ESTIMATING DISTRIBUTION AND HABITAT ASSOCIATIONS OF THE ENDANGERED ADERS' DUIKER (CEPHALOPHUS ADERSII): IMPLICATIONS FOR RESEARCH AND CONSERVATION

by

Franziska Schrodt

Thesis submitted to the University of Plymouth in partial fulfilment of the requirements for the degree of

MSc Biological Diversity

University of Plymouth
Faculty of Science

in collaboration with

Paignton Zoo Environmental Park, England
and
Kenyan Wildlife Service, Kenya

September 2005
THIS COPY OF THE THESIS HAS BEEN SUPPLIED ON CONDITION THAT ANYONE WHO CONSULTS IT IS UNDERSTOOD TO RECOGNISE THAT ITS COPYRIGHT RESTS WITH THE AUTHOR AND THAT NO QUOTATION FROM THE THESIS AND NO INFORMATION DERIVED FROM IT MAY BE PUBLISHED WITHOUT THE AUTHOR’S PRIOR WRITTEN CONSENT.
Abstract

Habitat destruction and degradation as well as over hunting are major causes for the decline of duiker in Africa. Conservation is hampered by lack of funding and information on duiker ecology. Habitat characteristics were examined at 40 localities in the Arabuko-Sokoke Forest, Kenya, in 8 of which sightings of the semi-endemic and endangered Aders’ duiker were reported. Disturbance levels of human and elephant activities, duiker pellet piles and antelope tracks were quantified. Uni- and multivariate analysis was combined to overcome limitations of this study and the methods used. Nonmetric multidimensional scaling and correlation analysis showed significant differences in areas with signs of duiker and Aders’ duiker sightings, as well as between the individual forest types. Of the 17 variables quantified, visibility, number of duiker food plants and elephant induced disturbance were most important and showed highest correlations with the number of duiker signs (pellet piles and paths) and the individual forest types. Usage of few unconfirmed reports of animal sightings was rendered inappropriate for this kind of study, whereas indirect methods like pellet pile and antelope track counts, as well as habitat analysis (visibility, canopy cover, vegetation and disturbance), morning walks and hair traps are proposed as fast and economic methods to obtain basic information on small secretive forest mammal abundance and distribution in order to increase effectiveness of conservation strategies.

Keywords: duiker, Cephalophus, habitat associations, indirect density estimation, antelope conservation
1. Introduction

In coastal East Africa, increases in human population size, migration, and poverty have brought about large scale destruction of tropical forests and a rapidly growing bush meat trade. The Arabuko-Sokoke Forest (Kenya) is the largest single block of coastal tropical forest remaining as part of the Zanzibar-Inhambane phyto-geographical region which stretches along the East African coast from northern Mozambique to southern Somalia (White, 1983). Due to its high species diversity and endemism, this forest forms part of the East African Coastal Forests/Eastern Arc Forest complex that ranks eighth among the top 25 biodiversity hotspots globally (Myers et al., 2000). It is home to three threatened mammals, the Sokoke dog mongoose (*Bdeogale omnivora*), Golden-rumped elephant shrew (*Rhynchocyon chrysopygus*), and Aders’ duiker (*Cephalophus adersi*) (KIFCON, 1995).

Duiker (*Cephalophini*) are small forest antelopes restricted to Sub-Saharan Africa, ranging from 3.5 kg to 80 kg in body weight, and mostly featuring solitary habits and intense territoriality (Kanga, 2003; Kingdon, 2001). Evolutionary relationships of duiker species are still quite unresolved, with some populations not being analyzed at all (e.g. Aders’ duiker in the Arabuko-Sokoke Forest, White-bellied duiker in N Gabon; van Vuuren, 2002). So far 17 species are recognised, all of them undergoing rapid population declines with only two being classified as common by the IUCN (Kingdon, 2001; IUCN, 2004). Due to their behavior and habitat preferences, forest duiker are difficult to study and so far relatively little is known about their ecology. Many duiker species are coexisting, often without niche separation based on body size, dietary differences or different activity periods, and do not generally seem to follow ecological rules valid for bigger antelopes (Plowman, 2003). Several comparative studies on the nutrition of duiker showed that they do not seem to obey the Jarman Bell Principle in dietary selection and time budget, which relates the diet composition of ungulates to body sizes (Bowland and Perrin, 1998). They have been commonly classified due to their small rumen and narrow muzzle and lips as high-concentrate, frugivorous, and...
especially the bigger species folivorous selector, although this is still controversial and bigger species have been found feeding on animal matter as well (Wenninger and Shipley, 2000; Dierenfeld et al., 2002; Plowman, 2003; Finnie, in press). Studies on the feeding habits of duiker showed that they are unable to utilize single species diets and mainly feed on mature, freshly fallen dicotyledonous leaves, flowers, fruit and seeds, where available (fallen or dropped by monkeys or birds), and that food quality rather than abundance seems to be a limiting factor (Bowland and Perrin, 1998; Wilson, 1966; Kingdon, 2002; Finnie, 2002). These characteristics accentuate the difficulty and importance of assessing the habitat preferences of duiker species in order to appreciate their ecological and economic significance, estimate population size and density and to be able to implement appropriate conservation measures.

Aders’ duiker (Cephalophus adersi, Thomas, 1917) is endemic to coastal thickets on Unguja Island, Zanzibar (Tanzania) and the Arabuko-Sokoke Forest (Kenya), although Kingdon (1982) reported unconfirmed sightings in forests and thickets north of Mombasa up to the Somali border, and Finnie (2002) from the Sadani Game Reserve, Tanzania mainland. It is categorized as critically endangered in the IUCN red list with no more than 700 individuals surviving in the wild (Masoud, 2003; IUCN 2004). The Zanzibar population, which is believed to be the last remaining viable population, declined by 86.8% since 1983 (Mwinyi and Wiesner, 2003) and ongoing illegal activities are suspected to result in further decline (Finnie, 2002). The only surveys conducted in Kenya so far (Kanga 2002a, 2002b and 2003) have cited very low numbers (seven since 1999) and Aders’ duiker is expected to undergo local extinction in the near future due to continuous trapping, hunting, and habitat decline (Fitzgibbon et al., 1995; Fitzgibbon et al., 2000; Masoud, 2003; Kanga, 2002b).

Improving designated conservation areas for Aders’ duiker is difficult, as very little is known about the ecological requirements, population dynamics, reproductive biology and taxonomic status of Aders’ duiker, especially of the dichopatric population in Kenya ( Cotterill, 2003; IUCN, 2004). Its solitary habits, elusive nature and tendency to occupy dense, difficult habitats necessitate the collection of much indirect, rather than
direct, information. Pellet group counts and track counts have been applied widely as population indices for assessing trends of rare and secretive forest dwelling species (Koster and Hart, 1988) and have been used in former studies of Aders’ duiker population status (Kanga 2002b; Finnie, *in press*).

Although it was assumed that the feeding habits and food preferences of duiker are quite similar in similar sized species, recent research showed different results and little research has been done on Aders’ duiker specifically (Plowman, 2003). Some information from stomach analysis of Aders’ duiker in Zanzibar and Kenya and interviews with local hunters resulted in a list of possible Aders’ duiker food plants, whose validity and generality however has to be questioned (Finnie, *pers. comm.*, 2005).

As *in situ* conservation proves to be difficult due to lack of protected areas (less than 10% of the assumed habitat of Aders´ duiker is protected in Kenya), and control measures, captive breeding has been proposed as an alternative measure (Masoud, 2003; Kanga, 2003; Finnie, *in press*). However, except for one reported trapping and breeding program in the 1970s in Kenya, and one recently discovered female held in captivity in a private collection in Unguja Island (Zanzibar) for four years, little is known about the requirements of Aders´ duiker to survive and breed in captivity (Davies, 1993; Finnie, 2002; Kanga, *pers. comm.*). Thus, it is important, not only for the designation of conservation areas, but also for possible captive breeding programs as proposed for Zanzibar and Kenya, to know more about Aders´ duiker habitat associations.

The aim of this study is to estimate abundance, distribution and habitat associations of Aders’ duiker, having very little information about its ecology and status in the study area. This aim is approached in a direct way, through Aders’ duiker sightings and an indirect way, through duiker pellet pile and antelope path counts. Restricting variables are revealed and implications for similar studies on small secretive forest mammals and the management of deteriorating habitats with declining Aders’ duiker populations are drawn.
2. Methods

2.1 Study site

The study was conducted between May and August 2005 in the Arabuko-Sokoke Forest Reserve (ASF), situated in Kilifi and Malindi Districts, Kenya (39°50’E, 3°20’S; Figure 1). The ASF covers an area of approximately 416.8 km$^2$, 63 km$^2$ of which have been gazetted as a strict Nature Reserve since the 1970s (Mutie, 2002). Geological parameters are very variable within the Forest. Rainfall ranges from less than 600 mm/year in the north-west to over 1000 mm/year in the east. A flat coastal plain (45 m altitude) in the east, characterized by deep loose coarse sands and coral rags, elides into a plateau (60-135 m altitude) rising SW-NE through the centre, and featuring deep heavily leached infertile red Magarini soils (KIFCON, 1995). Temperatures and humidity are relatively constant throughout the year with high daily means of about 25°C and 60% respectively (Kanga, 2002b). The ASF has been classified into four vegetation types (Table 1), which show a lot of internal variation (ASFMT, 2002). Cynometra forest and thicket (Cf and Ct) occur on infertile red loam sandy soil in the west, old grown Brachystegia Miombo woodland (Bw) on white deep sandy soil covering the eastern side, so called Mixed forest (Mf) (although by some still named Afzelia forest, after the once dominant species) on white sandy and brown sandy soils occurring in patches of high rainfall over the southeast and northeast, and other undefined lowland mixed vegetation in the north west (Uf) (KIFCON, 2002).

Table 1: The vegetation types occurring in the ASF, acronyms used in this paper, their percentage cover in the ASF and dominant species occurring in them (KIFCON, 2002)

<table>
<thead>
<tr>
<th>Forest type</th>
<th>acronym</th>
<th>% cover in ASF</th>
<th>dominant species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachystegia woodland</td>
<td>Bw</td>
<td>19</td>
<td><em>Brachystegia spiciformis</em></td>
</tr>
<tr>
<td>Cynometra forest and thicket</td>
<td>Cf, Ct</td>
<td>57</td>
<td><em>Cynometra webberi</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Manilkara sucalata</em></td>
</tr>
<tr>
<td>Mixed (Afzelia) forest</td>
<td>Mf</td>
<td>16</td>
<td><em>Manilkara sansibarensis</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Combretum schumannii</em></td>
</tr>
<tr>
<td>Undefined lowland mixed forest</td>
<td>Uf</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Plantations</td>
<td>Pl</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 1: Position of sampling plots and vegetation types of the Arabuko-Sokoke Forest Reserve, Kenya. Dashed lines near plots 18 and 21 show areas where hair traps were set up (only at 18) and morning walks performed; red stars indicate Aders’ duiker sightings.
2.2 Study species - Duiker

Four duiker species occur in the forest (Table 2): Blue (Cephalophus monticola), Natal red (C. natalensis), Aders’ (C. adersi) and Bush (Sylvicapra grimmia) duiker.

Table 2: Duiker species occurring in the Arabuko-Sokoke Forest (Kenya) with their scientific and local Swahili names, average adult weight, the vegetation they occur in and their conservation status in the ASF (Kingdon, 2001; Kanga, 2003)

<table>
<thead>
<tr>
<th>Duiker species</th>
<th>Scientific name</th>
<th>Swahili name</th>
<th>average adult weight (kg)</th>
<th>Habitat</th>
<th>Conservation status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue duiker</td>
<td>Cephalophus monticola</td>
<td>Ndimba, Chesi</td>
<td>5</td>
<td>X</td>
<td>common</td>
</tr>
<tr>
<td>Natal red duiker</td>
<td>Cephalophus natalensis</td>
<td>Funo, Ngarombwi</td>
<td>12</td>
<td>X X X</td>
<td>common</td>
</tr>
<tr>
<td>Aders’duiker</td>
<td>Cephalophus adersi</td>
<td>Paa nunga</td>
<td>9</td>
<td>X - ?</td>
<td>endangered</td>
</tr>
<tr>
<td>Bush duiker</td>
<td>Sylvicapra grimmia</td>
<td>Nsyaa</td>
<td>19</td>
<td>- X -</td>
<td>common</td>
</tr>
</tbody>
</table>

The Aders’ duiker is easily recognized and distinguished from other duiker species by a broad white band from its forward lower midriff across the buttocks (not above the tail) and white and black freckling on the lower fore limbs against its washed out tawny red coat (for more detailed description see Kingdon, 2001). Adults weight between 6-12 kg and are with a height of 30-32 cm the smallest of the red duiker lineage, where Aders’ duiker has been placed after recent DNA analysis (which however was carried out with Aders’ duiker tissue from Zanzibar only) (Finnie, 2002). They are almost completely diurnal with very acute sense of hearing and smell, being most active from dawn until about 11am and from about 4pm until dusk (Finnie, 2002). Territories are marked with pellet piles and by facial gland secretions on prominent twigs (Finnie, 2002). In Zanzibar, Aders’ duiker were mostly observed singly, sometimes in pairs or trios and frequently following troops of monkeys, who provided fruits, seeds and leaves discarded and dislodged from the canopy (Finnie, 2002).
2.3 Habitat analysis

Plant composition and abundance were examined in a total area of 400 m$^2$ at 40 localities (Figure 1). 8 were selected because of their proximity to recent (since 1999) records of Aders` duiker (AD plots; 6 and 2 in the Cf and Mf respectively; red stars in Figure 1). The other 32 localities were randomly stratified selected, according to the percentage cover of the three main vegetation types and accessibility (non-AD plots; 8, 11 and 13 in Mf, Bw and Cf respectively). The locations were selected in order to cover as much of the variation within the forest as possible, and to examine the similarity of the plant communities of suspected and potential Aders` duiker habitats, especially in the relatively little surveyed south and east. Due to the difficult dense habitat and safety considerations regarding elephants in the forest, stratified random points were located on tracks within the aimed forest type rather than in the forest itself. Depending on the vegetation type surveyed and the location, one or two plots (Cf and Mf or Bw respectively) could be surveyed in one day. The sampling plots were situated in a random direction along a line about 130 m perpendicular to the track to avoid edge effects, taking the random point as starting position (Figure 3). At each sampling point, plant composition and abundance in square 10X10 m, 4X4 m and 2X2 m plots were studied, following the methods described by Cunningham (2001) and the sampling design used in former studies in the ASF by Kanga (2002b) and Mutangah and Mwaura (1992) (Table 3) Diameter at breast height (dbh) was measured using a dbh-tape and stem height was estimated directly using a 2 m measured pole rather than a clinometer due to very dense vegetation and respectively low visibility. Nomenclature of plants followed Robertson and Luke (1993). The % visibility at 5 m distance was determined at the four sides of the 10X10 m plot using a checkerboard and counting the squares which had more than 50% of their area covered by vegetation. Canopy cover was assessed by taking a digital picture vertically from the ground of the canopy in the middle of each of the four sides and at the centre of the 10X10 m plot. The percentage of light versus dark areas was calculated, and averaged over the five pictures taken, using ImageJ 1.31v (Appendix I).
Table 3: Sampling design

<table>
<thead>
<tr>
<th>Plot size (m)</th>
<th>Factor measured</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 X 10</td>
<td>Height and dbh of woody species with dbh ≥ 5 cm, canopy cover and visibility</td>
<td>within the 100 X 100</td>
</tr>
<tr>
<td>4 X 4</td>
<td>Height of saplings with dbh &lt; 5 cm and ≥ 1 m height</td>
<td>within the 10 X 10</td>
</tr>
<tr>
<td>2 X 2</td>
<td>Abundance of vascular plant species &lt; 1 m height</td>
<td>within the 4 X 4</td>
</tr>
<tr>
<td>100 x 100</td>
<td>elephant/human disturbance, duiker pellets and tracks</td>
<td>30 m perpendicular to track</td>
</tr>
</tbody>
</table>

2.4 Duiker abundance and disturbance measurement

Starting from the 10X10 m plot, a 100X100 m square transect was walked, and all signs of duiker one metre away on each side were noted and a digital picture was taken (Table 3; Figure 3). Pellet group counts and track counts have been used widely as population indices for assessing trends of rare and secretive forest dwelling species, however no universal procedure exists (Koster and Hart, 1988). In this study, pellets were counted as a group when 10 or more pellets were lumped together. If several pellet piles contained similar shaped pellets, and were close to each other, they were counted as separate piles only if no obvious scattered pellets connected them. Tracks could be distinguished between antelope and other mammals living in the ASF by their size, shape and patterns on the ground. Searches for Aders’ duiker were conducted
under meteorological conditions favourable for duiker activity (rainy and cool) from about 6:30 to 9:00 am (Finnie, 2002). Three walks were performed on the northern border line of the nature reserve (Komani) and two walks in the eastern Cf near Dida (Figure 1, dashed lines). Six hair traps were set up on the northern border line of the nature reserve in Cf and Ct over a length of about 3 km. Sticks were covered with sticky tape and placed approximately horizontally, supported by vegetation or other sticks at a height of about 30cm across a duiker track. Hair traps were placed such that the animals were only able to avoid crossing below them by taking detours around very dense vegetation. They were examined for hair after 2 days, one week and 2 weeks. The collected hair will be examined and compared with hair from museum specimen using an electron microscope.

2.5 Statistical analysis

The data was analyzed using correlation and multivariate analysis, to account for limitations of each method and provide information on the relationship between habitat/disturbance factors and the possible distribution of duiker as well as a general descriptive overview. Point-biserial correlation analysis was performed on the dichotomous nominal variables AD plot, presence/absence of elephant disturbance and human disturbance using MS-Excel (Kent and Coker, 2003, pp. 131-139). The Kruskal-Wallis test was applied to test the difference between the individual forest types, duiker signs and duiker sightings and the quantified variables. Results for the latter two were compared with point-biserial correlation analysis (Dytham, 2005, pp. 121). To test the 0-hypothosis of no difference between the fixed factors forest type and Aders’ duiker sighting or duiker signs, environmental and disturbance variables were compared using 2-way analysis of variance (ANOVA). Homogeneity of variance was tested using the Levene’s test and variables transformed if necessary. A dissimilarity matrix of the environmental/disturbance data was constructed using Spearman rank-order correlation analysis and the program SPSS 11.5 for Windows. Highly correlated
variables as well as those lacking any significant correlation where omitted from the
ordination.

Multivariate ordination with the matrix of environmental and disturbance data was
performed using Nonmetric Multidimensional Scaling (NMS; Mather, 1976; Kruskal,
1964) in the “slow and thorough” autopilot mode with Euclidean (Pythagorean) distance
measure in the program PC-ORD Version 4.27 (McCune and Mefford, 1999). NMS has
performed well with both simulated gradients and field data in former studies with
sparse and nonlinear, non-continuous data and has the advantage, compared to other
ordination methods, of relieving the “zero-truncation problem” (PC-ORD, 2005). The
dimensionality of the data set can be assessed and gradients of high β-diversity
(between habitat) can be recovered (Kent and Coker, 2003, pp.228). Therefore it
seemed appropriated for usage in this study. The species matrix was tested for outliers
and fourth root transformed to reduce the effects of rare species and increase linearity
of the data (Clarke, 1993). The after-the-fact coefficient of determination between
Relative Euclidean distance in the unreduced species space and Euclidean distance in
the ordination space was calculated to determine the %-variation explained by the
ordination axes. Classification of the sampling plots was preformed using Two-way
indicator species analysis (TWINSPAN; Hill, 1979) and the program PC-ORD on
presence/absence of species data.

Equation 1: The point-biserial correlation coefficient

\[ r_{pb} = \frac{|M_p - M_q|}{SD} \sqrt{p_1 q_2} \]

where: \( r_{pb} \) = point-biserial correlation coefficient
\( M_p \) = mean of the first group of values
\( M_q \) = mean of the second group of values
\( |M_p - M_q| \) = the absolute difference between the means
\( p_1 \) = proportion of observations in the first group
\( q_2 \) = proportion of observations in the second group
\( SD \) = the standard deviation of all observations on the
continuous variable
3 Results

3.1 Multivariate analysis and General Overview

Overview. - 89 species were recorded in the 40 plots located in the three main vegetation types (Mf, Bw and Cf/Ct), 18 of which were Aders’ duiker food plants (AD plants; sensu Kanga, 2002a; Table 4). Three AD plant species (namely *Cynometra webberi*, *Combretum illaiii* and *Manilkara sulcata*) accounted for 67% of the AD plant abundance in all plots, whereas 13 occurred in only 50% or less of the plots where Aders’ duiker sightings were reported (AD plots). Thus, few abundant duiker food species seemed to dominate over many rare ones.

Table 4 List of Aders’ duiker food species (sensu Kanga, 2002a), abbreviations used in the analysis, frequency (species/plot) in the 40 sample plots, life form and part(s) eaten by duiker

<table>
<thead>
<tr>
<th>Species</th>
<th>Abbreviation</th>
<th>frequency</th>
<th>Lifeform</th>
<th>Part(s) eaten</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ancylobotrys petersiana</em></td>
<td>Ap</td>
<td>12</td>
<td>Liana</td>
<td>Seeds, leaves</td>
</tr>
<tr>
<td><em>Canthium mombazense</em></td>
<td>Cm</td>
<td>13</td>
<td>Shrub</td>
<td>Leaves, fruits</td>
</tr>
<tr>
<td><em>Combretum illairii</em></td>
<td>Ci</td>
<td>11</td>
<td>Shrub</td>
<td>Fruits</td>
</tr>
<tr>
<td><em>Cissus rotundifolia</em></td>
<td>Cs</td>
<td>28</td>
<td>Liana</td>
<td>Fruits</td>
</tr>
<tr>
<td><em>Cynometra webberi</em></td>
<td>Cw</td>
<td>18</td>
<td>Tree</td>
<td>Leaves</td>
</tr>
<tr>
<td><em>Grewia ssp.</em></td>
<td>Gs</td>
<td>12</td>
<td>Shrub</td>
<td>Fruits</td>
</tr>
<tr>
<td><em>Haplocoelum inoploemum</em></td>
<td>Hi</td>
<td>6</td>
<td>Shrub</td>
<td>Fruits</td>
</tr>
<tr>
<td><em>Heinsia crinita</em></td>
<td>Hcr</td>
<td>11</td>
<td>Shrub</td>
<td>Flowers</td>
</tr>
<tr>
<td><em>Hugonia castaneifolia</em></td>
<td>Hca</td>
<td>15</td>
<td>Shrub</td>
<td>Seeds, fruits</td>
</tr>
<tr>
<td><em>Landolphia kirkii</em></td>
<td>Lk</td>
<td>19</td>
<td>Liana</td>
<td>Leaves, stems</td>
</tr>
<tr>
<td><em>Manilkala sulcata</em></td>
<td>Ms</td>
<td>25</td>
<td>Tree</td>
<td>Seeds, leaves</td>
</tr>
<tr>
<td><em>Psychotria ambioniana</em></td>
<td>Pa</td>
<td>11</td>
<td>Shrub</td>
<td>Leaves</td>
</tr>
<tr>
<td><em>Salacia elegans</em></td>
<td>Se</td>
<td>18</td>
<td>Shrub</td>
<td>Leaves</td>
</tr>
<tr>
<td><em>Salacia madagascariensis</em></td>
<td>Sma</td>
<td>11</td>
<td>Shrub</td>
<td>Leaves</td>
</tr>
<tr>
<td><em>Schlecterina mitostematoides</em></td>
<td>Smi</td>
<td>5</td>
<td>Shrub</td>
<td>Fruits</td>
</tr>
<tr>
<td><em>Strychnos ssp.</em></td>
<td>Ss</td>
<td>24</td>
<td>Tree</td>
<td>Leaves</td>
</tr>
<tr>
<td><em>Synaptolepis kirkii</em></td>
<td>Sk</td>
<td>22</td>
<td>Shrub</td>
<td>Leaves</td>
</tr>
<tr>
<td><em>Uvaria acuminata</em></td>
<td>Ua</td>
<td>18</td>
<td>Shrub</td>
<td>Leaves</td>
</tr>
</tbody>
</table>
The Kruskal-Wallis test (3 d.f.) showed that the number of AD species ($\chi^2 = 14.489; p = 0.01$) and plants ($\chi^2 = 14.489, p < 0.01$; Figure 5) visibility ($\chi^2 = 16.458, p = 0.001$) and canopy cover ($\chi^2 = 9.217, p < 0.05$), as well as presence/absence of duiker signs ($\chi^2 = 19.28, p < 0.001$), the number of duiker pellet piles ($\chi^2 = 20.697, p < 0.001$), antelope paths ($\chi^2 = 22.022, p < 0.001$) and elephant induced disturbance ($\chi^2 = 10.342, p < 0.05$) counted in the 100X100 m plots varied significantly between the individual forest types, whereas disturbance by humans ($\chi^2 = 0.639, \text{ns}$), was not significantly different. Visual observation shows clearly that AD plots and Cf/Ct have similar high results compared to Bw and Mf (Figure 4) considering duiker signs. Whereas elephant induced disturbance was considerably higher in the Mf, illegal human activities did not vary as much.

Figure 4 Summary of Duiker signs and disturbance (mean % per plot) recorded along the 100X100 m square transects. Transects in areas where Aders' duiker were seen are denoted as dotted, where no duiker sighting was reported as light grey, in Brachystegia woodland as dark grey, in Mixed forest as white and Cynometra forest/thicket as dashed.
Figure 5 NMS biplot of relative position of the 18 Aders’ duiker food plant species to the polygons enclosing the three surveyed forest types (Bw = Brachystegia woodland, Mf = Mixed forest, Ct/Cf = Cynometra forest/thicket). For abbreviations of species names see Table 1.

**Ordination.** - Six outlier species were found prior to the ordination: *Cynometra webberi, Kyllinya bulbosa, Brachylaena huillensis, Manilkara sulcata, Combretum illarii* and *Croton pseudopulchellus*. Only the grass *Kyllinya bulbosa* was removed from the matrix before performing NMS. It had a very high standard deviation and abundance compared to the woody species or herbs and thus biased the results. The other species however, were included in the ordination as they belong to the main characteristic tree species in the individual forest types in the ASF, and are thus important for correct data analysis and interpretation (KIFCON, 2002). Variables showing high correlation or non-significance in the Spearman rank-order correlation analysis (Appendix D) have been omitted from the ordination in order to reduce the data. Of the 16 variables quantified (Appendix E), only elephant and human disturbance, visibility, canopy cover, number of duiker food plants, antelope paths, and duiker pellet piles were included, which resulted in the same %-variation explained as the ordination including all variables, which justified this data reduction. NMS was run in the “slow and thorough” mode, until 3-dimensions with a stress of 13.27 were selected as the optimal solution ten times in a row. After-the-fact coefficient
of determination revealed that the three NMS axes explained 14.1%, 43.9% and 26.7% of the variation in the data respectively and were essentially orthogonal. Thus, a total of 84.6% of the variance in the data could be explained by the graph. Biplots are shown with joint plot cut off of $r^2 = 0.100$, and Vector scaling = 200%. The NMS biplot of the three main forest types, where sampling plots were located, and the correlation to environmental, as well as disturbance variables, are shown in Figure 6 (axes 2 vs. 3 are shown, as they explain most of the variation). Polygons enclosing the individual forest types are drawn. The grouping of the sampling plots using TWINSPLAN presence/absence of plant species separated the plots in two big groups namely Bw in one and Ct/Cf and Mf in the other. Mf and Ct/Cf could then be divided once more to give three big groups in total. Apart from two plots (pointed out with arrows; Figure 7), all 40 plots were grouped in relation to their vegetation type.

The relative position of AD/non-AD plots and of plots where signs of duiker (pellet piles and/or antelope paths) were counted, are shown with respect to the forest type polygons and environmental/disturbance variables in NMS biplots (Figure 8 and 9 respectively).

Figure 6 NMS biplot of 40 sample plots based on the type of forest they were placed in. Plots occurring in Brachystegia woodland (Bw) are denoted by empty circles, plots in Cynometra thicket (Ct) by filled triangles, plots in Cynometra forest (Cf), by empty triangles and plots in Mixed forest (Mf) by filled squares. Polygons enclosing the individual forest types are drawn.
Figure 7 NMS biplot of TWINSPLAN groups according to the presence/absence of plant species. Individual TWINSPLAN groups are enclosed by polygons. Plots occurring in group 1 (equivalent to Brachystegia woodland (Bw)) are denoted by empty circles, in group 2 and 3 (equivalent to Cynometra thicket and forest (Ct, Cf)) by filled triangles, and in group 4 (equivalent to Mixed forest (Mf)) by stars. Two plots whose TWINSPLAN grouping did not match the vegetation type are pointed out by arrows.

Figure 8 NMS biplot of 40 sample plots based on presence/absence of duiker signs (pellet piles and/or antelope paths). Plots in areas where no signs of duiker were seen are shown as empty circles; where only antelope paths were found are denoted as triangles pointing down; where only duiker pellet piles were found as triangles pointing up; where duiker pellet piles and antelope paths were encountered as stars. Overlay of environmental/disturbance variables is shown. Length of arrows is proportional to the importance of variables (Visibility = most important). Polygons enclosing the individual three forest types (Bw = Brachystegia woodland, Mf = Mixed forest, Cf/Ct = Cynometra forest/thicket) are drawn.
3.2 Correlation analysis

Aders’ duiker sighting. – Point-biserial correlation analysis, as well as the Kruskal-Wallis test, showed persistent non significant relationships between the sighting of Aders’ duiker and elephant, as well as human disturbance, the number of duiker signs (pellet piles and antelope paths), duiker food plants and species, visibility and canopy cover. Levene’s Test revealed heterogeneity of variances for the dependent variables elephant- and human disturbance, number of duiker food plants, antelope paths and duiker pellet piles. Non-significant results for human disturbance and number of duiker food plants rendered the increased possibility of Type I error, a result of this heterogeneity, neglect able. The other variables however, all having strongly right screwed non-normal distributions, were log 10 transformed after increasing the value of sparse cells to 0.01 for the purpose of this calculation. Although the variances remained heterogeneous, correlations after the transformation changed to non-significant, again rendering Type I error neglect able (square brackets in Table 5).
2-way ANOVA showed significant correlations between Forest type and visibility or number of duiker food species, as well as between Aders’ duiker sightings and canopy cover (Table 5).

**Duiker pellet piles and antelope paths.** – Point-biserial correlation analysis between the presence/absence of disturbance and count of duiker signs (pellet piles and antelope paths) gave the same result as the Kruskal-Wallis test. Significant correlations only with visibility, number of duiker food plants and elephant disturbance were found (Table 6). Of the variables having heterogeneous variances (accentuated in Table 7 by lack of boldness), only “number of duiker food plants” yielded lower significance values in this analysis. Square root transformation was performed which increased the homogeneity of variances for this variable considerably ($p > 0.05$). Results of ANOVA with the transformed variable are given in square brackets. 2-way ANOVA gave significant results for the interaction of number of duiker food species and visibility with forest type and canopy cover with duiker signs (Table 7).

Table 5 Results of 2-way ANOVA. Dependent variables which are not bold lack homogeneity of variances (Levene’s test). F-ratios and significance levels are given ($p$ values: *0.05, **0.01, ***0.001, ns > 0.05). Values in square brackets indicate results of ANOVA after log 10 transformation.

<table>
<thead>
<tr>
<th>Variables</th>
<th>F_{1,33}</th>
<th>p</th>
<th>F_{3,33}</th>
<th>p</th>
<th>F_{2,33}</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aders’ duiker sighting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest type</td>
<td>2.22</td>
<td>ns</td>
<td>9.46</td>
<td>***</td>
<td>1.24</td>
<td>ns</td>
</tr>
<tr>
<td>Visibility</td>
<td>4.02</td>
<td>*</td>
<td>2.23</td>
<td>ns</td>
<td>0.59</td>
<td>ns</td>
</tr>
<tr>
<td>Canopy cover</td>
<td>1.29</td>
<td>ns</td>
<td>9.04</td>
<td>***</td>
<td>0.76</td>
<td>ns</td>
</tr>
<tr>
<td>Number of duiker food</td>
<td>0.32</td>
<td>ns</td>
<td>3.52</td>
<td>ns</td>
<td>0.20</td>
<td>ns</td>
</tr>
<tr>
<td>species</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of duiker food</td>
<td>0.02</td>
<td>ns</td>
<td>6.16</td>
<td>**</td>
<td>7.83</td>
<td>**</td>
</tr>
<tr>
<td>plants</td>
<td>[0.232]</td>
<td>[ns]</td>
<td>[0.296]</td>
<td>[ns]</td>
<td>[2.883]</td>
<td>[ns]</td>
</tr>
<tr>
<td>Pellet piles</td>
<td>1.57</td>
<td>ns</td>
<td>12.47</td>
<td>***</td>
<td>6.05</td>
<td>**</td>
</tr>
<tr>
<td>Antelope paths</td>
<td>[0.159]</td>
<td>[ns]</td>
<td>[4.403]</td>
<td>[ns]</td>
<td>[1.931]</td>
<td>[ns]</td>
</tr>
<tr>
<td>Elephant disturbance</td>
<td>0.35</td>
<td>ns</td>
<td>4.61</td>
<td>*</td>
<td>0.89</td>
<td>ns</td>
</tr>
<tr>
<td>Human disturbance</td>
<td>[0.386]</td>
<td>[ns]</td>
<td>[5.505]</td>
<td>[ns]</td>
<td>[0.893]</td>
<td>[ns]</td>
</tr>
<tr>
<td>disturbance</td>
<td>0.75</td>
<td>ns</td>
<td>0.19</td>
<td>ns</td>
<td>0.43</td>
<td>ns</td>
</tr>
</tbody>
</table>

Table 6 Correlation analysis of point-biserial correlation with visibility, number of duiker food plants, elephant disturbance and human disturbance.
Table 6 Results of the point-biserial correlation analysis between the presence/absence of duiker signs and environmental/disturbance variables. \( r_{pbi} \) = point-biserial correlation coefficient, \( t \) = t-test, ns = non significant, vs. = versus. Significance levels are given with \( p \) (2-tailed) *0.05, **0.01, ns > 0.05.

<table>
<thead>
<tr>
<th>Presence/absence of duiker signs vs.</th>
<th>Visibility</th>
<th>Canopy cover</th>
<th>Elephant disturbance (tracks+clearings)</th>
<th>Human disturbance (paths+poaching)</th>
<th>Number of duiker food species</th>
<th>Number of duiker food plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.48</td>
<td>0.08</td>
<td>0.34</td>
<td>0.2</td>
<td>0.27</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>3.37 **</td>
<td>0.52 ns</td>
<td>2.23 *</td>
<td>1.25 ns</td>
<td>1.74 ns</td>
<td>2.18 *</td>
</tr>
</tbody>
</table>

Table 7 Results of 2-way ANOVA. Dependent variables which are not bold lack homogeneity of variances (Levene's test). F-ratios and significance levels are given (\( p \) values: *0.05, **0.01, ***0.001, ns > 0.05). Values in square brackets indicate results of ANOVA after square root transformation.

<table>
<thead>
<tr>
<th>Duiker signs</th>
<th>Forest type</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( F_{1,33} )</td>
<td>( p )</td>
</tr>
<tr>
<td>Visibility</td>
<td>1.73 ns</td>
<td>5.45 **</td>
</tr>
<tr>
<td>Canopy cover</td>
<td>3.51 *</td>
<td>2.25 ns</td>
</tr>
<tr>
<td>Number of duiker food species</td>
<td>0.95 ns</td>
<td>7.85 ***</td>
</tr>
<tr>
<td>Number of duiker food plants</td>
<td>0.03 ns</td>
<td>5.86 **</td>
</tr>
<tr>
<td>[1.105] [ns]</td>
<td>[0.154] [ns]</td>
<td>[0.228] [ns]</td>
</tr>
<tr>
<td>Elephant disturbance</td>
<td>2.68 ns</td>
<td>1.40 ns</td>
</tr>
<tr>
<td>Human disturbance</td>
<td>0.61 ns</td>
<td>0.15 ns</td>
</tr>
</tbody>
</table>

3.3 Morning walks and hair traps

Aders' duiker were seen on two of the three occasions when morning walks were performed (Appendix F). Hair was found about two weeks after setting up the hair traps on five of the six traps (Appendix F) The sticky tape stayed sticky, despite of rough weather conditions (alternating heavy rain and very hot and dry). Unfortunately, time restrictions did not allow for control traps set up in "non-AD areas" and so far, the hair could not be examined microscopically.
4. Discussion

This study has some basic albeit unavoidable flaws which undermine the strength of its conclusions. The two main tenets, areas where Aders’ duiker were sighted and Aders’ duiker food plants are based on very arbitrary information. To locate plots in areas where the Aders’ duiker was likely to dwell, the study had to rely on reports mainly from local guides. Although this duiker is quite easily distinguished from other small antelopes occurring in the ASF, identification skills of the guides were not assessed. Most importantly, tourists and researcher are mainly guided along the tracks and in areas of the forest which are readily accessible from the Gede forest station, especially in the east up to the Jilore Forest station and in the South up to the Nyari View Point, as well as around the nature reserve, omitting the north-western corner. Thus, the better part of the Cynometra vegetation, especially the more dense area with low visibility associated with many duiker signs and duiker sightings in this study is rarely visited by people that could report an Aders’ duiker sighting. Correspondingly little reports on Aders’ duiker sightings existed, additionally decreasing the power of this part of the study.

Justification of the list of Aders’ duiker food plants used in this study is complicated by lack of reliable information. A statement from Zanzibar (Aplin 1998) was compiled merely on the basis of an interview with a local hunter (Finnie, pers. comm. 2005), which is the case for one list from ASF as well (Kanga, 2002a). Records from the ASF used in this paper (Kanga, 2002a) stem from stomach analysis of just one individual, whose descent is unclear. Attempts to analyze the stomach content of 5 animals in Zanzibar failed due to technical problems and the only individual known to live in captivity is fed *inter alia* with cultivated plants (Finnie, pers. comm. 2005). Species occurrence by itself indicates little or nothing about the capability of the associated environment to support long-term persistence of populations (Conroy and Noon 1996, Conroy *et al.* 1995). However, pellet pile and track counts have been used successfully to predict habitat suitability and abundance of small antelopes (Koster and Hart, 1988; Bowland and Perrin, 1994; Komers and Brotherton, 1997). Obstacles like
dung defaecation rates depending on the fibre levels in the (unknown) diet, age and season, decomposition because of dung beetle activity, and coverage by leaf fall, as well as the difficulty of knowing pellet-group production and disappearance rates in absence of data from captive animals aggravate their use as density estimates in this study (Koster and Hart, 1988; Bowland and Perrin, 1994). Results were biased by the considerable differences in density and colour of the ground especially between Ct and Mf, and due to time constrains, pellet piles could not be related to individual duiker species (but see Kanga, 2002b; Finnie, in press, for guidelines on how to distinguish Aders’ duiker pellets). Thus, pellet pile counts were only used as very rough estimator of duiker abundance alongside track counts in this study. Keeping in mind the limited precision and accuracy associated with the factors discussed above, the following conclusions are drawn.

Although classification of the forest into four main vegetation types is still controversial, significant differences in visibility, and canopy cover, together with the NMS showing relatively clear partition between Ct/Cf, Mf and Bw, and the TWINSPAN grouping, support this division. Two outliers in the TWINSPAN can be explained by their position in small patches of Bw and Ct close to other vegetation. Additional division of the Cynometra into forest (canopy height > 6m) and thicket (canopy height < 6m) used in this study was not supported, as TWINSPAN only recognized one big Cynometra group and not enough plots were surveyed in the thicket for the separation observed in the NMS biplot to be interpretable. However, it is worthy to note that half of the Aders’ duiker sighting plots and a high proportion of duiker signs, were situated in overlapping Cynometra forest-thicket areas in the NMS biplot, although the power of this factor is with 8 unconfirmed sightings not high enough to draw any conclusions. It should also be kept in mind that the optimal solution being 3-dimensional, but NMS biplots being displayed only in 2-dimensional images together with a high final stress aggravate correct interpretation. The 15% of the variation not being explained by the 3 NMS axes and (in order of decreasing importance) visibility, number of duiker food plants, elephant clearing, duiker pellet piles, antelope paths, elephant tracks, canopy cover,
and human disturbance, might be due to seasonal effects (not only the vegetation, also elephant disturbance is highly seasonal), soil properties, elevation, and distance to edge or nearest village (ASFMT, 2002). Distance to closest water source is, unlike for other ungulates, probably not an important factor for Aders’ duiker, as it is able to take in enough water with its diet (Kingdon, 2002; Finnie, 2002).

Multidimensional ordination, as well as Spearman correlation analysis, the Kruskal-Wallis test, and point-biserial correlation showed significant correlations and interactions between high (good) visibility (-), elephant disturbance (-), the number of Aders’ duiker food plants (+) and the occurrence of duiker signs (pellet piles and/or paths) and forest types, respectively, thus supporting findings about Aders’ duiker preferring dense thicket as habitat (Finnie, in press; Mwinyi and Wiesner, 2003, personal observations during this study). Significantly higher elephant disturbance in Mf, and equally high abundance of suspected Aders´ duiker food plants (albeit possibly defined wrong) in Ct/Cf and Mf together with combined grouping of Cf/Ct and Mf in the TWINSPAN analysis supports the theory that Aders´ duiker potentially occurs in Mf as well, albeit being disturbed by elephant activity. However, counts of duiker signs (pellet piles and tracks) were highly significantly more successful in Cynometra vegetation. This may be partly due to three of the four duiker species in the ASF occurring in Ct/Ct, and the bigger sample size in this vegetation additionally increasing the probability of encountering duiker signs. Bias by this imbalanced design could be avoided by randomly choosing eight out of the 32 non-AD plots and adjusting the number of plots per forest type before conducting ANOVA.

Due to this imbalance and the nature of the data (heterogeneity of variances, non-linearity, some of the data for the dependent variable not being interval), ANOVA results could only be construed with care and the non-parametric Scheirer-Ray-Hare test might in this case have been a better choice, albeit being time consuming to calculate and not eliminating the problems of heterogeneity of variances and scarce data (Underwood, 2001). Thus, 2-way ANOVA, could only interpreted as supporting
results from multidimensional ordination regarding correlations between Forest type and visibility as well as the number of duiker food species.

The non-significant relationship of Aders’ duiker sightings with all variables in all tests is not surprising, considering the low sample size and uncertainty of the reports.

In the background of low recent sightings, it was promising, that three Aders’ duiker were seen during one month in the course of this study (Kanga, pers. comm.; Finnie, pers. comm.) However, considering time and personnel requirements, hair traps have been used more economically and successful in estimating species densities *inter alia* by genotyping DNA from hair, which could also provide important information about the taxonomic status and genetic diversity of the population in the Arabuko-Sokoke forest (Boersen *et al.*, 2003; Frantz *et al*, 2004). Although their applicability in this study warrants further investigation, hair traps have a high potential as fast and reliable density estimators in addition to pellet pile counts (including classification to individual duiker species), walks or infra red cameras, set up along the northern border of the nature reserve (with possible extension further west and over a longer time period to incorporate seasonal effects), and vegetation analysis (after confirming identification of Aders’ duiker food plants by stomach or pellet analysis). These methods could form the basis of a cost-effective, reliable and widely applicable method for the assessment of the population status and distribution of Aders’ duiker and other small rare and cryptic mammals.

However, not only Aders’ duiker ecology, also the role of interspecific competition, especially between Blue, Natal red, and Aders’ duiker, sharing with *Cynometra* vegetation the same habitat, warrants investigation. If separation is due to competition rather than fundamental niche constraints, the proposed zoning as conservation measure for the Aders’ duiker could have indirect effects on its population (Newing, 2001). Thus, it is advisable to accomplish further research in duiker ecology, and behavior before deciding on conservation measures which may be counterproductive being based on the insufficient information available to date.
Acknowledgements

I am grateful to Paignton Zoo Environmental Park for financial support and advice during this study and to the Kenya Wildlife Service for kindly allowing me to work in the Arabuko-Sokoke Forest Reserve. I thank my guide Willington Kombe and Alex Prendergast for assisting in my field work and Ann Robertson for helping with identification and pressing of numerous plant specimens.

I especially thank Eirene Williams, Natasha De Vere, Amy Plowman, the staff from the “Mwamba” Arocha Field study centre, Erustus Kanga, Matthias Mwavita, Derek Finnie and Martin Kent for giving me access to unpublished information, advice and support during the field work and help with the data analysis. My biggest gratitude however goes towards my family for their incredible love and support.
References


World Wide Fund for Nature Project AT104

density and genetic diversity at Tensas River, Louisiana using microsatellite


Philantomba monticola and red duikers Cephalophus natalensis in Natal. South

Clarke, M.G., 1993. Habitat complexity and beetle diversity. Diversity and Distributions
11, 73-82

Parameter estimation, reliability, and model improvement for spatially explicit
models of animal populations. Ecological Applications 5, 17-19.

biological diversity: conceptual and methodological issues. Ecological
Applications 6, 763-773.

Cotterill, F.P.D., 2003. Species concepts and the real diversity of antelopes. In:
Proceedings of an International Symposium on Duiker and Dwarf Antelope in
Africa. Filander Verlag. Furth


