works on the principle that the flies, which come to feed on cattle or other treated domestic livestock, will be killed by picking up lethal deposits of insecticide (Leak 1999). The treated livestock are then equivalent to moving insecticide-treated targets, complete with built-in odour attractants, and have been referred to as "mobile targets". Cattle have often been used with success as mobile targets, where they are treated with a pyrethroid pour-on or dip (Thomson 1987; Thomson *et al.* 1991; Horeth-Bontgen 1992, cited in Vreysen 1995; Bauer *et al.* 1995; Warnes *et al.* 1997; 1999). The control of tsetse flies by this method, however, depends upon a relatively large proportion of feeds being taken from domestic rather than wild animals (Leak 1999). The proportion of tsetse flies that feed on hosts also has a major bearing on the epidemiology of tsetse-borne diseases (Vale 1977b). To assess the importance of this problem it is necessary to know the proportion of flies that feed after visiting a natural host. Furthermore, since treatment with insecticides will not prevent infection, disease challenge could also be high in these areas and it may be necessary to protect cattle from tsetse fly attack. Improved knowledge of the times and situations when cattle are at most risk of tsetse challenge could be beneficial to develop strategies for minimizing contact.

In N.E. KwaZulu-Natal there is a network of plunge dips mainly for the control of ticks on cattle and thereby tick-borne diseases. There is also a high number (*c.* 130 000) of small ruminants, i.e. goats in the rural areas (De Waal *et al.* 1998), however, they are never dipped. In many communal farming areas virtually no wild animals remain on which tsetse flies can feed so their main blood sources have to be cattle or goats. For the mobile target approach to have a chance of success most tsetse must then attempt to feed on treated cattle. What proportion of *G. brevipalpis* and *G. austeni* would feed on cattle, is however, not certain. If tsetse also feed on goats, these could accordingly be used as mobile targets. The role/importance of livestock, therefore, needs to be established in the Zululand situation for tsetse control management.

This work attempted to evaluate the potential of cattle and goats as mobile targets. It consisted of studies where the attraction and feeding responses of tsetse to cattle, goats and bushpig (*Potamochoerus porcus*) were measured. The bushpig was included since bushpigs are an important host for *G. austeni* (Moloo 1993). The responses of flies to these hosts were compared in ideal tsetse habitat, i.e. in sand forest situation. Furthermore, because *G. brevipalpis* and *G. austeni* have different times of activity and since the former has also been found active at night (Kappmeier 2000), attraction and feeding responses of tsetse to cattle were also determined at various times of day including dark. Since it was indicated in the previous chapter, that both species traverse open areas to an extent, this study was also conducted in open grassland areas adjacent to forest vegetation. This could also indicate whether tsetse challenge will be lower in open grassland areas adjacent to forested areas.

6.3 MATERIALS AND METHODS

6.3.1 Attraction and feeding

Responses of tsetse to various hosts

Studies were made of the responses of *G. brevipalpis* and *G. austeni* to various host animals, namely an adult cow (*c.* 350 kg), three adult goats (*c.* 68 kg) and a juvenile bushpig (female, 6 months, *c.* 50 kg), within sand forest where high densities of both tsetse species occur. The animals were placed in the centre of an incomplete ring (8 m diam.) of six electric nets following the methods of Vale (1977b) and Torr (1994). The six nets covered 35 % of the circumference of the ring. The animals were tethered to a pole(s) at the centre of the ring to prevent them from touching the nets. They were allowed to move freely within a 2 m radius of the pole (Fig. 6.1). Fresh water and food were supplied throughout the experimentation.

The electric nets (1,5 x 1 m) were mounted on corrugated iron sheets as explained in Chapter 2.2. Tsetse flies that were attracted to the cow were either electrocuted on approach or passed unscathed between the electric nets. Once in the circle, they either escaped directly, or were electrocuted on the insides of the nets or fed on the animal(s). Thereafter fed flies either escaped or were electrocuted on the inside of the nets. A mathematical formula exists which allows these results to be analysed and interpreted (Vale 1977b). It was, therefore, necessary that electrocuted tsetse flies were separated according to the side of the net on which they were caught and categorized as fed or unfed by the presence or absence of red blood visible through the abdominal wall. Flies caught on the outside or inside of the ring were presumed to be approaching or leaving the vicinity of the animals, respectively (Vale 1977b).

Fig. 6.1 Cow in the centre of an incomplete ring of six electric nets (8 m diam.) covering 35 % of the circumference of the ring

Experiments of the comparison of various host treatments were carried out from noon until dark, a period when both tsetse species are active (Kappmeier 2000). Wind direction was noted by means of observations with a wind pane after the start of each daily experiment.

Comparison of tsetse responses inside and outside forest vegetation

Attraction and feeding responses of flies to a cow were determined at various times of day, with a similar incomplete ring of nets as described above. These incorporated the two species' main activity times (Kappmeier 2000), i.e. from noon - 16:00 (for *G. austeni*), from 16:00 - dark (for *G. brevipalpis*) and at night from dark -23:00. These respective treatments will be referred to as Times I, II and III, respectively. The experiment was repeated in an open area about 750 m away from the main forest. Wind direction was recorded.

6.3.2 Experimental design and analysis

In any one experiment only one site was used so that the various treatments being compared were incorporated in a randomized block design. To normalize data, catches (n) and proportions (p) were transformed to $\log_{10}(n+1)$ and $\arcsin(\sqrt{p})$, respectively, and then subjected to analysis of variance using GLIM4.

6.4 Experiments and Results

6.4.1 Ring of nets

The ring was operated for a total of 53 days within sand forest in three separate experiments. During these experiments the mean inside catch of the ring comprised 46,9 % (± 0,079 s.e.) and 53,8 % (± 0,024 s.e.) of total *G. brevipalpis* male and female catches, respectively, and 28,7 % (± 0,192 s.e.) and 48,1 % (± 0,0213 s.e.) of total *G. austeni* males and females, respectively. If the ring was operated in the way described by Vale (1977b), who assumed a random approach and departure of flies to and from a host, then the inside catch should make up 39 % of the total (inside + outside) catch instead (Torr 1994).

For both the inside and outside catches for the three experiments combined (53 replicates), some of the nets caught significantly more than others ($p < 0,001$) for both *G. brevipalpis* and *G. austeni* (males and females combined). This suggested that arrivals and departures from the ring were not random (as suggested by Vale's (1977b) assumption). Outside catches of individual nets, expressed as a percentage of the total outside catch, ranged from 0 - 90 % for *G. brevipalpis* and 0 - 57,7 % for *G. austeni*. Furthermore, nets with significantly larger outside catches correlated with wind direction. The downwind nets had outside catches of 24,6 % (± 0,624 s.e.) for *G. brevipalpis* and 20,1 % (± 0,0711 s.e.) for *G. austeni* as opposed to the opposite upwind catches of 3,1 % and 2,1 % for the two species, respectively. The downwind catches were significantly higher ($P < 0,05$) than all the remaining nets for *G. austeni* and also for *G. brevipalpis* ($P < 0,001$) and specifically 9,6 times and 7,9 times higher than the opposite upwind net catch for the two species, respectively.

6.4.2 Attraction and feeding

Since the presumption of random approaches was not supported by the data, it was not possible to obtain absolute estimates of the numbers of tsetse attracted to a host. Therefore, attraction was determined as an index of the total catches obtained from the inside plus outside ring of nets as was also suggested by Torr (1994). The feeding proportion consisted of the percentage of fed flies on the inside ring. Indices of the detransformed means are reported.

Responses of tsetse to various hosts

Studies of tsetse responding to a live cow, goats and a bushpig were carried out in two separate experiments (Exp. 1 & 2). Attraction of the two tsetse species to these animals is summarized in Table 6.1. The results are expressed as an index of attraction relative to the attraction to the cow with detransformed mean catches obtained by the latter given in brackets. The proportion of flies caught on the inside of the ring of nets that had fed are given in Table 6.2. These results are expressed as detransformed percentages. The number of replicates (n) for each treatment, the degrees of freedom (df) for error, the transformed standard errors (s.e.) as well as the levels of probability (P) that the means are different at $P < 0,05$ (*), $P < 0,01$ (**), $P < 0,001$ (***), or not significantly different (n.s.) are given in the Tables.

The results showed that *G. brevipalpis* males and females were significantly more attracted to cow (*c.* 4,0 - 6,5 x and *c.* 2,7 - 2,8 x) than to either bushpig or goats, respectively. The percentage of males and females feeding on cow (*c.* 19,2 - 49,7 %) were also significantly greater than those feeding on bushpig (*c.* 0,01 - 9,60 %) or goats (*c.* 0,3 - 0,4 %).

Table 6.1 Relative attraction of *G. brevipalpis* and *G. austeni* males and females to cow, bushpig and goats (in two experiments within sand forest) [Results are expressed as indices of increase relative to the cow (index = 1) with detransformed mean catches of the cow given in brackets. The number of replicates (*n*), the degrees of freedom for error (df), the transformed standard errors (s.e.) and the probability that the means are different at the $P < 0,05$ (*), $P < 0,01$ (**), $P < 0,001$ (***) levels of probability or not significantly different (n.s.) are indicated]

	Exp. 1						Exp. 2					
	Indices of increase						Indices of increase					
Species/sex	Cow	Bushpig	*n*	df	*P*	± s.e.	Cow	Goats	*n*	df	*P*	± s.e.
G. brevipalpis												
Males	1(40,534)	0,153	7	13	***	0,089	1(41,870)	0,377	9	17	***	0,040
Females	1(43,040)	0,253	7	13	*	0,109	1(33,390)	0,354	9	17	***	0,038
G. austeni												
Males	1(11,667)	0,331	7	13	n.s.	0,136	1(8,267)	0,904	9	17	n.s.	0,061
Females	1(42,720)	0,470	7	13	*	0,088	1(65,49)	0,400	9	17	**	0,070

Table 6.2 Feeding percentages of *G. brevipalpis* and *G. austeni* males and females on cow, bushpig and goats (in two experiments within sand forest) [The number of replicates (*n*), the degrees of freedom for error (df), the transformed standard errors (s.e.) and the probability that the means are different at the $P < 0,05$ (*), $P < 0,01$ (**) and $P < 0,001$ (***) levels of probability are indicated]

	Exp. 1						Exp. 2					
	Feeding %						Feeding %					
Species/sex	Cow	Bushpig	*n*	df	*P*	± s.e.	Cow	Goats	*n*	df	*P*	± s.e.
G. brevipalpis												
Males	43,9	9,60	7	13	**	0,206	19,2	0,30	9	17	**	0,161
Females	42,0	0,01	7	13	***	0,132	49,7	0,40	9	17	**	0,176
G. austeni												
Males	24,5	9,70	7	13	*	0,212	8,9	0,04	9	17	*	0,272
Females	45,0	5,00	7	13	**	0,164	80,0	11,10	9	17	*	0,117

For *G. austeni* males the attraction towards the cow was not significantly different from attraction to bushpig and especially to goats, while the percentage of males feeding on cow (*c.* 8,9 - 24,5 %) was still significantly more than those feeding on either bushpig (*c.* 9,7 %) or goats (*c.* 0,04 %). For females attraction to cow was significantly greater (c. 2,1 - 2,5 %) than for bushpig and goats. The percentage of females feeding on cow (*c.* 45 - 80 %) was also significantly higher than those feeding on bushpig (*c.* 5 %) and goats (*c.* 11 %).

Comparison of tsetse responses inside and outside forest vegetation

Comparisons of the responses of *G. brevipalpis* and *G. austeni* to a live cow were compared at two sites i.e. inside and outside forest vegetation (referred to as Site 1 and 2, respectively) during various times (I - III) of tsetse activity as set out in Materials and Methods above. The results for attraction of tsetse to the cow for the two sites and various times are summarized in Table 6.3. These results are given as the indices of increase relative to a time period when each species was most active (Kappmeier 2000), i.e. for *G. austeni* it was Time I (noon - 16:00) and for *G. brevipalpis* this is Time II (16:00 - dark). The proportion of fed flies, caught on the inside of the ring of nets, is given in Table 6.4. These results are once again expressed as detransformed percentages. Again, the number of replicates (n) for each treatment, the degrees of freedom (df) for error, the transformed standard errors (s.e.) as well as the levels of probability (P) that the means are different at $P < 0,05$ (*), $P < 0,01$ (**), $P < 0,001$ (***), or not significantly different (n.s.) are given in the Tables.

For *G. brevipalpis* there were no significant differences between the number of both males and females attracted to a cow inside the forest for the various times of experimentation. A high percentage of these males and females also fed on the cow, especially after dark (*c.* 58,5 - 70,0 %) when the percentage of fed females were significantly higher than those fed during the preceding test times until dark. Outside the forest, more males and females were attracted to the cow during daytime hours (noon until dark) than after dark. However, virtually no flies (*c.* 0,02 – 4,6 %) fed on the cow outside during any of the times experimented.

For *G. austeni* males and females there were no significant differences in attraction to cow inside the forest between any of the times and they were also attracted to the cow at night. However, the greatest percentage of feeds took place between 16:00 until dark, although some feeding took also place at night (*c.* 4,4 - 15,7 %) Outside the forest, basically no males or females (mean number of flies attracted *c.* 1,2 - 1,3) were attracted during daytime periods until dark. Also no flies were attracted to the cow at night, thus the feeding percentage of the cow at all times outside the forest was essentially zero (0 - 0,02 %).

Table 6.3 Relative attraction of *G. brevipalpis* and *G. austeni* males and females at various times of day inside sand forest (Site 1) and in the adjacent open grassland area (Site 2) [Results are expressed as indices of increase relative to Time I for *G. austeni* and Time II for *G. brevipalpis* (index = 1). Detransformed mean catches of the control Time are given in brackets. The number of replicates (n), the degrees of freedom for error (df), the transformed standard errors (s.e.) and the probability that the means are different at the $P < 0,05$ (*) level of probability or not significantly different (n.s.) are indicated]

	Site 1 (Forest)							Site 2 (Grassland)						
	Indices of increase							Indices of increase						
Species/sex	Time I	Time II	Time III	n	Df	P	± s.e.	Time I	Time II	Time III	N	df	P	± s.e.
G. brevipalpis														
Males	0,712	1(49,38)	0,896	7	20	n.s.	0,085	1,160	1(19,877)	0,431	6	17	n.s.	0,152
Females	1,009	1(51,33)	0,957	7	20	n.s.	0,082	0,754ab	1(32,788)a	0,290b	6	17	*	0,123
G. austeni														
Males	1(7,958)	1,004	1,122	7	20	n.s.	0,131	1(1,245)a	0,085a	0,000b	6	17	*	0,098
Females	1(24,71)	0,534	0,513	7	20	n.s.	0,111	1(1,289)a	1,059a	0,000b	6	17	*	0,108

ab treatments followed by the same symbols are not significantly different

Table 6.4 Feeding percentages of *G. brevipalpis* and *G. austeni* males and females at various times of day inside sand forest (Site 1) and in the adjacent open grassland area (Site 2) [The number of replicates (n), the degrees of freedom for error (df), the transformed standard errors (s.e.) and the probability that the means are different at the $P < 0,05$ (*) levels of probability or not significantly different (n.s.) are indicated]

	Site 1 (Forest)							Site 2 (Grassland)						
	Feeding percentage							Feeding percentage						
Species/sex	Time I	Time II	Time III	n	df	P	± s.e.	Time I	Time II	Time III	n	df	P	± s.e.
G. brevipalpis														
Males	13,8	9,5	58,5	7	20	n.s.	0,196	0,45	0,48	0,70	6	17	n.s.	0,294
Females	39,6a	38,0a	70,0b	7	20	*	0,044	0,02	0,02	4,60	6	17	n.s.	0,260
G. austeni														
Males	6,7	23,5	4,4	7	20	n.s.	0,313	0,00	0,02	0,00	6	17	n.s.	0,150
Females	22,0	68,7	15,7	7	20	n.s.	0,200	0,02	0,02	0,00	6	17	n.s.	0,223

ab Treatments followed by the same symbol are not significantly different

6.5 DISCUSSION

6.5.1 Ring of nets

Except for *G. austeni* males, the proportion of flies caught on the inside ring of nets was about 9 % (for *G. austeni* females) and 8 – 15 % (for *G. brevipalpis*) greater than the 39 % expected if a random approach or departure to hosts occurs. Torr (1994) found exactly the same proportion of greater than expected inside catches for tsetse in Zimbabwe as here obtained for *G. brevipalpis*. Vale (1977b) implied that flies approaching a host were flying higher than those leaving after feeding, therefore the higher inside catch. According to Torr's (1994) explanation the estimated 75 % efficiency of electric nets would increase the inside catch of nets. However, he indicated that, as a result of lower efficiency, the inside catch would actually comprise 46 % of the total catch, which is more or less identical to the proportion observed for *G. brevipalpis* males, but still a little less than for female *G. brevipalpis* and *G. austeni*.

Torr (1994) furthermore suggested another reason why flight to and from a host is unlikely to be random. Some nets are in the flight paths to and from the host, in that tsetse attracted to the odour of the host will approach from downwind (Vale 1974b), while also departing downwind after feeding (Vale 1977a). This study showed that some nets caught significantly more than others both at the inside and outside of the ring, thus also suggesting that arrivals and departures were not random. It was furthermore shown for both species that the downwind nets had significantly more outside catches than any of the other nets, which suggests an upwind flight response towards the host. This is expected for *G. brevipalpis* which reacts strongly to odours, but is a very interesting observation for *G. austeni*, for which olfaction played a less important role compared to visual attraction, as indicated in Chapter 3.

6.5.2 Attraction and feeding

The present study showed that male and female *G. brevipalpis* and female *G. austeni* were significantly more attracted to cow than to either bushpig or goats, with a significantly higher percentage (19,2 - 49,7 % *G. brevipalpis* and 45 - 80 % *G. austeni*) feeding on cow. Even though a low number of *G. austeni* males were attracted to cow (as well as to goats and bushpig) there was still a significant proportion of them feeding on cow as compared to goats and bushpig. Vale (1977a) found similar results for tsetse in Zimbabwe where, amongst other hosts, goats and bushpig were less attractive than cow and the proportion of flies feeding was also very low (8 - 15 %).

During the various times of experimentation, i.e. between noon until well after dark, *G. brevipalpis* and *G. austeni* males and females were equally attracted to a cow inside the forest vegetation. A high percentage of the *G. brevipalpis* fed on the cow, especially after dark when 58,5 % of the males and 70,0 % of the females that were attracted, fed. However, the greatest percentage of feeds for *G. austeni* took place from 16:00 until dusk, although some feeding also took place at night. The results of the "cow in forest" attraction trials differed in many ways from the results of "target trials" conducted during the same season (autumn) (Kappmeier 2000). For example, only individual *G. brevipalpis* were attracted to targets between noon and 16:00 and were mainly active during the two hours preceding dark. *G. austeni* was attracted to targets from noon until darkness fell. Both species were, however, "unavailable" to targets as soon as it was dark. The reason for this was thought that, although odour was present to attract flies to the vicinity of the target, the flies could not visually perceive the target. The cow, however, attracted both species well after dark, with many feeding. This indicates that non-visual host-finding mechanisms continued to act in the dark. Apart from host-odour, which was also present during the day, radiating body heat would appear to be the most likely source of close-range attraction in the absence of visual stimuli. This heat factor might also be the important factor for *G. brevipalpis* during the day when flies were largely active around a live host but not around an odour-baited target.

At the site in an adjacent grassland area about 750 m outside the forest, more *G. brevipalpis* were attracted to a cow during daytime hours including dusk than after dark. Since this experiment was conducted during winter, when daytime temperatures are much lower, it is not surprising that the flies left the cover of shade since they were also found "available" to targets during daytime in winter (Kappmeier 2000). It also supports the findings in the previous chapter, which showed that this species has the tendency to roam out of the forest especially at lower temperatures. However, virtually no *G. brevipalpis* fed on the cow during any of these times with at most only 4,6 % of the females feeding after dark. Only individual *G. austeni* were attracted during daytime periods until dusk and no flies were attracted at night. The feeding percentage was thus basically naught. In the previous chapter it was also shown that this species was able to traverse open distances, but essentially not as far as 750 m.

6.5.3 Implications

The control of a tsetse population by means of pour-ons used on domestic animals depends upon a relatively large proportion of flies feeding on the treated animals. The present investigation suggested that cattle could be used as viable mobile targets for the control of *G. brevipalpis* and *G. austeni* in communal farming areas where cattle are present. Since domestic goats were relatively unattractive to, and infrequently fed upon by tsetse, there would be little point in treating them for use as mobile targets. Also untreated goats are unlikely to provide a major alternative blood-source to the treated cattle.

Regarding the protection of cattle from tsetse fly attack, it is clear that disease challenge by these two forest-dwelling species will be lower if cattle are kept from direct contact with forest situations. This may not always be possible, since cattle are nowadays forced to make closer contact with tsetse habitat because of overgrazing. However, since tsetse feeding outside the forest areas seems to take place mostly at night and also takes place less outside forest vegetation, it might be of benefit to at least shelter animals at night at a distance from forested areas. For *G. austeni* this distance is obviously less than for *G. brevipalpis*.

7. TSETSE DISTRIBUTION AND ABUNDANCE

7.1 ABSTRACT

Tsetse surveys were conducted from 1993 - 1999 in the northeastern parts of KwaZulu-Natal. A large proportion of the nagana-infected area of N.E. KwaZulu-Natal has now been surveyed. A successful surveying system was developed and has been refined at each successive survey. Trap sites were mapped as positive or negative for tsetse fly presence. Maps of the apparent densities of each species in terms of flies/trap/day are also presented. For *Glossina brevipalpis* there appeared to be two distinct bands of distribution, i.e. one in the southern one-third of the area and the other just south of the Mozambique border, but it seems to be inexplicably absent from Tembe Elephant Park, the central Makhathini/Mkuze area and most of the Coastal Reserve between the Eastern Shores of Lake St. Lucia and Kosi Bay. *G. austeni* appeared to be more widespread from north to south but is absent from Hluhluwe/Umfolozi Game Reserve and from the Eastern Shores of Lake St. Lucia northwards along the Coastal Reserve to Kosi Bay. Results were incorporated into a Geographic Information System (GIS). Reference was made to the historical distribution of the two species and current trends in cattle distribution, trypanosomosis prevalence, landcover and vegetation types, which were also mapped.

7.2 INTRODUCTION

Before a tsetse control campaign is implemented it is necessary to be able to answer certain questions, for example: Where exactly do tsetse flies occur? Which species occur where? Are they restricted to certain types of vegetation? For some activities, such as planning a control campaign where the same solution is to be applied throughout the affected area, only accurate information on distribution is required. For others, such as determining the amount of control/intervention, abundance and prevalence information is also required (Rogers & Randolph 1986).

Early work on tsetse flies concentrated on their distribution and habitats, with the objective of determining priority areas for the control of the flies and areas where people or domestic livestock are at risk. The general distribution of tsetse flies, determined principally by climate and influenced by altitude, vegetation and the presence of suitable host animals, has been known for a long time. However, more precise limits of distribution, particularly in areas of low population density, were not well defined. Since the 1960s more precise limits of tsetse distribution have been obtained from surveys using various sampling techniques (Leak 1999).

A long-term solution to the nagana problem in KwaZulu-Natal depends on the control and/or eradication of the tsetse flies. It is, therefore, essential to know the distribution of the two tsetse species and to relate this to outbreaks of the disease so that possible control strategies can be developed. Ford and Katondo's (1977) distribution maps are not very accurate regarding the present distribution of *G. brevipalpis* and *G. austeni* in South Africa. The historical distribution of these two species (Fig. 7.1) in N.E. KwaZulu-Natal was given more accurately by Du Toit in 1954 and in a small area surrounding Lake St. Lucia in 1956. Aerial smoking with DDT and HCH also eradicated *G. pallidipes* from the Zululand region (Du Toit 1954) and possibly also *G. brevipalpis* and *G. austeni* where their distributions coincided with that of *G. pallidipes*. However, since 1954 various changes in land use and development have occurred in the region (Kappmeier *et al.* 1998). In certain areas the human and stock population increase resulted in bush removal, making those areas less favourable for the two shade requiring tsetse species. On the other hand, the planting of pine and eucalypt trees between 1953 - 1960, which was mostly on grassland and shrubland in the Hlabisa District, may have created artificial but suitable habitat for shelter and even reproduction of the two species. This also resulted in the expansion of thickets in certain areas, due to the excessive use of water by the plantations and concomitant lowering of the water table, as well as their protection from fire and clearing for cropping (Jacobs, Schafer & Robertson 1989).

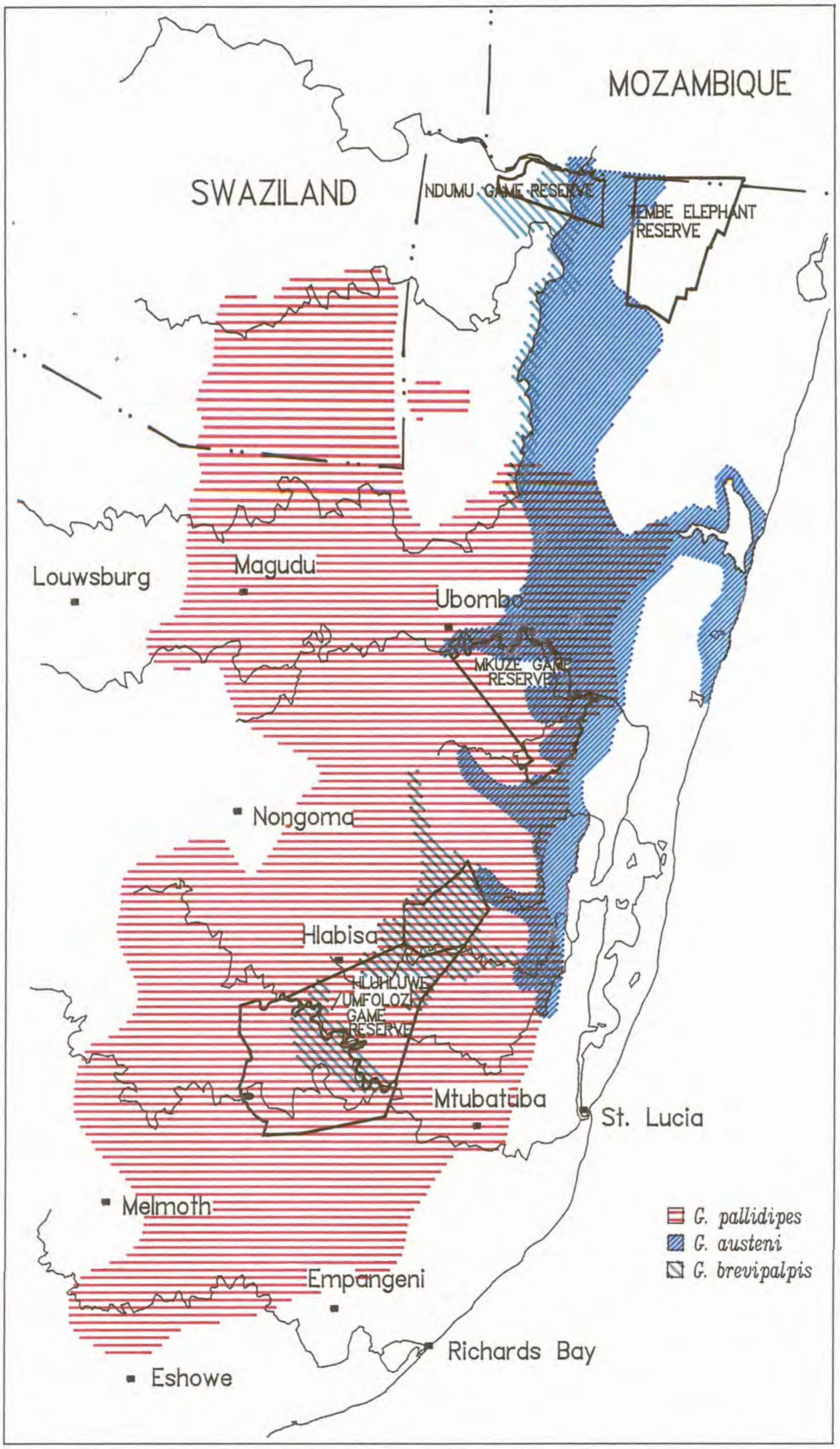

Fig. 7.1 Historical distribution of the tsetse flies *Glossina pallidipes*, *G. austeni* and *G. brevipalpis* (after Du Toit 1954)

Meaningful changes could, therefore, have occurred regarding the distribution of both tsetse species given by Du Toit in (1954) so that accurate information on the present distribution of tsetse and/or trypanosomosis in South Africa is not available. Moreover, the information that is available and obtained through tsetse surveys in the late 1940s is dated. Also, within that wide geographical range, the distribution of *G. brevipalpis* and *G. austeni* seems to be rather patchy and their abundance will vary dramatically from one location to another. Greater knowledge of the detailed distribution of these species is essential for surveillance and control measures. In order to develop a strategy to plan tsetse fly eradication or control in the region successfully it was necessary to re-survey the area to establish the present relative distribution of the two species. Such a survey was possible using technology, which has been developed elsewhere in Africa (Schonefeld 1988 cited in Hall 1990) and modified for our species (see Chapter 4).

Recently remote sensing techniques and GIS (Geographic Information System) have been utilized as means of supplementing and evaluating survey information to obtain more precise limits of distribution. GIS is an invaluable tool for integrating and manipulating available data sources into useful studies. GIS contain spatial data sets that are accessible to display, manipulation and analysis (Clarke *et al.* 1996; Ndegwa & Dwinger 1998) and has been applied to tsetse and trypanosomosis (Rogers & Williams 1993; Rogers *et al.* 1996; Robinson *et al.* 1997a, 1997b; Allsopp 1998; Robinson 1998a, 1998b; Rogers 1998; Erkelens *et al.* 2000; Hendrickx *et al.* 2000). Most of the studies referred to above used GIS to combine survey results with climate and remote sensing data to predict the distributions of the disease vectors. The critical role of GIS is to collect, rationalize and merge information in a way that facilitates data analysis to help with decision-making and to assist with planning interventions and can be used to model epidemiological problems in time and space (Erkelens *et al.* 2000).

The effective control of tsetse and trypanosomosis must be carried out in relation to the threat to cattle and land use. It is clear that a GIS would be a great help in mapping the distribution flies from survey data. Accurate tsetse distribution maps are needed if tsetse distribution data are to be integrated with data on trypanosomosis prevalence and/or incidence, livestock distribution and current land use, in order to identify areas where trypanosomosis is a constraint to rural development and to determine high priority intervention areas. The principal function of the GIS for this study will ultimately be to manage tsetse survey data and to collate it with other relevant information. This will be used to assist with the planning and intervention of trypanosomosis and allocating resources to tsetse control, which will be dealt with in Chapter 8. The data needed to do this will be, e.g. livestock (cattle) distribution and/or abundance, trypanosomosis incidence and/or prevalence as well as land tenure/designation, landcover and vegetation types.

7.3 MATERIALS AND METHODS

7.3.1 Sampling area

The sampling/survey area extended from about 28°31' S in the south to 26°50' S in the north (up to the Mozambique border) and from about 31°40' E in the west up to the eastern coastline of N.E. KwaZulu-Natal. The area of interest has a total surface of about 12,000 km^2. It covers the magisterial districts of Ingwavuma, Ubombo, Hlabisa and parts of Nongoma. The region mainly consists of a number of Game Reserves and conservation areas, communal and commercial farming areas, State Forests and commercial plantations as well as a number of large lakes and a network of rivers. The Ubombo Mountain range lies from north to south on the western border of Swaziland and ranges southward to the southwest of the Mkuze Game Reserve (see Fig. 7.2).

Tsetse surveys were done systematically from December 1993 based on collections with XT sticky traps (see Chapter 4), which were at that time found to be the most appropriate survey tool. The surveys covered in the first phase (1993-1995) the major part of game reserves, nature conservation areas and commercial farming areas since accessibility to these areas was easy to arrange. In a following phase (1996-1999) surveys were mainly concentrated in the communal farming and diptank areas, where permission from Zulu chiefs was needed prior to surveys and where a close liaison between Animal Health Technicians and the communal populations was essential.

7.3.2 Sampling method

Survey sites were selected using 1:50,000 topographical maps. Initially the survey method that was developed in Zambia was adopted (T. Robinson, pers. comm., 1993). The 1:50,000 maps were divided in 3 x 3 minutes of latitude and longitude (*c.* 5 x 5 km 'cells'). The first consideration was to have an even distribution of traps throughout the area to be surveyed. The traps were placed systematically along roads and tracks to cover most of the 'cells'. It was attempted to place an optimum of about 4 - 5 traps/cell. However, it became clear that this system was not appropriate for detailed surveys of these particular species of tsetse fly. Because of the cryptic habitats of *G. austeni* and because of the preference of both species for dense bush, traps needed to be set in what was considered to be suitable habitat. Thereafter the most suitable tsetse habitats per survey site were sampled at about 2 km intervals (in suitable areas) or greater in apparently unsuitable areas. Traps were sited either along the edge of inaccessible bush or thickets, where possible along roads that wound through the bush, or were hung 5 - 50 metres into the bush in what was considered to be the most suitable situation for both fly species.

For practical reasons each survey lasted approximately 12 days and involved setting up to 75 traps. The traps operated over a period of 5 - 7 days. Due to the physical or ownership differences between the various areas surveyed during this period the different areas were designated as sampling or survey units. These were, for example, different farms, plantations, game reserves, diptank areas, etc. Trap sites were selected inside and adjacent to thickets and wooded areas and also in plantations where colonization of *G. brevipalpis* and *G. austeni* has taken place. The exact location of each trap site was recorded using a handheld Pyxis®, Magellan® or Garmin II Plus® Global Positioning System (GPS). In order to relocate traps quickly on returning after about five days, numbered markers (chevron tape) were tied to a tree near the trap or at the roadside near the spot where traps were hung.

Initially e.blue/l.blue XTs (as described in Chapter 4) were used in the surveys. During 1995 these were replaced by e.blue/black XTs which proved at that time to be significantly more effective for *G. austeni* (see Chapter 4).

Traps were painted with polybutene, which was first diluted with hexane for easy application. Because *G. austeni* is known to be a low-flier, traps were hung about 10 - 15 cm above the ground from tree branches. A plastic sheet was pegged below the sticky traps to collect flies that dripped off the trap over the sampling period. Traps were baited with the Zim-mix, as described in Chapter 2.2.2, to attract *G. brevipalpis*.

During the first phase of surveys a total of 11 surveys and 51 survey units were sampled. The survey units and the number of traps placed per unit for this phase are summarized in Table 7.1 in the Results. GIS coordinates for each trap placed in the various survey units are given in Appendix 1. As the first phase of the survey only included areas of easy access i.e. Game Reserves, conservation areas, game farms, commercial cattle/sugar-cane/pineapple farms, State Forests and commercial pine and eucalypt plantations, these will be referred to as "natural and commercial areas". The second phase of surveys, which covered diptank and communal farming areas, was divided into State Veterinary Areas. A total of 14 surveys consisting of 38 survey units were sampled in the Hluhluwe State Veterinary Area (i.e. Hlabisa and Nongoma Magisterial Districts) and 10 surveys consisting of 56 survey units in the Jozini State Veterinary Area (i.e. Ubombo and Ingwavuma Districts). The survey units and the number of traps placed per unit for the second phase are summarized in Table 7.2 in the Results. GIS coordinates of each trap site are also given in Appendix 1.

On the day of setting the trap the following data were recorded: date and time trap set; coordinates; map code; survey unit/locality; general vegetation type and soil type. Upon removal of the trap the two tsetse species, if present, were identified, sexed and counted. The date and time that the trap was removed was recorded. The approximate numbers of other biting flies were also recorded and then placed in 80 % alcohol and identified back in the lab.

7.3.3 Sampling data

From field data books the tsetse distribution data were entered onto tsetse data input sheets. From these the data were entered into a Disease and Vector

Integrated Database (DAVID), which was developed at Oxford University and installed at ARC-OVI for use and collaboration in its de-bugging and development to ensure that it met with operational requirements. DAVID is a geographical information management system for tsetse, trypanosomosis and livestock field data (Robinson *et al.* 1997c; Robinson 1998b). It greatly facilitates entry, display and analysis of field data, and their integration with other data within GISs. The input fields consisted of: Trap number/sample site; Longitude; Latitude; Sample method; Start date; Start time; End date; End time; Species; Flies caught (males and females). For the present work the database was used for the trap coordinates and to calculate the trapping period as well as the apparent densities expressed as numbers of flies/trap/day to be incorporated into a GIS and to facilitate mapping in ArcView GIS.

7.3.4 Base maps

Results of tsetse distribution surveys, diptank localities, landcover and vegetation types were mapped using ArcView GIS version 3.2. All other maps were produced with ArcInfo. Separate coverages of some base maps of the region, consisting of national and magisterial district boundaries, major towns, lakes, major rivers, game reserves, other major conservation areas and forestry areas, were used in the generation of the maps produced in the Results below. A background map (Fig. 7.2) shows the locality of the study area and should be referred to for locations of the magisterial districts, major game reserves and conservation areas, lakes, major rivers and the Lebombo Mountain range. Also refer to this map for the scale.

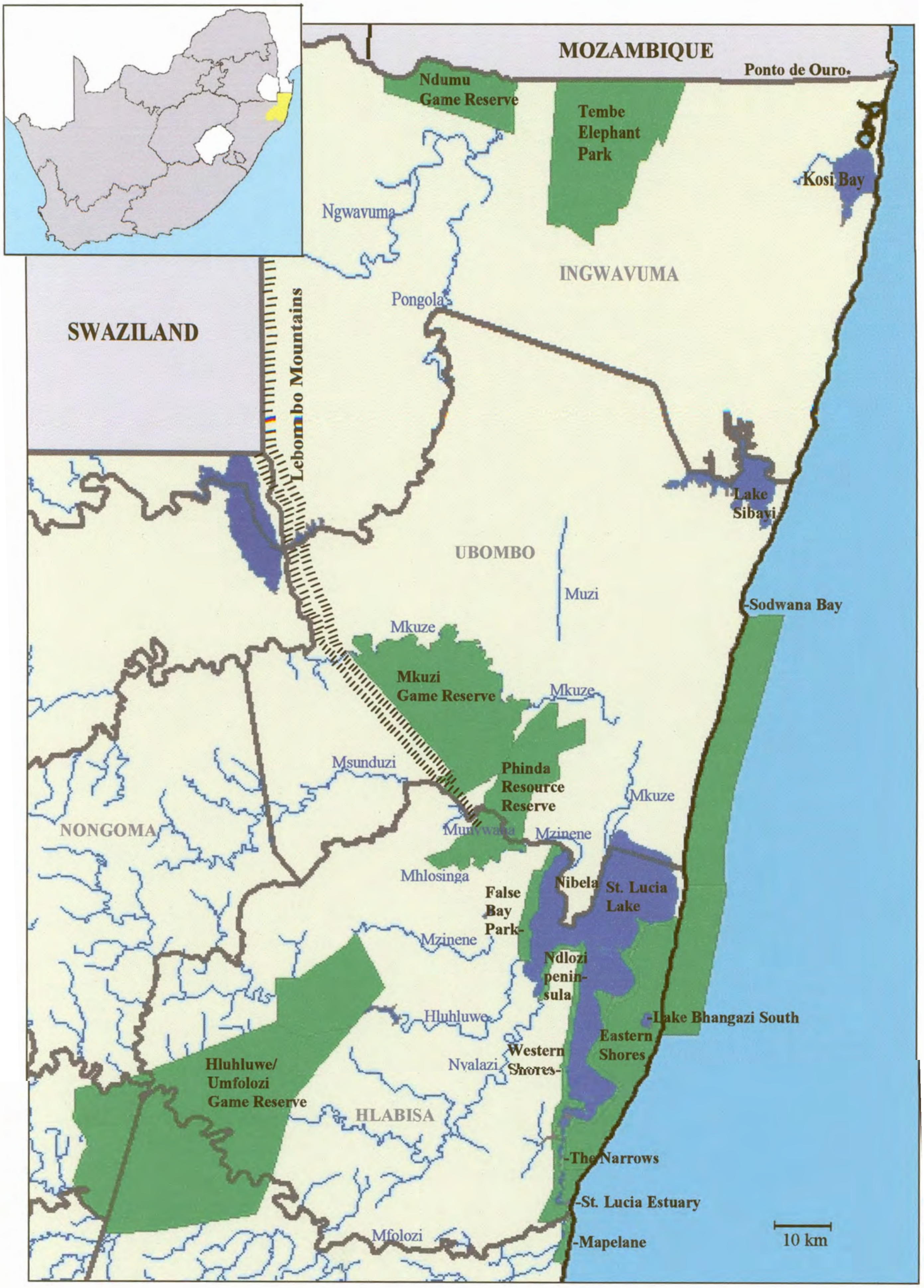

Fig. 7.2 Reference map to indicate localities of magisterial districts, major game reserves and conservation areas, lakes and major rivers

7.4 RESULTS

7.4.1 Tsetse distribution and apparent densities

Other biting flies

The sticky traps also caught a variety of flies other than tsetse flies. Some of these were specifically attracted to these traps (as evidenced by their numbers) and were therefore, identified to family or genus level and recorded. Many of these flies are also known to feed on the blood exudates and lachrymal secretions of livestock and wild animals (Lancaster & Meisch 1986). Their identification, especially the biting flies, is important for two main reasons. Firstly, because of their possible role in the mechanical transmission of trypanosomosis (Jordan 1986). Secondly, because they, especially blood-dependent *Stomoxys* spp., are an indicator that the flies had access to host animals nearby. This confirms that the absence of tsetse flies on such traps cannot be attributed to a lack of host animals. The biting flies identified were Tabanidae (*Tabanus* spp., *Haematopota* spp., *Philoliche* spp. and other Tabanidae) as well as the Stomoxyinae (*Stomoxys nigra*, other *Stomoxys* spp., *Parastomoxys* spp., *Prostomoxys* spp., *Haematobia* spp. and *Haematobosca* spp.). So-called non-biting flies of the subfamily Muscinae (*Musca* spp., *Morellia* spp. and others), although fewer in numbers than the biting flies, were identified to genus. The present study will concentrate only on analysis of the tsetse fly catches.

Tsetse positive/negative trapping sites

The e.blue/l.blue and e.blue/black XTs, developed in Chapter 4, were successful in surveying the distribution of both *G. austeni* and *G. brevipalpis*. A summary of the surveys with details of survey units, month and year of survey, the number of traps operated and the number of positive traps for each species is given in Table 7.1 for natural and commercial areas and in Table 7.2 for communal farming areas. The distribution of the two species was mapped (Fig. 7.3) according to catches of flies in terms of fly presence (one or both species) and where zero catches were obtained. Details of the survey results are discussed separately for the natural and commercial areas and for the communal areas. The results will be discussed under three main geographical areas, i.e. south (Hlabisa and Nongoma Districts), central (Ubombo District) and north (Ingwavuma District).

- **Natural and commercial areas**

A total of 514 traps were placed in the 51 survey units sampled in the natural and commercial areas. Refer to Fig. 7.2 for locations of game reserves, lakes and rivers and to Table 7.1 for the details of the survey units and the survey number. (The number of positive traps for each species was also given in the Table. Detailed summaries of results at each trap site are given in Appendix 1.)

SOUTH

Around Lake St. Lucia (surveys no. 1, 7 & 10), *G. brevipalpis* was found as far north as northern False Bay Park, as far south as St. Lucia Estuary and along the western and eastern shores of the lake. *G. austeni* was found accordingly except on the Eastern Shores and to the west of The Narrows of Lake St. Lucia (namely Dukuduku/ Futululu Forest area) where only *G. brevipalpis* was caught.

The survey (no. 4), which filled the gap between the rivers in the central area and the Hluhluwe River in the south, included the Mhlosinga, Mzinene, Ngweni (north of Mzinene – not indicated in Fig. 7.2) and Ncemane (north of Hluhluwe River – not indicated in Fig. 7.2) rivers.

Table 7.1 Summary of survey units surveyed in natural and commercial areas* (Details of trap localities and catches in each survey unit is given in Appendix 1)

Survey	Survey unit (locality)	No. of traps set	No. of positive traps	
			G.brevipalpis	*G. austeni*
1) Dec 1993	Nyalazi plantation (Mondi Forest, SAFCOL)	26	20	15
	Dukuduku plantation (SAFCOL)	6	1	-
	Fernwood plantation (Mondi Forest)	7	2	-
	Shire plantation (Mondi Forest)	8	-	-
	Futululu Research Station (CSIR-Forestek)	7	1	-
	Boomerang (cattle farm)	8	-	-
	Total	**62**	**24**	**15**
2) Feb 1994	Mkuzi Game Reserve (KZNNCS)	43	-	8
	Sodwana State Forest	13	-	4
	Phinda Resource Reserve	20	-	16
	Total	**76**	**0**	**28**
3) May 1994	Sungulwane Game Lodge (game and cattle)	3	-	-
	Mduna Estates (game and cattle farm)	4	-	-
	Sipofu (cattle farm)	3	-	-
	Kube Yini (game farm)	6	-	2
	Sutton (game farm)	5	-	3
	Panata (game farm)	5	-	5
	Mziki (game farm)	2	-	2
	Zulu Nyala (game farm)	5	-	5
	Total	**33**	**0**	**17**
4) Jun 1994	False Bay Park (KZNNCS)	13	8	12
	Kuleni (ARC-ITSC pineapple research farm)	5	-	5
	Somerset (cattle farm)	6	-	4
	Doringkuil (cattle farm)	5	-	1
	Ezulwini (game farm)	4	-	4
	Bonamanzi (game farm)	5	1	5
	HH Ranch (cattle farm)	4	-	-
	Ubizane Game Reserve (game farm)	3	1	2
	Total	**45**	**10**	**33**
5) Sept 1994	Ndumu Game Reserve (KZNNCS)	34	25	8
	Tembe Elephant Park (KZNNCS)	29	-	3
	Total	**63**	**25**	**11**
6) Jan 1995	Hluhluwe-Umfolozi Game Reserve (KZNNCS)	71	58	-
	Total	**71**	**58**	**0**
7) Jan 1995	Eastern Shores (KZNNCS)	15	14	-
	Mapelane (KZNNCS)	8	1	1
	St. Lucia	3	3	-
	Boomerang (cattle farm)	5	-	-
	Southern limit farms	6	-	-
	Teza plantation (Mondi Forest)	4	-	-
	Shire plantation (Mondi Forest)	3	-	-
	Fernleas plantation (Mondi Forest)	5	-	-
	Nyalazi plantation (SAFCOL)	5	2	2
	Dukuduku plantation (SAFCOL)	11	5	-
	Futululu plantation (Sappi Forest)	6	-	-
	Futululu Research Station (CSIR-Forestek)	4	-	-
	Total	**75**	**25**	**3**

Survey	Survey unit (locality)	No. of traps set	No. of positive traps	
			G.brevipalpis	*G. austeni*
8) Jun 1995	Sodwana Bay Park (KZNNCS)	14	-	-
	Lake Bhangazi North	9	-	-
	KwaMbila	7	-	-
	Lake Sibaya (KwaZulu-Natal Coastal Reserve)	14	-	-
	Manzengwenya (")	3	-	-
	Mabaso plantation (KwaZulu-Natal Forestry)	4	-	-
	Mbazwane plantation (")	12	-	-
	Manzengwenya plantation (")	8	-	-
	Total	**71**	**0**	**0**
9) Oct 1996	Ndumo Game Reserve (KZNNCS)	10	4	5
	Total	**10**	**4**	**5**
10) Nov 1996	Hellsgate Military Base (SANDF)	8	8	6
	Total	**8**	**8**	**6**
11) Apr 1998	Lake Sibaya (KZN Coastal Reserve)	10	0	0
	Total	**10**	**0**	**0**
	Grand Total	**524**	**154**	**118**

*Natural and commercial areas: included areas of Game Reserves, conservation areas, game farms, commercial farms, State Forests and commercial pine and eucalypt plantations.

These flow in various directions but all eventually enter the Mzinene and flow through a treeless flood plain into the northern part of False Bay Park (Lake St. Lucia). Both species of tsetse were captured. *G. austeni* was present in False Bay Park and on all the farms except HH Ranch (28°04'45"S 32°12'58"E), which may, however, not have been adequately surveyed (farms are not indicated on maps but listed in Table 7.1). *G. brevipalpis* was restricted to False Bay Park, Bonamanzi (which adjoins it) and Ubizane Game Reserve (along the Mzinene River).

Only *G. brevipalpis* was collected in the Hluhluwe-Umfolozi Game Reserve (survey no. 6). Despite traps being set in suitable *G. austeni* habitat in these areas no *G. austeni* were collected. Only half the traps were positive in the Umfolozi area, which were concentrated mainly around the rivers, in *Spirostachys* sp. thickets and along drainage systems. The remaining area has a more savanna type vegetation, especially in the southwest where all traps were negative. The southern part of Umfolozi Game Reserve is a declared Wilderness Area and no roads exist in this part of the reserve. As it was not possible to set traps in this area, the southernmost distribution of *G. brevipalpis* in the reserve could not be established.

To determine the southern limits of tsetse distribution, a survey (no. 7) included areas south and north of the Mfolozi River as well as forestry areas north of the river. Single specimens of each of *G. brevipalpis* and *G. austeni* were caught at Mapelane. They were the only tsetse caught south of the Mfolozi River and were collected in coastal dune forest. On the northern side of Mfolozi single specimens of *G. brevipalpis* were caught but no *G. austeni*. In the Safcol Dukuduku plantations, to the west of St. Lucia Estuary, only *G. brevipalpis* was trapped. No tsetse were collected in the plantations of the southwesterly areas.

CENTRAL

G. austeni was also found to the east of the Lebombo Mountains (see locality on Fig. 7.2) throughout parts of the Mkuze Game Reserve, the north-western part of Sodwana State forest (see locality west of Sodwana Bay in Fig. 7.7) and Phinda Resource Reserve (survey no. 2). The Sodwana State Forest area is used for cattle grazing. Most of this area is sandy with copses of dense bush. The traps that were positive in the Mkuze Game Reserve were mostly placed in the sandveld area where vegetation is dense and in the north-east in a well wooded area near the Mkuzi river (E.M. Nevill & J. Greger, unpublished report, 1994; also see Fig.7.9). Phinda Resource Reserve consists, in the north, mostly of dense sand bush and sand forest while in the south it contains mostly mixed bush ranging from *Acacia*, *Combretum*, *Schotia* to *Spirostachys* (also see Fig. 7.9). The southern part has three rivers (Munywana, Mzinene and Mhlosinga) and traps were often set near these rivers or in bushed gullies leading to these rivers. Of much significance was the collection of *G. austeni* along the Mhlosinga River at a point where it breaks through the last hills of the Lebombo Mountains. No *G. brevipalpis* were found in these areas to the east of the Lebombo even though traps were set along rivers (Mkuzi, Msunduzi, Munywana, Mzinene and Mhlosinga) where they could be expected to occur (nor west of the Lebombo Mountains) (E.M. Nevill & J. Greger, unpublished report, 1994).

A survey (no. 3) west of the southern extent of the Lebombo Mountains, an area which included both game farms and/or cattle ranches, revealed that 50 % traps placed in this area were positive for *G. austeni*. No tsetse were caught along the Msunduzi River although *G. austeni* was caught on an adjoining game farm in a wooded gully leading to the river. The absence of tsetse along the Msunduzi is thought to be due to dipping of cattle with pyrethroids at that time in the diptank area (diptank no. 766 – see Fig. 7.6) along the river. The traps placed along the Mhlosinga and Munywana rivers west of the Lebombo Mountains were positive for *G. austeni* but not for *G. brevipalpis*.

The survey (no. 8) in the Lake Sibayi/Sodwana Bay area (June 1995) included coastal reserves (dune forests) as well as other natural and forestry areas between Lake Sibayi to Lake Bhangazi North (situated about halfway between Lake St. Lucia and Lake Sibayi – not indicated on the map). The plantations concerned were Mabaso, Mbazwana and Manzengwenya to the south and north of Lake Sibayi (see localities in Figs. 7.7 and 7.8). No tsetse flies were trapped during this survey. The narrow dune forest strip between Lake Sibayi and the Indian Ocean, which seemed to be suitable tsetse habitat, was re-surveyed in April 1998. Once again no flies were caught. Also, no sign of wild animals or cattle was seen in that strip.

NORTH

G. austeni was present at both Ndumu Game Reserve and Tembe Elephant Park (surveys no. 5 & 9). However, only 11 of the 63 traps set were positive and numbers low. This is probably a reflection of reduced habitat due to many leafless trees at the time surveyed (Sept. 1994). *G. brevipalpis* was only present in Ndumu.

- **Communal areas**

Surveys of communal areas followed the completion of surveys in most of the conserved and commercial areas. A total of 24 surveys was carried out in which 644 traps were placed in the communal areas surrounding 79 diptank localities. Of these, 311 traps were set in the Hluhluwe State Veterinary Area (34 diptank localities) and the remaining traps were set in the Jozini S.V. Area (also see Table 7.2). Details of trap sites and catches are given in Appendix 1.

SOUTH

In the Hluhluwe S.V. Area (Hlabisa & Nongoma Districts - surveys no. 1 - 14) only one diptank was found positive for *G. austeni*, namely Qakweni (diptank no. 692 – see Fig. 7.6), where traps were actually set across the Nyalazi River in a conserved area. *G. brevipalpis* was widespread with 21 of the 34 diptank localities being positive (positive diptanks are those numbered in Fig. 7.6). The average number of *G. brevipalpis* collected on each of the 71 positive traps (out of 300) was 4,34.

CENTRAL

In the Jozini S.V. Area the Ubombo magisterial district was covered by surveys 15 - 21 (also see Table 7.2). The Makhathini Flats cover a great deal of the area. The vegetation in the area consists of thicket and bushland as well as forest and woodland (see Fig. 7.9). *G. austeni* was collected at 8 of 21 diptank localities. No *G. brevipalpis* were collected.

NORTH

In the northern parts of Jozini S.V. Area (Ingwavuma district), surveys 22 - 24 were covered (also see Table 7.2). *G. austeni* was present in six and *G. brevipalpis* in seven of 24 diptank localities. The vegetation and topography ranged from coastal dune forest, coastal lakes and marsh areas

Table 7.2 Summary of survey units (diptank localities) surveyed in communal farming areas. (Details of trap localities and catches in each survey unit is given in Appendix 1)

Survey	Survey unit (diptank locality)	No. of traps set	No. of positive traps	
			G.brevipalpis	*G. austeni*
	HLUHLUWE STATE VETERINARY AREA:			
1) Oct 1995	Mahiya 517	2	-	-
	Qakweni 692	3	-	-
	Ngodini 944	6	3	-
	Total	**11**	**3**	**0**
2) Jan 1996	Ngodini 944	10	1	-
	Total	**10**	**1**	**0**
3) Feb 1996	Mzinene 526	7	2	-
	Qakwini 692	10	8	-
	Mahiya 517	7	3	-
	Gunjaneni 523	9	4	-
	Mvutshini 945	10	9	-
	Hlazane 519	10	1	-
	Machibini 746	3	3	-
	Total	**56**	**30**	**0**
4) Mar 1996	Nhlwathi 525	9	-	-
	Mquthungu 726	9	4	-
	Hlambanyathi 754	6	2	-
	Total	**24**	**6**	**0**
5) Apr 1996	Mpenbeni 528	8	4	-
	Gwegwede 524	10	-	-
	Sangoyana 946	10	2	-
	Total	**28**	**6**	**0**
6) Nov 1996	Ngwenyambili 778	7	4	-
	Hluhluwe 518	5	-	-
	Total	**12**	**4**	**0**
7) Oct 1996	Makhatini communal areas	6	-	-
	Total	**6**	**0**	**0**
8) Mar 1997	Mahlabinyathi 963	9	7	-
	Sakwini 842	10	-	-
	Bukhipha 962	10	-	-
	Total	**29**	**7**	**0**
9) Jun 1997	Matshamhlophe 326	10	1	-
	Mfanelo 327	7	-	-
	Qunwane 964	6	-	-
	Mgangado 694	6	-	-
	Total	**29**	**1**	**0**
10) Jan 1998	Dabedabe 527	5	-	-
	Total	**5**	**0**	**0**
11) Mar 1998	Nkolokotho 744	10	3	-
	Hoho 522	9	-	-
	Nyalazi 520	10	-	-
	Dukuduku 967	10	1	-
	Gwedla 669	10	2	-
	Total	**49**	**6**	**0**
12) Apr 1998	Nsane 521	9	-	-
	Nomathiya 966	10	-	-
	Total	**19**	**0**	**0**
13) May 1998	Kwamsane 323	10	1	-
	Ekuphudisweni 328	7	4	-
	Total	**17**	**5**	**0**
14) Jun 1998	Mpanzakazi 325	6	2	-
	Total	**6**	**2**	**0**

Survey	Survey unit (diptank locality)	No. of traps set	No. of positive traps	
			G.brevipalpis	*G. austeni*
	JOZINI STATE VETERINARY AREA:			
15) Oct 1996	Zidlele 701	3	-	-
	Zineshe 743	3	-	-
	Biva 936	3	-	-
	Total	**9**	**0**	**0**
16) May 1997	Zidlele 701	10	-	-
	Zineshe 743	10	-	3
	Biva 936	10	-	-
	Total	**30**	**0**	**3**
17) Mar 1998	Siphondweni 819	2	-	-
	Hlazane 937	7	-	-
	Mozane 938	11	-	-
	Total	**20**	**0**	**0**
18) Apr 1998	Munyu 820	11	-	1
	Mkhumbikazana 514	10	-	-
	Mseleni 512	10	-	8
	Total	**31**	**0**	**9**
19) May 1998	Manaba 500	20	-	13
	Mbazwana 513	4	-	3
	Ntenga 678	1	-	-
	Nibela 510	5	-	-
	Masakeni 679	4	-	2
	Total	**34**	**0**	**18**
20) Oct 1998	Zineshe 743	5	-	2
	Nibela 510	10	-	-
	Masakeni 679	9	-	2
	Mpempe 302	10	-	-
	Nkomo 698	7	-	-
	Total	**41**	**0**	**4**
21) Nov 1998	Biva 936	3	-	-
	Siphondweni 819	5	-	1
	Hlazane 006	4	-	1
	Munyu 820	6	-	-
	Mbazwana 530	5	-	1
	Mpini 849	1	-	-
	Manzibomvu 813	10	-	-
	Total	**34**	**0**	**3**
22) Apr 1999	Shemula 494	4	-	-
	Madlakude 803	5	-	2
	Namaneni 814	14	1	-
	Mengu 802	5	2	2
	Nhlathu 906	1	-	1
	Mpophomeni 682	1	-	-
	Phelandaba 503	3	-	-
	Kosibay 722	2	1	-
	Thengane 908	1	-	-
	Ndumu 130	2	-	-
	Nhlanjwana 320	6	2	-
	Ntabayengwe 827	8	-	-
	Nkawini 896	1	-	-
	Ezulwini 311	3	-	-
	Total	**56**	**6**	**5**
23) May 1999	Mahhashi 895	5	-	-
	Malangeni 864	11	2	-
	Thengane 908	3	-	-
	Mloli 683	14	4	1
	Phelandaba 503	3	1	1
	Manzibomvu 907	4	0	1
	Kosibay 722	8	3	0
	Total	**48**	**10**	**3**

Survey	Survey unit (diptank locality)	No. of traps set	No. of positive traps	
			G.brevipalpis	*G. austeni*
24) Nov 1999	Mlambongwenya 506	4	-	-
	Lubambo 789	5	-	-
	Singeni 787	5	-	-
	Mpeshane 898	2	-	-
	Mzinyeni 497	6	-	-
	Manqwashu 732	7	-	-
	Total	**29**	**0**	**0**
	Grand Total	**633**	**87**	**45**

in the east, to Lala palm grasslands in the central area (see Fig. 7.9) and sand forest near Tembe (see Fig. 7.10).

The Muzi depression (wetland - see Fig. 7.9) extends fingerlike south from the Mozambique border to south of Phelandaba (diptank no. 503 – see Fig. 7.6). Forest intrusions extended southwards from Mozambique into the more northerly areas (see Fig. 7.9). More to the west lie a number of pans, which form part of the Pongola River system. The results suggested an absence of tsetse along the Ingwavuma River and a north to south distribution of *G. brevipalpis* just south of Ndumu Game Reserve on the Pongola River and eastwards to the southwestern corner of Tembe Elephant Park. *G. brevipalpis* was also present in many parts of the area between Tembe and Ponto de Ouro border post (see locality in Fig. 7.2) in association with the forest intrusions and Muzi depression. The highest numbers of this species were recorded in Kosi Bay Reserve. *G. austeni* was found east from Pongola River to the southern boundary of Tembe. It was also collected in sandy bush areas roughly between Phelandaba and the Mozambique border, not very far from Tembe Elephant Park. No *G. austeni* were collected in the Kosi Bay coastal lake strip. No *G. brevipalpis* nor *G. austeni* were found in a survey concentrated west of the Pongola River, south of the Ingwavuma River and east of the Lebombo Mountains, mainly due to a lack of suitable tsetse habitat.

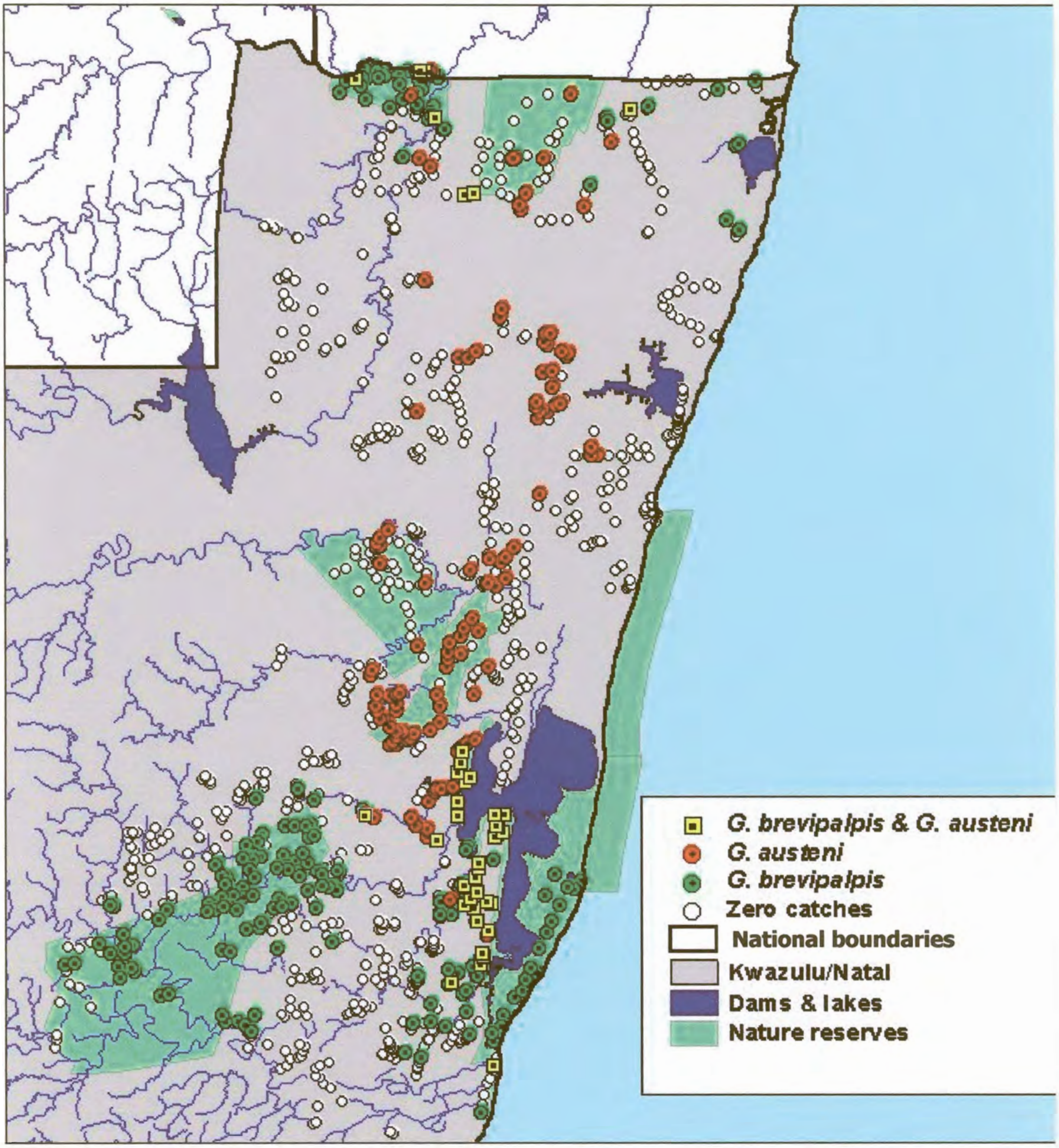

Fig. 7.3 Distribution of *Glossina brevipalpis* and *G. austeni* expressed as positive and negative trap catches

Apparent densities

To compare the apparent tsetse densities in the areas surveyed, catches were transformed to the number of flies/trap/day (also see Appendix 1). Maps showing the apparent densities of *G. brevipalpis* (Fig. 7.4) and *G. austeni* (Fig. 7.5) were generated using five density classes: for *G. brevipalpis* 0; 0,09 - 1,89; 1,89 - 4,87; 4,87 - 9,87 and 9,87 - 24,01 and for *G. austeni* 0; 0,11 - 2; 2 - 5; 5 - 10 and 10 - 15.

The maps might not be a true reflection of apparent densities for the two species, since surveys were conducted over several years and during various months of the year, although surveys were specifically not carried out during the cool dry season when tsetse numbers are at their lowest. Notwithstanding these short-comings it is still clear that both *G. brevipalpis* (Fig. 7.4) and *G. austeni* (Fig. 7.5) were both more plentiful in game reserves and other natural areas than in surrounding communal farming areas. Most *G. brevipalpis* (Fig. 7.4) were captured in an old established pine plantation in Eastern Shores of Lake St. Lucia (i.e. 24,01 and 21,47 flies/trap/day). *G. austeni* (Fig. 7.5) was most abundant in False Bay Park (12,76 flies/trap/day) and in a natural area adjacent to Lake St. Lucia (on the Nyalazi River – 11,14 flies/trap/day). It was noted during the survey that high tsetse populations usually accompany the presence of large numbers of wild animals, such as in game reserves.

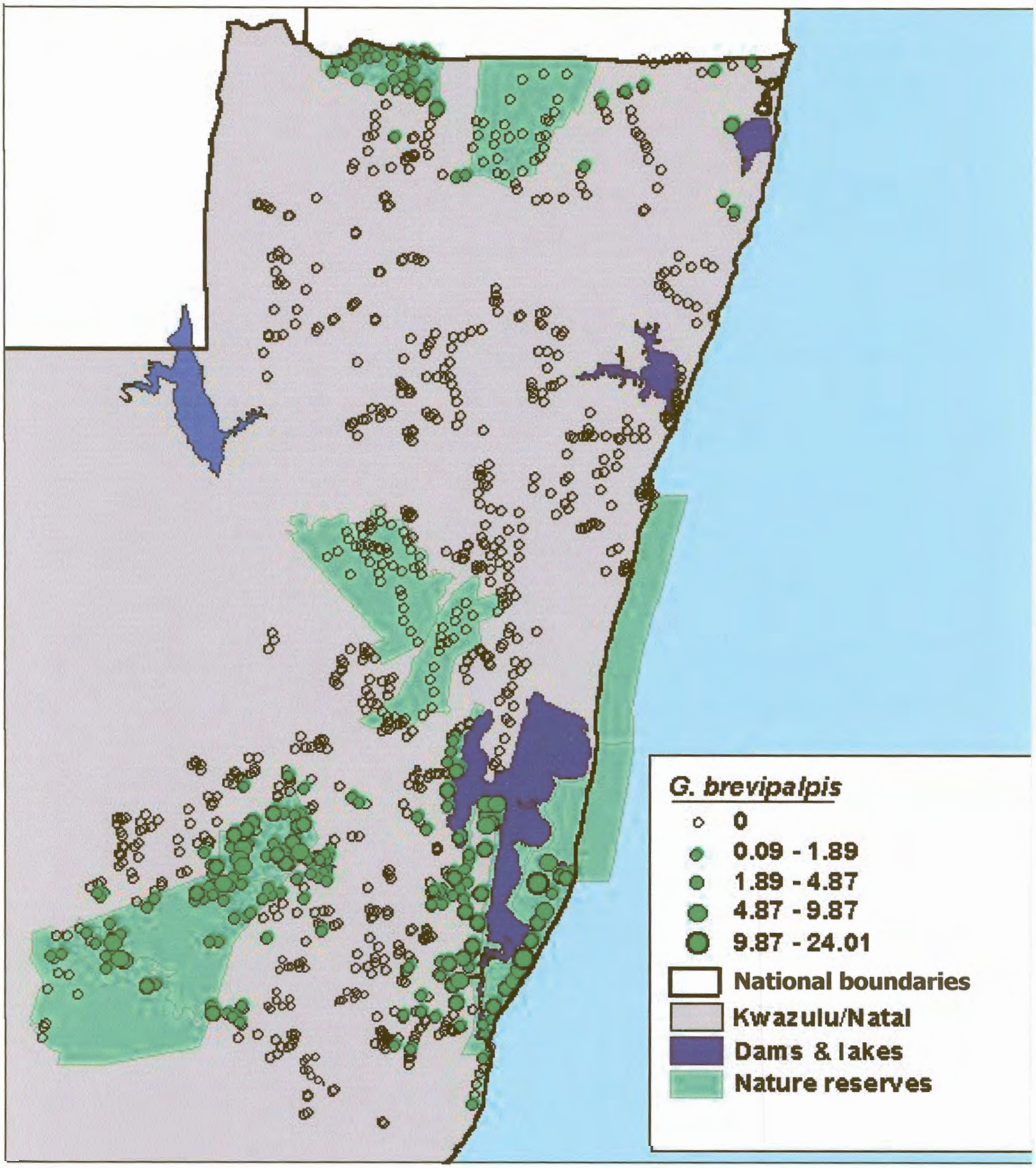

Fig. 7.4 Apparent density of *Glossina brevipalpis* expressed as the number of flies/trap/day

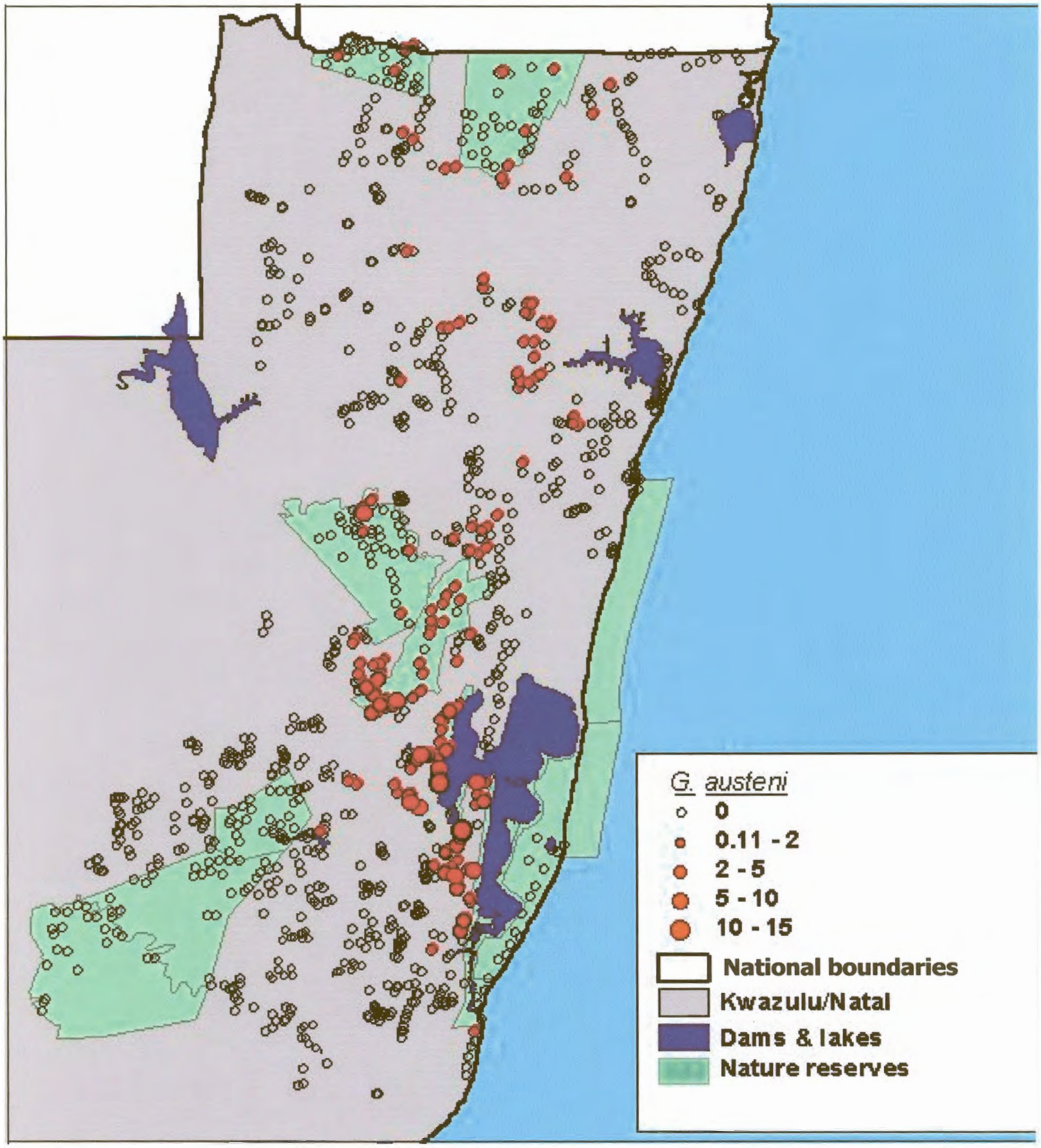

Fig. 7.5 Apparent density of *Glossina austeni* expressed as the number of flies/trap/day

7.4.2 Livestock distribution

Limited livestock census data are available for the area of concern so that accurate cattle densities could not be established and mapped (R. Williams, pers comm., 2001). Although some data are available on the number of cattle served by each diptank, these data are not accurate and will not be presented here. However, there is a network of plunge dips for the control of ticks on cattle in the region and cattle are allocated to diptanks according to the nearest walking distance. Topography and rivers/waterbodies also play a role in deciding diptank allocation (R.J. Bagnall, pers. comm., 2001). Coordinates of the diptanks in the area of interest (Hlabisa, Ingwavuma, Mhlabatini, Nongoma and Ubombo) were obtained (G.C. Bishop, Allerton Veterinary Laboratory, KZN Veterinary Services) and entered into DAVID. The diptank positions are given in Fig. 7.6.

The map of the distribution of diptanks can give a good estimate of the distribution of the *c.* 350,000 cattle belonging to communal farmers in the tsetse infested area, since they graze in permitted areas surrounding the game reserves and other nature conservation and forest areas.

It is assumed that where cattle, visiting a diptank, were diagnosed positive for trypanosomosis then all cattle in that diptank area were at risk of contracting nagana. Diptank areas that were found positive for tsetse are those numbered in Fig. 7.6 (number of traps positive are given in Table 7.2). They were the following: in Ingwavuma - 802, 803, 814, 906, 503, 907, 683, 684, 323, 722 and 937; in Ubombo - 819, 500, 512, 820, 937, 936, 960, 513, 813, 743, 679 and 766; in Hlabisa - 726, 528, 946, 325, 523, 328, 326, 944, 526, 517, 945, 519, 746, 744, 323, 669, 967, 963, 962 and 788; and in Nongoma - 754.

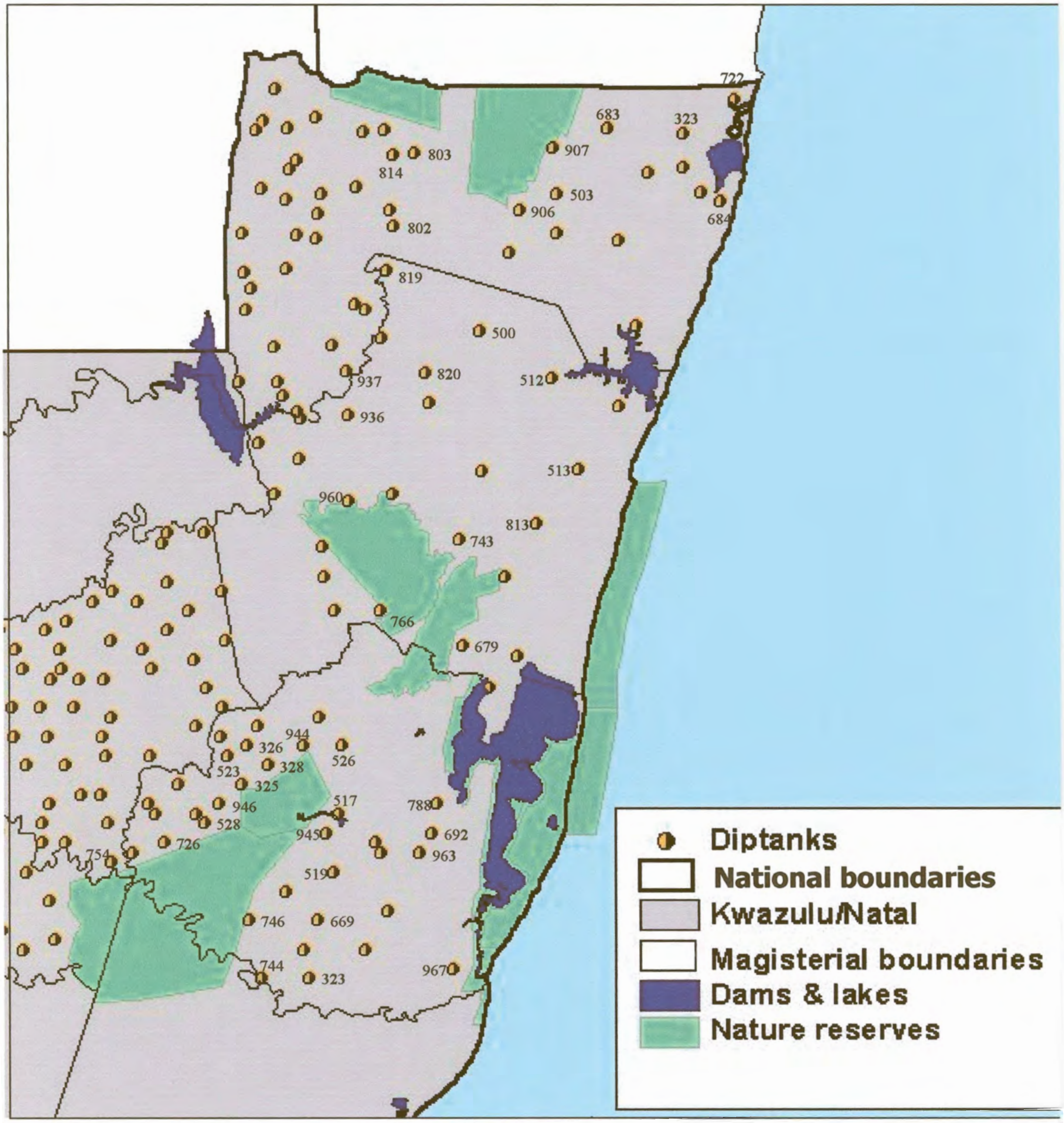

Fig. 7.6 Diptank positions in magisterial districts of Ingwavuma, Ubombo, Hlabisa, Nongoma and Mhlabathini indicating the distribution of cattle of communal farmers (diptank areas positive for tsetse during surveys are numbered)

7.3.5 Trypanosomosis distribution and prevalence

In 1990 trypanosomosis was diagnosed in cattle served by diptanks close to Hluhluwe-Umfolozi Game Reserve (Bagnall 1993). These were infected with both *Trypanosoma congolense* and *T. vivax*. A survey of infection in cattle was started in May 1990, making use of thick and thin blood smears from cattle showing signs of chronic trypanosomosis, to determine the extent of the outbreak. By the end of 1992, infection was found at 61 out of 132 diptank areas between the Mfolozi River and the Mozambique border (Carter 1993; 1994; Bagnall 1993) and 16 additional diptank areas of infection were confirmed by 1994 (R.F. Carter, unpublished information, 1998). Fig. 7.7 is a summary of trypanosome infected areas based on Carter's (1993, 1994) results of positive and negative diptank areas. The areas endemic for trypanosomosis extended from Mozambique in the north to the Mfolozi River in the south, including the low lying areas in Ingwavuma, Ubombo and Hlabisa districts as well as those areas adjacent to the Hluhluwe-Umfolozi Game Reserve in the Mahlabathini and Nongoma districts. This map also highlights the fact, as mentioned under 7.4.2, that cattle are uniformly distributed around diptanks except in game reserves and forest areas (where grazing is prohibited).

Fifty-nine diptank areas were again surveyed in 1994 (Bagnall 1994). The geographical prevalence of *Trypanosoma* spp. as determined by Ag-ELISA and BCT (Buffy Coat Technique) is summarized in Fig. 7.8 (from De Waal *et al.* 1998). According to BCT results the highest trypanosomosis prevalence (10 - 15 % and > 15 %) was in the Ubombo district. Medium prevalence (4 - 10 %) was indicated in the Ingwavuma District south of the Ndumu Game Reserve, east of the Pongola River and in the southern parts of Ubombo. Low (0 - 2 % and 2 - 4 %) to zero prevalence occurred in areas surrounding the Hluhluwe-Umfolozi Game Reserve (Hlabisa and Nongoma districts) and also west of the Pongola River (Ingwavuma district). The estimated prevalence of trypanosomosis as determined by Ag-ELISA (Fig. 7.8) indicated generally higher prevalence in all areas, with Ingwavuma and Ubombo Districts being the highest.

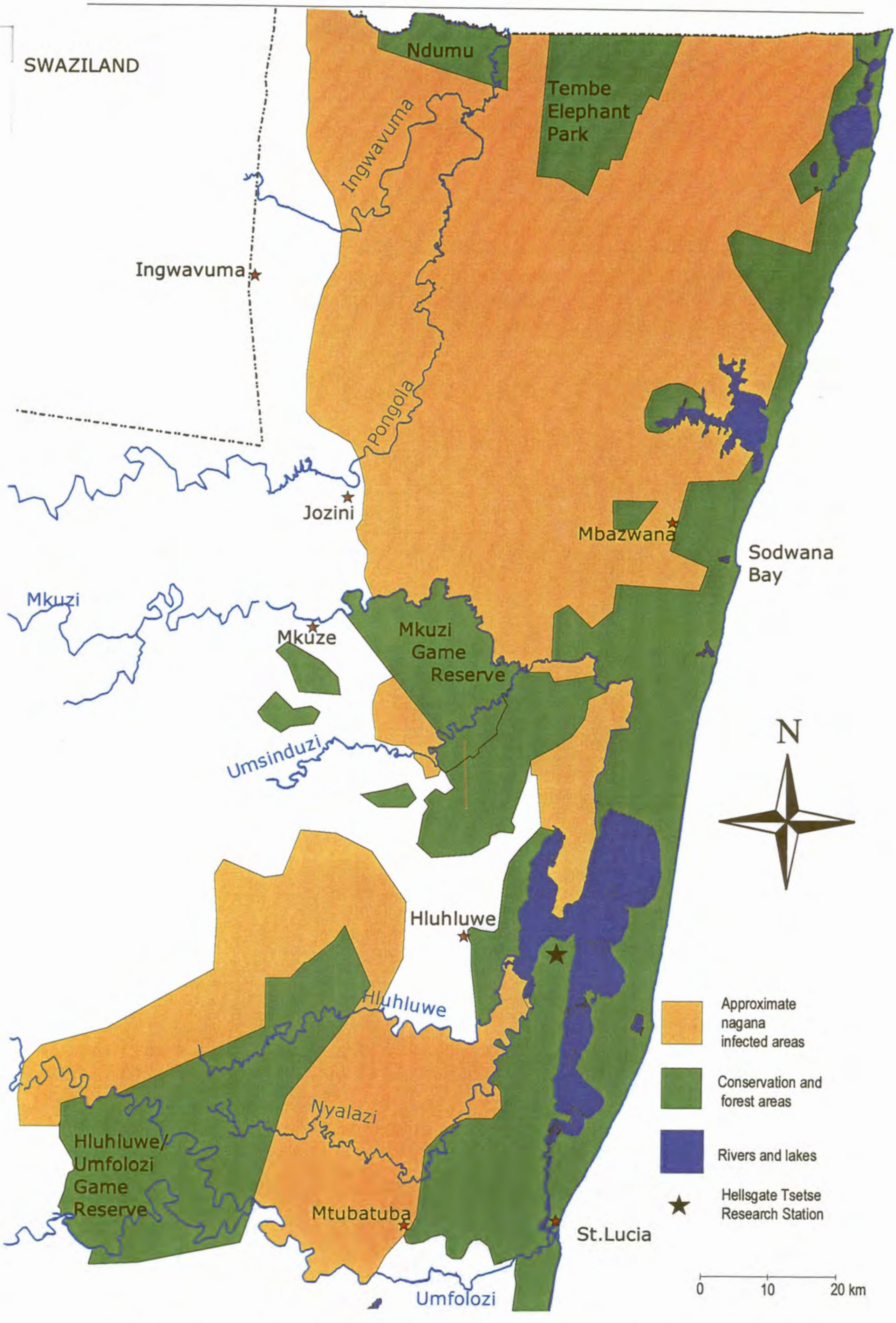

Fig. 7.7 Approximate distribution of cattle affected by trypanosomosis during 1990 - 1992 in N.E. KwaZulu-Natal (drawn from results from Carter 1993, 1994)

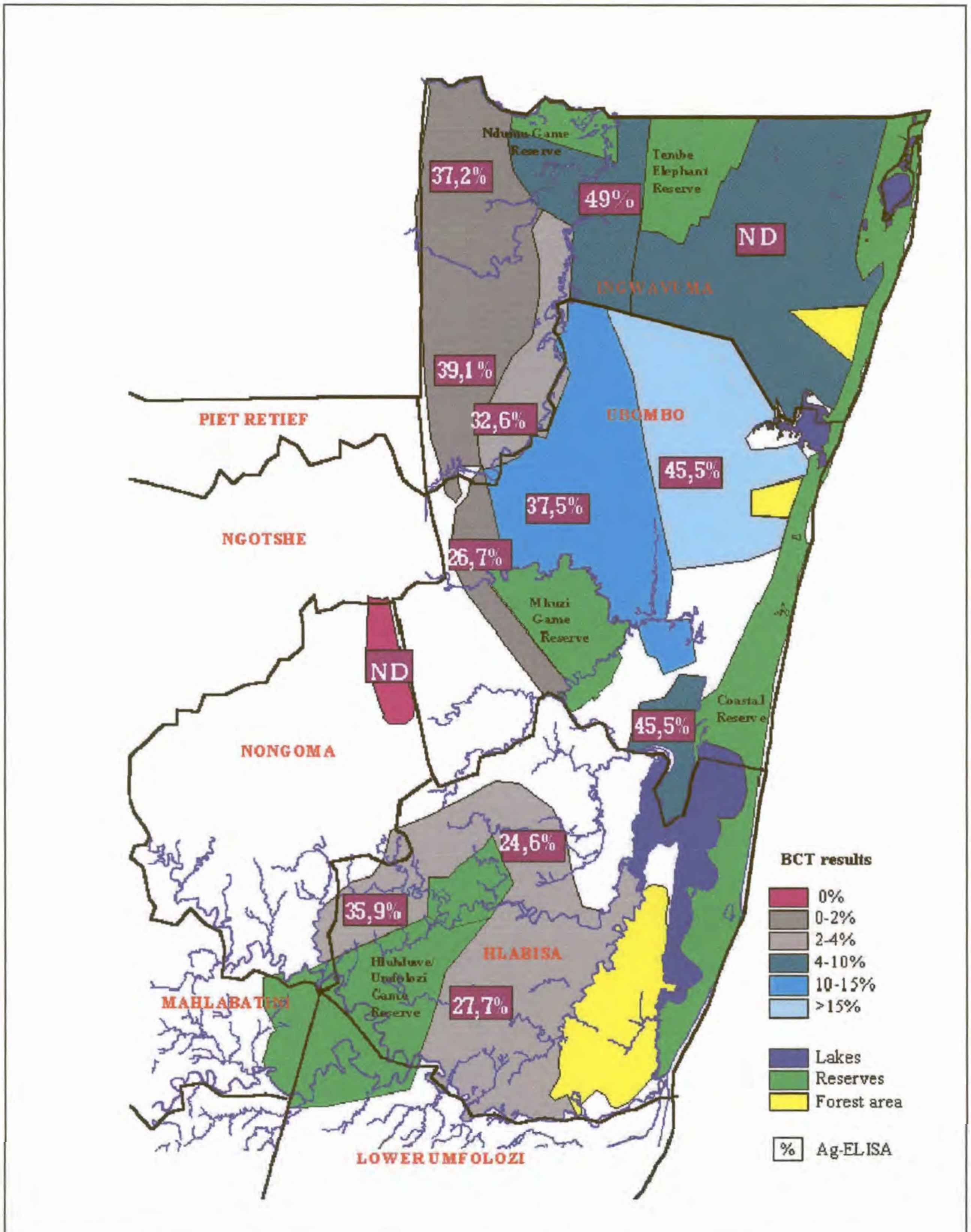

Fig. 7.8 Prevalence of trypanosomosis in N.E. KwaZulu-Natal as determined by BCT and Ag-ELISA (from De Waal *et al.* 1998)

However, according to De Waal *et al.* (1998), the estimated prevalence obtained with Ag-ELISA appeared to be much higher than expected and did not reflect the clinical position on the ground.

7.3.6 Landcover and vegetation type

Land use covers a range of types of data, many of which are relevant to tsetse-transmitted trypanosomosis. Furthermore, a classification of the area into different vegetation types is of importance particularly in determining the habitat suitability for tsetse. Datasets on landcover (Fairbanks & Thompson 1996; Fairbanks *et al.* 2000) and vegetation types (Low & Rebelo 1996) were obtained from ARC-ISCW (Agricultural Research Council – Institute for Soil, Climate and Water). Fig. 7.9 shows the landcover data for the region. Vegetation types are indicated in Fig. 7.10.

According to the landcover map (Fig. 7.9) the tsetse infested area consists mainly of thicket and bushland, and forest and woodland with patches of forest, sandforest, degraded thicket and bushland, and degraded forest and woodland. There are also great open areas of degraded grassland and wetlands along the eastern parts, which have not yet been surveyed due to unsuitability of the habitat for tsetse flies.

The map of vegetation types (Fig. 7.10) shows the tsetse infested area to contain mainly coastal bushveld/grassland with patches of sand forest, bordered by subhumid lowveld bushveld and Natal lowveld bushveld (Low & Rebelo 1996).

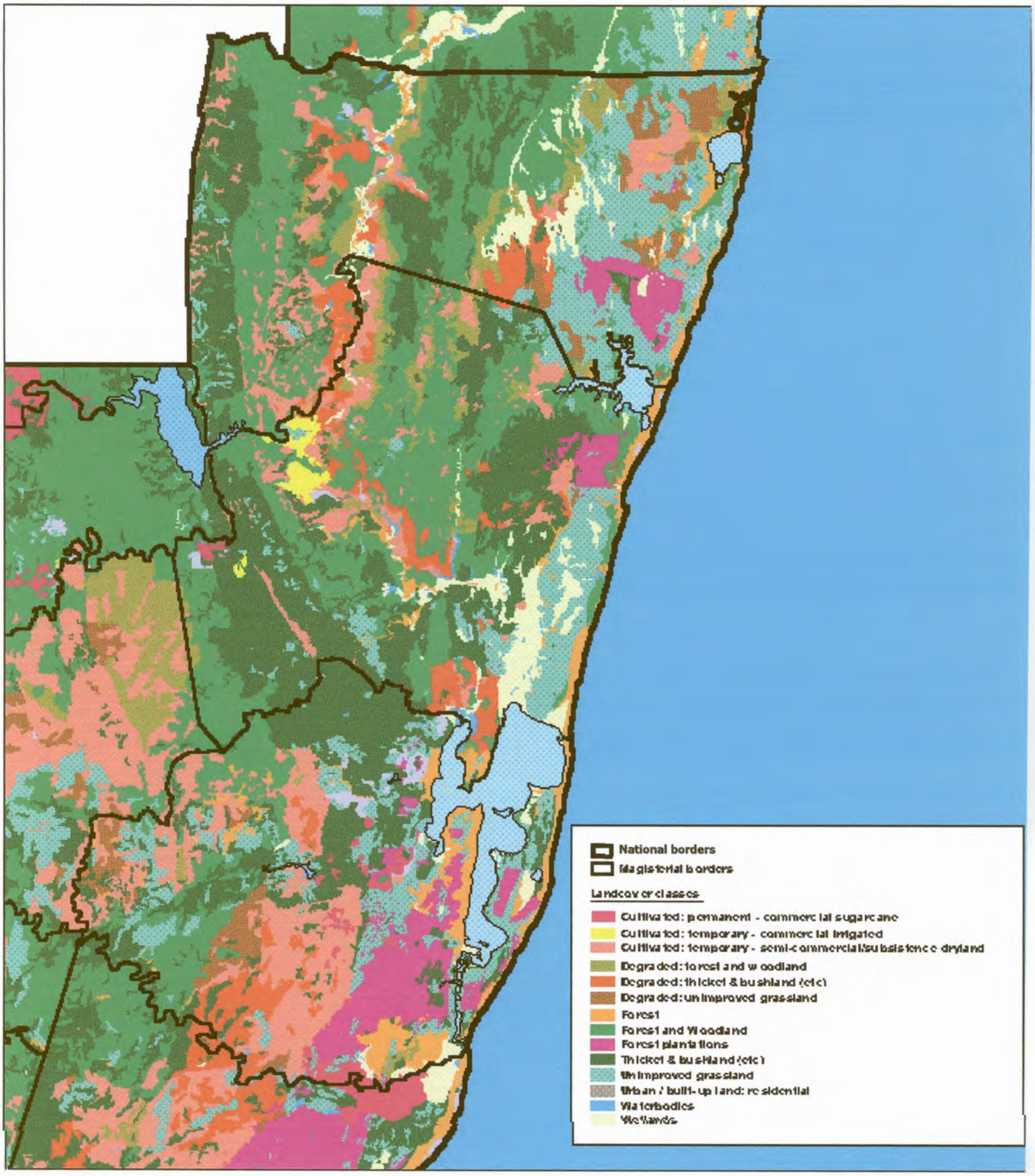

Fig. 7.9 Landcover map (Fairbanks & Thompson 1996; Fairbanks *et al.* 2000 – ArcView data from ARC-ISCW)

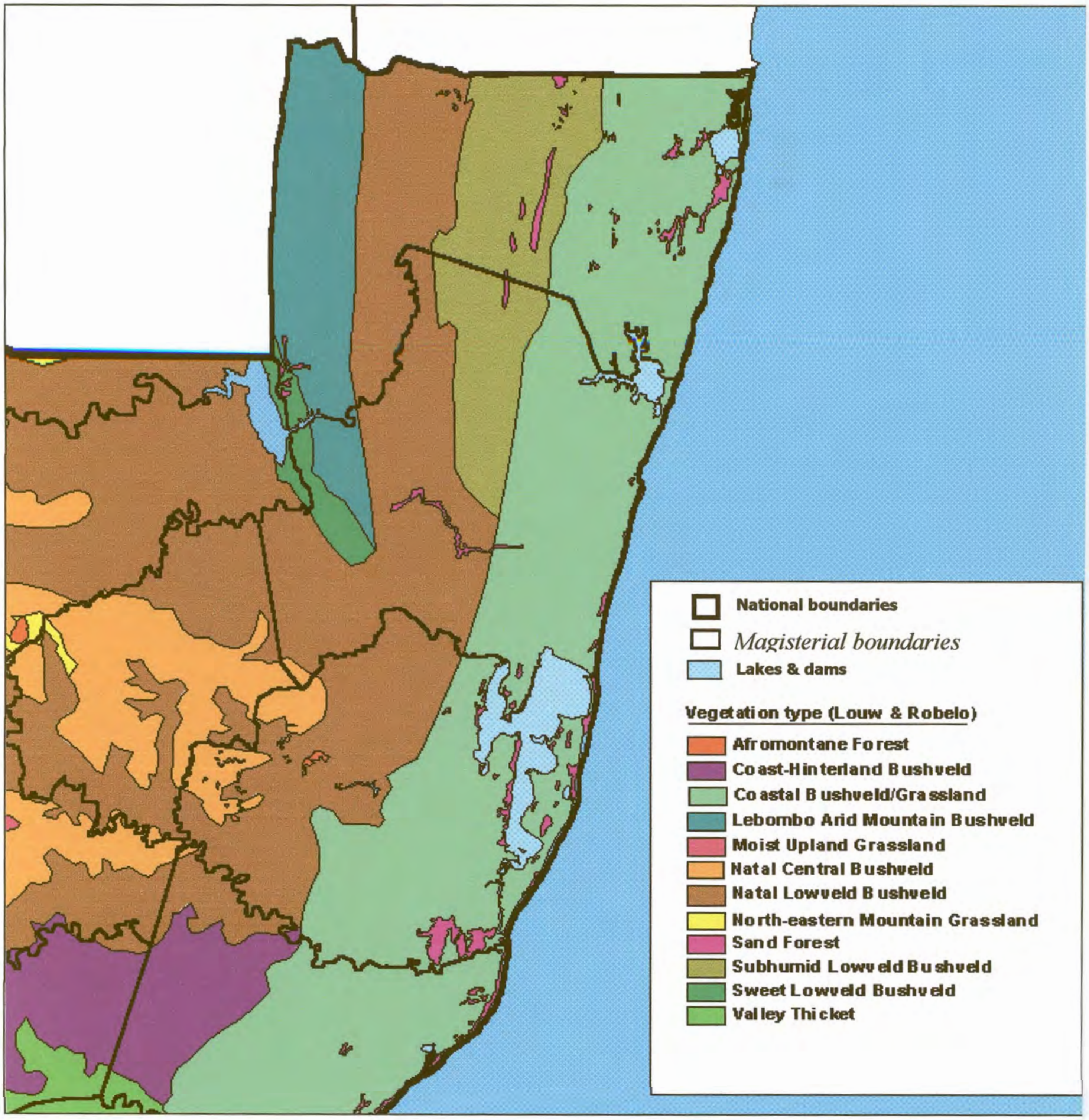

Fig. 7.10 Vegetation type map (Low & Rebelo 1996) (data from ARC-ISCW)

7.3.7 Land designation and tenure

In managing the intervention of tsetse-transmitted trypanosomosis it is essential to have accurate and updated information on land designation and tenure. This will distinguish for example areas classified as Game Reserves and other game or conservation management areas, state forests, commercial plantations, commercial farming areas and communal farming areas. Fig. 7.7 indicates areas designated as game and nature conservation areas as well as forest plantations in the region of concern. Forest areas and/or commercial plantations are also indicated in Fig. 7.9. Communal farming areas occur in all areas surrounding the diptanks shown in Fig. 7.6. It has not been possible to obtain precise data covering commercial cattle farm boundaries and these are therefore not indicated in any of the Figures. They are, however, mostly situated in areas between the west of False Bay Park (i.e. around Hluhluwe village) and surrounding the southern parts of Phinda Resource Reserve (see areas around Hluhluwe village, which form gaps (indicated white) between the nagana infected communal areas shown in Fig. 7.7)

7.5 DISCUSSION

7.5.1 Comparison of past and present distributions of *G. brevipalpis* and *G. austeni*

The historical survey by Du Toit (1954) (Fig. 7.1) showed the presence of *G. brevipalpis* to be mainly in and around the Ndumu Game Reserve and along the Pongola River in the north. In the south it occurred in the Hluhluwe-Umfolozi Game Reserve and its surroundings with a finger-like extension to the north and following the Hluhluwe River to the east. Du Toit (1956) also indicated *G. brevipalpis* in areas around Lake St. Lucia in a later survey. *G. austeni* was more widely distributed and was present in areas surrounding Lake Sibayi on the coast and in a low-lying belt *c.* 145 km long reaching from the Mozambique border in the north to about the Nyalazi River in the south, with a width ranging from *c.* 15 - 54 km inland from the coast.

The present survey results (Fig. 7.3) showed that there are two distinct bands of occurrence for *G. brevipalpis* and that *G. austeni* is more widely distributed, as was also the case in Du Toit's survey (Fig. 7.1). Certain changes in land use and development have occurred during the past fifty years. This is clearly illustrated by the differences of historical and present distribution maps. Possible reasons for the changes in distribution are discussed below.

North

Starting from the north, the present survey results indicated that *G. austeni* was present at both Ndumu Game Reserve and Tembe Elephant Park (in apparent densities < 5 flies/trap/day (Fig. 7.5)) while *G. brevipalpis* was only present in Ndumu (in apparent densities < 5 flies/trap/day (Fig. 7.4))[1]. For the past 19 years *G. brevipalpis* has not been seen in Tembe (E.M. Nevill & G.J. Venter, unpublished report 1994). Nevill and Venter theorized the reason for this as follows: Ndumu is bounded in the north by the Usuthu River. The Pongola River passes through the eastern part of Ndumu. Planned flooding, through releases from the Jozini Dam leads to inundation of the flood plain and filling of pans, which abound with animal life such as nyala and impala. In the large pans hippos are also abundant. A human-inhabited corridor, approximately 5 km wide, separates Tembe from Ndumu. Tembe is predominantly sandy except for the Muzi swamp in the east. The swamp is covered with reeds and has only the occasional open area of water. This is the only part of Tembe that has permanent natural surface water. There had been a marked difference in the types and numbers of animals seen at Tembe during the survey as opposed to those seen at Ndumu. Red and grey duiker and suni were very common in Tembe, while very few Nyala were seen. The impression they obtained is that at Tembe *G. austeni* would flourish since it prefers to feed on small antelope (Moloo 1993). However, *G. brevipalpis*, a stronger flier, would have to search far and wide at Tembe in order to find the same large animals on which it prefers to feed (Moloo 1993) and probably feeds on at Ndumu, such as nyala, hippo, etc. In Du Toit's 1946 survey (Du

[1] The low apparent densities of both species could give a wrong impression in that those surveys were conducted at the beginning of the warm season (Oct. 1994) before any rains had yet fallen when apparent densities are still relatively low. Densities could in reality be expected to be as high as in other game reserves.

Toit 1954) *G. austeni* was also shown to be present in the Tembe area, although only in the northwestern corner, and in the eastern parts of Ndumu. *G. brevipalpis* was only found in and around Ndumu and along the Pongola valley. In this area no profound changes have occurred in their distribution over the last fifty years, except that *G. austeni* is nowadays more widely distributed in Tembe, which had not yet been established at the time of Du Toit's survey. The factors that govern tsetse distribution must therefore be very basic and constant.

Surveys in the communal and diptank areas of the Ingwavuma district in the north indicated no tsetse to be present along the Ingwavuma River, except for one positive site between the Ingwavuma and Pongola Rivers just south of Ndumu Game Reserve. This supports du Toit's (1954) negative survey results of 1954 along this river. The area between the Ingwavuma River and Ndumu Game Reserve, which was positive for *G. brevipalpis* in 1946, was not surveyed. However, Fig. 7.9 indicates patches of semi-commercial/subsistence dryland, which would be unsuitable for tsetse. No *G. brevipalpis* were found along the Pongola River outside the Ndumu Game Reserve. However, in 1946 *G. brevipalpis* occurred in a narrow band along the river (Du Toit 1954). The area had at some stage in the past been deforested for cultivation and grazing (see Fig. 7.9 – degraded forest and woodland). The area immediately bordering the Pongola River is at present being cultivated (see Fig. 7.9 – semi-commercial/subsistence dryland). It would seem that the permanent breeding of this species could no longer take place along the river but it is possible that there is a southerly movement from Ndumu Game Reserve, at least for a short distance which extends eastwards to the southwestern corner of Tembe where this species was found. No *G. brevipalpis* were captured further to the west of the Pongola River, mainly due to lack of suitable habitat (degraded forest and woodland) as is presented in Fig. 7.9. *G. brevipalpis* was present in the area between Tembe and Ponto de Ouro border post and Kosi Bay with highest numbers at Kosi Bay (apparent density between 5 - 10 – Fig. 7.4). No tsetse were indicated on du Toit's (1954) map in this area (Fig. 7.1), but it may be that this area was not surveyed by him.

G. austeni was also found along the Pongola River just south of Ndumu Game Reserve but not further southward as was indicated by Du Toit (1954). The present survey suggests that the southern section of the Pongola River is no longer suitable for either tsetse species possibly due to population growth accompanied by deforestation and cultivation (see Fig. 7.9). During the 1946 survey by Du Toit (1954), the Pongola River formed the western boundary for *G. austeni* and for some reason it did not (and still does not) occur west of the river. *G. austeni* was also found west and east of Tembe at very low densities (< 2 flies/trap/day – Fig. 7.5), whereas no *G. austeni* were indicated east of Tembe on du Toit's (1954) map (Fig. 7.1). It is possible that Du Toit's surveys did not extend as far east.

Central

Du Toit (1954) indicated that *G. brevipalpis* was absent from Lake Sibayi and its surrounds but that *G. austeni* was present in a narrow strip around the lake and in a 5 km-wide coastal strip from Lake Sibayi southwards as far as Lake Bhangazi North (indicated in Fig. 7.1). It is not known, however, if Du Toit's survey extended any further. However, the area further south currently consists of unimproved grassland and wetland (see Fig. 7.9), which was probably also the case at that time. The present results of the survey in the Lake Sibayi/Sodwana Bay area concluded that no tsetse flies were present in this area. Moloo (1993) summarized all known results of tsetse blood-meal identifications made to date. The apparent favoured hosts of *G. brevipalpis* are bushpig (42,5 %), hippo (30,0 %), buffalo (8,4 %), bushbuck (6,3 %) and elephant (2,1 %) and of *G. austeni*, bushpig (46,6 %), cattle (14,5 %), duiker (7,1 %) and humans (4,9 %). With these facts as a guide one can theorize that the presence or absence of these tsetse species could largely be affected by the presence and abundance of their apparent hosts. It is accepted by many of the people consulted that there has been heavy poaching resulting in no wild animals nor signs of animals seen in the plantations nor in the indigenous bush around Lake Sibayi. Except for a narrow strip along the eastern shore of the lake where no cattle were seen, cattle were, however, common in the plantations, especially grazing along fire-breaks, so would be a possible blood-meal source. This is supported by the high numbers of *Stomoxys* spp. present on the sticky traps. The apparent absence of tsetse from this specific area, which had been surveyed twice (June 1995 and again in April 1998) could therefore be due to lack of sufficient hosts or the failure of the survey system to reveal low tsetse numbers.

The survey in the communal farming and diptank areas of the Makhathini Flats, which lie west of Lake Sibayi indicated that *G. austeni* are widespread although in low densities (Fig. 7.5) and eight of 43 diptank areas were found positive. No *G. brevipalpis* were found here as was also reflected by Du Toit (1954) (Fig. 7.1).

The present distribution of *G. austeni* in the central area (Ubombo District) agrees to a great degree with du Toit's (1954) distribution. No *G. brevipalpis* were found in these areas even though traps were set along rivers where it could be expected to occur (nor west of the Lebombo). Du Toit (Fig. 7.1) also reflected the absence of *G. brevipalpis* in these areas.

South

Around Lake St. Lucia *G. brevipalpis* was found as far north as northern False Bay Park, as far south as St. Lucia as well as on the Eastern Shores of the lake. Highest apparent densities were found here (with highest density of 24 flies/trap/day in an old established pine plantation (indicated in Fig. 7.9)). *G. austeni* was also found around Lake St. Lucia in relatively high numbers (highest apparent densities at False Bay Park and Nyalazi River – Fig. 7.5). However, although vegetation and presence of hosts were suitable, this species was not collected on the Eastern Shores. They were also absent west of St. Lucia where cattle had been dipped in pyrethroids. Du Toit's (1954) survey only indicated *G. austeni* in the False Bay area (Fig. 7.1). However, *G. brevipalpis* was also found during a later survey (Du Toit 1956) in False Bay and also other areas surrounding Lake St. Lucia (i.e. on Eastern Shores, Nibela Peninsula, Ndlozi Peninsula and Western Shores). Without proper knowledge of landcover for those years, it is not possible to make comparisons for the whole of the area. The reason for the absence of *G. austeni* from Eastern Shores should ideally be determined as this could throw light on its dispersal and reinvasion behaviour. Conversely the reasons for the large population of *G. brevipalpis* on Eastern Shores (Fig. 7.4) could provide clues as to why this species occurs in some areas of N.E. KwaZulu-Natal and not in others.

On one particular farm (Boomerang – 28°14'00"S 32°18'15"E) located east of Charter's Creek (Lake St. Lucia), which was surveyed on two occasions (Dec. 1993 and Apr. 1995), no tsetse and very few biting flies were captured even though the traps were set in what appeared to be "ideal" indigenous bush and tsetse had been captured immediately south and north of this farm. The reason for the absence of tsetse and biting flies appeared to be the regular treatment of 300 cattle on this farm with a 1 % deltamethrin pour-on. The cattle are allowed to graze all over the farm so would serve to attract and kill any tsetse flies which might be present. However, for two successive years (both during March) the farmer had outbreaks of nagana on his farm (five of 20 cattle bled were positive for trypanosomes). In May 2000 ten H traps were deployed for 14 days. The traps captured both *G. brevipalpis* (3 females and 2 males) and *G. austeni* (4 females) for the first time (J.R. Esterhuizen, pers. comm., 2000). Many of the other negative catches obtained during surveys with the XT could, therefore, have been false negatives. It may also be that the H trap, due to its better performance (as was discussed in Chapter 4), would have been a better survey tool than the XT. However, its development was only completed in 1998 and it was decided to use the same sampling method throughout the surveys for suitable comparison of apparent fly densities.

Only *G. brevipalpis* were collected in the Hluhluwe-Umfolozi Game Reserve. Despite traps being set in suitable *G. austeni* habitat in these areas no *G. austeni* were collected (Figs. 7.3 & 7.5). The southernmost distribution of *G. brevipalpis* in the reserve could not be established due to lack of roads. Du Toit (1954) also recorded only *G. brevipalpis* in this area (Fig. 7.1). Aerial smoking with DDT and HCH, which eradicated *G. pallidipes* from Zululand, also eradicated *G. brevipalpis* from Hluhluwe-Umfolozi Game Reserve. However, according to Hargrove (2000) a treated area of 10,000 km^2, which is subjected to reinvasion from all sides, could be invaded and tsetse populations can recover within two years. Reinvasion of *G. brevipalpis* must, therefore, have occurred from outside the reserve and the large numbers of hosts present as well as suitable breeding grounds encouraged the current stable population in this reserve.

The surveys in the communal farming and diptank areas of the Hluhluwe State Veterinary Area, surrounding the game reserve, revealed that *G. brevipalpis* was widespread with 21 of the 34 diptank areas being positive. Although the apparent density of this species was relatively low in certain areas (Fig. 7.4), it could still be suggested that local breeding and/or invasion from nearby game reserves constantly takes place.

7.5.2 Southernmost limit

Neither species was collected south of the Mfolozi River (except at Mapelane). The southern-limit survey has shown that the present surveying system, designed to determine the broad distribution limits of each tsetse species, is too coarse to determine actual limits (even if these were static). Using more traps placed for much longer and also using the better H trap with more artificial odour would obtain finer results, as was discussed earlier, but this may still not be sufficiently intensive. The limit of transmission in these marginal areas will have to be determined by sentinel cattle. Until finer data are obtained the southernmost limit of tsetse distribution in South Africa, and therefore Africa, could roughly be regarded as the southernmost extent of the Mfolozi River.

7.5.3 Distribution in association with cattle distribution

According to the survey results, tsetse are more plentiful in game reserves and seem to be positively associated with the presence of game. However, they were also present in surrounding communal farming areas, where 42 diptank localities (Fig. 7.6) were found positive with tsetse during the surveys. Although communal areas are often deforested, there are usually trees along the rivers and drainage lines. These won't be indicated on vegetation or landcover maps (Figs. 7.9 & 7.10) but *G. brevipalpis* and *G. austeni* were caught in such situations. Furthermore, shortage of sufficient grazing in communal areas places pressure on cattle so that they are forced into forested areas in their search for grazing and they also graze right up to the fences of the game reserves. In total 350,000 cattle are at risk of contracting nagana.

In the past (prior to 1992) the cattle-dipping regime in Zululand consisted of 2-weekly dipping of cattle in Amitraz [Triatix® - Hoechst Roussel Vet. (Pty) Ltd.], a tick-detaching agent, which does not kill flies. This programme was interrupted for two years (1992-1993) by dipping cattle in a pyrethroid cyhalothrin [Grenade® - Hoechst Roussel Vet. (Pty) Ltd.] during an attempt to control tsetse flies during an outbreak of nagana (Kappmeier *et al.* 1998). Since then diptanks reverted to Amitraz so as to prevent the development of tick resistance to pyrethroids. Currently, the state provides Amitraz for dipping once a month (R.J. Bagnall & M. Nel, pers. comm., 2001), which, however, will not be of any use for the control of tsetse. Novartis SA (Pty) Ltd. provides Ektoban®, a pyrethroid (cypermethrin) and cymiazol combination dip, for sale to the community to use as a handspray (M. Nel, pers. comm., 2001).

The surveys in the communal farming areas of Jozini State Veterinary Area (magisterial districts of Ubombo and Ingwavuma) revealed that *G. austeni* was more widespread than *G. brevipalpis*. Since *G. austeni* doesn't fly far, is restricted to dense bush and appears, in these areas, to feed mainly on cattle, control of *G. austeni* by treating cattle with pyrethroids should have a profound effect on nagana transmission and could lead to eradication of the fly. However, the success of control by means of mobile targets (insecticide-treated livestock) depends upon a sufficient proportion of the livestock population treated, and a sufficiently low level of reinfestation (Leak 1999). Chances of reinvasion from untreated areas are high in the Zululand situation, since the adjacent Game Reserves have high populations of flies (Fig. 7.4 & 7.5).

7.5.4 Distribution in association with trypanosomosis prevalence

By comparing the distribution of the two tsetse species (Fig. 7.3) to the distribution of nagana (Figs. 7.7 & 7.8) it is clear that the cause of nagana in the Mkuzi area (Ubombo District) is *G. austeni* and not *G. brevipalpis*, as the latter species does not occur in this area while the areas surrounding

Hluhluwe-Umfolozi Game Reserve are infested with *G. brevipalpis*. The high prevalence of trypanosomosis (10 - 15 % and >15 % - as determined by BCT) (Fig. 7.8) in the Ubombo district is associated with *G. austeni* while very low prevalence (2 - 4 %) occurs in the *G. brevipalpis* areas around Hluhluwe-Umfolozi Game Reserve. The prevalence of *Trypanosoma* spp. as determined by Ag-ELISA (Fig. 7.8) was higher in areas where *G. austeni* occurs but is also quite high in the surrounding areas of Hluhluwe-Umfolozi where *G. brevipalpis* was found. De Waal *et al.* (1998) estimated the prevalence obtained with Ag-ELISA to be much higher than expected and that it did not reflect the clinical position on the ground. They discussed shortcomings of the Ag-ELISA test.

7.5.5 Distribution in association with land designation, landcover and vegetation

The presence/absence of flies in relation to land designation (i.e. game reserves, plantations, communal farming areas, etc.), landcover and vegetation types has already been mentioned. From the surveys it was clear that the presence of tsetse appeared to be mostly associated with forests, forests and woodland, forest plantations, thickets and bushland, while fly absence in this survey could be associated with unimproved grassveld, degraded forests and woodland, subsistence dryland and wetland areas (Low & Rebelo 1996).

A large area of the southern part of the affected area of N.E. KwaZulu-Natal is under pine and eucalypt plantations. Both tsetse species have been trapped in both types of plantation and, in fact, the highest number of *G. brevipalpis* (144) ever collected on one trap was in an isolated 35 year-old pine plantation on Eastern Shores of Lake St. Lucia. Many of these flies were also teneral. There is, therefore, a strong indication that at least *G. brevipalpis* can breed in such an established plantation where there are suitable hosts. This was not previously certain.

7.5.6 Other flies

Much effort has been spent estimating the number of other flies attracted to and captured on the sticky traps used in the surveys. They were all identified to family, subfamily or genus level, but are not reported on in this study. Analysing total biting fly catches has the following value: There is an ongoing debate as to whether other biting flies play a role in the mechanical transmission of nagana (Jordan 1986; Leak 1999). The survey shows that if this is so then the most likely mechanical transmitters would be the Stomoxyinae and Tabanidae and that these flies are found in the bush where cattle feed. Stomoxyine biting flies are extremely common in plantations and some bush situations. Both sexes of *Stomoxys* and *Glossina* spp. survive solely on blood (Lancaster & Meisch 1986) and females must feed even more often to produce their eggs. Therefore, the presence of large numbers of *Stomoxys* spp. is an indicator that sufficient blood is available to support the survival of tsetse flies and that if tsetse flies are not caught it is not due to a shortage of hosts. *Stomoxys* and *Glossina* spp., however, differ in other respects. For example *Stomoxys* may breed in rotting vegetation, sometimes cow dung, and does not like densely shaded situations. The two tsetse species, however, require densely shaded areas in which to breed and are very selective as to the sites where they will deposit their larvae. Stable flies are, therefore, prime candidates for the mechanical transmission of trypanosomes. They should not be overlooked in a study of the epidemiology of trypanosomosis. The experience in Zanzibar, however, indicated that despite the presence of a widespread *Stomoxys* fly population on the island at high densities (up to 1000 flies/trap/day in certain areas), these stable flies failed to sustain a trypanosome prevalence in domestic livestock in the absence of tsetse flies (Saleh *et al*. 2001).

7.5.7 Shortcomings

There are certain variables and shortcomings that make it impossible to draw absolute conclusions on the distribution results.

- The surveys were conducted over several years and over several months each year so that direct comparison regarding the apparent density results is not possible.
- Trap catches that were negative do not necessarily reflect total fly absence (and could be false negatives) as the trapping system might have been too coarse. Better results may have been obtained if a trap like the H trap was available at the time. This trap could also have been baited with a better odour (best SA odour – see Chapter 2.2.2), which was also not available at the time.
- The same persons did not carry out the surveys each time, so that the selection of optimal trap sites would have been inconstant.
- The period over which the traps were set could have been insufficient, especially where populations were very low.
- The lack of roads in many of the areas left large areas unsurveyed.

7.5.8 Implications/Future use of GIS

The present results of the surveys, i.e. positive/negative sites (Fig. 7.3), are incomplete descriptions of fly distribution in terms of fly presence vs. zero catches. For example flies may be present in some areas but have not yet been caught (i.e. false negative sites) or the region may contain areas suitable for, but are presently uninhabited by flies. Therefore, the present results may be inaccurate especially where zero catches are indicated. Furthermore some areas that have not yet been surveyed include the eastern coastal area between Lake Bhangazi North (situated about halfway between Lakes Sibayi and St. Lucia) and Lake Bhangazi South; from Kosi Bay to Lake Sibayi; and commercial farming areas to the west of the Lebombo Mountains between Mkuzi River and approximately the Ncemane River, especially the river valleys. However, these are relatively small areas. The use of GIS and remote sensing to define tsetse distributions and update distribution maps in the Zululand area will be of enormous value. Remote sensing can also be used to predict the levels of abundance of the two species.

In the last few years several attempts have been made to improve tsetse distribution and abundance maps using relationships between historical map data and recent satellite imagery (Rogers & Randolph 1993; Rogers *et al.* 1996; Robinson *et al.* 1997a, 1997b) as well as present satellite and fly data (Hendrickx *et al.* 1993; Rogers *et al.* 1994; Hendrickx 1999, cited in Hendrickx *et al.* 2000). Various studies and application of GIS technology defining the epidemiological and related aspects of trypanosomosis have been published. For example, the use of remote sensing technology to better understand the natural habitat and epidemiology of tsetse and to explain or predict tsetse and disease distribution in East, West and Southern Africa was described (Rogers & Randolph 1985, 1991; Rogers 1991; Rogers & Williams 1993; Rogers *et al.* 1994; Rogers *et al.* 1996; Robinson *et al.* 1997a, 1997b; Rogers 1998). For West Africa the use of GIS and remote sensing was used as a decision and management tool for trypanosomosis control (Hendrickx 1998, cited in Erkelens *et al.* 2000). Focusing on smaller scale areas, GIS and remote sensing was used to study the effects of tsetse fly presence and control methods on land-use, environmental change and biodiversity, (Reid *et al.* 1997; Reid *et al.* 1999; Bourn *et al.* 2001) and also to select priority areas for tsetse control (Robinson 1998a; Erkelens *et al.* 2000).

In order to improve the present maps on the distribution and abundance of *G. brevipalpis* and *G. austeni*, we need to increase our understanding of why the two species are distributed in the way they are, and to produce empirical models that enable prediction on the likely distribution of these two species. When working with *G. brevipalpis* and *G. austeni* the over-riding question is: "Why do the two species sometimes occur in the same area and sometimes not?" Correlation with climate and other predictor variables can in future assist in answering this question and in predicting distribution and abundance of the two species in N.E. KwaZulu-Natal.

The principal factors that influence tsetse population development are climate, vegetation cover (which provides shade for tsetse) and host availability (Robinson *et al.* 1997a). Tsetse flies are particularly sensitive to temperature, rainfall and saturation deficit (Rogers & Randolph 1991). Other predictor variables may include atmospheric moisture, heavy rainfall and interactions with hosts (Rogers *et al.* 1994). Information on each of these factors may be gathered together with GIS to facilitate further analysis. Computerized maps of climate variables such as rainfall, temperature and saturation deficit can be generated by ground-based measurements (Hutchinson 1989, cited in Robinson *et al.* 1997a). Modern satellites produce data that can be analyzed to reveal the ecological condition of the lands they pass over (Brady 1991). Especially useful is the Normalized Difference Vegetation Index (NDVI), which, in effect, indicates the level of photosynthetic activity in plants (Tucker & Sellers 1986, cited in Rogers *et al.* 1994), and thus the vegetation cover. Channel 1 and 2 data of the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanographic and Atmospheric Administration (NOAA) meteorological satellites, which circle the polar orbit, are used to produce NDVIs related to the intercepted photosynthetically active radiation (IPAR) and vegetation type on continental scales (Rogers *et al* .1994). Satellite data have also been shown to act as surrogates for a number of meteorological variables. From NDVIs can be inferred functions of moisture, such as soil moisture (Narasimha Rao *et al.* 1993, cited in Baylis *et al.* 1999), saturation deficit (Rogers & Randolph 1991; Rogers *et al.* 1994) and recent levels of rainfall (Rogers & Randolph 1991; Schultz & Halpert 1993, cited in Baylis *et al.* 1999). Rainfall has also been correlated with cloud-top temperatures and cold-cloud duration (CCD) from METEOSAT data. It was shown that the abundance of clouds with cloud-top temperatures of between -30 °C and -60 °C or less is correlated with rainfall at ground level (Rogers *et al.* 1994).

The ground-collected tsetse distribution data of N.E. KwaZulu-Natal can now be complemented with information derived from remote sensing satellites (e.g. high-resolution satellite data) to make increasingly accurate predictions in areas where ground data are sparse or absent. Once data have been incorporated into a GIS, extensive multivariate analyses will have to be carried out in order to produce reliable predictions. Such analysis can distinguish between sites that are suitable and unsuitable for these species. It will also provide challenging insights into the relationships between vectors, hosts, habitats and disease agents and a prediction of the importance of tsetse-transmitted diseases in the KwaZulu-Natal area.

7.5.9 Conclusion

In conclusion, the map of the distribution of the two tsetse species indicates that there are two distinct bands of distribution for *G. brevipalpis*. These are well separated and could be treated as independent distributions when planning for intervention. The surveys also indicated that the main sources of *G. brevipalpis* are the game reserves and natural areas whereas this is not necessarily the case for *G. austeni*. The latter species is more widely distributed and may be able to be satisfactorily controlled by reversion to pyrethroid dipping when the incidence of trypanosomosis warrants it. The results can be fruitfully used to indicate where resources for disease control should be directed. With such information it should be possible to plan cost effective control measures, which may improve the productivity of the livestock sector in Zululand. The completed surveys will help decide if control or eradication should be undertaken, i.e. where, for what species, in what order and with what techniques.