

Monitoring population trends of introduced rusa deer (*Cervus timorensis russa*) in New Caledonian sclerophyll forests: tests and relevance of methods for management programmes

Guillaume Roques-Rogery

A dissertation submitted in fulfilment of the requirements of the degree of Masters Technologiae in Nature Conservation, Nelson Mandela Metropolitan University, Port Elizabeth

Promotor: Dr Laurence Watson

Co-promotor: Dr Michel de Garine-Wichatitsky

Date of submission

31/01/2008

Table of contents

List of figures	iv
List of tables	vii
Abstract	ix
Acknowledgements	xi
Declaration	xii
Chapter 1: Introduction	1
1.1 Rusa deer status	1
1.2 Background to the study	3
1.3 Monitoring tools	4
Chapter 2: Study area	7
2.1 New Caledonia	7
2.2 Sclerophyll forests	9
2.3 Study sites	11
2.3.1 Beupré	12
2.3.2 Gouaro Deva	13
2.3.3 Mèpouiri	13
2.3.4 Montagnès	13
2.3.5 Pointe Maa	14
Chapter 3: Faecal pellet group surveys: determining the optimal number of plots per transect and number of transects per site	15
3.1 Introduction	15
3.2 Study site	16
3.3 Methods	16
3.4 Results	19
3.4.1 Optimal number of plots per transect	19
3.4.2 Optimal number of transects per study site	20
3.5 Discussion	21

Chapter 4:	Estimation of rusa deer density using direct and indirect census methods	23
4.1	Introduction	23
4.2	Study site	24
4.3	Methods	25
4.3.1	Direct census	25
4.3.1.1	Spotlight counts	25
4.3.1.2	Drive counts	28
4.3.2	Indirect census - faecal standing crop method	28
4.3.2.1	Faecal pellet groups per hectare	29
4.3.2.2	Decay rate of faecal pellet groups	29
4.3.2.3	Defecation rate of faecal pellet groups	29
4.3.3	Subjective ranking of rusa deer density	30
4.3.4	Statistical analysis	30
4.4	Results	30
4.4.1	Direct census	30
4.4.1.1	Spotlight counts	30
4.4.1.2	Drive counts	31
4.4.2	Indirect census - faecal standing crop method	31
4.4.2.1	Number of faecal pellet groups per hectare	31
4.4.2.2	Decay rate of faecal pellet groups	32
4.4.2.3	Defecation rate of faecal pellet groups	32
4.4.2.4	Deer density estimated from the faecal standing crop method	33
4.4.3	Subjective ranking of rusa deer density	33
4.4.4	Correlations between methods	34
4.5	Discussion	36
Chapter 5:	Evaluation of three indices to assess rusa deer trends: the faecal pellet groups index, the browsing index and the antler rubbing index	41
5.1	Introduction	41
5.2	Study site	42
5.3	Methods	42
5.3.1	Faecal pellet groups index	43

5.3.2	Browsing index	43
5.3.3	Antler rubbing index	45
5.3.4	Statistical analysis	45
5.4	Results	46
5.4.1	Faecal pellet groups index, browsing index and antler rubbing index	46
5.4.2	Correlations between methods	47
5.5	Discussion	56
Chapter 6:	Management recommendations	60
6.1	Introduction	60
6.2	Monitoring tools	60
6.3	Rusa deer management in New Caledonian sclerophyll forests	62
6.4	Participative management	63
6.5	Management procedure	65
Chapter 7:	References	66

List of figures

Figure 1.1 :	The natural range of rusa deer (<i>Cervus timorensis</i>) (1 = <i>C. t. moluccensis</i> , 2 = <i>C. t. macassaricus</i> , 3 = <i>C. t. djonga</i> , 4 = <i>C. t. florensiensis</i> , 5 = <i>C. t. timorensis</i> , 6 = <i>C. t. russa</i> ; Whitehead 1993).	1
Figure 2.1:	New Caledonia and its provinces (Institut de Recherche pour le Développement).	7
Figure 2.2:	Original and actual distribution of sclerophyll forests in New Caledonia and location of the six study sites of sclerophyll forests (Institut de Recherche pour le Développement).	10
Figure 2.3:	Mean monthly temperature and mean monthly rainfall for the Païta district in 2001 (Institut Agronomique néo-Caledonien).	12
Figure 3.2:	The influence of the number of plots per transect and of the number of transects per site on the coefficient of variation of the mean number of intact faecal pellet groups per plot per transect in Pointe Maa.	19
Figure 3.3:	The influence of the number of transects per study site on the coefficient of variation of the mean number of intact faecal pellet groups per plot per transect (for 15 plots per transect) in the six study sites.	20
Figure 4.1:	Basic measurements taken in a line transect survey (O = observer, Δ = animal, κ = angle, r = radial distance, θ = perpendicular distance; Burnham, <i>et al.</i> 1980; Buckland, <i>et al.</i> 2001).	26
Figure 4.2:	Correlation between the combined spotlight and drive count estimates and the faecal standing crop estimates for six sites of sclerophyll forest (the formulae gives no confidence interval for the indirect count).	34

Figure 4.3:	Correlation between the combined spotlight and drive count estimates and the subjective ranking of rusa deer density for six sites of sclerophyll forest (no confidence interval for Montagnès and Beaupré as they are total counts).	35
Figure 4.4:	Correlation between the faecal standing crop estimates and the subjective ranking of rusa deer density for six sites of sclerophyll forest (the formula gives no confidence interval for the faecal standing crop estimates).	35
Figure 5.1:	Correlation between the faecal pellet groups index and the browsing index for (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).	49
Figure 5.2:	Correlation between the faecal pellet groups index and the antler rubbing index for six sclerophyll forests (n = 450 plots).	50
Figure 5.3:	Correlation between the antler rubbing index and the browsing index for (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).	51
Figure 5.4:	Correlation between the combined spotlight and drive count estimates of rusa deer density and the faecal pellet groups index for six sclerophyll forests (n = 450 plots).	52
Figure 5.5:	Correlation between the combined spotlight and drive count estimates of rusa deer density and the browsing index of (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).	53
Figure 5.6:	Correlation between the combined spotlight and drive count estimates of rusa deer density and the antler rubbing index for six sclerophyll forests (n = 450 plots).	54

Figure 5.7:	Correlation between the subjective ranking of rusa deer density and the faecal pellet groups index for six sclerophyll forests (n = 450 plots).	54
Figure 5.8:	Correlation between the subjective ranking of rusa deer density and the browsing index of (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).	55
Figure 5.9:	Correlation between the subjective ranking of rusa deer density and the antler rubbing index for six sclerophyll forests (n = 450 plots).	56

List of tables

Table 4.1:	Length of transects and number of replicates for spotlight counts in each sites.	26
Table 4.2:	Rusa deer density per study site estimated from spotlight counts done during the 2005/2006 dry season (October to February).	31
Table 4.3:	Rusa deer density per study site estimated from drive counts done during the 2005/2006 dry season (October to February).	31
Table 4.4:	Total number of faecal pellet groups/ha on six sclerophyll forest sites (n = number of plots).	32
Table 4.5:	The mean decay rate of faecal pellet groups in the sclerophyll forest of Pointe Maa.	32
Table 4.6:	Mean defecation rate of captive rusa deer in Port Laguerre.	32
Table 4.7	Deer density estimated from the faecal standing crop method.	33
Table 4.8:	Subjective ranking of rusa deer density (1 = lowest deer density, 6 = highest deer density).	33
Table 4.9:	Correlations between the various methods of deer density estimation.	34
Table 4.10:	Decay rate of five deer species according to the vegetation type and/or maturity of the vegetation (from Mayle <i>et al.</i> 1999).	39

Table 4.11:	Defecation rate of eight deer species (animal weight is for an adult male).	39
Table 5.1:	Browse species recorded in the study sites (B - Beaupré; GDN - Gouaro Deva Nord; GDS - Gouaro Deva Sud; Me - Mèpouiri; Mo - Montagnès; PM - Pointe Maa) and their palatability (+++ - very palatable; ++ - palatable; + - unpalatable) (* - species relevant to one or few sites).	44
Table 5.2:	The mean number of faecal pellet groups per plot per site recorded in six sclerophyll forest sites (450 plots) (n = total number of faecal pellet groups per site).	46
Table 5.3:	The browsing index (mean and 95% confidence interval) according to the palatability status of the browse species in the six study sites (n = 450 plots).	46
Table 5.4:	The mean number of rusa deer antler rubbings per plot recorded in six sclerophyll forest sites (450 plots) (n = total number of antler rubbings per site).	47
Table 5.5:	Correlations between the faecal pellet groups index, the browsing index and antler rubbing index.	48
Table 5.6:	Correlation between indices and combined spotlight and drive count estimates of rusa deer density.	48
Table 5.7:	Correlation between the subjective ranking of rusa deer density and indices.	48

Abstract

New Caledonia, an archipelago situated in the South-West Pacific Ocean has a very high biodiversity of which many flora and fauna species are endemic, and is therefore considered as one of the world hotspots for the biodiversity conservation. Sclerophyll forests, one of the five main vegetation types occurring on the island are mainly threatened by anthropogenic activities. Rusa deer (*Cervus timorensis rusa*) were introduced into New Caledonia from Java in 1870. They have colonised all the biotopes of the main island, and represent one of the major threats to the New Caledonian sclerophyll forests. Currently, there is a lack of management tools to monitor the trends of rusa deer in New Caledonian sclerophyll forests. To test monitoring methods for use as management tools, six sclerophyll forests study sites were studied using direct census methods (*i.e.* spotlight count and drive count), indirect census methods (*i.e.* faecal standing crop method) and three indices (*i.e.* the faecal pellet groups index, the browsing index and the antler rubbing index).

The faecal pellet groups index is based on sampling pellet groups in plots along transects. To ensure reliable data collection with a coefficient of variation of the mean number of intact faecal pellet groups per plot per transect of less than 20%, my study indicated that 15 plots per transect and 20 transects per sites should be sampled in New Caledonian sclerophyll forests whereas previous studies conducted in New Zealand indicated that a minimum of 25 plots per transect and of 18 transects per site should be sampled. The advantages of reducing the number of plots per transect and of transects per site is that it reduces the expenses (*e.g.* time, finance) and the bias due to data collection (*e.g.* fatigue, boredom and visual activity) which will improve the precision of the data recorded.

Estimates of rusa deer density obtained from the census methods were not correlated ($r = -0.425$, $df = 4$, $P = 0.401$) due to my small sample size. The reliability of these estimates is questionable because of biases. Previous publications have shown that biases are difficult to avoid when using direct census methods and that it is difficult to estimate the size of animal populations with accuracy and precision. The faecal standing crop method was subjected to bias because the estimation of the decay rate and the defecation rate were unreliable. These methods were not recommended for rusa deer management in New Caledonian sclerophyll forests.

Of the three indices tested, the faecal pellet groups index and the browsing index based on unpalatable browse species were the most reliable as the confidence intervals of these two indices were small (*i.e.* from ± 0.08 to ± 0.11 for the faecal pellet groups index; from ± 0.04 to ± 0.27 for the browsing index of unpalatable browse species), and they also showed significant correlations with a subjective ranking of the rusa deer density based on expert knowledge ($r_s = 0.829$, $df = 4$, $P = 0.042$ and $r_s = 0.829$, $df = 4$, $P = 0.042$ respectively). These two indices appear to show the most promise for use as management tools, as they could reliably track local variations of rusa deer densities on the sclerophyll forests.

These two indices could be used by wildlife technicians in New Caledonia to establish management plans of rusa deer populations which rely on participative management involving the stakeholders (*e.g.* hunters, forest managers, local communities). We believe that the faecal pellet groups index and the browsing index could be useful to monitor rusa deer populations in New Caledonian sclerophyll forests, and meet conservation and hunting objectives of the local population and authorities. Management tools such as culling and hunting operations will be implemented in New Caledonian sclerophyll forests where monitoring of indices I recommended show an increase in the deer population. Stakeholders will be involved in the implementation of the monitoring tools (*i.e.* indices) and of the management tools (*e.g.* culling and hunting operations, fencing) but also in decision making for the management of the rusa deer in New Caledonian sclerophyll forests.

Acknowledgements

I would like to acknowledge the research assistance and the patience that my supervisor Doctor Laurence Watson and my co-supervisor Doctor Michel de Garine-Wichatitsky gave me. I also would like to acknowledge the research assistance provided by Doctor Philippe Chardonnet, Doctor Mathieu Bourgarel, Doctor David Forsyth and Fabrice Brescia.

For the data collection, I would like to acknowledge Patrick Mercier, Sylvain Dauré, Frédéric Desmoulins, Vivien Chartendrault, Jérôme Spaggiari, Yann-Eric Boyeau, René Guiglion, Bruno Lafage and all the people from New Caledonia that helped me such as my guides, the owners of the properties where the studies were conducted and the villagers that let me work on their territories.

I would like to acknowledge the Institut Agronomique néo-Caledonien (IAC) and more particularly Doctor Nicolas Barré and Thierry Mennesson for allowing me to use their facilities, and Thérèse Mekenese for the time she gave me to sort out paperwork.

Last and not least, I would like to acknowledge my parents and my brother that supported me during all my studies as well as some of my friends that helped me to focus on my study.

Thank you to all of you.

Declaration

I, Guillaume Roques-Rogery, declare that:

- the work in this thesis is my own original work;
- all sources used or referred to have been documented and recognised; and
- this thesis has not been previously submitted in full or partial fulfilment of the requirements for an equivalent or higher qualification at any other recognised education institution.

Signed:

Date:

(Guillaume Roques Rogery)

Chapter 1: Introduction

1.1 *Rusa deer status*

Rusa deer (*Cervus timorensis*) is divided into six sub-species distributed in various islands of Indonesia (Whitehead 1993) (Figure 1.1). *Rusa deer* have also been introduced into other areas and presently wild populations occur: (a) in the Indian Ocean islands of Comoro; Madagascar, Mauritius, (b) in the Indonesian islands of Borneo and Moluccas islands; (c) on the Australian mainland; (d) in the South-West Pacific Ocean islands of Hermit, Ninigo, New Britain, New Caledonia, New Guinea and New Zealand (Whitehead 1993).

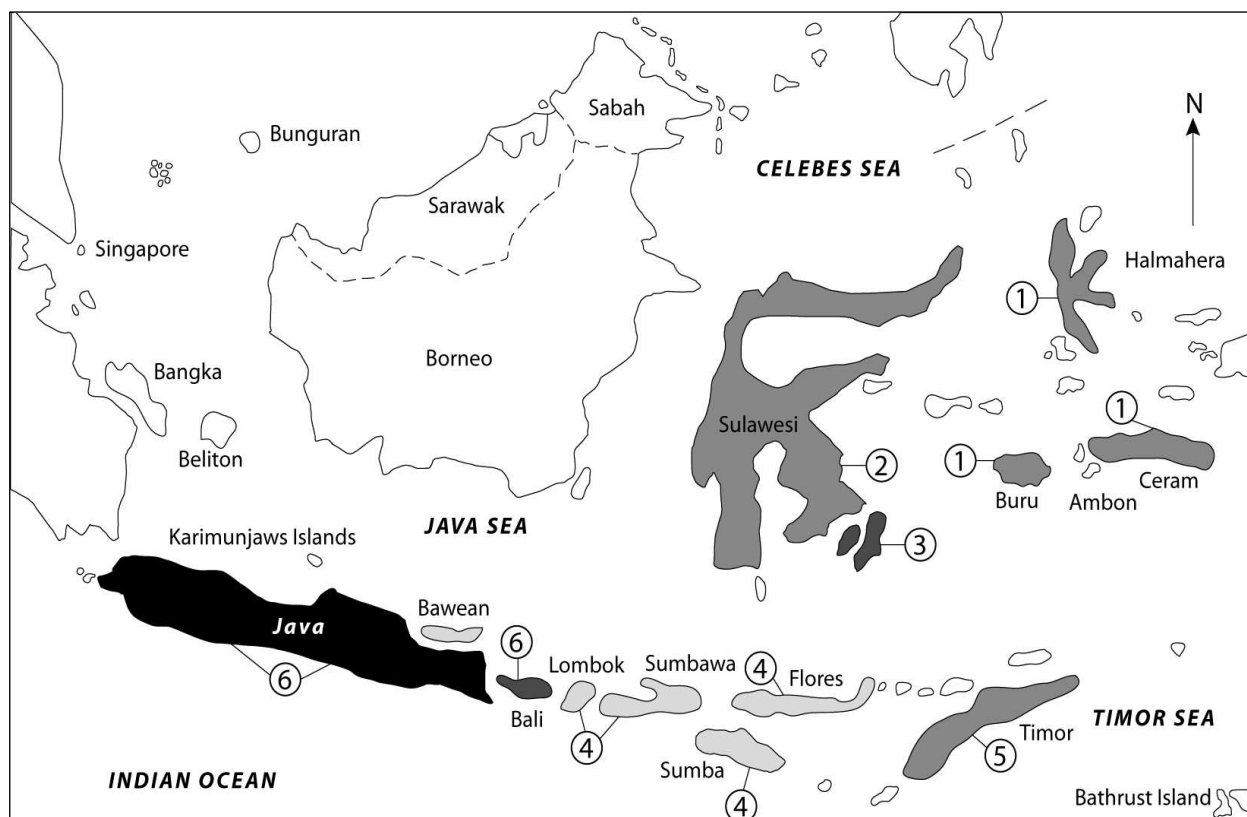


Figure 1.1: The natural range of rusa deer (*Cervus timorensis*) (1 = *C. t. moluccensis*, 2 = *C. t. macassaricus*, 3 = *C. t. djonga*, 4 = *C. t. florensiensis*, 5 = *C. t. timorensis*, 6 = *C. t. russa*; Whitehead 1993).

The rusa deer sub-species introduced into New Caledonia is *Cervus timorensis rusa* and was introduced from Indonesia (Java; Whitehead 1993). The first rusa deer were brought into New Caledonia in 1870 when the Governor of Java gave 12 rusa deer as a gift to the wife of the governor of New Caledonia (Whitehead 1993). After a short stay in Governor Park in Nouméa, the New Caledonian capital situated at the South-East of the main island, the deer were released into the educational farm of Yahoué, close to Nouméa. Some animals managed to escape, and a short while after their introduction the first rusa deer was killed close to Nakutakoin, 10 km away from Yahoué (Chardonnet 1988). This population expanded rapidly and by 1882 people were complaining about the damage to crops caused by rusa deer and in 1885 rusa deer were considered a problem and hunting was encouraged. At the beginning of the twentieth century, rusa deer were encountered in almost half of the main island and were spreading on average at 14 km per year (Chardonnet 1988). This rapid expansion can be explained by the capacity of rusa deer to adapt to their new environment and by the low predation due to a lack of large carnivores. In addition, rusa deer are opportunistic mixed-feeders (Nugent, *et al.* 2001) and consume a large variety of alien and native plants in New Caledonia, facilitating the spread of the species over the island (de Garine-Wichatitsky, *et al.* 2004b).

The last census of rusa deer on the main island was done in 1992 using interviews of experts with knowledge of rusa deer (Chardonnet and Lartiges 1992). This census estimated the population at approximately 110 000 rusa deer (Chardonnet and Lartiges 1992). Presently, most hunters and farmers consider that the number of rusa deer has increased since 1992 even though the hunting pressure has increased (de Garine 2002). Rusa deer are now widespread over the main island, but the highest concentrations are found on the west coast, especially in the north where savanna, *Melaleuca quinquenervia* savanna and sclerophyll forest are the dominant habitats (Chardonnet 1988).

Since they were introduced into New Caledonia, rusa deer have become an important game species and have acquired cultural, nutritional and economic importance for New Caledonians (Chardonnet 1988; de Garine-Wichatitsky, *et al.* 2004b). Hunting is important as it provides meat and surveys have shown that rusa deer is one of the most frequently consumed animal foods, especially in rural areas (de Garine 2002). Most of the deer meat is obtained from hunting, while meat from rusa deer farming only represents a minor proportion of the meat consumed locally (de Garine-Wichatitsky and Roques-Rogery 2007). Rusa deer hunting also provides

prestige, recreational and social activity for the hunters and their families, and also provides an opportunity for many people, especially the children to discover their environment (de Garine-Wichatitsky, *et al.* 2004b; de Garine-Wichatitsky and Roques-Rogery 2007). Although, 50% of adult men in rural areas are estimated to hunt rusa deer over week ends (de Garine 2002), poaching (*i.e.* hunting on private properties without the owners authorization and/or spotlight hunting) is a common practise in New Caledonia (de Garine 2002; de Garine-Wichatitsky and Roques-Rogery 2007).

Rusa deer is also economically important in New Caledonia (de Garine-Wichatitsky, *et al.* 2004b; Grimaud, *et al.* 2004; de Garine-Wichatitsky and Roques-Rogery 2007). The rusa deer farming industry has slowly increased since the 1980's (de Garine-Wichatitsky, *et al.* 2004b; de Garine-Wichatitsky and Roques-Rogery 2007) and presently more than 30 deer farms, situated mainly in the Southern Province rear approximately 13 000 rusa deer annually that are caught from the wild and then reared in enclosures (Grimaud, *et al.* 2004; de Garine-Wichatitsky and Roques-Rogery 2007). In 2004, 256 tons of rusa deer meat were produced, representing 106 million Pacific francs (DAVAR 2005) and most of the venison production is exported to the European Union (de Garine-Wichatitsky, *et al.* 2004b). Export of live animals to Asian countries and velvet production has also been attempted but without commercial success (Le Bel 1998).

1.2 Background to the study

World wide biodiversity is threatened, mainly as the result of anthropogenic activities (Primack 1993; Myers, *et al.* 2000). New Caledonia, a tropical archipelago of the south Pacific has a unique biodiversity and is considered one of the world's hotspots for the conservation of biodiversity (Mittermeier, *et al.* 1996; Myers 1998; Myers, *et al.* 2000). This archipelago has five major vegetation types: rain forest, sclerophyll forest, macchia, savanna which includes *Melaleuca quinquenervia* savanna and mangrove forests (Morat 1993; Jaffré, *et al.* 2001). In general, island fauna and flora have not been subjected to high predation pressure compared to their mainland counter parts and the restricted genetic diversity and reduced competitive ability of island species make them vulnerable to invasive species (MacArthur and Wilson 1963; Vitousek 1988; Paulay 1994; Simberloff 1995; Dulloo, *et al.* 2002). Invasive species are being monitored and control measures (*e.g.* reeducation and/or eradication of the invasive

species) are being implemented in the most critical areas (Vitousek 1988; Paulay 1994; Dulloi, *et al.* 2002; Keith and Pellow 2005).

Only nine mammal species, all bats, are native to New Caledonia (Flannery 1995). The vegetation of New Caledonia has therefore not co-evolved with mammalian herbivores and the plant species have not developed appropriate defence mechanisms against herbivores (de Garine-Wichatitsky, *et al.* 2003). Since their introduction into New Caledonia, rusa deer are considered to have important impacts on the vegetation, particularly on the sclerophyll forests (Bouchet, *et al.* 1995; Mittermeier, *et al.* 1996; de Garine-Wichatitsky, *et al.* 2003; Rouys and Theurerkauf 2003). Despite some studies on the diet and the homerange of rusa deer in New Caledonian sclerophyll forests (Le Bel, *et al.* 2001; de Garine-Wichatitsky 2003; de Garine-Wichatitsky, *et al.* 2003; de Garine-Wichatitsky, *et al.* 2004a), few studies have evaluated and monitored the trends of rusa deer populations on these forests (de Garine-Wichatitsky, *et al.* 2004a).

Currently, there is little management of wild rusa deer populations. This is partly due to a lack of knowledge about the species but important constraints are the lack of relevant monitoring tools and social and economic issues. Indeed, as rusa deer have acquired traditional importance (*e.g.* hunting) and are a source of income to the community (*e.g.* deer farming), local stakeholders have conflicting interests that have precluded the establishment of clear management strategies (de Garine-Wichatitsky and Saint-Andrieux 2003). This study aims to address the monitoring aspects of these constraints.

1.3 Monitoring tools

Reliable monitoring tools are urgently needed to improve the management of rusa deer in the sclerophyll forests of New Caledonia (de Garine-Wichatitsky and Saint-Andrieux 2003). Two broad groups of monitoring tools are available: (a) census methods that count and/or estimate the density of animals occurring on a study site (Sutherland 1996b; Mayle, *et al.* 1999; Forsyth and Scroggie 2003); (b) index methods that do not estimate the density of animals but rather allow the manager to follow the trends of an animal population by monitoring the changes of some variable in the habitat (Morellet, *et al.* 2007). Census methods have been used worldwide but in some cases have been shown to provide low accuracy and precision (Morellet, *et al.* 2001; Forsyth and Scroggie 2003; Morellet, *et al.* 2007). Census methods can be divided into

two groups: (a) direct census methods and (b) indirect census methods (Sutherland 1996b; Mayle, *et al.* 1999; Forsyth and Scroggie 2003). Direct census methods record sightings of animals whereas indirect census methods focus on recording signs left by the animal (e.g. faecal pellet groups, browsing marks and antler rubbing) and estimating density from this (Sutherland 1996b; Mayle, *et al.* 1999; Forsyth and Scroggie 2003).

Direct census methods are assumed to be more accurate and precise than indirect census methods in estimating density of animal populations (Morellet, *et al.* 2007). However, both census methods have their advantages depending on the environment in which they are used (Mayle, *et al.* 1999; Forsyth and Scroggie 2003). In open habitats, direct census methods such as aerial censuses are efficient because they can cover a large surface area in a short time (Bothma 1996; Mayle, *et al.* 1999; Forsyth and Scroggie 2003). However, many biases have to be taken in consideration such as vegetation cover, survey specifications, observer experience and meteorological conditions (Forsyth and Scroggie 2003). In closed habitats where it is difficult to spot animals, indirect census methods are preferred to direct census methods because they are more reliable (Mayle, *et al.* 1999; Forsyth and Scroggie 2003).

Index methods have been developed relatively recently, and researchers have started to look at these methods to replace census methods, with the initial focus of the research centred around the management of roe deer (*Capreolus capreolus*) in Europe (Morellet, *et al.* 2001). Few studies have been published about index methods, but they appear to be useful monitoring tools because they are easy to use and involve lower costs than census methods (Morellet, *et al.* 2001; Morellet, *et al.* 2007).

The main objective of my study is to test methods to follow the trends of rusa deer populations in New Caledonian sclerophyll forests. Chapter 4 covers the use of direct census methods (*i.e.* spotlight counts and drive counts), indirect census methods (*i.e.* faecal standing crop method) and a subjective ranking of rusa deer density to estimate rusa deer population in six study sites. Spotlight counts consist in recording animals at night along transects with the aid of spotlights which pick out the eyes of the animals facing the observer (Fafarman and DeYoung 1986). Indeed, due to the cryptic behaviour of deer, it is easier to detect the deer during the night than during the day (McCullough 1982). This method is particularly suitable in large areas (Forsyth and Scroggie 2003). Drive counts consist in pushing the animal toward a line of counters that record the animals moving past them. This method is particularly suitable in small areas as it can cover the whole area and it gives a total count of all the deer occurring in the study area (Bothma 1996; Mayle, *et al.* 1999). The faecal standing crop methods

which consist in measuring the density of faecal pellet groups are considered the more precise of the faecal pellet counts methods and are cost effective (Mayle, *et al.* 1999; Smart, *et al.* 2004).

I evaluated each method to assess their reliability and their possible use as monitoring tools for rusa deer in New Caledonian sclerophyll forests. Chapter 5 evaluates three indices: (a) the faecal pellet groups index, (b) the browsing index and (c) the antler rubbing index to assess rusa deer trends in native New Caledonian sclerophyll forests. Indices describe the relation between the ungulate population and its habitat (Groupe-Chevreuril 1996) and allow the manager to follow population trends of the ungulate population within the environment (Boiseaubert, *et al.* 1990). Indices are easy to measure and cost effective (Morellet, *et al.* 2007). The faecal pellet groups index which consists in measuring the density of faecal pellet groups density (Forsyth and Scroggie 2003) has already been used successfully in Europe (Mayle, *et al.* 1999) and in New Zealand (Forsyth and Scroggie 2003). The browsing index which consists in recording the browse marks on a list of indicator browse species have been used successfully in Europe (Aldous 1944; Boiseaubert, *et al.* 1990; Morellet, *et al.* 2001; Morellet, *et al.* 2003; Morellet, *et al.* 2007). To my knowledge, there are no publications relating to the use of the antler rubbing index which consists in measuring the density of antler rubbings, to monitor ungulate population trends.

For some of the methods described above, data were collected in plots along transects randomly distributed within the study sites. Therefore, it was necessary to determine the optimal number of plots to be sampled per transect and of the number of transects to be sampled per site to ensure reliable data collection with a coefficient of variation of the recorded data of less than 20%. This aspect is discussed in Chapter 3.

Chapter 6 combines recommendations about how to monitor rusa deer population trends in New Caledonian sclerophyll forests and a discussion on how to involve the local stakeholders. Efficient management relies on participative management of local stakeholders (Veitch and Clout 2001). As described previously, rusa deer have acquired a traditional and economic importance, and social and economic issues are one of the main constraints for the management of rusa deer in New Caledonian sclerophyll forests. Therefore, it is necessary to involve local stakeholders in decision making about the management of rusa deer in New Caledonia sclerophyll forests, but also involve them in the management operations such as the data collection and also in the culling and hunting operations.

Chapter 2: Study area

2.1 New Caledonia

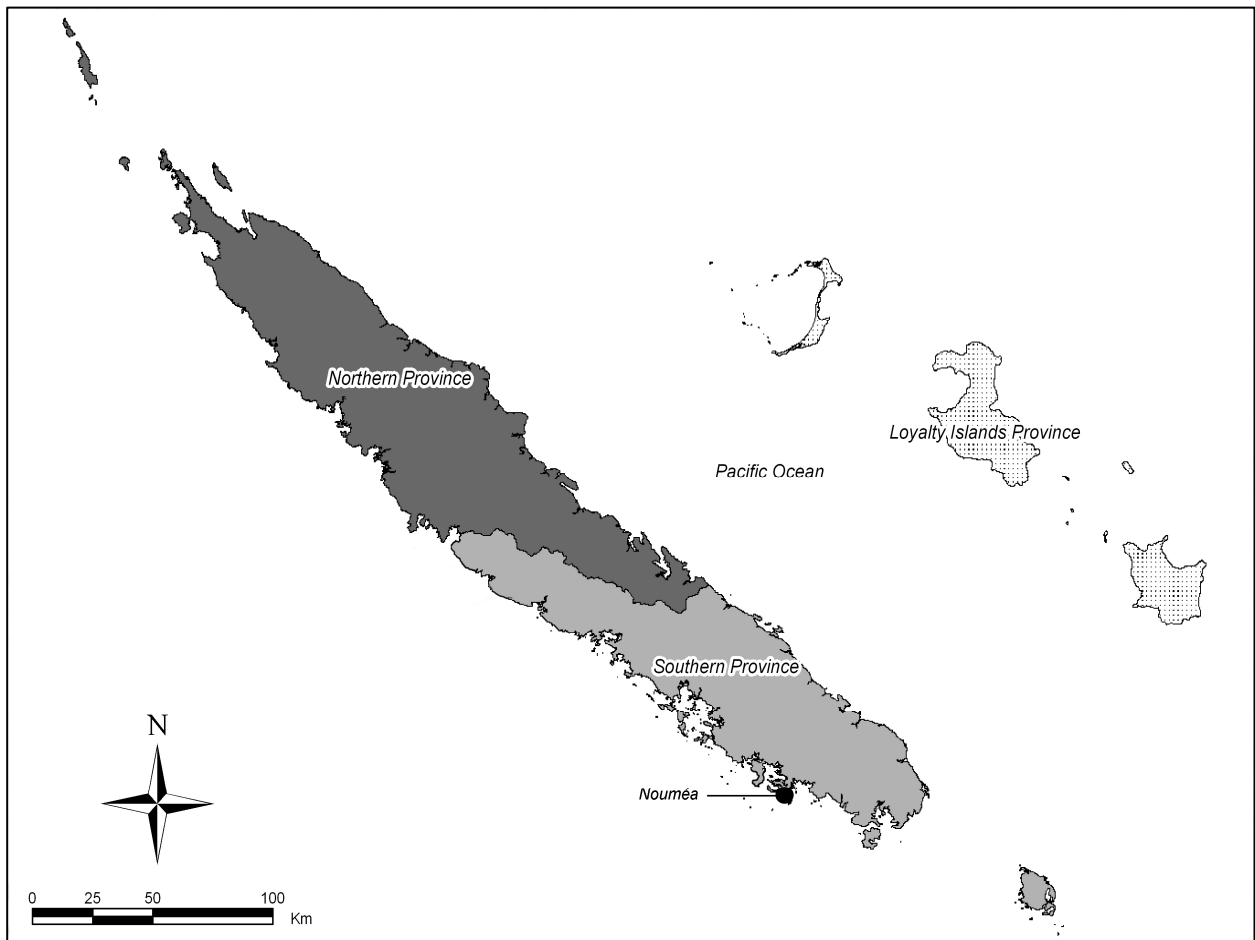


Figure 2.1: New Caledonia and its provinces (Institut de Recherche pour le Développement).

New Caledonia is an atoll of 19100 km² situated 150 km north of the Tropic of Capricorn in the Pacific Ocean, at approximately 22° south and 166° east. New Caledonia consists of a number of islands, divided into three provinces (Figure 2.1). The main island is called “Grande Terre” (*Large Island*) and represents the majority (88%) of the total surface of New Caledonia and is approximately 400 km long and 50 km wide

and is surrounded by the largest lagoon in the world. Grande Terre is divided into the Northern Province which includes the Belep Islands and the Southern Province which includes “Ile des pins” (*Pine Island*). The third province is called “Iles Loyauté” (*Loyalty Islands*) and includes the islands Ouvéa, Lifou and Maré. Numerous islets and reefs occur within the lagoon (Figure 2.1) (ORSTOM 1981).

In 2007, the population of New Caledonia was estimated at approximately 221 943, representing seven ethnic groups: Melanesian (42.5%), European (37.1%), Wallisian (8.4%), Polynesian (3.8%), Indonesian (3.6%), Vietnamese (1.6%) and other (3%) (www.cia.gov 2002). Most of the population is located on the west coast of Grande Terre and almost half of the population lives in Nouméa, the capital of the archipelago. The rest of the population lives in rural areas, called “la brousse” (“*the bush*”) and most of these people are farmers.

There are five major vegetation types in New Caledonia that are distributed according to the soil characteristics (Morat 1993; Jaffré, *et al.* 2001). These vegetation types contain 3261 known vascular plant species with an endemism rate of 74.3 % (Jaffré, *et al.* 2001) and it is estimated that there are still 5-10% species to be discovered (Morat 1993). Approximately 1600 species have been introduced mainly for agricultural purposes (MacKee 1994). Rain forests cover 22% of the total surface of New Caledonia and are mostly scattered over the central mountain chain of Grande Terre (Morat 1993). Rain forests contain 2 119 vascular plant species of which 82.9% are endemic (Jaffré, *et al.* 2001). Macchia is a specialized edaphic formation that covers 26% of the land area of Grande Terre and contain 1031 species of which 91% are endemic (Morat 1993). Savannas which include *Melaleuca quinquenervia* savanna, are degraded vegetation types (*e.g.* fire, agriculture, introduced invasive species) mainly composed of introduced plant species including several grass species that have been introduced to improve grazing (MacKee 1994). Mangroves cover approximately 200km², mostly along the western coast Grande Terre where the estuaries of the main rivers are wider and deeper than on the east coast (Morat 1993). Mangroves contain 17 species of which 11.3% are endemic (Jaffré, *et al.* 2001). Sclerophyll forests are described in more detail in the next section.

The tectonic history of New Caledonia is important in understanding its geology. Unlike Vanuatu, the Solomon Islands and Fiji which are of volcanic origin, New Caledonia was once part of the continent of Gondwanaland from which it became separated 65-80 million years ago (Mittermeier, *et al.* 1996). The geology of New Caledonia is interesting because 11 of the 12 types of soil existing in the world occur on

the island (Bonzon and Becquer 1996). The high biodiversity of New Caledonia is mainly due to its geology, as the native fauna and flora was isolated from other continents a long time ago and adapted to specific geological conditions (Morat 1993; Mittermeier, *et al.* 1996). Ultrabasic soil types dominate over one third of Grande Terre, especially in the south and the plant adaptation to these soils favoured the development of microendemism (Morat 1993; Mittermeier, *et al.* 1996).

The climate of New Caledonia is tropical with a strong oceanic influence (CTRDP-ORSTOM 1989; Grimaud, *et al.* 2004), but several microclimates are recognized on Grande Terre and these are mainly influenced by the mountain range dividing the island down its length. The east coast receives high rainfall and is characterized by humid vegetation occurring on steep mountain slopes, whereas on the west coast rainfall is lower favouring drier vegetation occurring mainly on plains. This is the consequence of trade winds occurring in the Pacific Ocean that blow westward. The east coast receives higher rainfall as a consequence of these winds, whereas the mountain range dividing the island causes a rainfall shadow on the west coast (CTRDP-ORSTOM 1989).

2.2 Sclerophyll forests

This study focused on the sclerophyll forests of Grande Terre. Morat, *et al.* (1981) first used the name of sclerophyll forest in 1981. The term “sclerophyll” (Greek *skleros* hard, *phullon* leaf) is related to the fact that sclerophyllous leaves are stiff and leathery with a shiny and thick cuticle (Edwards, *et al.* 2000). According to the UNESCO classification of 1973, dry sclerophyll forests are part of the tropical and subtropical evergreen forests (Veillon, *et al.* 1999).

In New Caledonia, sclerophyll forests only occur on the Grande Terre dry west coast (Figure 2.2) (Bouchet, *et al.* 1995) and include all forest formations that occur at altitudes below 300 m on various sedimentary rocks but seldom on basalts (Veillon, *et al.* 1999). Presently, only 2% of the sclerophyll forests (*i.e.* less than 100 km²) that once extended over the lowlands of the west coast (*i.e.* 4500 km²) remain (Figure 2-2) (Bouchet, *et al.* 1995). Much of the original sclerophyll forests have disappeared because of the intensive use of fire, agricultural activities and introduced invasive species and have been replaced through the process of colonisation by extensive savannas dominated by *Melaleuca quinquenervia*. Pristine sclerophyll patches are

typically less than 5 ha in size, and none is larger than 200 ha (Figure 2-2) (Bouchet, *et al.* 1995). Because of this fragmentation, many sclerophyll endemic plant species are restricted to one or a few patches of forest. For example, the tree *Ochrosia inventorum* is endemic to a single patch of sclerophyll forest at Pointe Maa and *Diospyros veillonii*, another endemic tree is restricted to a small patch at Gadji (Bouchet, *et al.* 1995).

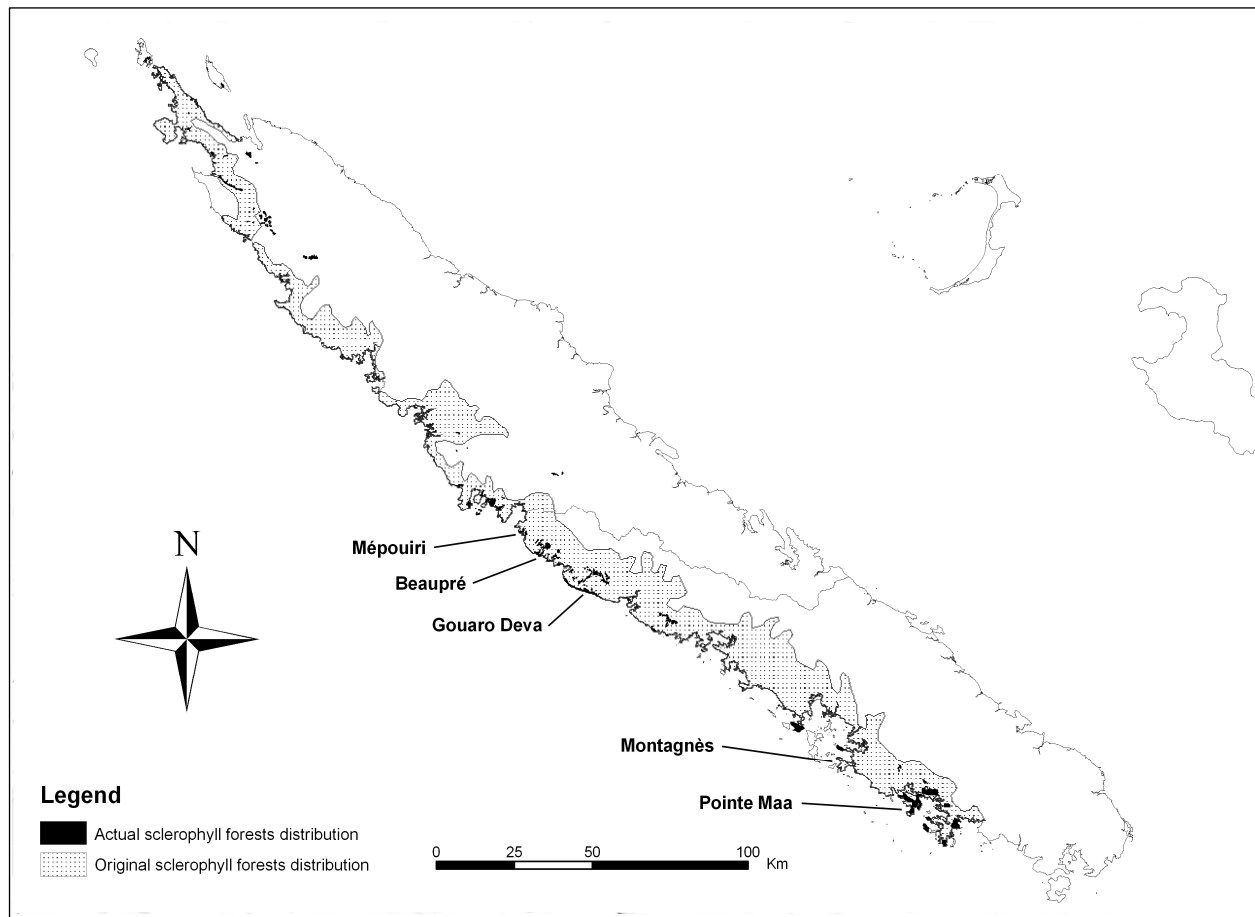


Figure 2.2: Original and actual distribution of sclerophyll forests in New Caledonia and the location of the six study sites of sclerophyll forests (Institut de Recherche pour le Développement).

New Caledonian sclerophyll forests have a thick canopy filtering the light. The tallest trees generally do not exceed 15 m, with a trunk diameter of 40 cm on average (Bouchet, *et al.* 1995). The shrub layer is heterogeneous and varies in thickness and vines are abundant (Morat 1993; Bouchet, *et al.* 1995). The herbaceous layer is composed of Graminaceae and Cyperaceae, sometimes associated with ferns (Morat 1993). The phanerogamic flora of the sclerophyll forests comprises 83 families, 227 genera and 409 species (Veillon, *et al.* 1999). Only 12.2% of the total flora of New Caledonia occurs in the sclerophyll forest, which is due to the limited area that is

occupied by this type of forest (Veillon, *et al.* 1999). Of the 233 endemic species occurring in sclerophyll forests, 59 species are restricted to these forests while the other 164 also occur in rainforests and macchia (Bouchet, *et al.* 1995). Of the 227 genera occurring in the sclerophyll forest, 168 are monotypic genera (*i.e.* *Captaincookia margaretae* (Rubiaceae), *Trigonostemon cherrieri* (Euphorbiaceae)) (Bouchet, *et al.* 1995). Eleven genera endemic to New Caledonia occur in the sclerophyll forests, among which the monospecific genus *Captaincookia* that is restricted to sclerophyll forest. It is important to emphasize the presence of 41 species of vines which are characteristic of sclerophyll forests (Bouchet, *et al.* 1995; Veillon, *et al.* 1999).

2.3 Study sites

The Institut de Recherche pour le Développement (IRD) completed an inventory of the sclerophyll forests occurring in New Caledonia. The sites used in this study were chosen according to the maps made by the IRD and according to preliminary studies done by the Institut Agronomique néo-Calédonien (IAC) (de Garine-Wichatitsky 2003; de Garine-Wichatitsky, *et al.* 2004a). Six sites in the Southern Province were chosen: (a) Beupré (Poya district), (b) Gouaro Deva divided into two sub-sites, north and south (Bourail district), (c) Mépouiri (Poya district), (d) Montagnès (Païta district) and (e) Pointe Maa (Païta district) (Figure 2.2). The study sites were chosen according to two main criteria: (a) Presumed rusa deer density. For the study, a gradient of rusa deer density was required to compare the estimates across sites. The presumed rusa deer densities were estimated from preliminary studies based on spotlight counts and faecal pellet group counts (de Garine-Wichatitsky 2003; de Garine-Wichatitsky, *et al.* 2004a); (b) Access to the site. Sites were chosen according to proximity of the research centre near Nouméa, relations with the owners and the interest of the owners in biodiversity management (de Garine-Wichatitsky, *et al.* 2004a).

On the west coast of Grande Terre where the study was conducted, the heaviest rainfall occurs from January to March (from 128.7 to 222.0 mm per month), but progressively decreases until May. Rainfall from June to September (dry season) is low (from 4.7 to 187.3 mm per month) and virtually absent from September to December (hot dry season; from 31.0 to 82.1 mm per month), with September being the driest month (CTRDP-ORSTOM 1989). However, as shown in Figure 2-3, rainfall can occur any time of the year, including during the dry season. The maximum mean monthly

temperature occurs in March (*i.e.* 27.0°C) whereas the minimum mean monthly temperature occurs in July (*i.e.* 18.8°C) (ORSTOM 1981).

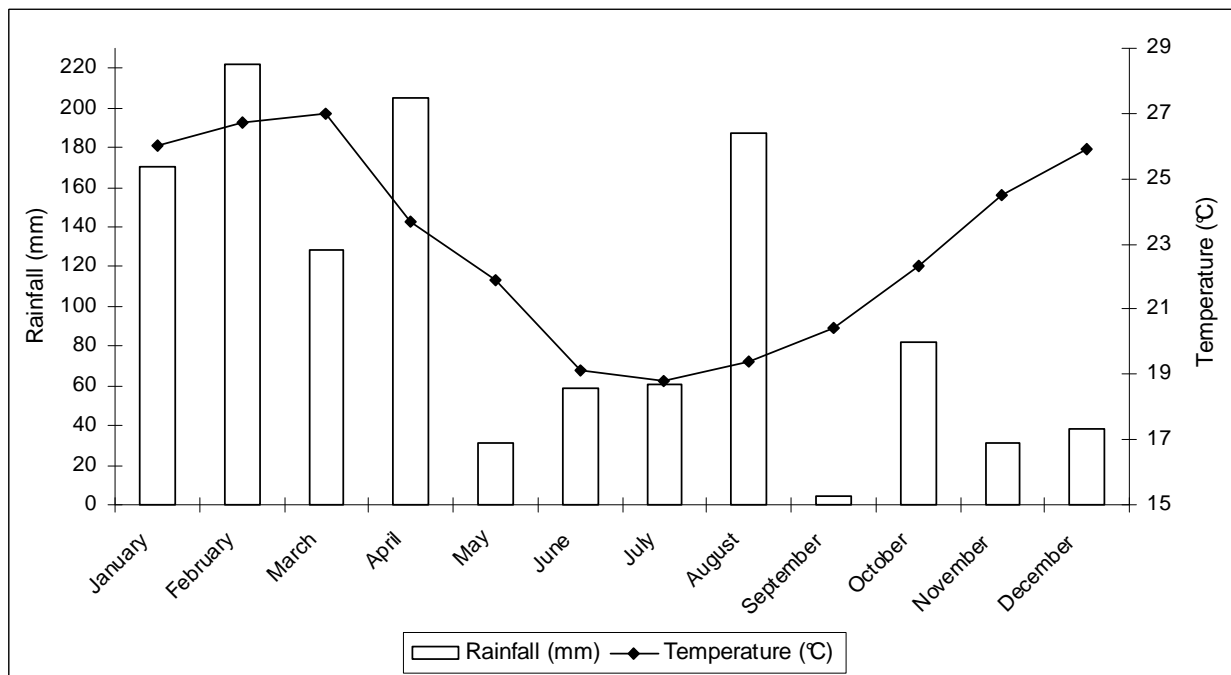


Figure 2.3: Mean monthly temperature and mean monthly rainfall for the Païta district in 2001 (Institut Agronomique néo-Calédonien).

2.3.1 Beauré

Beauré is situated on the property of Mr. Alain Dalstein in the Poya district (Figure 2.2). The sclerophyll forest (6.1 ha) was fenced in 1995 to decrease the impact of wild ungulates (*i.e.* rusa deer and feral pigs) inside the enclosure and to allow the regeneration of plant species. Therefore, the rusa deer density is assumed to be zero. However, it seems that this fence is not totally efficient and that rusa deer and feral pigs get inside the enclosure. Previous studies identified 42 plant species in the site, of which 19 are endemic, 13 native non-endemic and 10 introduced (de Garine-Wichatitsky, *et al.* 2004a). Endemic plant species include *Diospyros* sp. (un-identified), *Eugenia* sp. (un-identified) and *Terminalia cherrieri* (de Garine-Wichatitsky pers. comm. 2005a).

2.3.2 Gouaro Deva

Gouaro Deva is the property of the Southern Province and is situated in the Bourail district (Figure 2.2). It is the largest sclerophyll forest in New Caledonia (de Garine-Wichatitsky 2005a). In this area, two sites were chosen: (a) the northern forest (167.5 ha) that is composed of closed and open sclerophyll forest and (b) the southern forest (306 ha) that is composed of riverine sclerophyll forest. Few data were available about the vegetation of this site but studies are on going. In both sites of Gouaro Deva, endemic plant species include *Diospyros* sp. (un-identified), *Emmenosperma pancherianum* and *Eugenia* sp. (un-identified) (de Garine-Wichatitsky pers. comm. 2005a).

2.3.3 Mèpouiri

Mèpouiri is situated on the property of Mr. Claude Metzdorf in the Poya district (Figure 2.2). The sclerophyll forest (7.7 ha) was fenced in 1994 to prevent any ungulate impact and to allow the regeneration of plant species, and the rusa deer density is assumed to be zero. However, it seems that this fence is not totally efficient and that rusa deer and feral pigs get inside the enclosure. During the study, a dead deer was found inside the fenced area and signs of rusa deer and feral pigs were observed (e.g. tracks, antlers rubbing, faecal pellet groups). Previous studies have shown that the vegetation diversity on this site is high with 63 plant species (this number is non-exhaustive) of which 24 are endemic, 26 native non-endemic and 13 introduced (de Garine-Wichatitsky, *et al.* 2004a). Endemic plant species include *Diospyros* sp. (un-identified), *Terminalia cherrieri* and *Trigonostemon cherrieri* (de Garine-Wichatitsky pers. comm. 2005a).

2.3.4 Montagnès

Montagnès is situated in the Païta district on a small peninsula (Figure 2.2) and a fence prevents rusa deer from moving in and out of the property. The sclerophyll forest studied covers a surface of 17.7 ha. Previous studies have shown that the

vegetation diversity is relatively low with 43 identified plant species (this number is non-exhaustive) of which 16 are endemic, 21 native non-endemic and six introduced. Endemic plant species include *Ancistrachne numaeensis*, *Eugenia* sp. (un-identified) and *Solanum pancheri* (de Garine-Wichatitsky, *et al.* 2004a).

2.3.5 Pointe Maa

Pointe Maa is situated in the Païta district on a small peninsula (Figure 2.2) and a fence prevents rusa deer from moving in and out of the property. The sclerophyll forest covers a surface of 56.3 ha and contains 56 plant species (this number is non-exhaustive) of which 18 are endemic, 28 native non-endemic and 10 introduced. One ligneous species, *Ochrosia inventorum*, is of particular conservation interest as it is endemic to this sclerophyll forest. This site also contains *Emmenosperma pancherianum* another rare tree endemic to New Caledonian sclerophyll forests (de Garine-Wichatitsky, *et al.* 2004a).

Chapter 3: Faecal pellet group surveys: determining the optimal number of plots per transect and number of transects per site

3.1 Introduction

The current management of wild populations of rusa deer in New Caledonia is not efficient due to several factors including: conflicting interests between conservation, hunting and deer farming; the absence of clear devolution of management responsibility; a lack of sufficient financial and human resources; the lack of reliable monitoring tools to follow local rusa deer population trends and adjust management actions accordingly (de Garine-Wichatitsky and Saint-Andrieux 2003). Faecal pellet group surveys have been used as a tool to monitor deer populations in closed habitats (e.g. forests) since the 1930's (Bennett, *et al.* 1940) and this method is considered a reliable and inexpensive method (Mayle, *et al.* 1999). Forsyth and Scroggie (2003) have adapted this method to New Zealand forests and the protocol they developed may be a suitable monitoring tool to manage the rusa deer populations within New Caledonian sclerophyll forests.

The method of Forsyth and Scroggie (2003) increases the sample size, as many smaller plots are used instead of the few larger plots usually sampled for traditional deer faecal pellet surveys (Morellet, *et al.* 2001; Forsyth and Scroggie 2003). A large sample size increases the reliability of the data (Morellet, *et al.* 2001) but also increases the time spent collecting the data and the expense of the monitoring programme.

The objective of this chapter was to design a protocol to estimate the mean number of intact faecal pellet groups plot per transect, with a coefficient of variation of less than 20%. Estimates with a coefficient of variation of less than 20% are considered reliable by Forsyth and Scroggie (2003). In the first part of the study, the minimum number of plots per transect needed to obtain a coefficient of variation of the mean of less than 20% was determined in a single site. In the second part of the study, the minimum number of transects per site needed to obtain a coefficient of variation of the mean of less than 20% was determined across the six study sites.

3.2 Study site

Refer to Chapter 2.

3.3 Methods

The method of Forsyth and Scroggie (2003) is based on recording the number of rusa deer faecal pellet groups inside circular plots, along transects randomly located in a study site. In this study, 30 transects were sampled in each study site (Forsyth and Scroggie 2003). The positioning of these transects in each site was done using ArcMap 8.3.800.d. The principle of a Geographic Information System (GIS) is to create data layers that can be modified and are overlapping. An aerial picture of the sclerophyll forests was used as the first data layer. The second layer was the boundaries of each sclerophyll forest as delineated by the Institut de Recherche pour le Développement (IRD) (www.foretseche.nc). On this layer, a buffer area was created in each forest to prevent the transects from occurring on the boundaries of the forest. The buffer area was variable (from 10 m to 50 m) according to the size of the study site. For each site, 30 points were randomly selected using Hawth's Analysis Tools (available from <http://www.spatial ecology.com/htools/>) with ArcGis 8.3 software and each of these points was the starting point of a transect.

Along each transect, a circular aluminium frame was used to demarcate a 2 m diameter plot (3.14 m²) and these were placed every 5 m along the transect. The minimum number of plots per transect needed for a coefficient of variation of the mean of less than 20% was determined in Pointe Maa. In this site, 30 transects of 150 m (30 transects x 30 plots = 900 plots) were sampled. From the results (see below), it was found that the number of plots per transect could be reduced and subsequent sampling in the other five sites (*i.e.* Beaupré, Gouaro Deva Nord and Sud, Mèpouiri and Montagnès) used 30 transects of 75 m (30 transects x 15 plots = 450 plots). The faecal standing crop method was used to measure the total number of faecal pellet groups inside a plot (Mayle, *et al.* 1999; Campbell, *et al.* 2004). Three pellet categories were identified according to their decay status (Forsyth and Scroggie 2003): (a) Fresh pellets - intact pellets which were soft, slippery and had surface slime. They typically had a shiny appearance and an odour was present. (b) Non-degraded pellets - intact pellets which did not show a matter loss due to decay or trampling. They were typically dark in

appearance with a dull appearance. (c) Degraded pellets - pellets which showed signs of matter loss due to decay or trampling. They were typically faded and plant fibre was apparent in the pellets (Figure 3.1). A faecal pellet group was characterised by pellets with the same colour, texture and decay rate and consisted of a minimum of 10 pellets (de Garine-Wichatitsky, *et al.* 2004a). Only pellets situated on the surface litter were recorded and if less than half of a faecal pellet group was inside a plot, it was not recorded (Forsyth and Scroggie 2003). Data collection were not done on rainy days as it made pellet classification difficult and inaccurate (Forsyth and Scroggie 2003). The study was done during the 2005/2006 dry season (*i.e.* October to February) by one recorder.

The coefficient of variation of the mean should decrease as the number of plots per transect and the number of transects per site increases. In the first part of the study, the change in the coefficient of variation of the mean was determined for varying numbers of plots per transect (*i.e.* 10, 15, 20, 25 and 30 plots) in Pointe Maa. In the second part of the study, the change in the coefficient of variation of the mean was determined for varying numbers of transects (*i.e.* 10 to 30 transects) for each of the six study sites.

A bootstrap technique was used to examine the influence of the variation of the number of plots per transect and of the number of transects per site on the coefficient of variation of the mean number of intact faecal pellet groups per plot per transect. This was done using the add-in "Poptools" under Microsoft Excel software (<http://www.cse.csiro.au/poptools/download.htm>), following the recommendations of Forsyth and Scroggie (2003). For each of the six sites, the mean number of intact faecal pellet groups per plot per transect was calculated. The bootstrap mean of intact faecal pellet groups per plot per transect and the bootstrap standard deviation were calculated and used to calculate the coefficient of variation. The calculations were based on 10 000 bootstrap resamplings of the data from the six sites. For Pointe Maa, where 30 plots per transect were sampled, bootstrap resampling was done for five smaller subsets of the data recorded. For the five other sites (*i.e.* Gouaro Deva Nord and Sud, Montagnès, Beaupré and Mèpouiri), only the influence of the number of transect per site on the pellet group density was examined because only 15 plots per transect were done.

Intact pellets / pellet groups. To be recorded.



Very fresh pellets, all pellets are intact



Very fresh clumped pellets, all pellets are intact



Non-degraded pellets, no loss of material



Non-degraded pellets, although cracked, no loss of material has occurred

Degraded pellets / pellet groups. Not to be recorded.



Degraded pellets, all show loss of material

Figure 3.1: Pellet classification according to their decay status.

3.4 Results

3.4.1 Optimal number of plots per transect

Figure 3.2 shows the influence of both the number of plots per transect and the number of transects per site, on the coefficient of variation of the number of intact faecal pellet groups per plot in Pointe Maa. When 10 transects were sampled, the highest coefficient of variation of the mean was 20.19% for 10 plots per transect and the lowest was 14.82% for 30 plots per transect. However, if 30 transects per sites were sampled, the highest coefficient of variation of the mean was 11.64% for 10 plots per transect and the lowest was 8.44% with 30 plots. Moreover, Figure 3.2 shows that the number of transects per site has a greater effect on the coefficient of variation of the mean than the number of plots per transect.

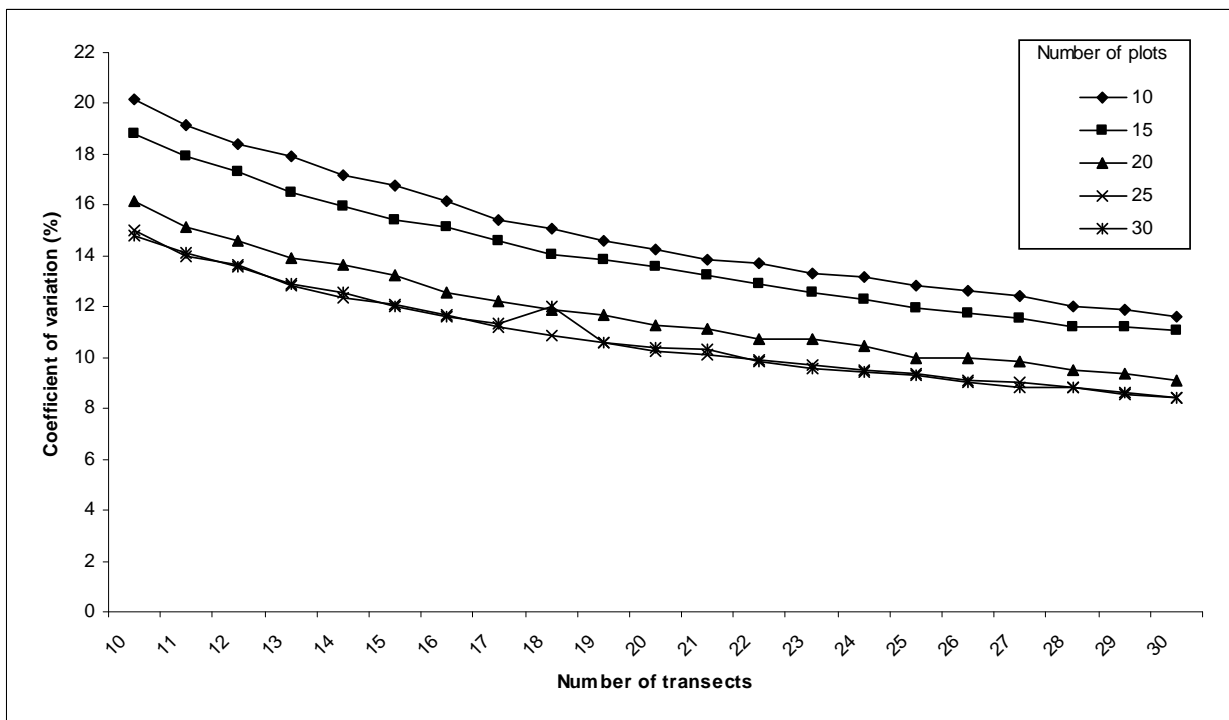


Figure 3.2: The influence of the number of plots per transect and of the number of transects per site on the coefficient of variation of the mean number of intact faecal pellet groups per plot per transect in Pointe Maa.

3.4.2 Optimal number of transects per study site

The previous section showed that a minimum of 15 plots per transect is required to obtain a coefficient of variation of the mean of less than 20% regardless of the number of transects. Therefore, 15 plots per transect were used to test the optimal number of transects per study site. Figure 3.3 shows that for each of the six sites the coefficient of variation of the mean decreases as the number of transects per sites increases. If 10 transects per sites are sampled, the coefficient of variation of the mean plot varies from 24.82% in Montagnès to 12.52% in Gouaro Deva Sud. If 30 transects per sites are sampled, this coefficient of variation of the mean varies from 14.33% in Montagnès, to 7.07% in Gouaro Deva Sud.

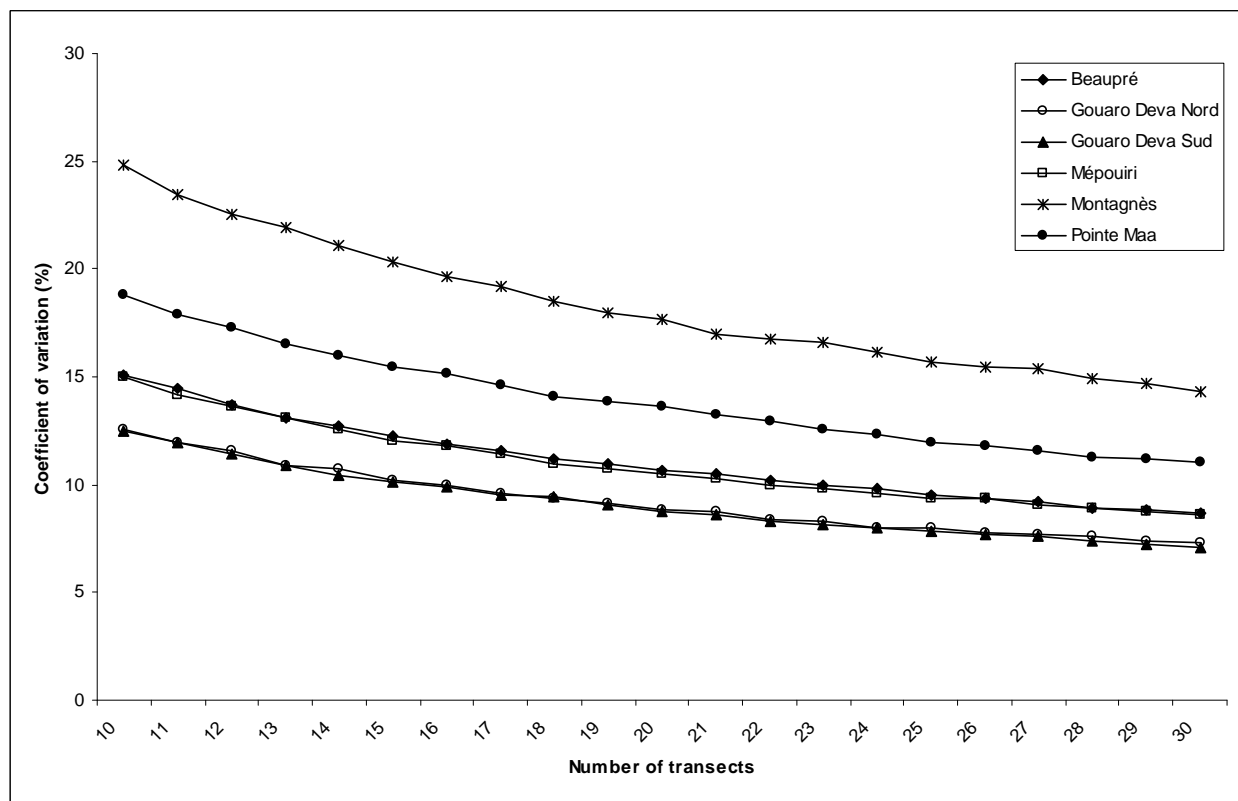


Figure 3.3: The influence of the number of transects per study site on the coefficient of variation of the mean number of intact faecal pellet groups per plot per transect (for 15 plots per transect) in the six study sites.

3.5 Discussion

The coefficient of variation of the mean number of intact faecal pellet groups per plot per transect was calculated to determine the optimal number of plots per transect and transects per site that has to be sampled to record reliable data. A coefficient of variation of the mean of less than 20% is considered adequate to ensure an efficient sampling of a study area (Forsyth and Scroggie 2003). In Pointe Maa, where the minimum number of plots per transect required to obtain a coefficient of variation of the mean of less than 20% was determined, it was found that the number of plots per transect could be reduced to 15. That is, if 15 plots are sampled regardless of the total number of transects sampled, the coefficient of variation of the mean remained less than 20%. Therefore, when determining the minimum number of transects across all sites, the number of plots per transect was reduced to 15 plots per transect. In determining the latter, it was found that the number of transects per study sites could be reduced to 20. That is, if 15 plots per transect and 20 transects per site are sampled, the coefficient of variation of the mean remained less than 20% in each site.

These results are similar to those of Forsyth and Scroggie (2003) in New Zealand. They found that the number of plots per transect and the number of transects per site could be reduced, but that a minimum of 25 plots per transect and 18 transects per site was required to obtain a coefficient of variation of the mean of less than 20%, whereas in New Caledonian sclerophyll forests, a minimum of 15 plots per transect and of 20 transects per site were required to obtain a coefficient of variation of the mean number of intact faecal pellet group per plot per transect of less than 20%.

These differences can be attributed to several factors. Firstly, it seems that the density of deer faecal pellet groups density is higher in New Caledonia than in New Zealand, as a result of differing deer species, higher deer densities that can be 100 times higher in New Caledonia than in New Zealand and climatic conditions (Forsyth pers. comm. 2005; Chardonnet pers. comm. 2008). Therefore, fewer plots have to be sampled to record the same number of faecal pellet groups and to obtain a coefficient of variation of the mean of less than 20%. Secondly, this could be as a result of differences in searching for faecal pellets groups as the recording of faecal pellet groups is not equally efficient in different habitat types (Bailey and Putman 1981; Putman 1984; Forsyth, *et al.* 2007). For example, the presence of litter, rocks and the herbaceous layer make the recording of faecal pellet groups difficult. Sclerophyll forests have a less diverse flora than the evergreen forests of New Zealand (Morat 1993) and the latter also

have a thicker litter layer reducing the visibility of faecal pellet groups in these forests (Forsyth, *et al.* 2007).

Although Forsyth and Scroggie (2003) recommend using more plots per transect than transects per site (*i.e.* 30 plots per transect and 20 transects per site), my results indicate that the number of transects per site should be increased rather than the number of plots per transect. I would therefore recommend that future surveys of rusa deer faecal pellet groups in New Caledonian sclerophyll forests sample 15 plots per transect and 20 transects per site. This will also ensure that a greater number of transects will be spread over a larger area than a greater number of plots.

During data collection, fatigue, boredom and visual acuity of the recorder can favour a poor detection of faecal pellet groups (Dhungel 1985; Campbell, *et al.* 2004; Forsyth, *et al.* 2007). I would recommend two persons (specifically trained at the same time to reduced the bias that could occur when data collector changes) to do the data collection to reduce these biases (Eberhardt and Van Etten 1956).

Implementing the above recommendations should improve the precision and the cost efficiency of future faecal pellet group surveys of rusa deer populations in New Caledonian sclerophyll forests. Collecting data along transects requires a large amount of time (*i.e.* approximately 24 hours if 30 plots per transect and 30 transects per site are sampled). The longer the data collection time is, the greater the bias due to fatigue, boredom and visual acuity of the recorder will be (Dhungel 1985; Campbell, *et al.* 2004; Forsyth, *et al.* 2005). The latter bias will be reduced by reducing the number of plots per transect and of transect per sites as it will reduce the time spent collecting data (*i.e.* approximately 10 hours if 15 plots per transect and 20 transects per site are sampled) and the expense.

Chapter 4: Estimation of rusa deer density using direct and indirect census methods

4.1 Introduction

Reliable estimates of population density and trend are important to ensure an efficient management of rusa deer in New Caledonia. Two main categories of census techniques are available to estimate the density of animals: (a) direct census methods which record sightings of animals and (b) indirect census methods which record the signs left by the animals (e.g. faecal pellet groups, antler rubbing) (Sutherland 1996a).

Many direct census methods are available to estimate animal density (Bothma 1996; Mayle, *et al.* 1999; Forsyth and Scroggie 2003). The most commonly used of the direct census methods are the vantage-point counts (an observer records the animals from a vantage point during a known period of time) (Ratcliffe 1987), aerial counts (animals are recorded from an aircraft along predetermined transects) (Bothma 1996), mark-recapture methods (population size is estimated from the proportion of recognisable individuals in the observed sample) (Thompson, *et al.* 1998). Spotlight counts (animals are recorded at night along transects with the aid of spotlights which pick out the eyes of the animals facing the observer) are also a popular method because of the low cost and simplicity (Fafarman and DeYoung 1986). Moreover, it is easier to detect the deer during the night than during the day due to their cryptic behaviour (McCullough 1982). Another popular method is drive counts (a beater team pushes the animal toward a line of counters that record the animals moving past them). This method is particularly suitable in small areas as it can cover the whole area and it gives a total count of all the deer occurring in the study area (Bothma 1996; Mayle, *et al.* 1999).

Many indirect census methods have been used in different parts of the world to estimate animal density (Mayle, *et al.* 1999; Forsyth and Scroggie 2003). The most commonly used of the indirect methods are: track counts where animals densities are estimated from the number of recorded tracks (Mandujano and Gallina 1995; Mayle, *et al.* 1999); vocalisations where deer densities are estimated from the number of recorded

roaring stags (Bobek, *et al.* 1986; Forsyth and Scroggie 2003); the use of cull and hunting information where animal densities are estimated from the number of animals killed by hunters (Baddeley 1985). Faecal pellet groups counts have been used extensively in Europe (Mayle, *et al.* 1999; Marques, *et al.* 2001; Smart, *et al.* 2004), Australia and New Zealand (Lewin 2002; Forsyth and Scroggie 2003), North America (White and Eberhardt 1980; Rowland, *et al.* 1984), South America (Rivero, *et al.* 2004), Africa (Barnes 2001) and Asia (Dinerstein and Dublin 1982; Jessop, *et al.* 2006) to estimate animal densities. The density of animals is estimated from the number of faecal pellet groups recorded using either (Neff 1968): (a) faecal accumulation rate methods or (b) faecal standing crop methods (Mayle, *et al.* 1999). Faecal accumulation rate techniques record the accumulation rate of faecal pellet groups, while faecal standing crop methods measure the density of faecal pellet groups. Although the former are considered less prone to bias, they are time consuming because the study sites have to be visited at least twice to record the accumulation rate of the faecal pellet groups (Mayle, *et al.* 1999). The faecal standing crop methods are considered the more precise of the two methods (Mayle, *et al.* 1999; Smart, *et al.* 2004) and only requires the study site to be visited once and are therefore also more cost effective (Mayle, *et al.* 1999; Campbell, *et al.* 2004).

The objective of this chapter is to compare estimates of rusa deer density across six study sites obtained from: (a) spotlight and drive counts; (b) the faecal standing crop method. Estimates derived from these methods are also compared to a subjective ranking by local experts of rusa deer density.

4.2 Study site

Refer to Chapter 2.

4.3 **Methods**

4.3.1 Direct census

Spotlight counts were applied in four study sites (*i.e.* Gouaro Deva Nord and Sud, Montagnès and Pointe Maa) and drive counts in two study sites (*i.e.* Beaupré and Mèpouiri) due to the feasibility of the methods in the various sites.

4.3.1.1 *Spotlight counts*

A line transect method was used for the spotlight counts. One transect was identified in each study site to cover the area (Table 4.1). To increase the sampling effort, each transect was done several times (*i.e.* between four to eight times depending on the sites; Table 4.1). All transects were done during the 2005/2006 dry season (*i.e.* October to February).

At night, the eye reflection in the spotlight makes rusa deer easier to detect than during daylight, when the deer have a cryptic and secretive behaviour. Moreover, they tend to be less alarmed allowing easier aging and sexing (McCullough 1982). Whenever it was possible, spotlight counts were done during cloudy nights and dark phases of the moon as it is the best conditions for spotlight counts (Baddeley 1985). Spotlight counts were done two hours after sunset by a driver and spotlight operator.

The driver travelled at a speed of <15 km/h (McCullough 1982; Cypher 1991) and also recorded the data. The spotlight operator stood on the back of a pickup and used a spotlight (Lightforce™ spotlight of 100 watts) to cover an area of 180° in front of the vehicle. When deer were spotted, the driver stopped and recorded the following information (Figure 4.1): (a) the radial distance (r) from the vehicle to the deer using a rangefinder (Bushnell® YardagePro® Compact 600); (b) the angle (α) between the deer and the vehicle using a protractor fixed on the vehicle roof; (c) and group details (group size, sex and the age of individuals when possible). Data collection was done as fast as possible to prevent disturbance of upcoming observations.

The assumptions of the line transect theory (Buckland, *et al.* 2001) were followed as much as possible during data collection: (a) deer on the transect were

always detected; (b) deer were detected at their original location, prior to any movement in response to the observer; (c) distances and angles were measured accurately.

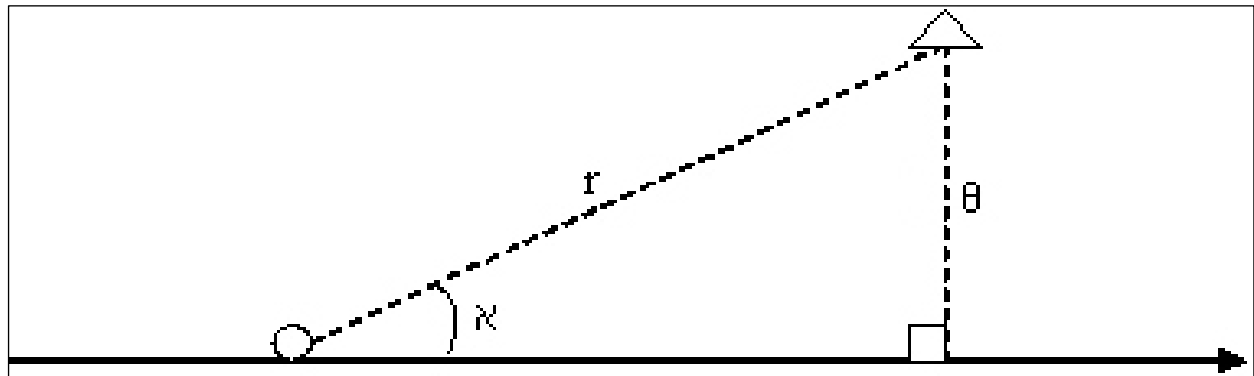


Figure 4.1: Basic measurements taken in a line transect survey (O = observer, Δ = animal, κ = angle, r = radial distance, θ = perpendicular distance; Burnham, *et al.* 1980; Buckland, *et al.* 2001).

Table 4.1: Length of transects and number of replicates for spotlight counts in each sites.

Sites	Transect length (m)	Number of replicates	Number of observations
Gouaro Deva Nord	2200	8	9
Gouaro Deva Sud	7200	4	96
Montagnès	2900	6	51
Pointe Maa	4300	6	171

Data were analysed using Distance sampling theory (Buckland, *et al.* 2001; Thomas, *et al.* 2002) and Distance software (available from <http://www.ruwpa.st-and.ac.uk/distance>). In practise, to perform Distance sampling analysis, 60 to 80 observations are necessary to obtain a robust model of animal detection probability, but 40 observations can be enough (Buckland, *et al.* 2001).

Distance sampling theory uses the following formula to calculate animal density:

$$D = \frac{n \cdot f(0)}{2 \cdot L}$$

where $f_{(0)} = g_{(0)} / \mu$ with $\mu = \int_0^w d(x)dx$; x is the given distance and $g_{(0)}$ the detection probability when $x = 0$; n the number of groups detected and D is the density of animal (animal/ha) (Buckland, *et al.* 2001).

As rusa deer live in groups (Whitehead 1993), the sampling unit is the group and not the individual. The density estimate is given as the number of groups per surface unit from the function of detection probability of the groups. Then, the mean of group size is used to calculate the density of individuals/ha (Buckland, *et al.* 2001). However, as the group detection probability decreases with the perpendicular distance, the density estimates may be subjected to bias (Buckland, *et al.* 2001).

To decrease this bias, the mean of group size is estimated from the regression of the neperian logarithm of the group size compared to the detection function $g_{(y)}$ estimated from the right model selected from the Akaike's Information Criterion (AIC) (Buckland, *et al.* 2001).

Every Distance sampling analysis starts with a frequency histogram presenting the number of groups recorded according to the perpendicular distances. Then, the key function with their series expansion is used to calculate the detection probability function $g_{(y)}$. The detection probability function is calculated from the following formula:

$$g_{(y)} = \text{key function } (y) [1 + \text{series expansion } (y)]$$

Different models are tested according to the frequency histogram. The best model is chosen according to the value of the AIC that gives a relative measure of fit and allows a ranking of all generated models (Akaike 1973). The AIC is calculated from the following formula:

$$AIC = -2\log_e(L) + 2q$$

where L is the maximized likelihood (evaluated at the maximum likelihood estimates of the model parameters) and q is the number of parameters in the model (Buckland, *et al.* 2001).

The model with the lowest AIC value is chosen when the gap with the second best model is >2 (Burnham and Anderson 2001). If the gap is <2 , the most parsimonious model is chosen (*i.e.* the model with the smallest number of parameters) (Akaike 1973; Anderson, *et al.* 1994). In this case, it is necessary that: (a) the estimates given by the models with similar AIC values are close; (b) the shape of the model function shows a “shoulder” for the low values of x ; (c) the detection function has an horizontal asymptote where $x = 0$, especially when the recorded animal species are easily detected (*e.g.* body size, open vegetation); (d) the estimates such as the effective strip width and the expected cluster size are consistent with the observations made on the field (Jachmann 2001).

4.3.1.2 Drive counts

Drive counts were used in the two fenced sites (*i.e.* Beaupré and Mèpouiri) where spotlight counts could not be done due to the absence of roads. Drivers with dogs walked through the forest during daytime, driving the rusa deer towards a line of observers who counted the deer passing them (Bothma 1996). Two drive counts were done in both study sites and the mean number of deer recorded per site used to calculate the deer density per hectare for both sites. Confidence intervals were calculated for the deer density per study site but could not be calculated for the deer density per hectare.

4.3.2 Indirect census - faecal standing crop method

To estimate deer density from the faecal standing crop method three variables need to be known: (a) the number of faecal pellet groups per hectare, (b) the decay rate of faecal pellet groups, and (c) the defecation rate of deer (Mayle, *et al.* 1999). These three factors were estimated and used in the following formula (Mayle, *et al.* 1999):

$$\text{Number of deer (ha}^{-1}\text{)} = \frac{\text{Number of faecal pellet groups (ha}^{-1}\text{)}}{\text{Average decay time for a pellet group (days) x Defecation rate (number of pellet groups per day)}}$$

4.3.2.1 *Faecal pellet groups per hectare*

The survey procedure is explained in detail in Chapter 3. In each plot, faecal pellet groups situated on the surface litter were recorded, but if less than half of a faecal pellet group was inside a plot, it was not recorded (Forsyth and Scroggie 2003). A faecal pellet group was characterised by pellets with the same colour, texture and decay rate, and consisted of a minimum of 10 pellets (de Garine-Wichatitsky, *et al.* 2004a). Data collection were not done on rainy days as it made pellet classification difficult and inaccurate (Forsyth and Scroggie 2003). The study was done during the 2005/2006 dry season (*i.e.* October to February).

4.3.2.2 *Decay rate of faecal pellet groups*

Fresh faecal pellet groups were located and marked clearly to follow their decay rate in Pointe Maa (Buckland, *et al.* 2001). Fresh faecal pellets were soft, slippery and had a slimy surface. They typically had a shiny aspect and an odour was present. A faecal pellet group was characterised by pellets with the same colour, texture and decay status, and consisted of a minimum of 10 pellets (Mayle, *et al.* 1999; de Garine-Wichatitsky, *et al.* 2004a). Marking was not done on rainy days (Forsyth and Scroggie 2003), and the location of the fresh faecal pellet group was recorded using a GPS, and marked with a pole, danger tape and spray paint. Eighteen faecal pellet groups were marked and visited every two months until the pellets in the group had decayed. Pellets were considered to be decayed when they were not visible, irrespective of the process by which they disappeared (*e.g.* trampling, rolling down slopes or due to rain) (Marques, *et al.* 2001).

4.3.2.3 *Defecation rate of faecal pellet groups*

The defecation rate of six tame rusa deer (*i.e.* three males and three females) confined in small individual enclosures (*i.e.* 16 m²) was determined by counting all the faecal pellet groups produced per deer per day. The faecal pellet groups were counted three times a day (*i.e.* morning, noon and evening) and the enclosures cleaned after

each count (Roques-Rogery 2002; Bergon 2004). The study was done during three periods, the 18th to 28th of February 2002, the 25th of March to 25th of April 2002, and the 20th to 29th of April 2004 (Roques-Rogery 2002; Bergon 2004).

4.3.3 Subjective ranking of rusa deer density

Four experts with knowledge of the various study sites were asked to rank the sites according to rusa deer density (rank 1 = lowest density; rank 6 = highest density). To obtain a rank score for each site, the ranks of each expert were summed per site and the total used to rank the sites from lowest to highest.

4.3.4 Statistical analysis

The results obtained from each method were compared with correlation analysis using the software SPSS 9.0. For all the tested correlations, a Pearson test was used, except for the correlations including the subjective ranking of rusa deer density where the Spearman rank test was used.

4.4 Results

4.4.1 Direct census

4.4.1.1 *Spotlight counts*

The highest deer density was recorded in Pointe Maa (1.17 deer/ha) whereas the lowest density was recorded in Gouaro Deva Nord (0.03 deer/ha) (Table 4.2). The Pointe Maa density was almost double that of the second highest estimate at Gouaro Deva Sud (0.54 deer/ha). Of the estimates Gouaro Deva Nord had the highest coefficient of variation (44.89%) that was almost double the second highest one in Montagnès (23.05%). The lowest coefficient of variation was in Point Maa (14.12%) (Table 4.2).

Table 4.2: Rusa deer density per study site estimated from spotlight counts done during the 2005/2006 dry season (October to February).

Site	Number of observations	Estimated density of deer (deer/ha)	Coefficient of variation (%)	df	95% confidence interval	
					Lower	Upper
Gouaro Deva Nord	9	0.03	44.89	19.28	0.01	0.07
Gouaro Deva Sud	96	0.54	19.98	24.38	0.36	0.82
Montagnès	51	0.30	23.05	14.19	0.19	0.49
Pointe Maa	171	1.17	14.12	78.85	0.89	1.55

4.4.1.2 Drive counts

The deer density is higher in Mèpouiri (0.66 deer/ha) than in Beaupré (0.39 deer/ha). Compared to the other four sites where the deer densities have been estimated from spotlight counts data, the densities found from the drive count in these two exclosures plots seem high (Table 4.3).

Table 4.3: Rusa deer density per study site estimated from drive counts done during the 2005/2006 dry season (October to February).

Site	Number of replicates	Estimated density of deer (deer/ha)	Mean number of deer	95% confidence interval	
				Lower	Upper
Beaupré	2	0.66	4.00	-1.88	9.88
Mèpouiri	2	0.39	3.00	1.04	4.96

4.4.2 Indirect census – faecal standing crop method

4.4.2.1 Number of faecal pellet groups per hectare

The highest numbers of faecal pellet groups/ha were recorded in both Gouaro Deva Nord and Sud (8343.95 and 7402.69 faecal pellet groups/ha respectively), and these were almost double that of the next highest number of faecal pellet groups/ha that was found in Pointe Maa (4182.59 faecal pellet groups/ha). The lowest number of faecal pellet groups/ha was found in Montagnès (3397.03 faecal pellet groups/ha) (Table 4.4).

Table 4.4: Total number of faecal pellet groups/ha in six sclerophyll forest sites (n = number of plots).

Sites	n	Total number of faecal pellet groups/ha	Mean number of faecal pellet groups per plot	95 % confidence interval	
				Lower	Upper
Beaupré	450	3665.96	1.15	1.04	1.26
Gouaro Deva Nord	450	8343.95	2.62	2.47	2.77
Gouaro Deva Sud	450	7402.69	2.32	2.17	2.47
Mépouiri	450	3467.80	1.09	0.99	1.19
Montagnès	450	3397.03	1.07	0.96	1.18
Pointe Maa	450	4182.59	1.31	1.20	1.43

4.4.2.2 Decay rate of faecal pellet groups

It took a mean of 226.6 days for faecal pellet groups to decay in the forest site of Pointe Maa (Table 4.5).

Table 4.5: The mean decay rate of faecal pellet groups in the sclerophyll forest of Pointe Maa.

Site	Number of replicates	Mean (days)	95% confidence interval	
			Lower	Upper
Pointe Maa	18	226.6	195.7	257.5

4.4.2.3 Defecation rate of faecal pellet groups

The mean defecation rate observed in Port Laguerre of captive rusa deer was 6.47 faecal pellet groups per day (Table 4.6).

Table 4.6: Mean defecation rate of captive rusa deer in Port Laguerre.

Site	Number of replicates	Mean (days)	95% confidence interval	
			Lower	Upper
Port Laguerre	204	6.47	5.99	6.94

4.4.2.4 Deer density estimated from the faecal standing crop method

The rusa deer densities in Gouaro Deva Nord and Gouaro Deva Sud (5.69 deer/ha and 5.05 deer/ha respectively) were almost double that of the next highest rusa deer density that was found in Pointe Maa (2.85 deer/ha). The lowest rusa deer density was found in Montagnès (2.32 deer/ha) (Table 4.7).

Table 4.7: Deer density estimated from the faecal standing crop method.

Site	Deer density (number of deer/ha)
Beaupré	2.50
Gouaro Deva Nord	5.69
Gouaro Deva Sud	5.05
Mépouiri	2.37
Montagnès	2.32
Pointe Maa	2.85

4.4.3 Subjective ranking of rusa deer density

The Gouaro Deva sites were rated as having the highest deer densities while the fenced sites of Mépouiri and Beaupré were rated as having the lowest densities (Table 4.8).

Table 4.8: Subjective ranking of rusa deer density (1 = lowest deer density, 6 = highest deer density).

Site	Subjective ranking of rusa deer density
Beaupré	2
Gouaro Deva Nord	6
Gouaro Deva Sud	5
Mépouiri	1
Montagnès	3
Pointe Maa	4

4.4.4 Correlations between methods

There was no correlation between the combined spotlight and drive count estimates and the faecal standing crop estimates ($r = -0.425$, $df = 4$, $P = 0.401$) (Table 4.9; Figure 4.2).

There was no correlation between the combined spotlight and drive count estimates and the subjective ranking of rusa deer density ($r_s = -0.371$, $df = 4$, $P = 0.468$) (Table 4.9; Figure 4.3).

There was a significant correlation between the faecal standing crop estimates and the subjective ranking of rusa deer density ($r_s = 0.829$, $df = 4$, $P = 0.042$) (Table 4.9; Figure 4.4).

Table 4.9: Correlations between the various methods of deer density estimation.

Methods	Correlations
Spotlight and drive counts vs faecal standing crop	$r = -0.425$, $df = 4$, $P = 0.401$
Spotlight and drive counts vs subjective ranking of rusa deer density	$r_s = -0.371$, $df = 4$, $P = 0.468$
Faecal standing crop vs subjective ranking of rusa deer density	$r_s = 0.829$, $df = 4$, $P = 0.042$

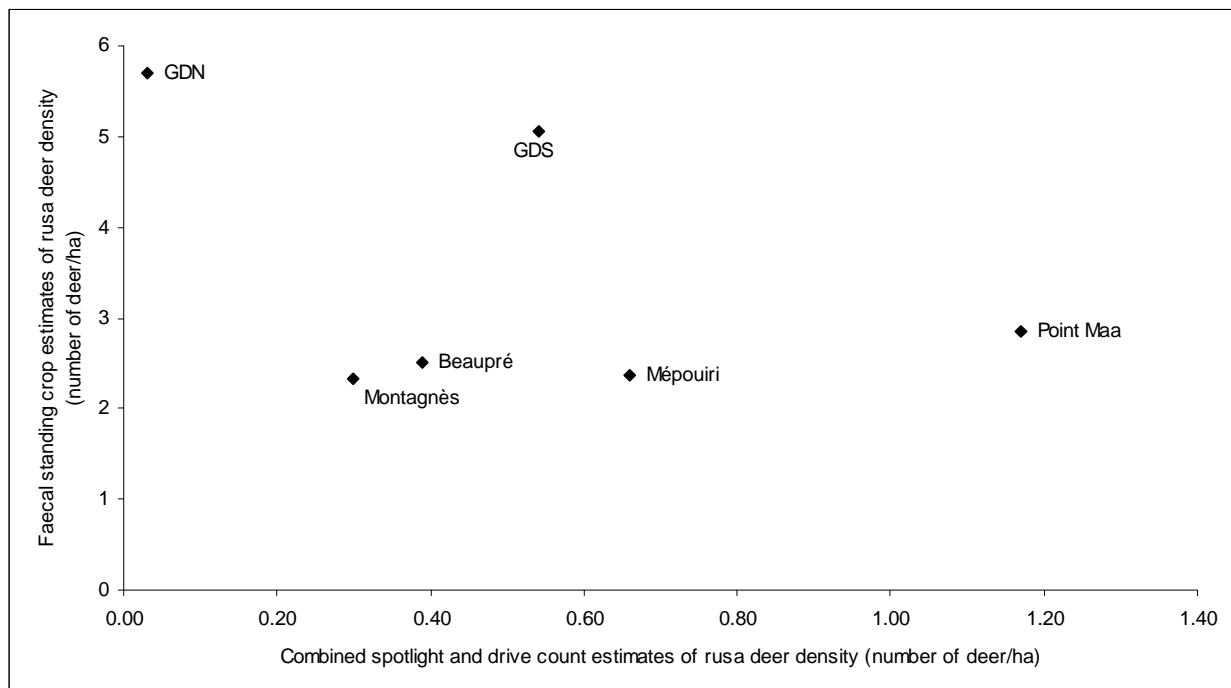


Figure 4.2: Correlation between the combined spotlight and drive count estimates and the faecal standing crop estimates for six sites of sclerophyll forest (the formulae gives no confidence interval for the indirect count).

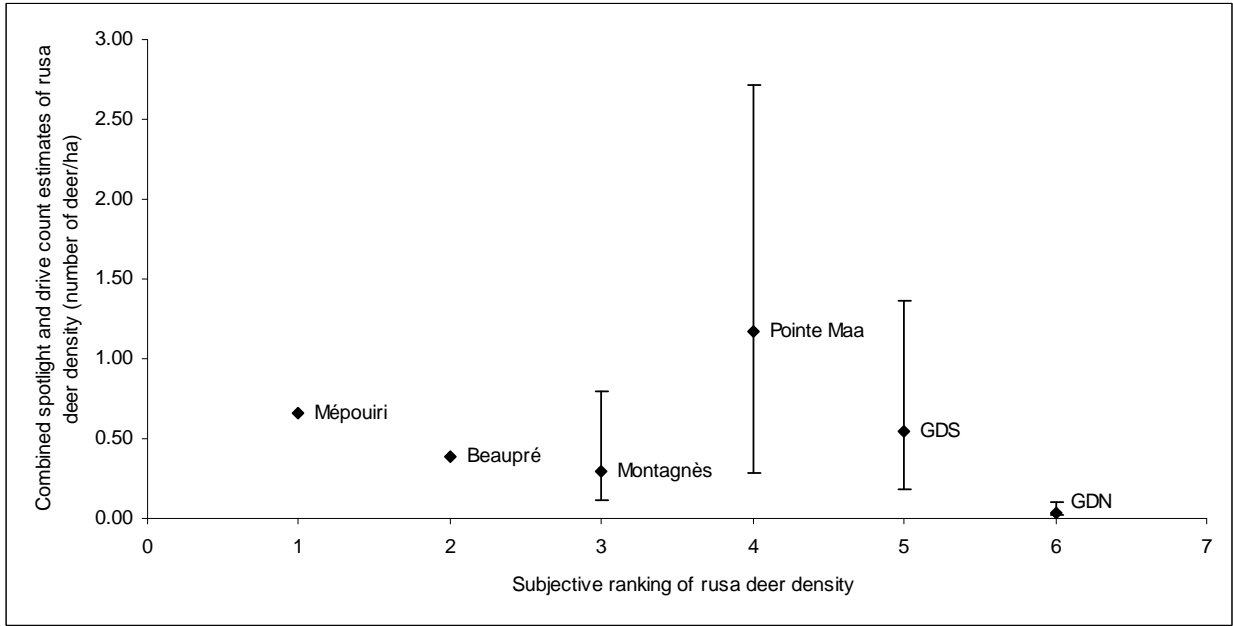


Figure 4.3: Correlation between the combined spotlight and drive count estimates and the subjective ranking of rusa deer density for six sites of sclerophyll forest (no confidence interval for Montagnès and Beaupré as they are total counts).

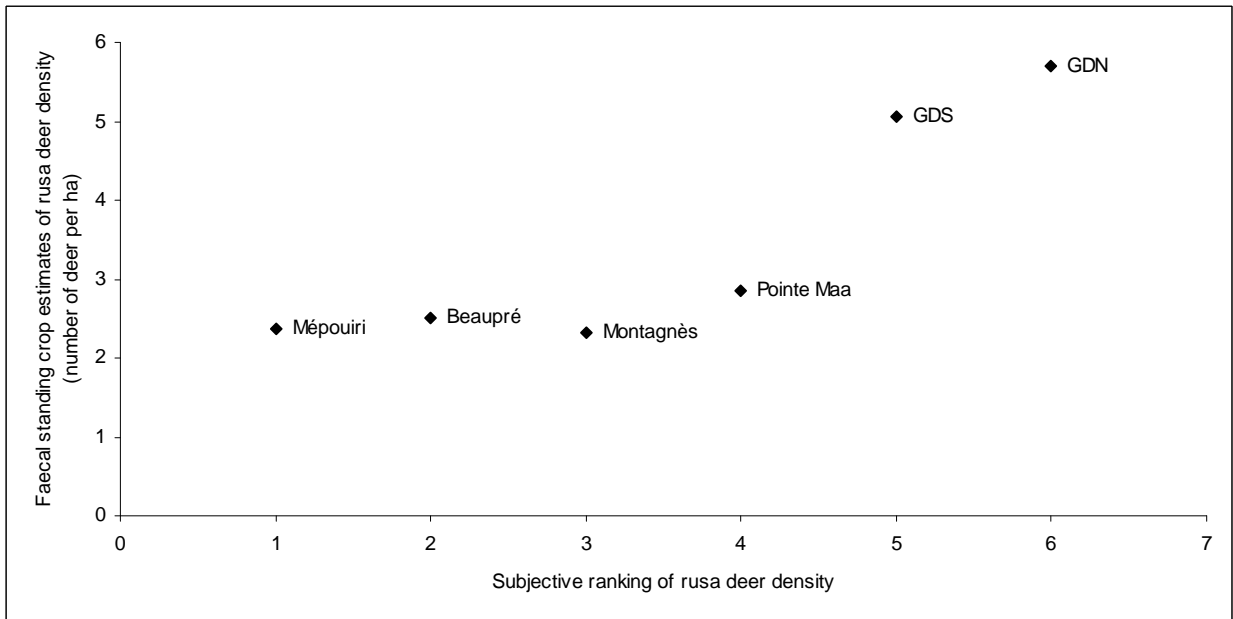


Figure 4.4: Correlation between the faecal standing crop estimates and the subjective ranking of rusa deer density for six sites of sclerophyll forest (the formula gives no confidence interval for the faecal standing crop estimates).

4.5 Discussion

The rusa deer densities estimated from the spotlight and drive counts were two to three times lower than the rusa deer densities estimated from the faecal standing crop method and these estimates were not correlated. Fuller (1991) tested the correlation between faecal pellet group counts and an aerial survey for white-tailed deer (*Odocoileus virginianus*). Fuller (1991) found no significant correlation between the two estimates and suggested that faecal pellet group counts may not be useful for monitoring wild deer population trends. However, White (1992) pointed out that the sample size used by Fuller (1991) was low ($n = 5$) and the power of the test therefore low, and that the conclusions of Fuller (1991) are therefore not valid. Similarly, the sample size of six sites in my study is small and is an important limitation of my study. However, time and practicability did not allow me to increase the sample size for the study. Interestingly, estimates from the faecal standing crop method had a low confidence interval (*i.e.* ranking from ± 0.10 to ± 0.15) and were positively correlated with the subjective ranking of rusa deer density across the study sites, while the spotlight count (*i.e.* coefficient of variation ranking from 44.89% to 14.12%) and drive count (*i.e.* ± 5.88 in Beupré; ± 1.98 in Mèpouri) estimates had high confidence intervals and were not correlated with the subjective ranking of rusa deer density. This suggests that as a monitoring tool the former has more promise than the latter and from the results the reliability of the latter is questionable as they appeared to suffer from a number of shortcomings discussed below.

To be reliable, spotlight counts have to be done under the same conditions (*e.g.* vegetation type, season, data collector, undisturbed areas) (McCullough 1982). Indeed, spotlight counts generally underestimate the true density of animals (Le Bel, *et al.* 1999). The heterogeneity of the vegetation between the six study sites may be one of the main causes of bias in these estimates. As the vegetation changes, deer detection changes, as well as the escape routes of the deer (McCullough 1982; Baddeley 1985; Forsyth and Scroggie 2003). In Pointe Maa, where the highest deer density was found (1.17 deer/ha), the vegetation was more open and it was easier to detect animals than in Montagnès where the vegetation was thicker and where the second lowest deer density was found (0.30 deer/ha).

Deer are likely to move away from the observer before being detected (Forsyth and Scroggie 2003). This is increased in areas where hunting pressure is high. In New Caledonia, poaching of deer is common and most of poachers use spotlights to

increase the efficiency of the hunt (Le Bel, *et al.* 1999; de Garine 2002; de Garine-Wichatitsky and Saint-Andrieux 2003). This can be a major source of bias as the deer associate spotlights with hunters and move into cover to avoid spotlights (Mayle, *et al.* 1999; Fraser and Burrows 2000). In both the Gouaro Deva sites, poaching is high (Blancher pers. comm. 2006) and avoidance of spotlights may explain the low density of deer recorded here, while the rusa deer density estimated from the faecal standing crop method and from the subjective ranking of rusa deer density appears to be high. In Pointe Maa, the high deer density (1.17 deer/ha) may also reflect the low poaching pressure (*i.e.* spotlight hunting) that is the result of an efficient fence and regular surveillance. The lowest density found in Gouaro Deva Nord (0.03 deer/ha) is questionable because of the low number of observations (9 observations). Indeed, Buckland *et al.* (2001) recommend a minimum of 40 observations to ensure a robust model of animal detection probability.

Deer spatial organisation can vary daily (*e.g.* feeding), seasonally (*e.g.* reproduction) and occasionally (*e.g.* hunting) (McCullough 1982; Mandujano and Gallina 1995; Mayle, *et al.* 1996; Fraser and Burrows 2000). As all spotlight counts in each site were not done during the same period, deer may have moved from one habitat to another, introducing bias into these estimates.

The estimates obtained from the drive counts seem high because the drive counts have been done in two enclosure plots where no rusa deer were supposed to occur. However, in small areas drive counts are more reliable and give better estimates than spotlight counts (Mayle, *et al.* 1999). Therefore, the estimates found from drive counts should be more reliable than the estimates found from spotlight counts. The high densities of rusa deer found in the two enclosure plots may be high due to an inefficient fence that let the deer getting into the enclosure plots. Moreover, drive counts are also subjected to biases. Only five drivers using dogs were used and at the end of the drive only one counter counted the deer passing. Previous drive counts have shown that many people are needed (40 - 120 people according to the size of the study site) (Bothma 1996; Mayle, *et al.* 1999). Unfortunately, in both study sites, the owners of the sites did not want other people on their property and drive counts were done with their employees. This made deer detection difficult because of the thick vegetation cover in the enclosures and because of the cryptic behaviour of the rusa deer during daytime (Mayle, *et al.* 1999). Indeed when alerted, deer may lie down in a thick cover and it is possible to walk past and not detect them (Semiadi, *et al.* 1994).

Two drive counts were done in the Beaupré and Montagnès sites. It would have been better to increase the number of drives to increase the reliability of the results. Unfortunately, the availability of the owners and their employees limited the number of counts.

The Beaupré and Montagnès sites were fenced to exclude deer from the sites. However, the efficiency of the fence was not guaranteed, especially in Beaupré where one section of the fence was open and allowed the deer to move in and out of the enclosure plot. This may explain the high confidence interval found in Beaupré (± 5.88) compared to Mèpouiri (± 1.96) where access was more limited.

The rusa deer densities estimated from the faecal standing crop method appear to be high (2.3 - 5.69 deer/ha). Indeed, during a study on the west coast of Grande Terre in 1999, the maximum rusa deer density estimated from spotlight counts was 1.22 ± 0.24 deer/ha, and this has been defined as a high rusa deer density (Le Bel, *et al.* 1999). Possible bias in the faecal standing crop method should also be taken into consideration. By this method, it is necessary to determine the decay rate and the defecation rate of the rusa deer. Decay rate varies according to many biotic and edaphic factors such as season, weather, habitat and diet (Mayle, *et al.* 1999; Nchanji and Plumptre 2001; Laing, *et al.* 2003; Chapman 2004). It is therefore difficult to use decay rate to obtain reliable results and Nchanji and Plumptre (2001) recommend developing other methods such as index methods. No decay rates have been estimated for rusa deer or any other species of deer in sclerophyll forests. Compared to the decay rate of roe deer (*Capreolus capreolus*) (138 days to decay) found in dry woodland (the closest biome to sclerophyll forest available in publications) (Mayle, *et al.* 1999), the decay rate found for rusa deer in sclerophyll forests is almost twice as long (226.6 days to decay) (Table 4.10). Decay rates vary according to habitat (Mayle, *et al.* 1999; Nchanji and Plumptre 2001; Laing, *et al.* 2003) because deer diet varies according to the vegetation available in the habitat, but also because of the moisture content of the soil and of the leaf cover that determine the microbial and invertebrate density that influence the decay rate (Mayle, *et al.* 1999; Nchanji and Plumptre 2001; Laing, *et al.* 2003). For example, fallow deer (*Dama dama dama*), faecal pellet groups took 46 days longer to decay in dry conifer pole-stage (265 days to decay) than in dry mature broadleaf (219 days to decay) (Table 4.10) (Mayle, *et al.* 1999). Similarly, sika deer faecal pellet decay rate was almost twice as long in moist conifer pole-stage (219 days to decay) than in moist conifer pre-thicket (134 days to decay) (Table 4.10) (Mayle, *et al.* 1999). The decay rates between my sites probably differed because even though

they were sclerophyll forests, there were variations in forest composition and structure. It is therefore important that future studies estimate the decay rate for each of the study sites.

Table 4.10: Decay rate of five deer species according to the vegetation type and/or maturity of the vegetation (from Mayle *et al.* 1999).

Deer species	Vegetation type	Decay rate (days)
Red deer (<i>Cervus elaphus scoticus</i>)	Dry conifer thicket	106
	Dry conifer pre-thicket	96
Roe deer (<i>Capreolus capreolus</i>)	Dry woodland	138
	Dry conifer thicket	91
Sika deer (<i>Cervus nippon nippon</i>)	Moist conifer pre-thicket	134
	Moist conifer pole-stage	219
Muntjac deer (<i>Muntiacus muntjak reevesi</i>)	Dry conifer thicket	99
	Dry conifer pole-stage	102
Fallow deer (<i>Dama dama dama</i>)	Dry conifer pole-stage	265
	Dry mature broadleaf	219

Except for my study, the defecation rate of rusa deer has never been estimated and my results can not be compared to other sites. However, compared to other deer the defecation rate of rusa deer is the lowest (6.47 faecal pellet groups/day) (Table 4.11).

Table 4.11: Defecation rate of eight deer species (animal weight is for an adult male).

Deer species	Animal weight (kg)	Defecation rate (number of faecal pellet groups per day)
Axis deer (<i>Axis axis</i>)	80-110	28.0 (Dinerstein and Dublin 1982)
Fallow deer (<i>Dama dama dama</i>)	80-120	21.4 (Mayle, <i>et al.</i> 1996; Mayle, <i>et al.</i> 1999)
		11.3 (Bailey and Putman 1981)
		26.5 (Massei and Genov 1998)
Hog deer (<i>Axis porcinus</i>)	36-55	20.3 (Dhungel 1985)
Muntjac (<i>Muntiacus muntjak reevesi</i>)	10-15	7.5 (Mayle, <i>et al.</i> 1999)
		7.0-8.2 (Chapman 2004)
Red deer (<i>Cervus elaphus scoticus</i>)	150-250	25.0 (Mayle, <i>et al.</i> 1999)
Roe deer (<i>Capreolus capreolus</i>)	20-25	20.0 (Mayle, <i>et al.</i> 1999)
		17.0 (Mitchell, <i>et al.</i> 1985)
Sika deer (<i>Cervus nippon nippon</i>)	50-65	25.0 (Mayle, <i>et al.</i> 1999)
White-tailed deer (<i>Odocoileus virginianus</i>)	80-120	33.0 (Fuller 1991)

The lowest defecation rate reported is for the muntjac (*Muntiacus muntjak reevesi*). However, muntjacs are smaller (10-15 kg) than rusa deer (150 kg) and the size and weight of species influences the defecation rate (Smith 1964; Rogers 1987).

Rusa deer defecation rates are three to five times lower than other deer species of the approximately same size (de Garine-Wichatitsky, *et al.* 2004d). Defecation rates vary according to many biotic and edaphic factors such as season, food quality, habitat, activity, sex and age class (Irby 1981; Mayle, *et al.* 1996; Mayle, *et al.* 1999; Roques-Rogery 2002). Defecation rate also varies from captive deer to wild deer (Neff 1968; Rogers 1987) because activity stimulates defecation rate (Irby 1981; Rollins, *et al.* 1984). Therefore, lower values are found in experiments conducted with tame deer in captive conditions where the activity is reduced (Massei and Genov 1998; Chapman 2004).

Decay rate and defecation rate are the two factors essential to estimate the density of deer populations (Smith 1964; Mayle, *et al.* 1996; Mayle, *et al.* 1999; Laing, *et al.* 2003). If these factors are not accurate, the deer densities estimated will not be accurate. In the case of my study, the overestimation of the rusa deer population appears to result from the biases due to the inaccuracy of the decay rate and the defecation rate. More studies have to be done in New Caledonian sclerophyll forests to increase the accuracy of the decay rate and the defecation rate and therefore of the faecal standing crop method.

Biases can result from the recording of the faecal pellet groups due to the habitats that can make the detection of the faecal pellet groups difficult (*e.g.* leaves, rocks, branches) (Bailey and Putman 1981; Putman 1984; Forsyth, *et al.* 2007), but also due to data collection that can be subjected by the fatigue, boredom and visual acuity of the recorder (Dhungel 1985; Campbell, *et al.* 2004; Forsyth, *et al.* 2007). The data collection should be done in the most similar conditions as possible.

Spotlight and drive counts as well as the faecal standing crop method were unreliable in my study, mainly due to biases, and were expensive to implement and required a large amount of time. However, even if the rusa deer densities estimated from the faecal standing crop method were high, this method showed promise because the coefficients of variation were low and it was correlated with the subjective ranking of rusa deer densities. The main problem was the validation of a reliable decay rate and defecation rate. I would recommend using the faecal standing crop method to monitor the rusa deer population trends in the New Caledonian forests but I would not recommend the faecal standing crop method to estimate rusa deer densities except if the decay rate and the defecation rate can be evaluated accurately.

Chapter 5: Evaluation of three indices to assess rusa deer trends: the faecal pellet groups index, the browsing index and the antler rubbing index

5.1 Introduction

To ensure efficient environmental management, it is important to consider the changes in herbivore populations and habitat features as well as their interactions (Bradshaw, *et al.* 2003; Keith and Pellow 2005; Morellet, *et al.* 2007). In New Caledonia, rusa deer impact negatively on the sclerophyll forests as they browse most of the browse species (Bouchet, *et al.* 1995; Rouys and Theurerkauf 2003; de Garine-Wichatitsky, *et al.* 2004b). It is therefore important to be able to follow the trends of the rusa deer populations in New Caledonian the sclerophyll forest (de Garine-Wichatitsky, *et al.* 2004b), in order to adjust the off take of deer through hunting operations.

Deer census methods typically show low reliability (Morellet, *et al.* 2001) and the results presented in Chapter 4 confirms this for New Caledonia. This precludes their use as management tools. New tools are therefore required to monitor the rusa deer population trends in New Caledonian sclerophyll forests (de Garine-Wichatitsky and Saint-Andrieux 2003).

When an herbivore population increases in abundance, the environment is expected to change due to the impact of the population (Morellet, *et al.* 2001; Wardle, *et al.* 2001; Dulloo, *et al.* 2002; Keith and Pellow 2005). Indices which are is defined as “any measurable correlative of density” (Forsyth, *et al.* 2007), are a set of indicators which describe the relation between the ungulate population and its habitat (Groupe-Chevreuil 1996), and allow the manager to follow population trends of the ungulate population within the environment (Boiseaubert, *et al.* 1990). Indices are easy to measure, sensitive to stresses on the system, reliable and give early warning signs of ecological changes (Dale and Beyeler 2001; Morellet, *et al.* 2001; Morellet, *et al.* 2007). Indices such as the faecal pellet groups index, the browsing index and the antler rubbing index are indices that could reliably track variations of rusa deer populations in New Caledonian sclerophyll forests.

Faecal pellet groups are one of the most obvious signs of deer presence in an area (Mayle, *et al.* 1999). This index has already been used in Europe and in New Zealand and is considered a reliable tool to monitor changes in deer abundance (Mayle, *et al.* 1999; Forsyth, *et al.* 2007). The browsing index is one of the most commonly used of the indices and has been shown to be reliable to follow roe deer population trends and their impact on the vegetation in European forests (Aldous 1944; Boiseaubert, *et al.* 1990; Morellet, *et al.* 2001; Morellet, *et al.* 2003; Morellet, *et al.* 2007). Few studies have been done on antler rubbing per se and to my knowledge there are no publications relating the use of a quantitative estimation of these marks as an index of deer local abundance. However, antler rubbings also indicate the presence of deer in an area and could be used as an index (Mayle, *et al.* 1999).

The objectives of this study are to evaluate the use of three indices within six study sites to manage the rusa deer population in New Caledonian sclerophyll forests: (a) the faecal pellet groups index, (b) the browsing index and (c) the antler rubbing index. Correlations between these three indices will be tested against each other and against the rusa deer densities estimated from direct census methods and the subjective ranking of rusa deer density described in Chapter 4. The faecal standing crop method described in Chapter 4 is derived from faecal pellet group counts and related to the faecal pellet groups index and therefore not referred to in this chapter.

5.2 Study site

Refer to Chapter 2.

5.3 Methods

The survey procedure is explained in detail in Chapter 3. Thirty random points within each of the study sites were used to sample each study site (Forsyth and Scroggie 2003). Each of these points was the starting point of a transect. Along each transect, 15 plots (2 m in diameter - 3.14 m²) were sampled as described below.

5.3.1 Faecal pellet groups index

The survey procedure is explained in detail in Chapter 3. In each plot, all intact faecal pellet groups situated on the surface litter were recorded, but if less than half of a faecal pellet group was inside a plot, it was not recorded (Forsyth and Scroggie 2003). A faecal pellet group was characterised by pellets with the same colour, texture and decay rate, and consisted of a minimum of 10 pellets (de Garine-Wichatitsky, *et al.* 2004a). Data collection was not done on rainy days as it made pellet classification difficult and inaccurate (Forsyth and Scroggie 2003). The study was done during the 2005/2006 dry season (*i.e.* October to February). For each site, the index was calculated as the mean number of faecal pellet groups per plot.

5.3.2 Browsing index

A list of indicator browse species have been established from previous studies on the ecology and the impact of rusa deer on the sclerophyll forests (de Garine-Wichatitsky, *et al.* 2004a). These species were chosen according to their palatability, ecological importance and invasive status (de Garine-Wichatitsky, *et al.* 2004a). Eighteen browse species chosen according to these criteria were used for the data collection in the six study sites, but browse species relevant to a particular site (*e.g.* endemism, rarity) were also added to the list (*e.g.* *Ochrosia inventorum* which is endemic to Pointe Maa) (Table 5.1).

In each plot, the presence of all indicator species was recorded and if the species was browsed or not (Morellet, *et al.* 2001). A plant was recorded as browsed if teeth marks were present on the plant. It was difficult to distinguish between recent and old browse marks and all browse marks were therefore considered browsing (Morellet 1998). Data collection (*i.e.* recording of browse marks) was done below the rusa deer browsing line (*i.e.* 1.80 m) (Le Bel, *et al.* 1999; de Garine-Wichatitsky and Chardonnet 2001). Browse species occurring in all six sites were grouped into three groups according to their palatability (Table 5.1): (a) very palatable, (b) palatable and (c) unpalatable (de Garine-Wichatitsky, *et al.* 2004a).

Table 5.1: Browse species recorded in the study sites (B - Beaupré; GDN - Gouaro Deva Nord; GDS - Gouaro Deva Sud; Me - Mèpouiri; Mo - Montagnès; PM - Pointe Maa) and their palatability (+++ - very palatable; ++ - palatable; + - unpalatable) (* - species relevant to one or few sites).

Browse species	Growth form	Palatability	Sites
<i>Acacia farnesiana</i>	Tree	++	B, GDN, GDS, Me, Mo, PM
<i>Acacia spirorbis</i>	Tree	++	B, GDN, GDS, Me, Mo, PM
<i>Ageratum conizoides</i>	Creeper	+	B, GDN, GDS, Me, Mo, PM
<i>Albizia guillainii</i> *	Tree	+++	B, Me, PM
<i>Archidendropsis paivana</i> *	Tree	++	B, Me
<i>Capparis artensis</i>	Creeper	++	B, GDN, GDS, Me, Mo, PM
<i>Captaincookia margaretae</i> *	Tree	+	B, Me
<i>Carissa ovata</i>	Shrub	++	B, GDN, GDS, Me, Mo, PM
<i>Codiaeum peltatum</i> *	Tree	+	B, GDN, GDS, Me, Mo
<i>Desmanthus virgatus</i>	Creeper	+++	B, GDN, GDS, Me, Mo, PM
<i>Diospyros sp.</i> *	Tree	+	B, GDN, GDS, Me
<i>Dysoxylum bijugum</i>	Tree	+	B, GDN, GDS, Me, Mo, PM
<i>Emmenosperma pancherianum</i> *	Tree	++	GDN, GDS, Mo, PM
<i>Eugenia sp.</i> *	Tree	+	B, GDN, GDS, Me, Mo
<i>Indigofera suffruticosa</i>	Shrub	++	B, GDN, GDS, Me, Mo, PM
<i>Jasminum spp.</i>	Creeper	+++	B, GDN, GDS, Me, Mo, PM
<i>Lantana camara</i>	Shrub	+	B, GDN, GDS, Me, Mo, PM
<i>Leucaena leucocephala</i>	Shrub	+++	B, GDN, GDS, Me, Mo, PM
<i>Malaisia scandens</i>	Creeper	++	B, GDN, GDS, Me, Mo, PM
<i>Ochrosia inventorum</i> *	Tree	++	PM
<i>Passiflora suberosa</i>	Creeper	++	B, GDN, GDS, Me, Mo, PM
<i>Phyllanthus deplanchei</i> *	Tree	+++	B, Me, PM
<i>Premna serratifolia</i>	Tree	+++	B, GDN, GDS, Me, Mo, PM
<i>Pseuderanthemum incisum</i>	Shrub	++	B, GDN, GDS, Me, Mo, PM
<i>Sida cordifolia</i>	Shrub	+	B, GDN, GDS, Me, Mo, PM
<i>Solanum pancheri</i>	Shrub	+++	B, GDN, GDS, Me, Mo, PM
<i>Stachytarpheta australis</i>	Creeper	+	B, GDN, GDS, Me, Mo, PM
<i>Streblus pendulinus</i> *	Tree	+++	B, GDN, GDS, Me, Mo
<i>Terminalia cherrieri</i> *	Tree	++	B, Me
<i>Trigonostemon cherrieri</i> *	Tree	++	B, Me
<i>Vitex trifoliata</i> *	Shrub	+	B, GDN, GDS, Me, Mo
<i>Wikstroemia indica</i>	Shrub	+	B, GDN, GDS, Me, Mo, PM

The browsing index was calculated for each site and for each palatability status (*i.e.* very palatable, palatable, and unpalatable). The browsing index was calculated as the number of plots with ≥ 1 browsed species per plot with ≥ 1 recorded plants were present (Morellet, *et al.* 2001). The browsing index (*bi*)

$$bi = nc / np$$

was determined according to the protocol used by Morellet, *et al.* (2001) and the parameters *a* and *b* have to be calculated

$$a = 1 + nc$$

$$b = 1 + np - nc$$

where nc is the number of plots in which browsing was recorded and np is the number of plots in which species were recorded as present. From these two parameters a browsing index and a 95% confidence interval were calculated using the function *high.density.beta3(a,b)* in the software R 2.2.1 (available from <http://cran.r-project.org>).

5.3.3 Antler rubbing index

During the rut between August and September, male rusa deer rub their antlers against trees leaving marks on the bark. This behaviour removes the velvet from the antlers and marks the territory of the male (von Kerckerinck Zur Borg 1987; de Garine-Wichatitsky, *et al.* 2004a). In each plot, the number of antler rubbing marks and the tree species concerned were recorded. Only the clearly identifiable antler rubbing marks were recorded and the marks for which origin was uncertain were ignored (*e.g.* cattle, anthropogenic activities). Marks could not be identified on dead trees and dead trees were therefore ignored (de Garine-Wichatitsky and Spaggiari 2003; de Garine-Wichatitsky, *et al.* 2004a). For each site, the index was calculated as the mean number of antler rubbings per plot.

5.3.4 Statistical analysis

The correlations between the various methods were determined using SPSS 9.0 software. For all the correlations, the Pearson test was used, except for the correlations including the subjective ranking of rusa deer density where the Spearman rank test was used.

5.4 Results

5.4.1 Faecal pellet groups index, browsing index and antler rubbing index

For the faecal pellet groups index, the highest mean faecal pellet groups per plot per site was recorded in the Gouaro Deva Nord (1.33) and Gouaro Deva Sud (1.35) sites and the lowest in the Beaupré site (0.59; Table 5.2).

The browsing index for browse species classified as very palatable was high in all six sites and ranged between 0.99 (Gouaro Deva South and Beaupré) and 0.86 (Gouaro Deva Nord; Table 5.3). The browsing index for palatable species was also relatively high for all sites, varying from 0.89 in Gouaro Deva Nord to 0.64 in Mèpouiri. In contrast to the above, the index for unpalatable species showed a wide range of values and ranged from 0.86 in Gouaro Deva Nord to 0.18 in Mèpouiri (Table 5.3).

The mean number of antler rubbings per plot per site ranged from 0.09 in Gouaro Deva Sud to 0.02 in Pointe Maa (Table 5.4).

Table 5.2: The mean number of faecal pellet groups per plot per site recorded in six sclerophyll forest sites (450 plots) (n = total number of faecal pellet groups per site).

Sites	Mean	95% confidence interval		n
		Lower	Upper	
Beaupré	0.59	0.51	0.67	265
Gouaro Deva Nord	1.33	1.22	1.44	600
Gouaro Deva Sud	1.35	1.24	1.46	609
Mèpouiri	0.64	0.57	0.72	289
Montagnès	0.76	0.67	0.85	343
Pointe Maa	0.71	0.63	0.79	320

Table 5.3: The browsing index (mean and 95% confidence interval) according to the palatability status of the browse species in the six study sites (n = 450 plots).

Sites	Browsing index		
	Very palatable	Palatable	Unpalatable
Beaupré	0.99 (0.97 - 1.01)	0.88 (0.85 - 0.91)	0.45 (0.18 - 0.72)
Gouaro Deva Nord	0.86 (0.82 - 0.90)	0.89 (0.86 - 0.92)	0.86 (0.82 - 0.90)
Gouaro Deva Sud	0.99 (0.97 - 1.01)	0.86 (0.80 - 0.92)	0.58 (0.52 - 0.64)
Mèpouiri	0.90 (0.88 - 0.92)	0.64 (0.61 - 0.67)	0.18 (0.13 - 0.23)
Montagnès	0.96 (0.94 - 0.98)	0.71 (0.67 - 0.76)	0.70 (0.59 - 0.81)
Pointe Maa	0.92 (0.89 - 0.96)	0.88 (0.84 - 0.91)	0.46 (0.40 - 0.52)

Table 5.4: The mean number of rusa deer antler rubbings per plot recorded in six sclerophyll forest sites (450 plots) (n = total number of antler rubbings per site).

Sites	Mean	95% confidence interval		n
		Lower	Upper	
Beaupré	0.04	0.02	0.06	17
Gouaro Deva Nord	0.06	0.04	0.08	25
Gouaro Deva Sud	0.09	0.06	0.12	39
Mépouiri	0.03	0.01	0.05	15
Montagnès	0.04	0.02	0.06	18
Pointe Maa	0.02	0.00	0.04	11

5.4.2 Correlations between methods

There was no correlation between the faecal pellet groups index and any of the browsing indices (*i.e.* very palatable, palatable and unpalatable) (Table 5.5; Figure 5.1) but increased sample size may improve the relation between the former and the browsing index of unpalatable species (Figure 5.1) In contrast, there was a significant positive correlation between the faecal pellet groups index and the antler rubbing index ($r = 0.857$, $df = 4$, $P = 0.029$) (Table 5.5; Figure 5.2). The latter also showed no correlation with any of the browsing indices (*i.e.* very palatable, palatable and unpalatable) (Table 5.5; Figure 5.3) but increased sample size may also improve the relation between the antler rubbing index and the browsing index of unpalatable species (Figure 5.3).

There was no correlation between the faecal pellet groups index and the rusa deer density estimated from the combined spotlight and drive counts in Chapter 4 ($r = -0.430$, $df = 4$; $P = 0.395$) (Table 5.6; Figure 5.4). Similarly, there was no correlation between any of the browsing indices (*i.e.* very palatable, palatable and unpalatable) and the rusa deer density estimated from the combined spotlight and drive counts (Table 5.6; Figure 5.5). There was no correlation between the combined spotlight and drive count estimate of rusa deer density and the antler rubbing density ($r = -0.400$, $df = 4$, $P = 0.432$) (Table 5.6; Figure 5.6).

There was a significant positive correlation between the faecal pellet groups index and the subjective ranking of rusa deer density ($r_s = 0.829$, $df = 4$, $P = 0.042$) (Table 5.7; Figure 5.7). There was also a significant positive correlation between the subjective ranking of rusa deer density and the browsing index of the unpalatable species ($r_s = 0.829$, $df = 4$; $P = 0.042$) (Table 5.7, Figure 5.8). There was no correlation

between the subjective ranking of rusa deer density and the antler rubbing index ($r_s = 0.600$, $df = 4$, $P = 0.208$) (Table 5.7; Figure 5.9).

Table 5.5: Correlations between the faecal pellet groups index, the browsing index and antler rubbing index.

Method	df	Faecal pellet groups index		Antler rubbing index	
		<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Browsing index					
Very palatable	4	-0.177	0.737	0.289	0.579
Palatable	4	0.426	0.400	0.290	0.577
Unpalatable	4	0.662	0.152	0.413	0.415
Antler rubbing index	4	0.857	0.029	-	-

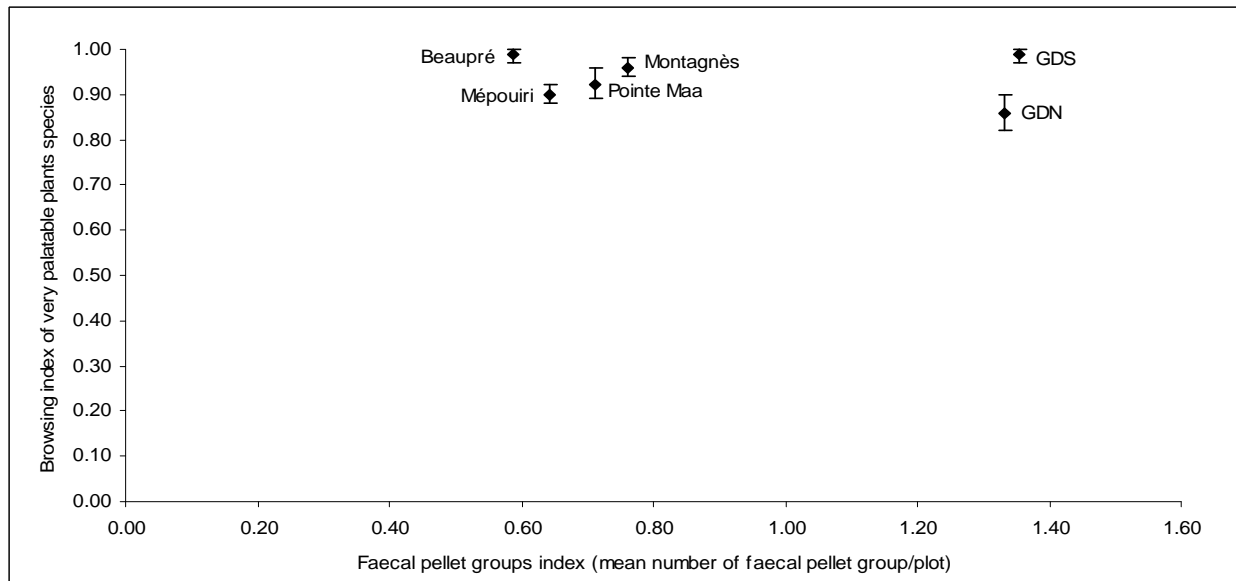
Table 5.6: Correlation between indices and combined spotlight and drive count estimates of rusa deer density.

Method	df	Spotlight and drive count estimates of rusa deer density	
		<i>r</i>	<i>P</i>
Faecal pellet groups index	4	-0.430	0.395
Very palatable	4	0.105	0.842
Browsing index			
Palatable	4	-0.017	0.975
Unpalatable	4	-0.622	0.188
Antler rubbing index	4	-0.400	0.432

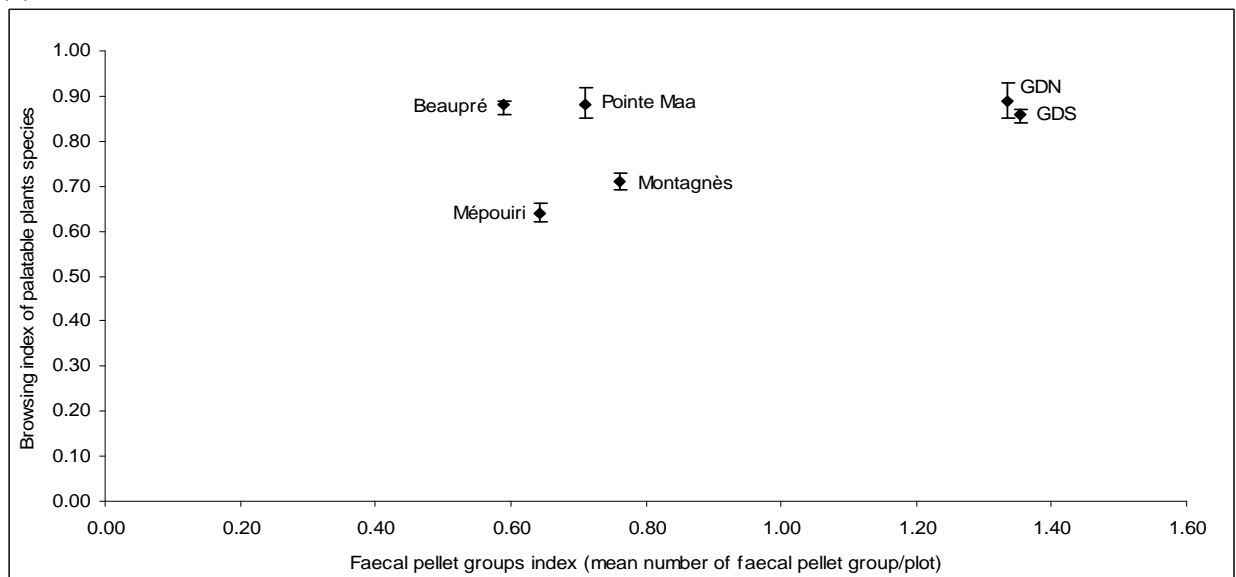
Table 5.7: Correlation between the subjective ranking of rusa deer density and indices.

Method	df	Subjective ranking of rusa deer density	
		r_s	<i>P</i>
Faecal pellet groups index	4	0.829	0.042
Very palatable	4	-0.174	0.742
Browsing index			
Palatable	4	0.677	0.148
Unpalatable	4	0.829	0.042
Antler rubbing index	4	0.600	0.208

(a)



(b)



(c)

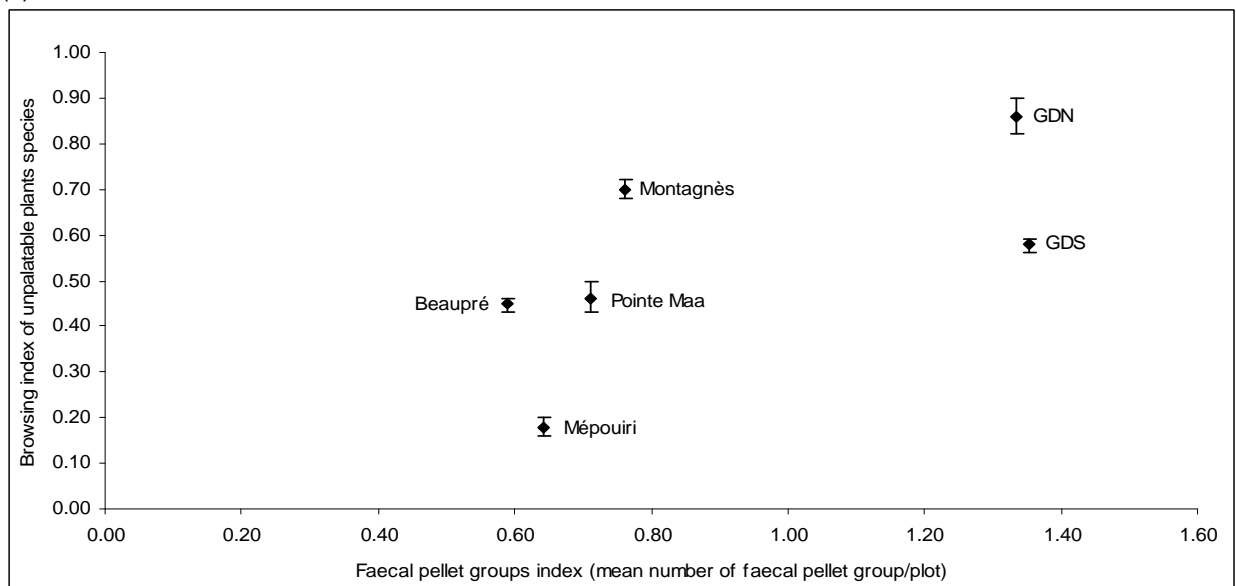


Figure 5.1: Correlation between the faecal pellet groups index and the browsing index for (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).

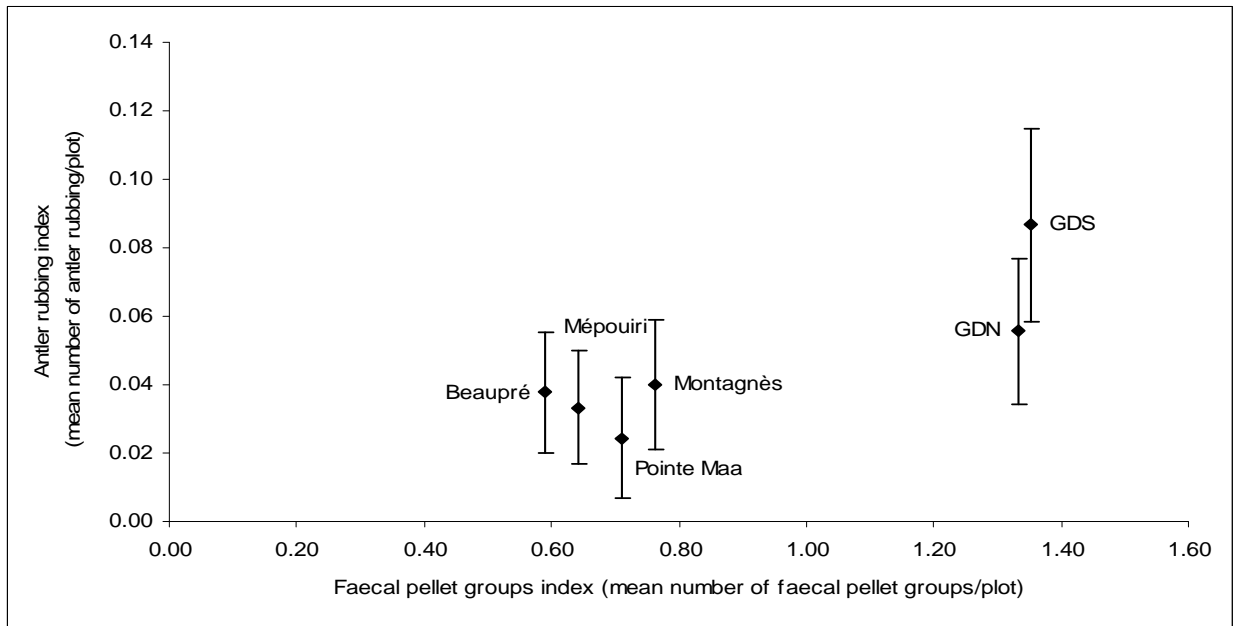
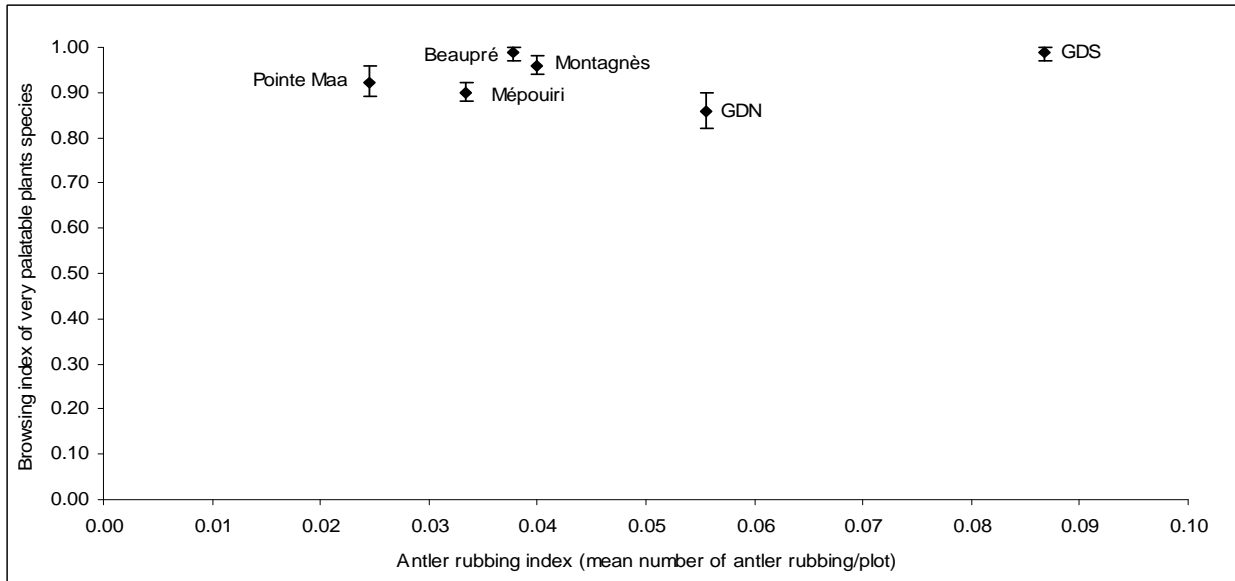
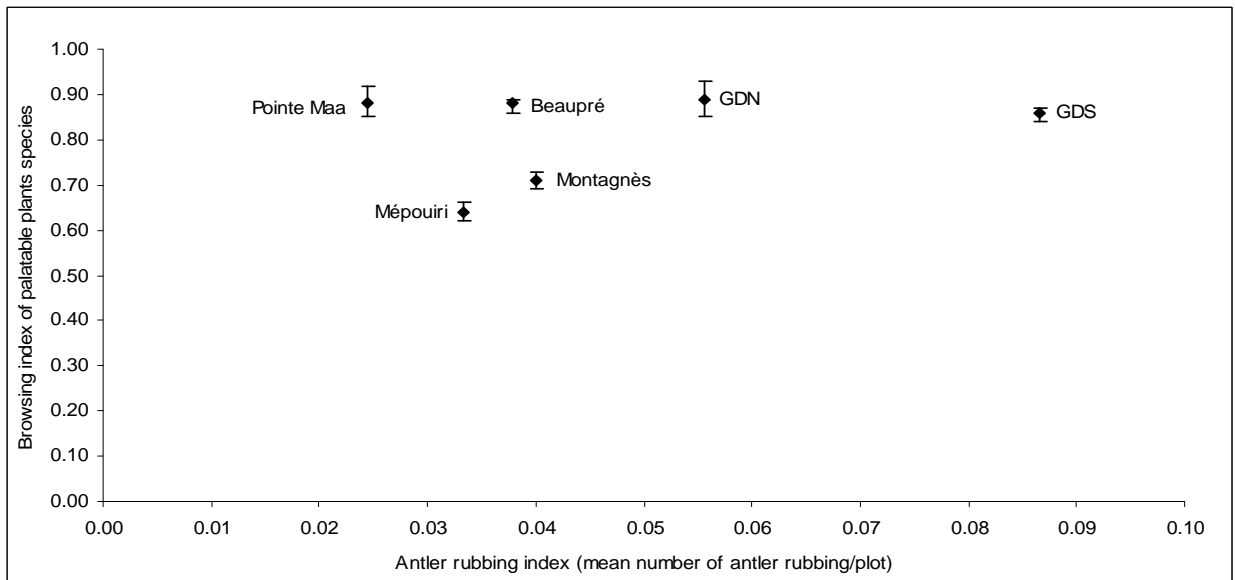


Figure 5.2: Correlation between the faecal pellet groups index and the antler rubbing index for six sclerophyll forests (n = 450 plots).

(a)



(b)



(c)

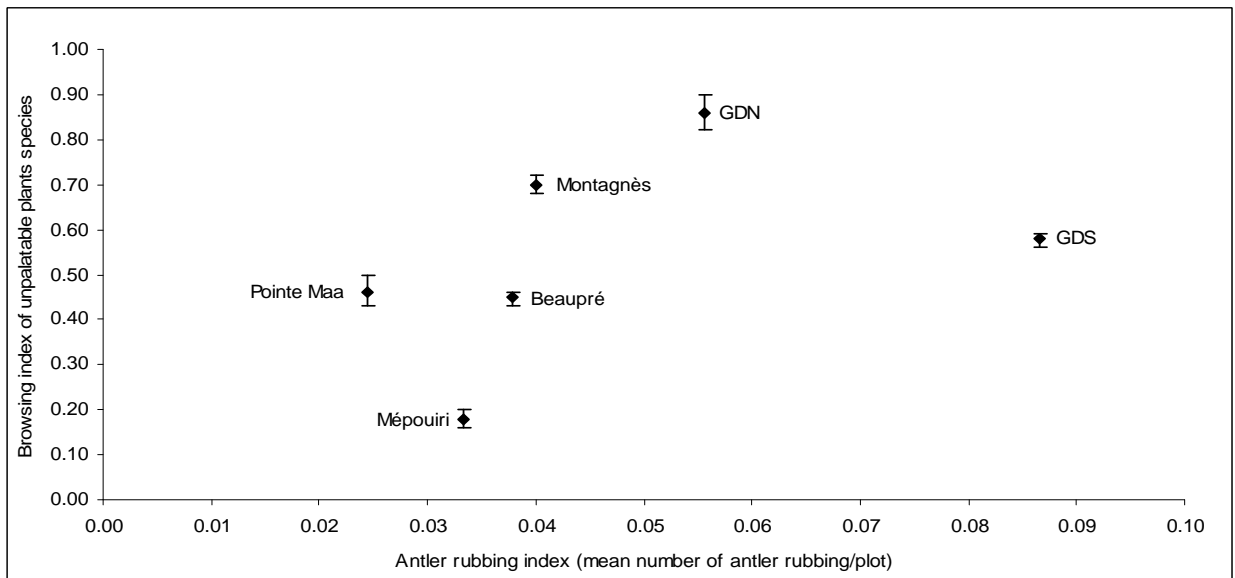


Figure 5.3: Correlation between the antler rubbing index and the browsing index for (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).

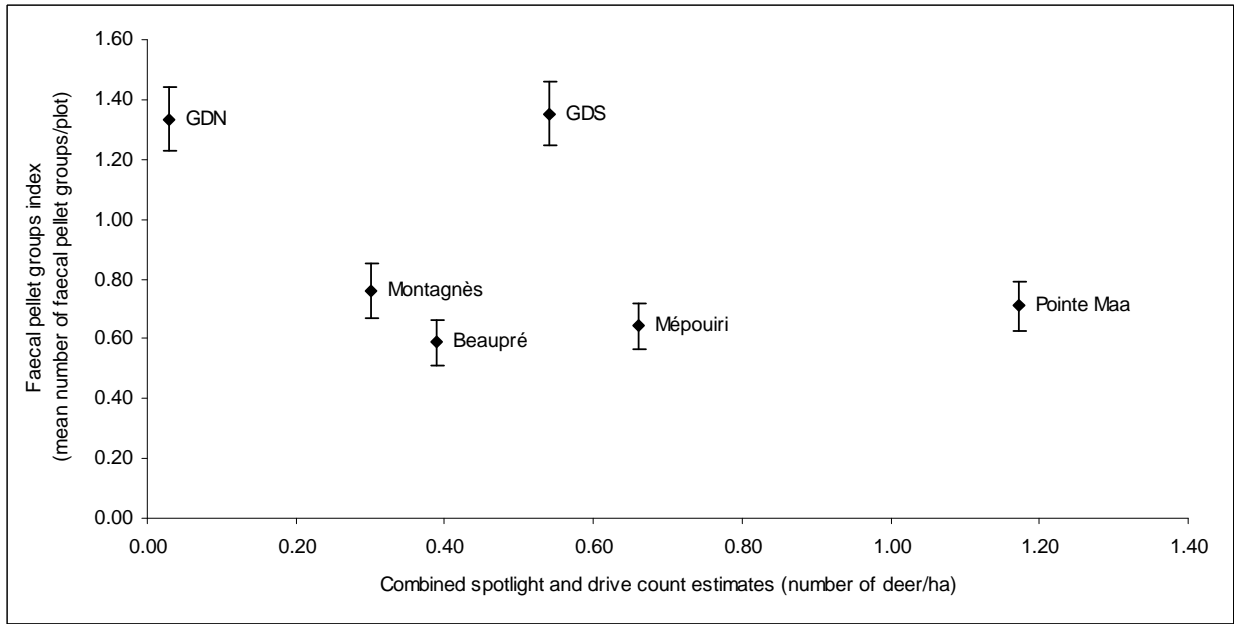
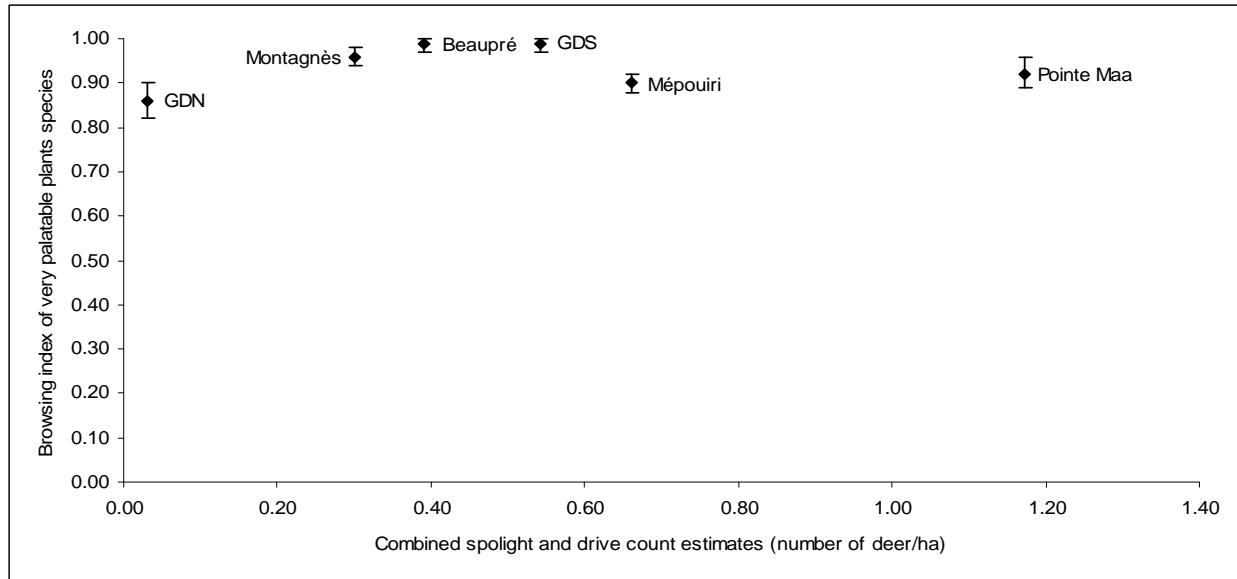
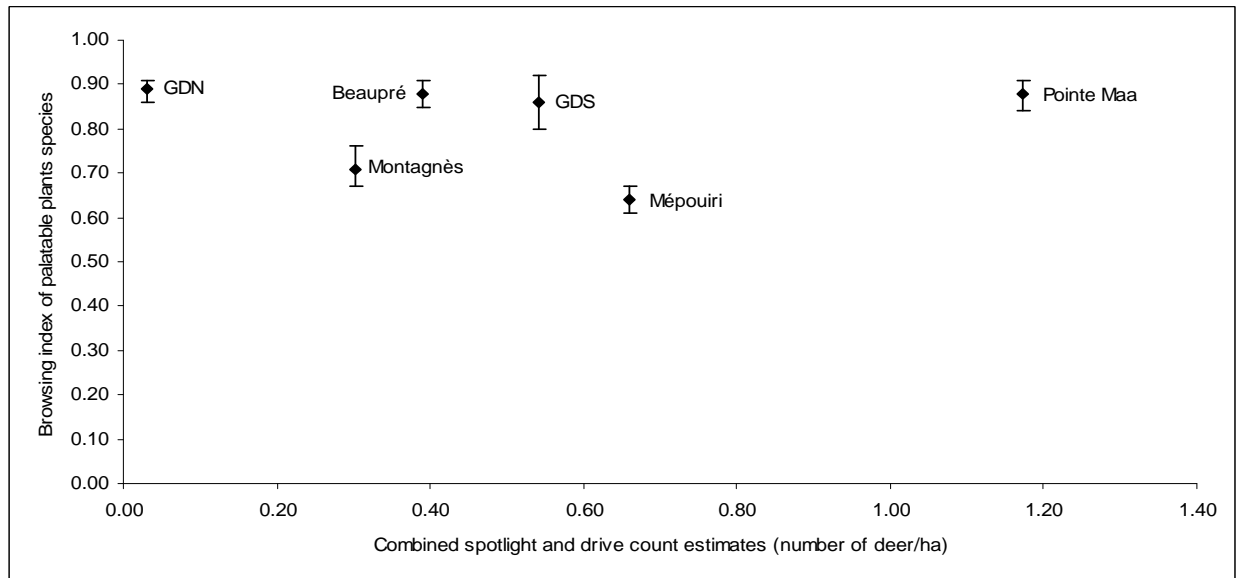


Figure 5.4: Correlation between the combined spotlight and drive count estimates of rusa deer density and the faecal pellet groups index for six sclerophyll forests (n = 450 plots).

(a)



(b)



(c)

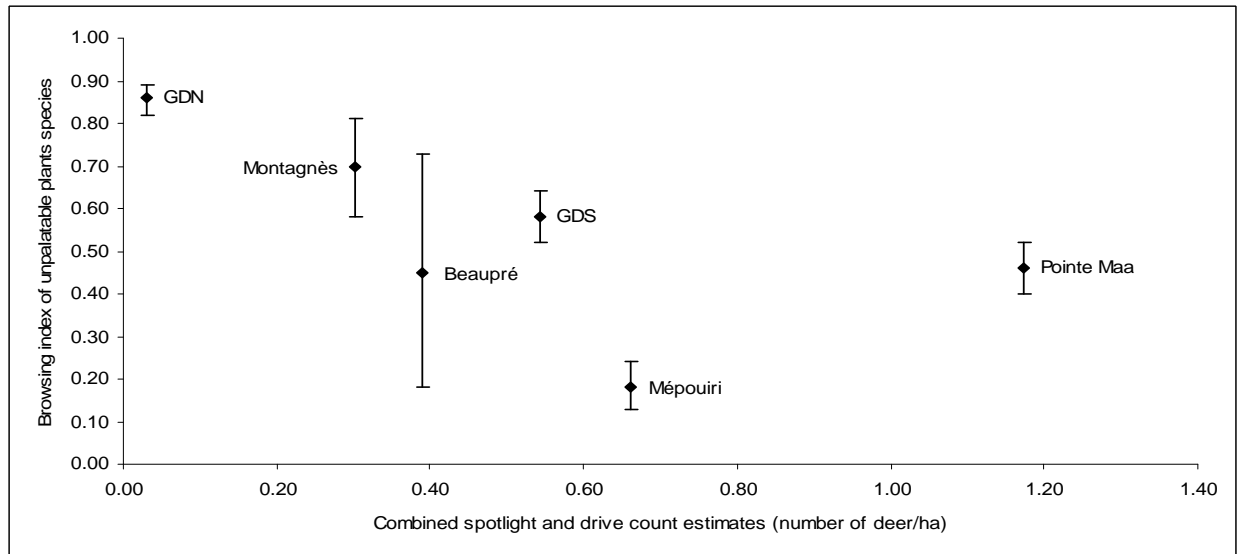


Figure 5.5: Correlation between the combined spotlight and drive count estimates of rusa deer density and the browsing index of (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).

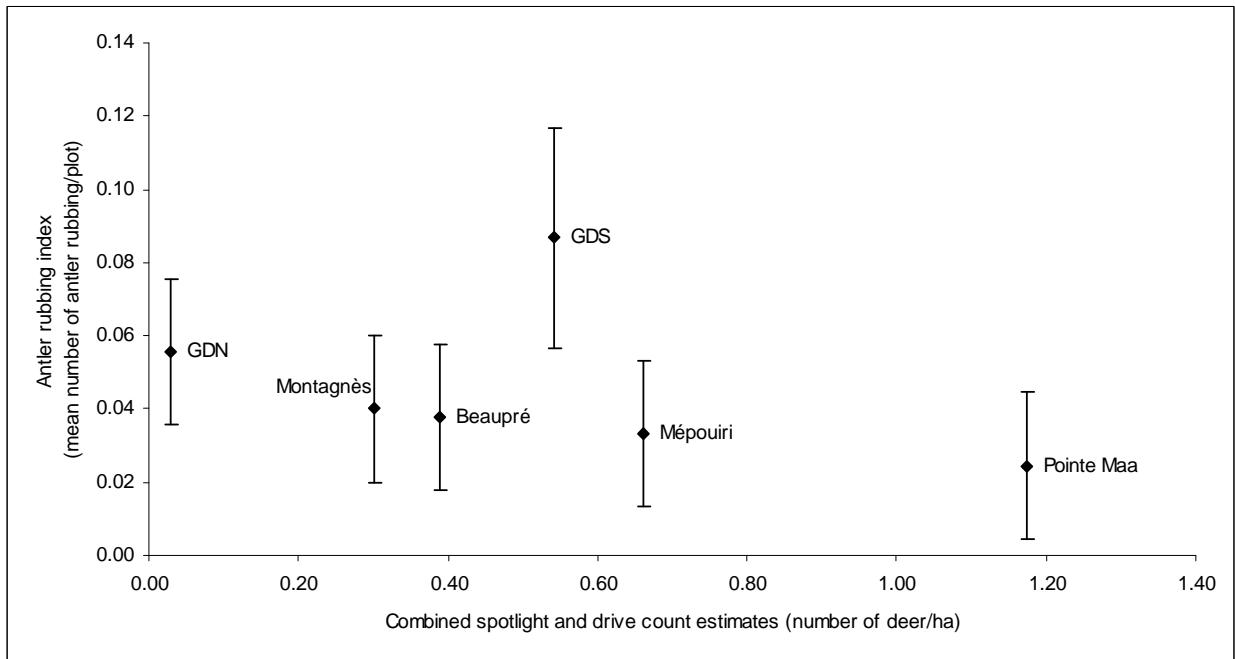


Figure 5.6: Correlation between the combined spotlight and drive count estimates of rusa deer density and the antler rubbing index for six sclerophyll forests (n = 450 plots).

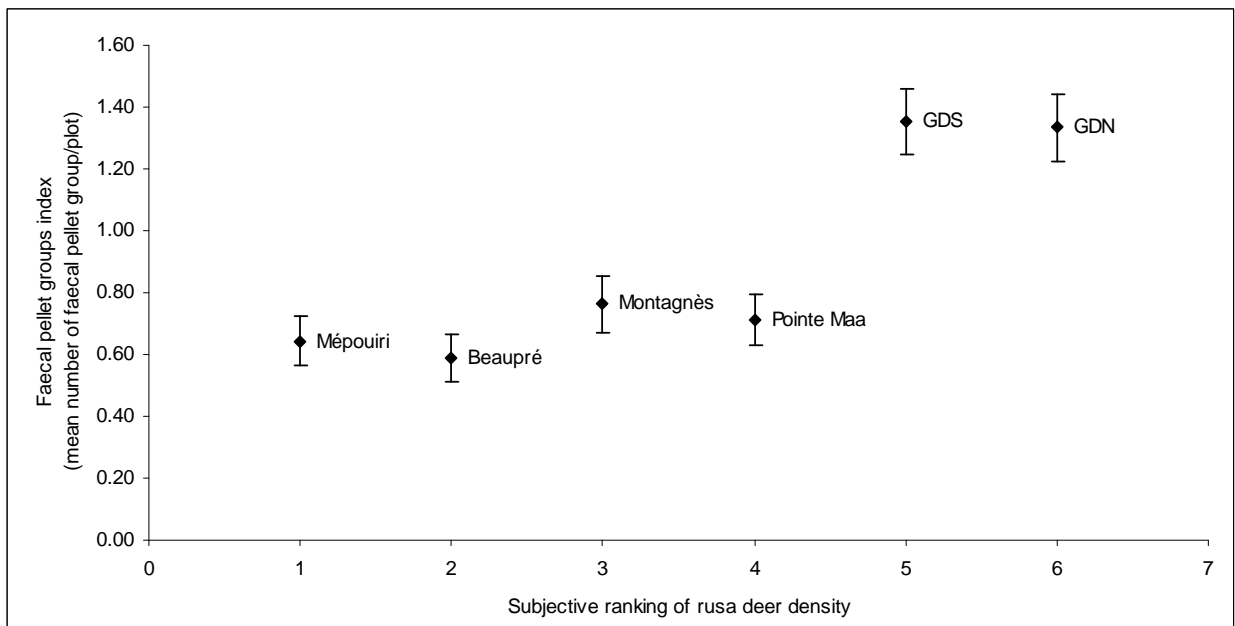
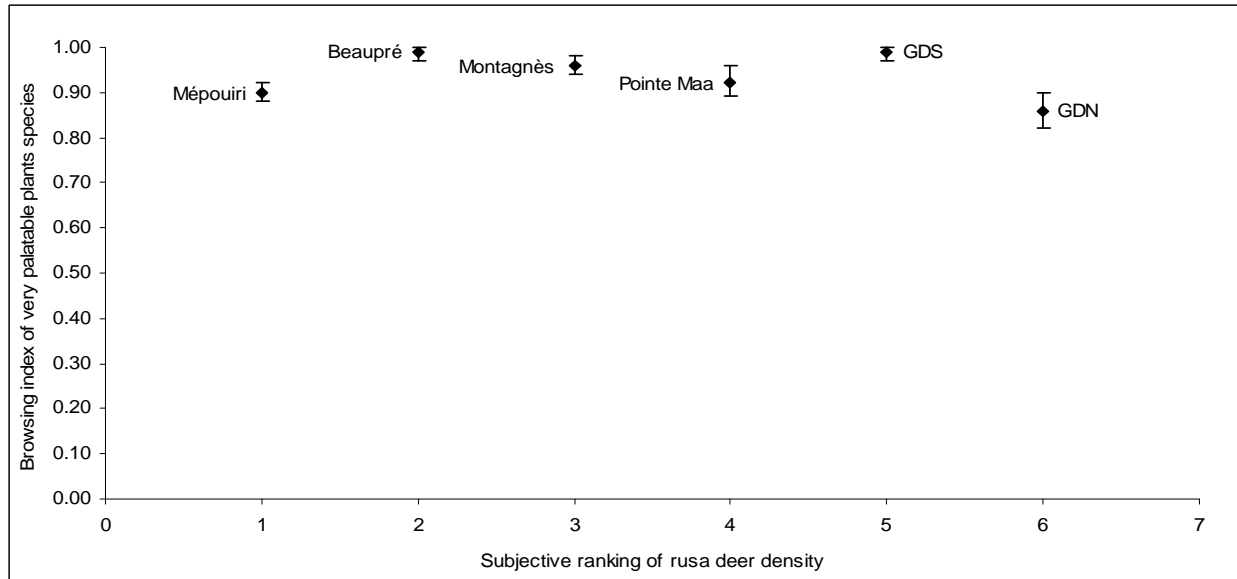
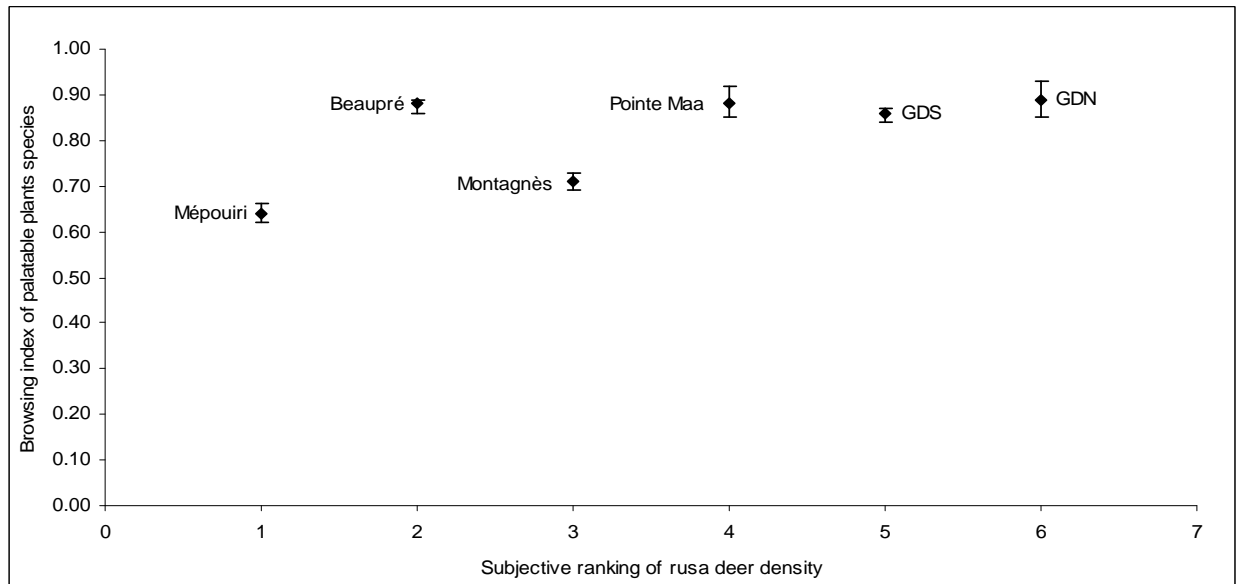


Figure 5.7: Correlation between the subjective ranking of rusa deer density and the faecal pellet groups index for six sclerophyll forests (n = 450 plots).

(a)



(b)



(c)

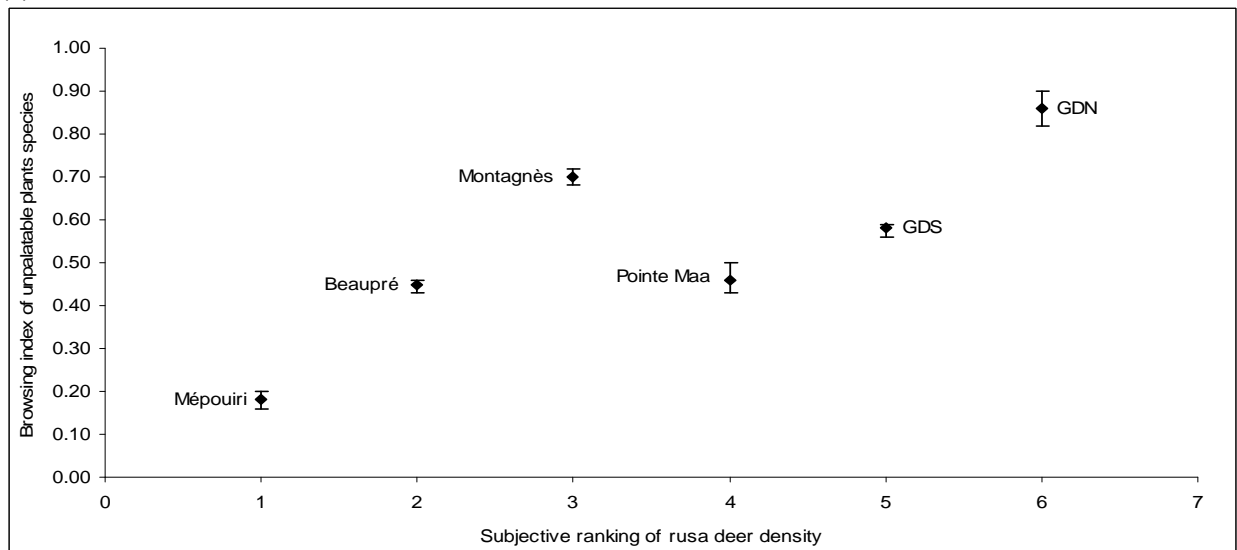


Figure 5.8: Correlation between the subjective ranking of rusa deer density and the browsing index of (a) very palatable, (b) palatable and (c) unpalatable browse species for six sclerophyll forests (n = 450 plots).

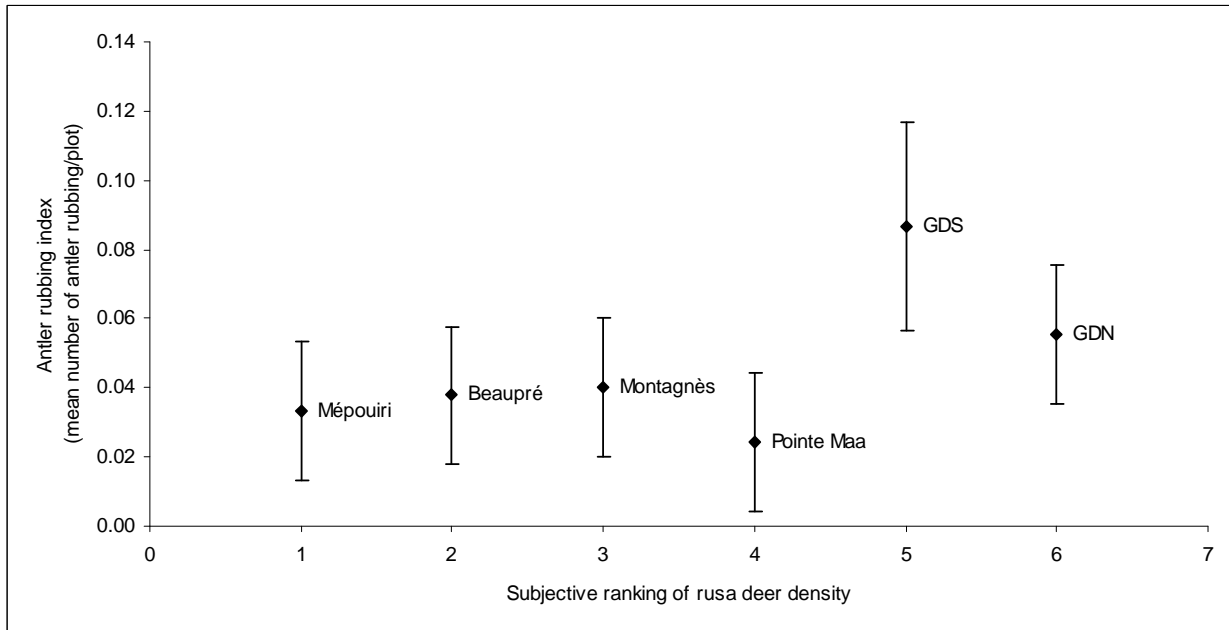


Figure 5.9: Correlation between the subjective ranking of rusa deer density and the antler rubbing index for six sclerophyll forests (n = 450 plots).

5.5 Discussion

An index is defined as “any measurable correlative of density” (Forsyth, *et al.* 2007). Therefore, to be useful for management purposes, the index has to be positively correlated with density (Fuller 1991; Forsyth, *et al.* 2007). I tested three potential indices (*i.e.* the faecal pellet groups index, the browsing index and the antler rubbing index) that could be used as monitoring tools to follow the rusa deer population trends in the New Caledonian sclerophyll forests.

The faecal pellet groups index have been used as an index (Neff 1968; Rowland, *et al.* 1984). It is commonly assumed that the number of faecal pellet groups recorded in an area is related to the density of animals occurring in this area (Neff 1968). The low confidence intervals found for the faecal pellet groups index in each sites (*i.e.* ranking from ± 0.08 in Beaupré and Pointe Maa to ± 0.11 in Gouaro Deva Nord and Sud) suggest that this index is reliable. Moreover, the correlation between the faecal pellet groups index and the antler rubbing index and the correlation between the subjective ranking of rusa deer density and the faecal pellet groups index were significant. These results suggest that the faecal pellet groups index is the index with

the most potential as a management tool to monitor rusa deer population trends in New Caledonian sclerophyll forests.

The browsing index appears to be a useful monitoring tool to follow rusa deer trends in New Caledonian forests. Indeed, it monitors the browse deer interaction as it reflects the changes in deer population size from the browsing pressure (Aldous 1944; Morellet, *et al.* 2003; Morellet, *et al.* 2007). The low confidence intervals found for the browsing index of unpalatable browse species in each sites (*i.e.* ranking from ± 0.04 in Gouaro Deva Nord to ± 0.27 in Beaupré) suggest that this index is reliable. Moreover, the significant correlation between the subjective ranking of rusa deer density and the browsing index of unpalatable browse species (Table 5.8; Figure 5.10 (c)) suggests that the browsing index of unpalatable browse species is related to the rusa deer densities in the study sites. The browsing index of unpalatable browse species shows promise. However, the browsing index should be used carefully as the palatability of browse species may vary depending on the plant community (Morellet, *et al.* 2003). Typically, unpalatable browse species are browsed when very palatable and palatable species become scarce (de Garine-Wichatitsky, *et al.* 2004c) due to pressure from the browser population that does not allow these plants to regenerate (Lindroth 1989; Partl, *et al.* 2002). That is, browsers have no choice but to browse the unpalatable browse species (Lindroth 1989; de Garine-Wichatitsky and Spaggiari 2005). In my study, the browsing index of unpalatable browse species showed a wider variation across sites than the browsing indices of very palatable and palatable browse species, which appear to be saturated. This suggests that the densities of rusa deer in the study sites were high. In areas where rusa deer densities appear to be lower, the browsing indices of very palatable and palatable browse species would certainly be different. I would therefore recommend using the browsing index of very palatable, palatable and unpalatable browse species to follow rusa deer trends in New Caledonian sclerophyll forests, and when unpalatable browse species are browsed it shows that the rusa deer are overexploiting the vegetation and that the populations should be reduced. I would recommend the use of my methods to managers in New Caledonia to follow the trends of rusa deer populations in sclerophyll forests.

The antler rubbing index cannot be used to estimate deer densities (Mayle, *et al.* 1999), however it indicates the presence of deer on the area (de Garine-Wichatitsky and Saint-Andrieux 2003; de Garine-Wichatitsky and Spaggiari 2003). This index has seldom been used because of the heterogeneity of the distribution of these marks in the study areas, and because no method has been validated to follow the population trends

from this index (de Garine-Wichatitsky and Spaggiari 2003). The use of antler rubbing density as an index to follow the population trends of male (and female if the sex ratio is known) rusa deer should be considered (de Garine-Wichatitsky and Spaggiari 2003). However, many factors still have to be known, such as the spatial distribution and the motion patterns of rusa deer during the rut. It should also be related with the vegetation type of each sites, as not every plant species are rubbed at the same intensity (de Garine-Wichatitsky and Spaggiari 2003).

The main bias of this study is the small sample size to test correlations between methods. Looking at the correlations, it is noticeable that with a larger sample size some correlations may have been positively correlated. Unfortunately, the sample size could not be increase because of the availability of study sites and the time period of the study that was too short for one recorder to collect the data on more than six sites. Fuller (1991) also had a small sample size for his study which was the main reason in the failure in detecting a significant relationship between deer density and faecal pellet group counts (White 1992). Eberhardt and Van Etten (1956) also tested the correlation between deer density and faecal pellet group count on two sites. For both studies their conclusions were based on small sample sizes which was the main methodological problem (Forsyth, *et al.* 2007).

Precautions should be taken during the data collection as it can be a source of bias (Neff 1968). For faecal pellet groups, biases can be classified in two groups: (a) Heterogeneity in environment. According to Bailey and Putman (1981) and Putman (1984), it results "in non-random use of population's range because of differences in vegetation and topography". Defecation rates vary according to the vegetation (*e.g.* defecation rate double from ligneous diet herbaceous diet) (Neff 1968; Rollins, *et al.* 1984; Dhungel 1985; Roques-Rogery 2002), different types of habitats (Irby 1981; Rogers 1987), seasons and climates (Dasmann and Taber 1955; Dhungel 1985; Mitchell, *et al.* 1985; Rogers 1987; Massei and Genov 1998; Nchanji and Plumptre 2001; Chapman 2004). Decay rates also vary according to vegetation types (Lewin 2002; de Garine-Wichatitsky, *et al.* 2004d), different types of habitats (Roques-Rogery 2002; Laing, *et al.* 2003), seasons (Coe and Carr 1983; Laing, *et al.* 2003; Chapman 2004) and climates (Laing, *et al.* 2003). Data collection were all done in sclerophyll forests, however the vegetation may vary between each sites (Morat 1993; Bouchet, *et al.* 1995). The weather during the data collection varied and the last two sites (*i.e.* Beaupré and Mèpouiri) were done at the very beginning of the rainy season. As the defecation rate and the decay rate, vary according to these factors, a bias may have

occurred. (b) Non-regular dunging. As seen previously defecation rates vary according to many factors (Neff 1968). Deer may have a preferred time of the day and preferred sites to defecate (Bailey and Putman 1981; Putman 1984). In areas where the vegetation within the sclerophyll forests was heterogeneous (e.g. Gouaro Deva Nord and Gouaro Deva Sud), faecal pellet groups density varies according to the vegetation (Nugent, *et al.* 1987). It can be a source of error as deer may not defecate regularly and randomly within the studied areas, and may be defecating in surrounding areas.

The differential search ability is also a bias when recording the faecal pellet groups, the browsing marks and the antler rubbings, as it may not be equally efficient in different habitat types (Bailey and Putman 1981; Putman 1984; Forsyth, *et al.* 2007). Leaves, grass, rocks, branches are example of factors that can make data collection difficult. Moreover, fatigue, boredom and visual acuity of the recorder can favour a poor detection of faecal pellet groups, browsing marks and antler rubbings (Dhungel 1985; Campbell, *et al.* 2004; Forsyth, *et al.* 2007). It would be advisable to be at least two persons (specifically trained at the same time to reduce the bias that could occur when data collector changes) to do the data collection to reduce these biases (Eberhardt and Van Etten 1956).

Only two indices (*i.e.* the faecal pellet groups index and the browsing index of unpalatable browse species) presented significant correlations. However for each index, the confidence intervals were low suggesting the reliability of these latter. Therefore, further studies have to be conducted to validate these indices. Biotic and edaphic factors are heterogeneous between sites and indices should be studied for each site in particular, and can not be compared between sites (Morellet, *et al.* 2007).

Although the use of indices to monitor population trends appears to be accurate (Dale and Beyeler 2001; Morellet, *et al.* 2001; Morellet, *et al.* 2007), I would recommend using a set of indices rather than only one. Biases may appear in the data collection of one index, and if a set of indices is collected, the general trends of the population over several years are more accurate because it is confirmed by several indices (Forsyth and Scroggie 2003). In New Caledonia, I would recommend using the faecal pellet groups index and the browsing index as a set of indices.

Chapter 6: Management recommendations

6.1 *Introduction*

Threats to the environment are a central issue worldwide and environmental conservation and management are one of the main concerns for most countries (Dincer and Rosen 1998; Myers, *et al.* 2000). One of the main threats to biodiversity conservation are biological invasions, especially for insular ecosystems (Paulay 1994; Mack, *et al.* 2000). New Caledonia, one of the world's hotspots is under threat of biological invasions (Mittermeier, *et al.* 1996; Myers, *et al.* 2000) and rusa deer have important impacts upon the remaining sclerophyll forest patches of this island (Bouchet, *et al.* 1995; Mittermeier, *et al.* 1996). Despite a high hunting pressure (de Garine 2002), the rusa deer population in New Caledonia appears to be increasing (de Garine 2002) and there is not only an urgent need for reliable management tools to improve rusa deer management in the New Caledonian sclerophyll forests, but also to involve the local communities in the management of biodiversity (de Garine-Wichatitsky, *et al.* 2004b). Rusa deer has a social and economic importance for the communities in New Caledonia, and most of the monitoring should be done on private properties and on lands that have cultural importance to these communities (de Garine 2002). Rusa deer management in New Caledonian sclerophyll forest should therefore rely on participative management.

6.2 *Monitoring tools*

An extensive list of monitoring tools is available for monitoring ungulate populations, but a careful choice should be made to select the most reliable monitoring tools for a specific case in a specific site (Forsyth and Scroggie 2003). Direct and indirect census methods have been used worldwide as tools to monitor ungulate population density (Morellet, *et al.* 2001; Forsyth and Scroggie 2003; Morellet, *et al.* 2007).

Initially in my study, combined spotlight and drive counts (direct census) and the faecal standing crop method (indirect census) were used to estimate rusa deer density in six sclerophyll forests sites. Estimates from combined spotlight and drive counts had high confidence intervals and were not correlated with the faecal standing crop method that had low confidence intervals, and although my sample size was small, this appears due to biases presented in Chapter 4. Biases are difficult to avoid when using census methods, and it is difficult to estimate the size of animal populations with accuracy and precision (Smart, *et al.* 2004; Morellet, *et al.* 2007). This was illustrated by Andersen (1953), who found that a direct census of roe deer in Denmark estimated a value which was the third of the true population, as established after the extermination of the total stock from the target area. The low reliability of the estimates is also confirmed by the study done by Fuller (1991). Indeed, the sample size of Fuller's study and of my study was small, which was an important limitation.

A reliable estimation of the decay rate and the defecation rate is necessary to get reliable results from faecal standing crop methods (Forsyth and Scroggie 2003). The decay rates and defecation rates that I measured were subject to bias due to heterogeneous biotic and edaphic factors between the study sites and these limited the reliability of the results that overestimated the rusa deer population in the study sites. Reliable decay rates and defecation rates are difficult to obtain and as they are varying according to many biotic and edaphic factors (Mayle, *et al.* 1999; Nchanji and Plumptre 2001; Laing, *et al.* 2003; Chapman 2004), they would have to be calculated for each sites separately to provide reliable results, which takes time (Morellet, *et al.* 2007). The low confidence intervals found for the faecal standing crop methods suggests that with a reliable estimation of the decay rate and of the defecation rate this method could be used as a management tool but would not be cost effective in term of time and expenses. Moreover, because of their low reliability in my study, I did not consider census methods as a suitable management tool for rusa deer management in New Caledonian sclerophyll forests.

It is not necessary to have an estimate of an ungulate population density to ensure efficient management of an area (Morellet, *et al.* 2007). Indices such as the faecal pellet groups index (Mayle, *et al.* 1999; Forsyth and Scroggie 2003; Forsyth, *et al.* 2007) and the browsing index (Morellet, *et al.* 2001; Morellet, *et al.* 2003; Morellet, *et al.* 2007) have been used elsewhere but have never been validated for rusa deer in New Caledonia (de Garine-Wichatitsky, *et al.* 2004b). All the tested indices had low confidence intervals suggesting that they are reliable. However, of the indices (*i.e.*

faecal pellet groups index, browsing index and antler rubbing index) tested in my study, only the faecal pellet groups index and the browsing index of unpalatable browse species were correlated to other indices and to the subjective ranking of rusa deer density suggesting that these indices are related to the deer densities in the study sites. Therefore, the faecal pellet groups index and the browsing index of unpalatable browse species showed some promise for the monitoring of rusa deer population trends in New Caledonian sclerophyll forests. However, I would recommend using a set of indices to reduce the bias as an index will confirm the other. Indeed, Morellet *et al.* (2007) recommend using an index to monitor the animal (e.g. the faecal pellet groups index) and an index to monitor the vegetation (e.g. the browsing index). I would recommend the use of the faecal pellet groups index and of the browsing index according to the palatability status of the browse species. These indices need yearly data to be used as monitoring tools, and it is necessary to use the method every year on the same conditions (e.g. period from October to December which represent the dry season, data recorder) and on the same sites. In Chapter 3, I found that the number of transects per site and of plots per transect could be reduced to 20 transects per site and 15 plots per transect. Therefore, reducing the sampling per site will be cost effective and will enable two recorders to sample more study sites. To follow the rusa deer population trends in New Caledonian sclerophyll forests and implement management plans, a minimum of two years of data will have to be recorded.

6.3 *Rusa deer management in New Caledonian sclerophyll forests*

New Caledonian rusa deer populations appear to have increased and management plans to control them have been established (de Garine-Wichatitsky, *et al.* 2004b; de Garine-Wichatitsky and Roques-Rogery 2007). Rusa deer can not be eradicated from New Caledonia for three reasons: (a) rusa deer have a cultural, nutritional and economic importance in New Caledonia (de Garine-Wichatitsky, *et al.* 2003; de Garine-Wichatitsky, *et al.* 2004b); (b) rusa deer consume most of the invasive plant species which could contribute to their control in sclerophyll forests (e.g. *Passiflora suberosa* invaded large areas where rusa deer were excluded) (de Garine-Wichatitsky and Roques-Rogery 2007); (c) it is probably not possible to eradicate rusa deer because of their large number and wide distribution over the island (de Garine-Wichatitsky, *et al.* 2004b). It is important to identify management units in New

Caledonian sclerophyll forests ranked according to their conservation values and priorities (Nugent and Fraser 1993) to implement the monitoring indices I recommended. Then, in the sites where the monitoring of indices shows an increase of the rusa deer population, solutions to reduce rusa deer densities should be implemented. Culling operations, a management tool that reduces herbivore pressure on natural resources, have been used in many parts of the world and are successful in the management of herbivores (Thomson 1992; Bothma and Teer 1993), even though ethical considerations have been raised in several situations to oppose culling. In New Caledonia, culling operations could be achieved in areas where rusa deer densities need to be significantly reduced. Rusa deer management should also rely on recreational and commercial hunting (Nugent and Fraser 1993). As presented in Chapter 1, recreational hunting is already important in New Caledonia, but hunting regulations are often questioned (de Garine-Wichatitsky, *et al.* 2004b). For example, the number of bullets allowed per hunter is currently regulated, and this number is considered low. It could be increased, which could lead to an increase of the hunting pressure on rusa deer (Canel 2005). Commercial hunting could be developed and would bring an income that could be used for the conservation of the New Caledonian biodiversity. To have an efficient impact on the rusa deer population, hunters should also shoot females which has been shown to have a significant impact on an ungulate population (Gogan, *et al.* 2001). Although, fencing these areas is expensive and labour intensive, fencing should be considered for the least impacted patches of sclerophyll forests. In Beauré and Mépouiri where patches of sclerophyll forests have been fenced, the vegetation has recovered even though rusa deer still manage to penetrate the enclosure plots.

6.4 Participative management

Efficient management should rely on participative management and should consider the public and political opinion (Veitch and Clout 2001). In other countries such as Zimbabwe, participative management has been implemented and has been successful before the economical and political crisis (Child 1996a; Child 1996b). In New Caledonia, projects relying on participative management have also been implemented successfully such as surveys of the flying fox (*Pteropus* spp.) colonies in New Caledonia implemented in 2005, as well as surveys of the avifauna of New Caledonia in

sclerophyll and rain forests implemented in 2004 (de Garine-Wichatitsky 2005b). These projects are still being conducted by the local communities showing the success of participative management in New Caledonia (de Garine-Wichatitsky 2005b). Another successful New Caledonian project relying on participative management have been implemented in 2003, and involves the local stakeholders in the management and the conservation of the biodiversity in Mont Panié, the highest mountain in New Caledonia situated in the Northern Province (de Garine-Wichatitsky 2005b).

As mentioned previously, rusa deer are an important species for New Caledonian and management of this species should integrate local stakeholders in various ways such as monitoring decisions, data recording and regulation of rusa deer populations (de Garine-Wichatitsky, *et al.* 2004b). The opinion of the stakeholders should be taken into consideration before taking management decisions (Nugent and Fraser 1993; de Garine-Wichatitsky and Roques-Rogery 2007), and conservation objectives, management units, population control strategies and hunting quotas should be decided with local stakeholders. Indeed, monitoring of rusa deer populations rely on the authorization of local stakeholders to use their hunting territories, their properties and their farms (de Garine-Wichatitsky, *et al.* 2004b; de Garine-Wichatitsky and Roques-Rogery 2007). One of the main advantages of the indices that I recommend for monitoring rusa deer in New Caledonia is that they follow simple protocols for data collection. This can facilitate the involvement of stakeholders after minimal training and can encourage them to participate in the conservation of the biodiversity surrounding them (de Garine-Wichatitsky and Roques-Rogery 2007).

Stakeholders should also be involved in culling and hunting activities. Culling operations should be organised with the local hunting associations and the meat distributed between the hunters. Meat should also be sold to generate an income that will be used for conservation purposes (Thomson 1992; Child 1996a; Child 1996b). Hunting regulations (*e.g.* hunting quotas, number of bullets per hunter per year, enforcement of hunting regulations) should be discussed with local hunters, wildlife technicians and researchers to increase the hunting pressure. Commercial hunting should involve stakeholders as professional hunters and should also generate an income (*e.g.* hunting fees that the foreign hunters would pay to the local hunting organisations) and provides meat to the stakeholders.

Access to hunting territories is a source of conflict between individuals and communities that could be reduced by involving them in culling and hunting operations and has already been done successfully in a New Caledonian site (de Garine-

Wichatitsky and Roques-Rogery 2007). For example, hunting operations have been successfully conducted in Forêt plate, a rain forest of the Northern Province of New Caledonia, with hunters from two conflicting villages (de Garine-Wichatitsky and Roques-Rogery 2007). Stakeholders should also be involved in the conservation of the sclerophyll forests by employing them for the fencing of the decided management units.

6.5 *Management procedure*

To prevent the overexploitation of the sclerophyll forests by rusa deer, an efficient management procedure should be established to manage efficiently the rusa deer populations. From my study the following management procedure could be established: (a) The management units should be identified with the local stakeholders according to their conservation values and priorities, and the boundaries of the sclerophyll forests delineated by the IRD used to apply the sampling protocol described in details in Chapter 3. (b) The monitoring indices (*i.e.* the faecal pellet groups index and the browsing index) should be implemented on each management units during the dry season (*i.e.* from October to December), and two recorders (*i.e.* local stakeholders) specifically trained should sample 20 transects per site and 15 plots per transect following the protocol described in details in Chapter 5. Two years of data are necessary to take management decisions. (c) If the unpalatable browse species are browsed, the vegetation is overexploited by the rusa deer and the populations should to be reduced. The same apply if the monitoring indices indicate that the rusa deer populations are increasing. If the results show that the rusa deer populations are decreasing or stable and that the unpalatable browse species are not browsed there is no need to regulate the rusa deer populations. (d) To reduce rusa deer populations, culling and hunting operations involving the local hunting associations should be done and shooting the females should be encouraged. Regulation operations should be conducted until the monitoring indices show that the rusa deer populations are decreasing and that the unpalatable browse species are not browsed.

This management procedure should be used in all New Caledonian sclerophyll forests to ensure an efficient management of the rusa deer populations, and therefore to preserve the remaining sclerophyll forests.

Chapter 7: References

- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In: International symposium of information theory. Petran, B. N. and Csàaki, F. (Eds). Akadèemia Kiadi: Budapest, Hungary, 267-281.
- Aldous, S. E. 1944. A deer browse survey method. *Journal of Mammalogy* **25**: 130-136.
- Andersen, J. 1953. Analysis of a Danish roe-deer population (*Capreolus capreolus* (L.)) based upon the extermination of the total stock. *Danish Review of Game Biology* **2**: 127-155.
- Anderson, D. R., Burnham, K. P. and White, G. C. 1994. AIC model selection in overdispersed capture-recapture data. *Ecology* **75**: 1780-1793.
- Baddeley, C. J. 1985. Assessments of wild animal abundance. *FRI Bulletin No. 106*, Protection Forestry Division, Forest Research Institute: Christchurch, New Zealand.
- Bailey, R. E. and Putman, R. J. 1981. Estimation of fallow deer (*Dama dama*) populations from faecal accumulation. *Journal of Applied Ecology* **18**: 697-702.
- Barnes, R. E. W. 2001. How reliable are dung counts for estimating elephants numbers? *African Journal of Ecology* **39**: 1-9.
- Bennett, L. P., English, P. F. and McCain, R. 1940. A study of deer populations by use of pellet-group counts. *Journal of Wildlife Management* **4**: 398-403.
- Bergon, S. 2004. Détermination du régime alimentaire du cerf rusa en Nouvelle-Calédonie : Utilisation de deux méthodes d'analyse des fèces. *Mémoire de DESS Productions Animales en Régions Chaudes*, USTL/CIRAD-EVMT: Montpellier.
- Blancher, S. 2006. Personal communication. Gouaro Deva, Province Sud, 98870 Bourail. Tél: (+687) 43 66 70.
- Bobek, B., Perzanowski, K. and Zielinski, J. 1986. Red deer population census in mountains: testing of an alternative method. *Acta Theriologica* **31**: 423-431.
- Boiseaubert, B., Maillard, D., Gaillard, J.-M. and Picard, F. 1990. Use of biological indicators (shrub browsing) to appraise roe deer density. In: The international union of game biologists, September 1989, Trondheim, Norway - Volume 1: Population dynamics. Myrberget, S. (Eds). Norwegian Institute for Nature Research: Trondheim, 308.

Bonzon, B. and Becquer, T. 1996. Un demi-siècle de recherches en Nouvelle-Calédonie. ORSTOM Actualités.

Bothma, J. d. P. 1996. Game counts. In: Game Ranch Management. Bothma, J. d. P. (Eds). J.L. van Schaik: Pretoria, 223-245.

Bothma, J. d. P. and Teer, J. G. 1993. The semantics and conservation value of some game production systems. International Wildlife Management Congress: San José, Costa Rica, pp. 313-317.

Bouchet, P., Jaffré, T. and Veillon, J. M. 1995. Plant extinction in New Caledonia: protection of sclerophyll forests urgently needed. *Biodiversity and Conservation* **4**: 415-428.

Bradshaw, R. H. W., Hannon, G. E. and Lister, A. M. 2003. A long term perspective on ungulate-vegetation interactions. *Forest Ecology and Management* **181**: 267-280.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. and Thomas, L. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press: Oxford.

Burnham, K. P. and Anderson, D. G. 2001. Kullback-Leibler information as a basis for strong interference in ecological studies. *Wildlife Research* **28**: 111-119.

Burnham, K. P., Anderson, D. R. and Laake, J. L. 1980. Estimation of density from line transect: Sampling of biological populations. The Wildlife Society: Louisville.

Campbell, D., Swanson, G. M. and Sales, J. 2004. Comparing the precision and cost-effectiveness of faecal pellet group count methods. *Journal of Applied Ecology* **41**: 1185-1196.

Canel, M. 2005. Le Guide du chasseur en Nouvelle-Calédonie. Les Guides de l'environnement Province Sud, Nouvelle-Calédonie: Nouméa.

Chapman, N. G. 2004. Faecal pellets of Reeves' muntjac, *Muntiacus reevesi*: defecation rate, decomposition period, size and weight. *European Journal of Forest Research* **50** (3): 141-145.

Chardonnet, P. 1988. Etude de factabilité technique et économique de l'élevage de cerfs en Nouvelle-Calédonie. IEMVT: Maison-Alfort.

Chardonnet, P. 2008. Personal communication. IGF, 15, Rue de Téhéran, 75008 Paris, France.

Chardonnet, P. and Lartiges, A. 1992. Gestion de la faune sauvage terrestre vertebrée dans la Province Sud de Nouvelle-Calédonie. *Avis et Propositions*, IEMVT: Maison-Alfort.

Child, B. 1996a. The practice and principles of community-based wildlife management in Zimbabwe: The CAMPFIRE programme. *Biodiversity and Conservation* **5**: 369-398.

Child, G. 1996b. The role of community-based wild resource management in Zimbabwe. *Biodiversity and Conservation* **5**: 355-367.

Coe, M. J. and Carr, R. D. 1983. The relationship between large ungulate body weight and faecal pellet weight. *African Journal of Ecology* **21**: 165-174.

CTRDP-ORSTOM 1989. Atlas de la Nouvelle-Calédonie. CTRDP and ORSTOM: Nouméa.

Cypher, B. J. 1991. A technique to improve spotlight observations of deer. *Wildlife Society Bulletin* **19**: 391-393.

Dale, V. H. and Beyeler, S. C. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* **1**: 3-10.

Dasmann, R. F. and Taber, R. D. 1955. A comparison of four deer census methods. *California Fish and Game* **41** (3): 225-228.

DAVAR 2005. Mémento année agricole 2004. Gouvernement de Nouvelle Calédonie. Direction des affaires vétérinaires alimentaires et rurales. Service de l'eau et des statistiques et études rurales: Nouméa, New Caledonia.

de Garine, I. 2002. Etudes des aspects socio-culturels de la chasse en Nouvelle-Calédonie. IAC / Programme Elevage et Faune Sauvage: Païta.

de Garine-Wichatitsky, M. 2003. Projet "Cerfs rusa et milieux naturels en Nouvelle Calédonie". *Rapport Final*, IAC / CIRAD: Païta.

de Garine-Wichatitsky, M. 2005a. Personal communication. IAC / Port Laguerre, BP 73, 98890 Païta, New Caledonia.

de Garine-Wichatitsky, M. 2005b. Chasse et conservation de la biodiversité: savoir naturalistes, usages et gestion des gibiers endémiques et introduits en Nouvelle-Calédonie. *Actes du Symposium IFB "Usages Locaux de la Biodiversité"*, Fréjus, Septembre 2005, pp. 18-23.

de Garine-Wichatitsky, M. and Chardonnet, P. 2001. Projet Cerfs rusa et milieux naturels en Nouvelle-Calédonie. *1er Rapport d'Etape*, IAC - Programme Elevage et Faune: Païta, Nouvelle Calédonie.

de Garine-Wichatitsky, M. and Saint-Andrieux, C. 2003. Faisabilité des méthodes de suivi-évaluation pour la gestion des populations sauvages de cerfs rusa en Nouvelle-Calédonie. *Rapport d'Expertise*, IAC - Programme Elevage et Faune Sauvage: Païta.

de Garine-Wichatitsky, M. and Spaggiari, J. 2003. Note sur les frottis provoqués par les cerfs rusa dans une zone de forêt sèche et sur l'utilisation potentielle de cet indice pour le suivi des populations sauvages de Nouvelle Calédonie. In: Projet "Cerfs rusa et milieux naturels en Nouvelle Calédonie". De Garine-Wichatitsky, M. (Eds). Institut Agronomique Néo-Calédonien: Païta.

de Garine-Wichatitsky, M. and Spaggiari, J. 2005. Alien plants in native sclerophyll forests of New Caledonia: the role of ungulates? *In Press*.

de Garine-Wichatitsky, M. and Roques-Rogery, G. 2007. Rusa deer *Cervus timorensis russa* in New Caledonia: Overview of current research and management perspectives. *Invasive Animals Cooperative Research Centre Workshop: What are the Issues for the Management of Wild Deer in Australia?*, Canberra, NSW (Australia). *in press*.

de Garine-Wichatitsky, M., Spaggiari, J. and Ménard, C. 2004a. Ecologie et impacts des ongulés introduits sur la forêt sèche de Nouvelle-Calédonie. *Rapport de Recherche*, Institut Agronomique néo-Calédonien: Port-Laguerre.

de Garine-Wichatitsky, M., Chardonnet, P. and De Garine, I. 2004b. Management of introduced game species in New Caledonia: Reconciling biodiversity conservation and resource use? *Game and Wildlife Science* **21** (4): 697-706.

de Garine-Wichatitsky, M., Fritz, H., Gordon, I. J. and Illius, A. W. 2004c. Bush selection along foraging pathways by sympatric impala and greater kudu. *Oecologia* **141**: 66-75.

de Garine-Wichatitsky, M., Duncan, P., Labbé, A., Suprin, B., Chardonnet, P. and Maillard, D. 2003. A review of the diet of rusa deer *Cervus timorensis russa* in New Caledonia: Are the endemic plants defenceless against this introduced, eruptive ruminant? *Pacific Conservation Biology* **9** (2): 136-143.

de Garine-Wichatitsky, M., Roques-Rogery, G., Bergon, S., Bastianelli, D., Spaggiari, J., Lecomte, P., Ducornez, S. and Barré, N. 2004d. Facts from faeces of wild rusa deer in New Caledonia: A review of current information on population monitoring diet analysis and parasites. *6th International Wildlife Ranching Symposium*, Paris, France, pp. 17-19.

Dhungel, S. K. 1985. Defecation rate of hog deer in captivity. *Journal of Wildlife Management* **49** (4): 925-926.

Dincer, I. and Rosen, M. A. 1998. A worldwide perspective on energy, environment and sustainable development. *International Journal of Energy Research* **22** (15): 1305-1321.

- Dinerstein, E. and Dublin, H. T. 1982. Daily defecation rate of captive axis deer. *Journal of Wildlife Management* **46** (3): 833-835.
- Dulloo, M. E., Kell, S. P. and Jones, C. G. 2002. Conservation of endemic forest species and the threat of invasive species: Impact and control of invasive alien species on small islands. *International Forestry Review* **4** (4): 277-285.
- Eberhardt, L. and Van Etten, R. C. 1956. Evaluation of the pellet group count as a deer census method. *Journal of Wildlife Management* **20**: 70-74.
- Edwards, C., Read, J. and Sanson, G. 2000. Characterising sclerophylly: Some mechanical properties of leaves from health and forest. *Oecologia* **123**: 158-167.
- Fafarman, K. R. and DeYoung, C. A. 1986. Evaluation of spotlight counts of deer in South Texas. *Wildlife Society Bulletin* **14**: 180-185.
- Flannery, T. 1995. Mammals of the South-West Pacific and Moluccan Islands. Cornell University Press: Ithaca, New York.
- Forsyth, D. M. 2005. Personal communication. Arthur Rylah Institute for Environmental Research, 123 Brown street, Heidelberg, Victoria 3084, Australia.
- Forsyth, D. M. and Scroggie, M. P. 2003. Review of methods to estimate the density of deer. *Contract Report*, Arthur Rylah Institute for Environmental Research: Victoria.
- Forsyth, D. M., Barker, R. J., Morriss, G. and Scroggie, M. P. 2007. Modelling the relationship between faecal pellet indices and deer density. *Journal of Wildlife Management* **71** (3): 964-970.
- Fraser, K. W. and Burrows, L. E. 2000. Changes in density and local distribution of red deer and their impacts on vegetation in the Arawhata Valley (South Westland) between 1969 and 1999. Landcare Research: Lincoln, New Zealand.
- Fuller, T. K. 1991. Do pellet counts index white-tailed deer numbers and population change? *Journal of Wildlife Management* **55**: 393-396.
- Gogan, P. J. P., Barrett, R. H., Shook, W. W. and Kucera, T. E. 2001. Control of ungulate numbers in a protected area. *Wildlife Society Bulletin* **29** (4): 1075-1088.
- Grimaud, P., Le Bel, S. and Sauzier, J. 2004. Farming rusa deer (*Cervus timorensis rusa*) in southern tropical islands: Slaughtering performances and alternative feeding strategies. *Game and Wildlife Science* **21**: 329-341.
- Groupe-Chevreuril 1996. Les Bio-Indicateurs: Futurs outils de gestion des populations de chevreuil (Fiche n°90). *Bulletin Mensuel de l'Office National de la Chasse (Supplement)* **209**.

Irby, L. R. 1981. Variation in defecation rates of pronghorns relative to habitat and activity level. *Journal of Range Management* **34** (4): 278-279.

Jachmann, H. 2001. Estimating abundance of african wildlife: An aid to adaptative management. Kluwer academic publisher.

Jaffré, T., Morat, P., Veillon, J. M., Rigault, F. and Dagostini, G. 2001. Composition and characterisation of the native flora of New Caledonia. Documents Scientifiques et Techniques. *Report*, IRD: Nouméa.

Jessop, T. S., Madsen, T., Sumner, J., Rudiharto, H., Phillips, J. A. and Ciofi, C. 2006. Maximum body size among insular Komodo dragon populations covaries with large prey density. *Oikos* **112** (2): 422-429.

Keith, D. and Pellow, B. 2005. Effects of javan rusa deer (*Cervus timorensis*) on native plant species in the Jibbon-Bundeena, Royal National Park, New South Wales. *Proceedings of the Linnean Society of New South Wales* **126**: 99-110.

Laing, S. E., Buckland, S. T., Burns, R. W., Lambie, D. and Amphlett, A. 2003. Dung and nest surveys: Estimating decay rates. *Journal of Applied Ecology* **40**: 1102-1111.

Le Bel, S. 1998. Production de velours chez le cerf rusa en Nouvelle Calédonie. Appréciation quantitative et qualitative du produit obtenu au stade d'aplatissement du merrain de la seconde branche. *Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux* **51**: 173-181.

Le Bel, S., Brescia, F. and Barré, N. 1999. Etude de la biologie du cerf rusa (*Cervus timorensis rusa*) en milieu naturel, base d'un plan de gestion des populations de cervidés sauvages. *Etude de Cas*, CIRAD - EMVT: Port Laguerre.

Le Bel, S., Sarrailh, J.-M., Brescia, F. and Cornu, A. 2001. Présence du cerf rusa dans le massif de l'Aoupinié en Nouvelle-Calédonie et impact sur le reboisement en kaoris. *Bois et Forêts des Tropiques* **269** (3): 5-18.

Lewin, J. 2002. The application of faecal accumulation surveys to estimate densities of wild sambar deer (*Cervus unicolor*) in Victoria. Department of Zoology, University of Melbourne: Parkville, Australia.

Lindroth, R. L. 1989. Mammalian herbivore-plant interactions. In: Plant-animal interactions. Abrahamson, W. G. (Eds). McGraw Hill: New York, 163-206.

MacArthur, R. H. and Wilson, E. O. 1963. An equilibrium theory of insular zoogeography. *Evolution* **17** (4): 373-387.

Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M. and Bazzaz, F. A. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecology* **10**: 689-710.

MacKee, H. S. 1994. Catalogues des plantes introduites et cultivées en Nouvelle-Calédonie. Flore de la Nouvelle-Calédonie et dépendances Muséum National d'Histoire Naturelle: Paris.

Mandujano, S. and Gallina, S. 1995. Comparison of deer censusing methods in tropical dry forest. *Wildlife Society Bulletin* **23** (2): 180-186.

Marques, F. F. C., Buckland, S. T., Goffin, D., Dixon, C. E., Borchers, D. L., Mayle, B. A. and Peace, A. J. 2001. Estimating deer abundance from line transect surveys of dung: sika deer in southern Scotland. *Journal of Applied Ecology* **38**: 349-363.

Massei, G. and Genov, P. V. 1998. Fallow deer (*Dama dama*) winter defecation rate in a Mediterranean area. *Journal of Zoology* **245** (2): 209-211.

Mayle, B. A., Peace, A. J. and Gill, R. M. A. 1999. How many deer? A field guide to estimating deer population size. Forestry Commission: Edinburgh.

Mayle, B. A., Doney, J., Lazarus, G., Peace, A. J. and Smith, D. E. 1996. Fallow deer (*Dama dama*) defecation rate and its use in determining population size. *Supplemento Alle Ricerche di Biologia Della Selvaggina* **25**: 63-78.

McCullough, D. R. 1982. Evaluation of night spotlighting as a deer study technique. *Journal of Wildlife Management* **46** (4): 963-973.

Mitchell, B., Rowe, J. J., Ratcliffe, P. R. R. and Hinge, M. 1985. Defecation frequency in roe deer (*Capreolus capreolus*) in relation to the accumulation rates of faecal deposits. *Journal of Zoology* **207**: 1-7.

Mittermeier, R. A., Werner, T. B. and Lees, A. 1996. New Caledonia - A conservation imperative for an ancient land. *Oryx* **30** (2): 104-112.

Morat, P. 1993. Our knowledge of the flora of New Caledonia: endemism and diversity in relation to vegetation types and substrates. *Biodiversity Letters* **1**: 71-81.

Morat, P., Jaffré, T., Veillon, J. M. and MacKee, H. S. 1981. Les formations végétales. In: Atlas de la Nouvelle-Calédonie et dépendances. ORSTOM (Eds). ORSTOM: Paris.

Morellet, N. 1998. Des outils biométriques appliqués aux suivis des populations animales: l'exemple des cervidés. *Thèse de Doctorat*, Université Claude Bernard: Lyon.

Morellet, N., Ballon, P., Boscardin, Y. and Champely, S. 2003. A new index to measure roe deer (*Capreolus capreolus*) browsing pressure on woody flora. *Game and Wildlife Science* **20**: 155-173.

Morellet, N., Champely, S., Gaillard, J.-M., Ballon, P. and Boscardin, Y. 2001. The browsing index: New tool uses browsing pressure to monitor deer populations. *Wildlife Society Bulletin* **29** (4): 1243-1252.

Morellet, N., Gaillard, J.-M., Hewison, A. J. M., Ballon, P., Boscardin, Y., Duncan, P. and Maillard, D. 2007. Indicators of ecological change: New tools for managing populations of large herbivores. *Journal of Applied Ecology* **44**: 634-643.

Myers, N. 1998. Threatened biotas: "Hot spots" in tropical forests. *The Environmentalist* **8**: 187-208.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. B. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

Nchanji, A. C. and Plumptre, A. J. 2001. Seasonality in elephant dung decay and implications for censusing and population monitoring in south-western Cameroon. *African Journal of Ecology* **39**: 21-32.

Neff, D. J. 1968. The pellet-group count technique for big game trend, census, and distribution: A review. *Journal of Wildlife Management* **35**: 597-614.

Nugent, G. and Fraser, K. W. 1993. Pests or valued resources? Conflicts in management of deer. *New Zealand Journal of Ecology* **20**: 361-366.

Nugent, G., Parkes, J. P. and Tustin, K. G. 1987. Changes in the density and distribution of red deer and wapiti in Northern Fiordland. *New Zealand Journal of Zoology* **10**: 11-21.

Nugent, G., Fraser, K. W., Asher, G. W. and Tustin, K. G. 2001. Advances in New Zealand mamalogy 1990-2000: Deer. *Journal of the Royal Society of New Zealand* **31**: 263-298.

ORSTOM 1981. Atlas de la Nouvelle-Calédonie et dépendances. ORSTOM: Paris.

Partl, E., Szinovatz, V., Reimoser, F. and Schweiger-Adler, J. 2002. Forest restoration and browsing impact by roe deer. *Forest Ecology and Management* **159**: 87-100.

Paulay, G. 1994. Biodiversity on oceanic islands: Its origin and extinction. *American Zoology* **34**: 134-144.

Primack, R. B. 1993. Essentials of conservation biology. Sinauer Associates: Sunderland Massachusetts.

- Putman, R. J. 1984. Facts from faeces. *Mammal Review* **14**: 79-97.
- Ratcliffe, P. R. 1987. Red deer population changes and the independent assessment of population size. *Symposium Zoological Society London* **58**: 153-165.
- Rivero, K., Rumiz, D. L. and Taber, A. B. 2004. Estimating brocket deer (*Mazama gouazoubira* and *M. americana*) abundance by dung pellet counts and other indices in seasonal Chiquitano forests habitats of Santa Cruz, Bolivia. *European Journal of Wildlife Research* **50**: 161-167.
- Rogers, L. L. 1987. Seasonal changes in defecation rates of free-ranging white-tailed deer. *Journal of Wildlife Management* **51**: 330-333.
- Rollins, D., Bryant, F. C. and Montandon, R. 1984. Fecal pH and defecation rates of eight ruminants fed known diets. *Journal of Wildlife Management* **48** (3): 807-813.
- Roques-Rogery, G. 2002. Faeces of rusa deer (*Cervus timorensis rusa*): Characteristics, defecation rate and application to the plot clearance counting method. *Technical report*, Port Elizabeth Technikon: George.
- Rouys, S. and Theurerkauf, J. 2003. Factors determining the distribution of introduced mammals in nature reserves of the southern province, New Caledonia. *Wildlife Research* **30**: 187-191.
- Rowland, M. M., White, G. C. and Karlen, E. M. 1984. Use of pellet-group plots to measure trends in deer and elk populations. *Wildlife Society Bulletin* **12**: 147-155.
- Semiadi, G., Muir, P. D. and Barry, T. N. 1994. General biology of sambar deer (*Cervus unicolor*) in captivity. *New Zealand Journal of Agricultural Research* **37**: 79-85.
- Simberloff, D. 1995. Why do introduced species appear to devastate islands more than mainland areas? *Pacific Science* **49** (1): 87-97.
- Smart, J. C. R., Ward, A. I. and White, P. C. L. 2004. Monitoring woodland deer populations in the UK: an imprecise science. *Mammal Review* **34**: 99-114.
- Smith, A. D. 1964. Defecation rates of mule deer. *The Journal of Wildlife Management* **28** (3): 435-444.
- Sutherland, W. J. 1996a. *Ecological Census Techniques A Handbook*. Cambridge University Press: Cambridge.
- Sutherland, W. J. 1996b. Mammals. In: Ecological census techniques. Sutherland, W. J. (Eds). Cambridge University Press: Cambridge, 260-280.
- Thomas, L., Buckland, S. T., Burnham, K. P., Anderson, D. R., Laake, J. L., Borchers, D. L. and Strindberg, S. 2002. Distance sampling. In: Encyclopedia of environmetrics. El-Shaarawi, A. H. and Piergorsch, W. W. (Eds). Chichester, 544-552.

Thompson, W. L., White, G. C. and Gowan, G. V. 1998. Monitoring vertebrate populations. Academic Press: San Diego.

Thomson, R. 1992. The wildlife game. The Nyala Wildlife Publications Trust: Westville.

Veillon, J.-M., Dagostini, G. and Jaffré, T. 1999. Etude de la forêt sclérophylle de la Province Nord en Nouvelle-Calédonie. *Convention Botanique*, Institut de Recherche pour le Développement: Nouméa.

Veitch, C. R. and Clout, M. N. 2001. Human dimensions in the management of invasive species in New Zealand. In: The great reshuffling: Human dimensions of invasive alien species. McNeely, J. A. (Eds). IUCN: Gland, Switzerland, 63-71.

Vitousek, P. M. 1988. Diversity and biological invasions of oceanic islands. In: Biodiversity. Wilson, E. O. (Eds). National Academy press: Washington D.C.

von Kerckerinck Zur Borg, J. 1987. Deer farming in North America: The conquest of a new frontier. Phanter Press: Rhinebeck.

Wardle, D. A., Barker, G. M., Yeates, G. W., Bonner, K. I. and Ghani, A. 2001. Introduced browsing mammals in New Zealand natural forests: Aboveground and belowground consequences. *Ecological Monographs* **71** (4): 587-614.

White, G. C. 1992. Do pellet counts index white-tailed deer numbers and population change?: A comment. *Journal of Wildlife Management* **56**: 611-612.

White, G. C. and Eberhardt, L. E. 1980. Statistical analysis of deer and elk pellet-group data. *Journal of Wildlife Management* **44**: 121-131.

Whitehead, G. K. 1993. The Whitehead encyclopedia of deer. Voyageur Press, Inc.: Shrewsbury.

www.cia.gov 2002. The world factbook - New Caledonia. In *CIA*.