IMPERIAL COLLEGE LONDON

Faculty of Natural Sciences

(University of London)

Centre of Environmental Policy

Modelling the biases in aerial survey techniques of the saiga antelope (*Saiga tartarica*) in Kazakhstan

By

Andrew-John McConville

A report submitted in partial fulfilment of the requirements for the MSc Environmental Technology

September 2006

DECLARATION OF OWN WORK

I declare that this thesis *Modelling the biases in the aerial survey techniques of the saiga antelope (*Saiga tartarica*)* is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given

Signature:……………………………………………………………………………………….

Name of student:……………………………………………………………………………..

Name of supervisor:……………………………………………………………………..

Abstract

Aerial surveys are routinely chosen as economic and efficient means for estimating wildlife populations in large and remote areas. They are affected however by a consistent negative bias as a result of animals being missed due to their sightability. While account can be taken of the factors affecting sightability, further problems arise when the sightability of animals changes due to either biology or abundance.

A case study of this scenario is the saiga antelope (*Saiga tartarica*) which inhabits the semi-arid rangelands of Central Asia. Following a population crash at the end of the 1990s, the past three years have seen a very encouraging recovery in saiga population in Kazakhstan according to the official national estimates and the population estimate for 2006 stands more than twice the estimate for 2003. There is reason to believe however that the methods used are not reliable and that sightability may have altered due to changes in herd size distribution.

A model was applied to the data to attempt to correct for the main biases that may be affecting the estimates. It was found that there is very large variability associated with the estimates. A review of the biases showed that the majority will lead to underestimates including the changes in herd sizes observed. A recommendation is made to investigate the distribution of saigas during the migration period to assess whether the animals till occur in concentrations, or if they are widely distributed in the landscape.

Acknowledgements

Many people are owed thanks for support during this project. I would firstly like to thank my supervisor E.J. Milner-Gulland, for her exceptional support during the course of the project and her generosity of time and ideas. Also I would like thank Aline Kuhl, for her support in preparing for Kazakhstan and endless patience in answering questions. I am indebted to INTAS for funding field work to Kazakhstan and despite the original project not coming to fruition, it enabled me to collect vital information and insight into the detail of this project. A huge thanks also goes to everyone in the Institute of Zoology, Almaty for their patience in my attempts to communicate with them especially Iuri Grachev and Alexandr Grachev, and Nina and Nele for logistic and culinary support. My friends in London and at home have put up with a lot. In particular I would like to thank Aidan Keane for his encouragement and willingness to talk about and share his innate knowledge of modelling. Lastly, I would like to thank my family for supporting me throughout the MSc.

List of Acronyms

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals (or the Bonn Convention)
IUCN	International Union for the Conservation of Nature and Natural Resources (The World Conservation Union)
AIC	Akaike's Information Criterion
GPS	Global Positioning System

1. Introduction

1.1 Estimating population size of large mammals

The population assessment of large mammals over extensive areas presents considerable challenges for wildlife managers. The resources and time required to cover vast areas can be very significant and limiting where funds are scarce. Ensuring that the whole area is searched requires careful survey design. Once a survey is underway, one must locate, detect and accurately count the numbers of animals present.

Aerial surveying has been a preferred and established method where the area is large or inaccessible. While it constitutes a practical means of assessing mammal populations, it is subject to "visibility bias," which arises from animals being missed within the area of search due to factors such as speed, observer fatigue and obstruction by vegetation. This negative bias can be as much as 50% or more (Caughley, 1974). While it is impossible to eliminate, it is normally sufficient to keep bias constant so that estimates are precise allowing trends over time to be estimated with confidence. When there is reason to believe that bias has changed or the counts are less precise, any stated trends must be treated with caution. Changes in biology or distribution can lead to uncertainties about the degree of bias in survey estimates.

1.2 The case of the saiga antelope

A case study of this scenario is the saiga antelope (*Saiga tartarica*). Saiga is a nomadic, herd-forming antelope that populates the steppe and desert of Central Asia. There are two sub-species; *Saiga tartarica tartarica*, which is the more abundant, found in Kazakhstan and the Russian Republic of Kalmykia, and *S.t. mongolica* in Mongolia (Khlodova *et al.* 2006).

Saigas have seen spectacular falls in population in recent years. Total population estimates indicate that numbers fell 92% between 1998 and 2003 (see Figure 1.1) with an average rate of decline of 44% per year. This led the IUCN, the World Conservation Union, to reclassify the species in 2002 as

Critically Endangered on its Red List and the inclusion of saiga in Appendix II of the Convention of Migratory Species (CMS) (relating to international co-operation from range states for its protection). The declines are blamed primarily on uncontrolled poaching for meat and commodities, particularly the horns, caused by economic collapse in rural areas (Milner-Gulland *et al.*, 2001).

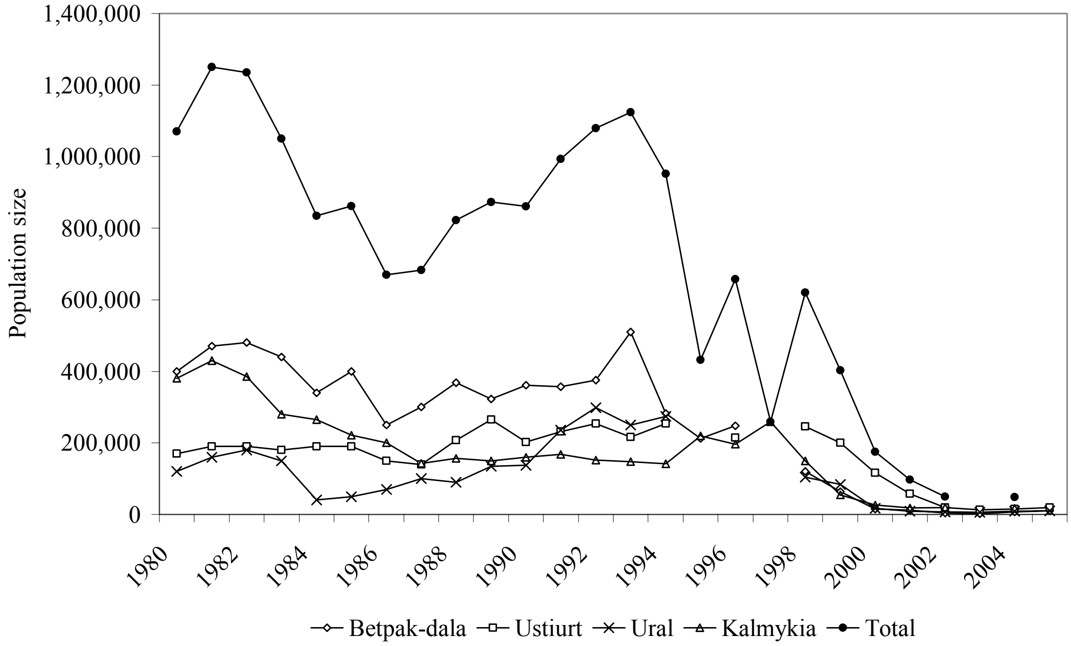


Figure 1.1 Declines of saiga (S.tartarica) throughout its range. (Data from the Institute of Zoology, Almaty).

In Kazakhstan, where counts are consistently carried out every year, numbers reached a record low for recent times in 2003, from 470,000 in 1998 to just 21,000 individuals. In the three years since, saiga appear to have made a recovery, increasing to 39,000 individuals in 2005; almost doubling its population in 2 years, and to 47,400 in 2006. However, a closer look seems to suggest the magnitude of this increase is unlikely. A population model created by Milner-Gulland (1994) quotes a maximum annual rate of population increase of 30%, assuming no poaching. Thus the rates of increase reported in 2004 & 2005 (46% and 29% respectively) would appear to be biologically unlikely given current knowledge, regardless of the activity of poaching. As there is no reason to suspect that poaching has stopped (personal observation; Iu. Grachev, personal communication), doubt must be cast on the accuracy of population estimation techniques.

1.3 Population assessment of saiga

Population censusing of saigas is, by the most part, carried out by the range states. Saigas exist in several discrete populations; one in the Russian Republic of Kalmykia, one in Mongolia and three in Kazakhstan, (known as the Ural, Betpak-dala and Ustiurt populations). Censusing on all populations except that in Mongolia were carried out during the Soviet Union period from as early as the 1950s and the methods have changed little since. The surveys were designed to take place when saigas form large migratory groups, generally in April, to increase the chance of sighting all of the animals. The method involves flying transects across the entire range of the populations and counting all the individuals within each herd encountered.

The disintegration of the Soviet Union meant fewer funds available to scientific research and saiga management and from 1995, the frequency and coverage of the population censusing decreased (Milner-Gulland *et al*., 2001). The population crash towards the end of the 1990s has lead to a change in behaviour of saiga, which could also be having an effect on population estimates. Formerly, saiga aggregated in large numbers during the spring migration, with approximately 40% of the groups occurring in numbers of 500 or over (Fadeev & Sludskii, 1982) and sometimes aggregations reaching as high as 5,000 individuals (Institute of Zoology Almaty, unpublished data). This has changed considerably in recent years, with the maximum herd sizes in certain populations at 300, 150 and 100 for 2004, 2005 and 2006 respectively (Institute of Zoology, unpublished data).

The extent to which these factors have affected the biases within population estimates is unclear. Population estimates are given without confidence intervals, hence giving no indication of the range of estimates that may be made if the studies were to be repeated.

With this situation in mind, it was decided to investigate what effect change in herd size and the current methods of surveying may be having on the overall population estimate. Raw data of the number of individuals seen from the aerial surveys was available for the Ustiurt population in Kazakhstan from 2 years before the population crash and 4 years after as well as the counts for Betpak-dala and Ural populations in 2006. However, the analysis is intended to be general and of relevance to all populations that are experiences similar changes.

The questions the project aims to explore are:

(1) What changes have occurred in the distribution of saiga herds and distribution.

(2) How this change may be affecting the population estimates.

(3) What improvements could be made to current aerial survey practices to improve estimates.

2 Population Assessment Techniques

2.1 Introduction

The management of wildlife populations requires reliable estimates regarding the abundance of the species. The specific requirements of a population assessment technique will vary depending the management strategies being applied. In harvested populations, managers are often concerned with absolute abundance, to ensure that the minimum sustainable population numbers are conserved. In other cases, the trends of relative abundance over time are sufficient.

Surveys can be designed for accuracy or precision. Accuracy is a measure of how close the estimated number is to the true number, while precision is a measure of how repeatable the estimates are. Surveys that are precise may be biased in a particular direction (i.e. give an over or under estimate of the true numbers), but the direction and the extent of the bias is consistent. In the case of populations where the overall discernable trends in population numbers are most important, the survey design would aim for precision as a priority rather than accuracy. Accuracy on the other hand aims to reduce the overall error of an estimate, although the errors may not necessarily be in a particular direction.

2.1.1 Total vs. sample counts

Wildlife estimates can aim to count every individual (i.e. total count) or to count within a proportion of the animals (i.e. sample count). A total count is effectively taking a 100% sample and thus there is presumed to be no sample error associated with the final estimate. For sample counts, the number of animals in the whole area (census zone) is estimated from the density of animals in the searched area (sample zone).

Because there is no presumed sampling error with total counts, other errors become relatively more important. Total counts are based on the three assumptions that:

- the whole area is in fact searched;

- all the groups are located; and
- all the individuals within the groups are accurately counted (Norton-Griffins, 1978).

For sample counts, the same three assumptions mentioned above also apply and a fourth assumption is added; that the area searched is representative of the areas that were not searched. Thus if 25% of an area was searched, the assumption is that it will contain 25% of the animals. This would be the case if animals were evenly distributed throughout the landscape. In reality, this is very rarely the case, as animals tend to occur in herds, with the herds themselves tending to occur in some places more than others creating a variation in density across a census zone (Norton-Griffiths, 1978). The error associated with this is known as random sampling error. With a sample survey, the standard error is assumed to mainly as a result of sampling error (Jolly, 1969b).

2.1.2 Errors in population assessments

The difference between true and observed numbers of a population can be said to be the sum of two components: random error and bias. Random error will change from one observation to the next, sometimes positive, sometimes negative but the errors tending to cancel each other out. This applies to animals moving in a census zone, those moving out will on average be balanced by those moving in. Bias, on the other hand, is an error in a constant direction that will occur consistently in repeated observations. This leads to either an over-estimation (positive bias) or under-estimation (negative bias) of the parameter in question. This may happen, for example, if the animals were shy of the plane and being constantly flushed out of the census zone by the aircraft. Jolly (1969b) cited three main sources of bias:

- consistent errors in counting;
- erroneous methods in sampling; and
- methods of obtaining the final estimate from the sample counts.

2.2 Methods of population assessment

Censusing of mammals is commonly used to find a range of information, including:

- total numbers;
- size and structure of populations; and
- distribution and movements.

The traditional methods of censusing include ground counts (i.e. on foot or from a vehicle counts) and aerial surveying. More recent technologies include infra-red thermal imaging, used from aircraft, and satellite tagging. The decision on which method to use depends on the information needed and the resources available. Factors such as the size of the area in question, the accessibility of the landscape (e.g. open plains or thick bush) and the nature of the animals themselves (secretive or tendency to stay in the open) are important considerations.

2.2.1 Ground counts

Ground counts for terrestrial mammals include foot and vehicle counts. They can provide information on seasonal habitat or vegetation preferences and behavioural information that is missed during aerial surveys. An advantage of ground counts over aerial surveys is that once a group has been spotted, one can stop moving to allow for more group accurate counting of individuals and gather information on sex/age ratios.

Foot counts are useful in terrain that is inaccessible by vehicle and may be obscured from the air, such as dense forest. They also may be essential for smaller species or where animals are vehicle shy. They are naturally limited by the area that they can cover and thus it is difficult to ascertain how representative they are of a whole area.

Counts from vehicles can be effective where the country can be crossed by vehicle and the animals are relatively tame to vehicles. While more limited in their range than aerial surveys, vehicles can still be used in large areas. Olsen *et al.* (2005) used ground counts for estimating Mongolian gazelle by driving long transects of 1,200-1,400km for an area of 80,000km^2. Problems arise when vehicles carry out counts strictly from roads, which may be necessary if cross-country access is limited. It is commonly associated with inbuilt biases, as roads are often designed through areas of high game, and are on good viewing points. Habitat on road verge is also commonly distinct from that of the landscape as a whole.

2.2.2 Aerial surveying

Aerial surveying by light aircraft is useful in situations where the areas are very large as it can cover ground quickly and economically. It has been used extensively in wildlife population censusing since the 1940s and remains a common technique. It is often the only option where land is difficult and inaccessible by vehicle. Aerial surveying, more than other methods is prone to bias due to missing animals and requires the availability of experienced observers year after year to reduce observer bias. Careful design of sample units is also vital. It is this method that is given the most attention in this report, as it is the predominant method used in Kazakhstan for estimating saiga populations.

2.3 Conducting aerial surveys

2.3.1 Principles in aerial surveying

Most aerial surveys of large mammals are carried out by sample rather than total counts. The area to be surveyed is divided into discrete sampling units, which are exhaustive and do not overlap. The units to be sampled are selected via:

- simple random sample,
- with probability according to size, or
- stratification according to some source of variation (Caughley, 1977).

The main methods used for sample counts are transect, block or quadrat sampling. Transect sampling is perhaps the most preferred aerial survey method. It involves flying at a constant altitude in straight, parallel lines from one side of the census zone to the other, and counting animals within a strip of known width from the aircraft. Strip width is generally delineated by markers on the wing struts, which has been calibrated to mark the edge of the strip at the chosen survey height. Surveying is generally carried out between 110-190 km/hr at a height of 100m. In open country, greater heights can be used (Sutherland, 1996) especially when animals occur in large groups.

Quadrat sampling involves dividing the census zone into exhaustive and non-overlapping zones, often rectangles, which are taken to be the sampling units. These are selected for censusing and searched intensively with the aim of counting all animals in the quadrat. They have the advantage that the aircraft can divert to where a large aggregation within the quadrat is seen and count it accurately. This is useful for animals that occur in large, conspicuous groups. Block sampling is essentially the same except units are delineated by physical landmarks, such as streams or roads.

The potential magnitude of sampling error is found in a single sample by examining the variation between the number of animals counted in each of the selected sample units, known as sample variance. If sample variance is large, the variation in the range of alternative estimates is also likely to be large. Calculating the 95% confidence intervals gives an indication of the range of alternative estimates, which is a measure of the estimate's precision. Stating an estimate of 20,000 with $\pm$4,000 animals 95% confidence interval means that if the sample was repeatedly carried out, 19 out of 20 times (95%) the estimate will be between 16,000 and 24,000. (See Appendix 2 for the calculation of confidence intervals).

One way of attempting this is stratification, which involves the splitting up of the census area, often according to a source of variation such as topographical features or type of vegetation, into several sections which together comprise the entire population. The reasoning for this is to find units, or strata, which are homogenous in density, thus making it possible to obtain a precise estimate of the population mean within that stratum from a small sample (see Siniff & Skoog, 1964). To keep the variance of the estimated population mean at a minimum, sampling effort is allocated proportionally to the strata standard deviation, which can achieve significant reduction in sampling error, especially when large differences exist between the strata means (Jolly, 1969a).

2.4. Biases in aerial surveying

The main problem with aerial surveying is the failure to observe all the animals within the sample zone or *visibility bias*. Visibility bias is due to abiotic factors such as the distance between the observer and the animal (Buckland *et al*., 1993); physical obstruction (Graham & Bell, 1969); observer experience, eye-sight and fatigue; background and animal colouration; lighting & weather; and biotic factors such as animal movement, size and group size (Samuel & Pollock, 1981); and vegetation cover (Samuel *et al*., 1987). All of these introduce a negative bias to the counts by reducing *sightability*, i.e. the probability that an animal within an observer's field of search will be detected. Factors that lead a positive bias are considered insignificant and can be ignored operationally (Caughley, 1974).

Survey design has a major impact on bias, in particular the selection strip width, altitude and speed. Increasing the strip width reduces sightability by increasing the mean distance between animals and observer, reducing the time available to locate and count animals and increasing obstructions between animals and observer. Increased altitude increases the distance between observer and animal, but also reduces the effect of obstacles (Caughley, 1974). Speed increases the counting rate or the number of animals to be counted per unit time (Norton-Griffiths, 1978).

Another potential source of bias is the rounding of counts. Without the use of correction photography, it is the natural tendency of observers to estimate group sizes to the nearest round number. For smaller groups this could be multiples of 5 and 10, but for larger aggregations the rounding off of groups can be to the nearest 100 or 1,000.

An important part to improving the reliability of aerial surveys is to keep the conditions of surveys as similar as possible. Design features such as strip width, speed and altitude should be optimised so as to reduce bias and maintained for subsequent surveys. The use of an experienced crew is essential and where possible the same crew should be used.

2.5 Addressing bias in aerial sampling

Initial attempts to address these biases suggested carrying out ground counts and aerial surveys of the same population and taking the ground counts to be an accurate and unbiased estimate of the true number (Jolly, 1969b). The ratio of ground-to-air counts was used in subsequent surveys to adjust the numbers seen to true counts. While in some cases it may be possible to carry out accurate ground counts, they will be limited in range, and in the case of large mammals would be very difficult to obtain.

Photography is frequently used for larger groups, often over 15 individuals, as a means of correcting visibility bias and is essential for accurately counting individuals within large groups. However it does not remove bias and can only correct for groups that have been detected. It also only gives one angle at a group while an observer has several opportunities to count a group as it is passed.

Another technique is to use mark-recapture model, deriving correction factors from the number of groups counted independently by two observers simultaneously scanning the same transect (Caughley & Grice, 1982; Bayliss & Yeomans, 1989). Problems with this method, by the authors' own admission, are the non-independence of marking and recapturing due to the almost identical search image transmitted to the two observers. This may cause a negative bias on population size estimates. It also fails to account for the unequal catchability of animals in different group sizes.

Samuel *et al.* (1987) used a marked subpopulation of radio-collared elk to assess the importance of specific visibility factors during quadrat helicopter surveys. Those elk that were missed by the survey were located using the receiver, and group size, behaviour, percentage vegetation and snow cover recorded. These were used to generate a predicted sightability curve for both percentage vegetation and group size, which were shown to have predominant influence on sightability. This method is labour intensive in terms of catching and radio-collaring a sufficient number of animals. It does not take into account the effect of distance on the sightability but would be suitable for quadrat sampling.

Other attempts have been made to model the effect of group size. Samuel & Pollock (1981) developed a two parameter asymptotic regression function of the sighting probability and group size, such that:

$$p(x) = 1 - \alpha e^{-\beta x}$$

where x is group size in excess of 1, α is the probability of missing single animals and β describes the rate at which function approaches a probability of 1. However, this does not take into account the distance from the line of groups, a factor that would tend to omit smaller groups found further away from the observer.

2.6 Distance sampling

Distance sampling describes a relatively new group of abundance estimation methods. While the censusing methods are based on the assumption that all the animals present within the sample area are detected, distance sampling recognizes that detection is not perfect and that there is a marked tendency for detection to decrease as distance between objects and observer increases. It takes into account much of the bias described by visibility bias above. Furthermore, census methods may be wasteful for scarce animals as any individuals detected outside the sample area are ignored.

The methods used are line transects and point samples. Line transects involve straight lines traversed by the observer who records perpendicular distances from the object to the line. A requirement is that the lines be placed randomly in relation to the objects to be detected.

Central to the methods is the detection function relating probability of detection to observed distances. This data can analysed the software program DISTANCE (Thomas *et al.*, 1998) which identifies a fall off in detection with distance. The software then selects a best fit model to represent this fall off according to Akaike's Information Criterion (AIC). The function is then used to estimate the proportion of animals missed.

The main assumptions of the method are:

- 100% detection on the line.
- there is no movement of objects before detection; and
- there is no error associated with the measurement of distances.

There is normally a 'shoulder' close to the line where detection remains 100% as visibility normally does not drop off instantly.

The use of distance sampling methods for large mammals has become widespread both for ground and aerial counts (Olsen, 2005; Andriolo, 2005; Guenzel, 1997). Its application to aerial counts requires a few adaptations. A blind area under the plane means that animals on the line are missed. Quang & Lanctot (1991) propose that perfect detection occurs at some unknown line parallel to the transect line. Counts from aerial surveys are dependent on where observers concentrate their efforts, with peaks often occurring in the central zones. Due to the speed of aerial surveys, it is not feasible to accurately record precise distances to the animals, thus distances are often in 4-5 classes (Pollock & Kendall, 1987). This is not a problem as grouping of distances can reduce the effect of the movement prior to detection.

Complications arise when groups form distinct groups as the probability of detection of animals increases as they occur in increasing group sizes. Buckland *et al*. (1993) suggest estimating group density and determine animal density by multiplying group density by mean group size. The problem is that the calculation of mean group size itself is biased, as larger groups are more likely to have been detected during the survey. This is known as *size bias* (Drummer & McDonald, 1987).

3. Background to saiga

3.1 The distribution and geography of saiga

There are five distinct populations of saiga, three in Kazakhstan, one in the Republic of Kalmykia and one in Mongolia. The locations of the four populations are shown in Figure 2.1. The three populations in Kazakhstan today are; the Ural population in the very north-west of Kazakhstan, above the Caspian Sea; the Ustiurt population on the steppe region between the Aral Sea and the Caspian Sea; and the Betpak-dela population in the middle of the country north and west of Almaty city. The population of *S.t. mongolica* is very small consisting of only a few hundred individuals and a genetic study found a very low level of genetic diversity, consistent with long isolation and small population size (Khodlova *et al.*, 2006). For the purpose of this project, saiga antelope will be taken to mean *Saiga tartarica tartarica* in Kazakhstan unless stated otherwise.

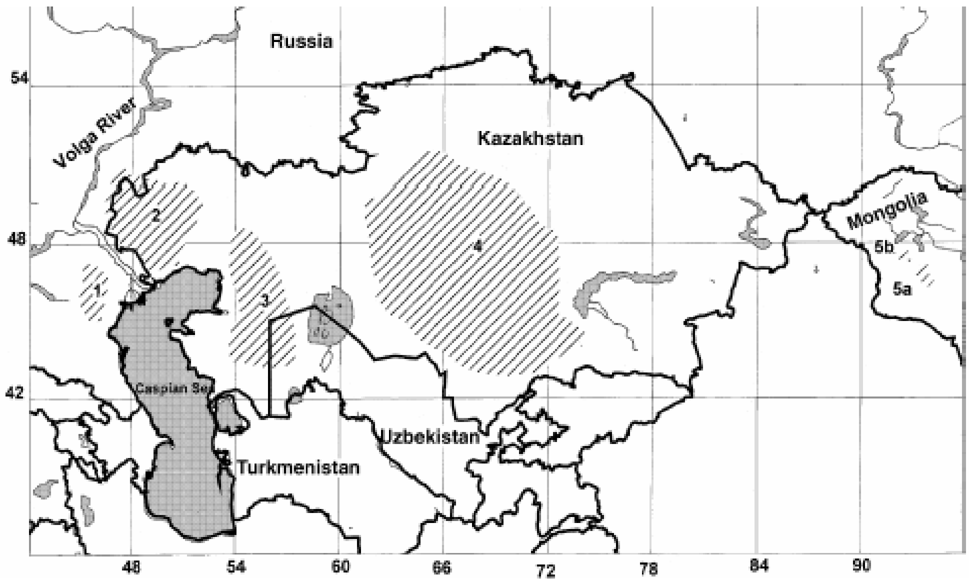


Figure 2.1. The distribution of saiga populations. 1. Kalmykia, 2. Ural, 3. Ustiurt, 4. Betpak-dala (all *Saiga tartarica tartarica*), 5. Mongolia (*Saiga tartarica mongolica*, 5a. Shargy Gobi population, 5b Mankhan population). (Source Milner-Gulland *et al*, 2001).

The saiga's geographic range was formerly considerably more extensive than it is now, and has been affected for thousands of years by both natural and anthropogenic factors. It was once an inhabitant of Britain before major climatic changes 10-12,000 years ago and up 400 years ago its range extended from Poland across to mid Mongolia (Bekenov *et al.*, 1998). Saigas' range was severely curtailed towards the end of the 19th century and into the 20th century by intensive hunting encouraged by the high price for saiga horn for use in Chinese medicine. Despite a poaching ban imposed in 1919, the 1920s saw saiga populations on the verge of extinction from the combination of continued poaching and a series of unfavourable climatic conditions. This left only a few hundred, or possibly a few thousand, existing in isolated pockets in remote areas (Bekenov *et al.*, 1998).

From the early 1930s, saiga numbers began to recover and increase their distribution. The recovery was so successful that by the 1950s the hunting ban was lifted and state managed harvesting of the populations began. Saigas failed to re-establish in certain areas of their former range and their expansion northward was blocked by cultivation of previously untouched land during Krushchev's 'Virgin Lands' campaign of the 1950s.

A continuous population of *tartarica* existed till probably 19th century crash, including what is now the Kalmykia population. The construction of new roads, settlements, the cultivation of land and other anthropogenic features reduced the amount of suitable habitat within the saiga's range. Irrigation canals built in Kalmykia in the 1970s effectively cut off the Kalmyk population from that in Kazakhstan (Milner-Gulland, 1994). Within Kazakhstan, the populations also now appear to be separated from each other. A survey involving the tagging of 14,000 calves between 1986 and 1993 (Grachev & Bekenov, 1993) showed that the three populations do not appear to mix.

3.2 Ecology and habitat

Saigas have been described on a range of habitats from steppe, desert to semi-desert (Bekenov *et al.*, 1998). They inhabit plains and prefer flat, open terrain with low-growing vegetation which allows it to run quickly. Saigas tend to avoid thick snow and need areas with watering places.

Saigas are exceptionally fecund animals and females are sexually mature at around 8 months of age, depending on conditions and can live for up to 10 years. Males become mature around 19 months but due to exertions of rutting tend to live only 5 years. In good years, up to 95% of females give birth in their first year and regularly twin in subsequent years, and even occasionally give birth to triplets. Saigas form harems of 1 male to 2-15 females though it can be of 30 or more (Bekenov *et al.*, 1998). Harems form in mid-November and mass mating generally occurs in the last 10 days of December. The herds are small and 81% of the groups consist of 50 animals or less (Fadeev & Sludskii, 1982). The harems break-up in January, leaving lone or small groups of adult males.

The first calves are born in late April and the last in June, but mass calving occurs over a 10 day period, generally in mid May. Formerly, saigas aggregated in groups of tens of thousands for mass calving (Milner-Gulland *et al*., 2003). Recently, however, it appears that the aggregations are significantly smaller, possibly in hundreds or thousands and have become increasingly difficult to find (Fry, 2004; personal observation). This means that calves are not afforded the same level of shelter during birth as was formerly the case and are likely to be more susceptible to predation.

3.2.1 Susceptibility and strengths

A strong female-biased sex ratio and the fact that males form harems of one male to numerous females give rise to the potential for rapid growth. This is taken to be an adaptation to living in harsh conditions where extreme weather conditions regularly lead to mass mortality, allowing the population to recover quickly.

Saigas are susceptible to extreme climatic conditions and occasionally suffer episodes of very high mortality. Males, weakened by the rut in December are more vulnerable to extreme winter conditions, in particular, a *dzhut*. A *dzhut* is a Kazakh word that describes a set of climatic conditions in which the rain is followed immediately by frost coating grass in ice. As animals eat the grass they ingest large amounts of ice, which kills them. Anecdotal evidence, cited in Milner-Gulland (1994), suggests that this happens on average once in every ten years. In the summer, droughts can also cause mass mortality and are said to happen about 3 years in ten (Milner-Gulland, 1994).

3.3 Migrations, movements and herding

Saigas undertake lengthy spring and autumn migrations between their summer in the more northern steppe regions and winter ranges in semi-desert habitat, prompted by unfavourable weather conditions. The distances of the migrations vary between the populations; 600-1200 km in Betpak-dala, 300-600 km for the Ustiurt population, and 200-300 for the Ural population (Bekenov *et al.*, 1998) although there is no literature examining if this has changed since the population crash after 1998. There are three occasions during the year when saigas are not migrating; in the southern part of their range during winter (November-December to early-mid March), late spring during calving (mid May) and in the northern part of their range during summer (early-mid June to early-mid September) though they frequently move within their summer and ranges. Bekenov *et al*. (1998) record occasions of saiga moving away from dry areas during the summer in various directions to areas with rain where puddles have formed. They may also react to human activity and have been known to move suddenly to tens of kilometres away after being hunted intensively. The overall range in Kazakhstan in summer is in the region of 300,000 – 350,000km^2 and while the winter range is 49,000 – 105,000 km^2 *(*Bekenov *et al*., 1998*).*

While the migrations themselves occur consistently every year, the precise periods, routes, distance and speed of migration can differ from year to year and in different areas. These depend on a complex combination of factors such as climatic conditions, the degree of disturbance experienced by the animals, the condition of the pastures, number of watering places, the nature of various artificial obstacles on migration routes, and so on (Bekenov *et al.*, 1998).

Saiga migration routes are confined to flat areas of plain, which skirt various natural and artificial obstacles (lakes, boggy salt marshes, mountains, fences, etc.) and pass through areas where there is plenty of food and water. When conditions are favourable, the animals migrate at a rate of 5-20 km a day, though this can increase to 40-45 km a day, if there is snow or rain, or if water is scarce (Bekenov *et al.*, 1998). The spring migration begins as the snow recedes, with groups of animals increasing in size as they move north. Saigas often reach their summer range in the first half of June. In years of droughts, they can arrive as early as May, while in wet years they may arrive in late June to July. During the summer, groups begin to aggregate in August to prepare for their southerly migration. By November, most animals have reached their winter range.

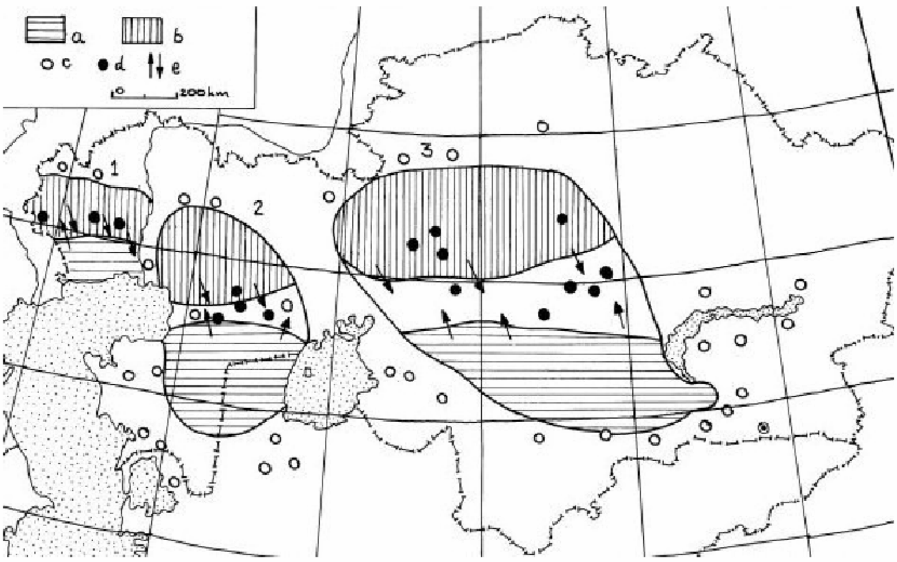


Figure 3.2. Approximate ranges of the three present day saiga populations in Kazakhstan. 1. Ural population; 2, Ustiurt population; 3. Betpak-dala population. (a) Winter ranges; (b) summer ranges; (c) occasional sightings; (d) usual birth areas; (e) migration routes. Taken from Bekenov *et al*. 1998.

3.3.1 Herding behaviour

The declines in saiga numbers have been accompanied by fewer large aggregations during migration and calving periods. Saiga herding in certain cases is thought to be an adaptation allowing animals to find food quicker and to move out of areas of heavy snow (Bekenov *et al*., 1998).

Saiga, in good years, occurred in groups of tens or hundreds throughout the year and formed large aggregations at specific times of the year (see above). Saigas also form larger groups in bad weather conditions such as heavy wind and snow, moving together out of the area (Bekenov *et al*., 1998). Fadeev &

Sludskii (1982) report on group sizes ratios throughout the year (see Figure 2.X). In the 1960s and 1970s, 38% of groups during April contained more than 500 individuals.

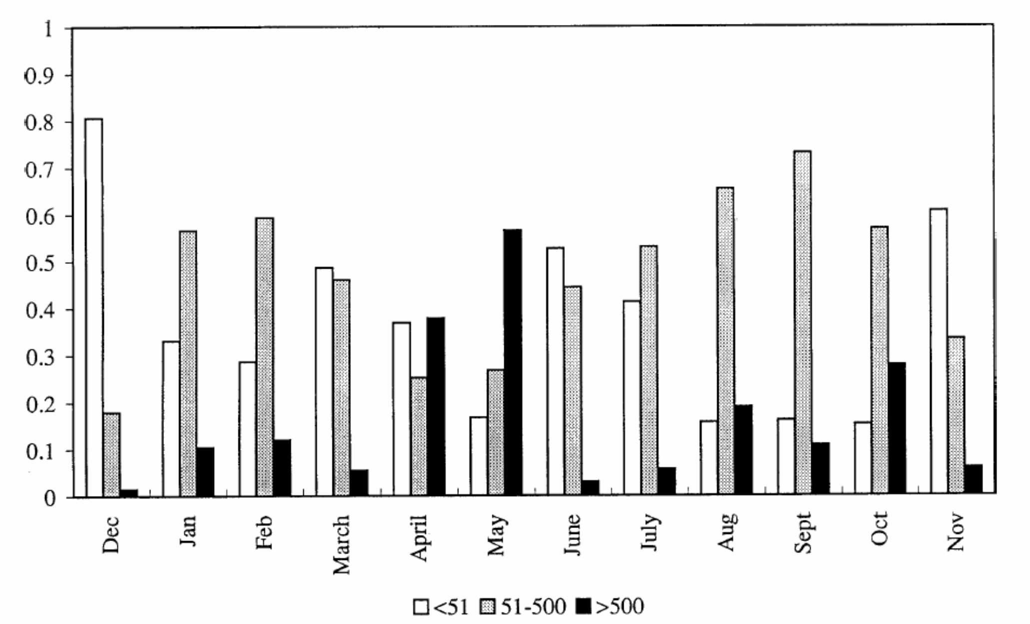


Figure 3.3 Proportion of herds of different sizes in Kazakhstan throughout the year. (From Bekenov *et al.*, 1998. Data from Fadeev & Slukskii, 1982).

3.4 Population crashes in saiga populations

Saiga populations throughout its range showed dramatic decreases in the latter part of the 1990s and reached a low point in 2003, standing at just 3% of the 1980-1990 mean in Kazakhstan. Modern day counts are frequently compared against the mean estimates of 1980 to 1990, as this is a period of relative stability poaching was limited, despite high state managed hunting. This decrease was accompanied with an observed collapse in birth rates and an increase in the number of barren females (Milner-Gulland *et al.*, 2003).

Saigas' high fecundity has meant in the past that under controlled hunting a high yield could be maintained. Saigas were heavily hunted during the Soviet era, through state-controlled hunting from the 1950s till the late 1980s. An adequate state hunting inspection system and the fact that the majority of the rural community were employed had meant that poaching was low and was predominately for meat. The closure of the border with China meant horns were of limited value, although there was some state sponsored horn export and commercial use of hides. The opening of the Chinese border in 1988 lead to increased pressure on males due to the demand for horns. The economic restructuring after the *Perestroika* in 1991 resulted in widespread unemployment and the lack of alternative poaching resulted in increased rates of poaching (Lundervold, 2001).

3.5 Conservation and management

Following years of very little management, saiga conservation has slowly gained momentum in recent years. International attention was focused on saiga following the documentation of rapid declines of all populations in 2000 (Milner-Gulland *et al.*, 2001). Within the range countries, approaches to conservation have differed. The Republic of Kalmykia has been reasonably proactive in saiga conservation. The Chernye Zemli reserve was set-up in 1990 to afford protection to the population and conservation efforts since have included livelihoods interventions, anti-poaching patrols and public awareness campaigns. In Kazakhstan, on the other hand, the three populations are afforded varying degrees of attention. The Ural population, being the furthest from Almaty, has received little or no intervention or research in the last ten years (CMS, 2006). The Ustiurt population has several protected areas within its range and has received socio-economic surveys in both Uzbekistan and Kazakhstan, with a pilot alternative livelihoods project in Kazakhstan. The Betpak-dala population has suffered the most serious declines being closest to populated areas where poverty is the highest. Reserves do exist within the range and a series of new reserves is planned.

A significant development is the creation of the Memorandum of Understanding (MoU) concerning conservation, restoration and sustainable use of the saiga antelope and associated Mid-Term Work Programme (MTWP) which was formally signed by Kazakhstan, Turkmenistan and Uzbekistan. The first meeting of the signatories of the MoU occurred in Almaty in September 2006. The main outcomes were an agreement on the status of saiga, and the commitment to work towards and report back on the MTWP.

The overview report (CMS, 2006) expressed concerns over the extent to which recent increases reflect real population growth or "sampling bias caused by changes in census methodology or in underlying saiga distribution and behaviour." It also states the need for the development of a standardized best practice for population size estimation, either by aerial survey or other means. Satellite tracking is being proposed as an option.

4. Population assessment of saigas in Kazakhstan

The predominant method for population assessment of saigas in Kazakhstan is by aerial survey. It is occasionally supplemented by counts from the ground which are added to the total numbers. Every year, an expedition of biologists from the Institute of Zoology in Almaty drive to Ustiurt plateau during the calving period (mid-April) to assess the success of the calving season. Foot counts have been used to gather information regarding the success of the calving seasons of saiga along with biological information (Kühl *et al.*, in review).

4.1 Development of current methods

Aerial surveying of saiga began in the mid-50s when the population in Kazakhstan was around 900,000 (Bekenov *et al.* 1998). The current method is little changed from the original, devised in the Institute of Zoology, Almaty. The methodology has been described by Grachev (2004). The following description is a combination of the methods in this chapter, as well as personal communications with Iu. Grachev and other observers on the surveys.

Aerial surveys are ideally carried out in spring, immediately after the melting of the snow, when saigas have not shed their white winter coat and are easily spotted against the darker background (see Figure 4.1). The animals begin their migration during this period and are still reasonably aggregated. The optimal period to survey is between 20 March to 20 April. The exact timing depends on factors such as weather conditions, date of the snow-melt and migration of animals. By the beginning of summer, the colouration of saigas blend with the background, rendering them difficult to see. The animals also tend to be more dispersed. In winter, while the animals are more aggregated, the camouflaging of their coats makes them harder to spot against the snow.

Figure 4.1 Aerial photograph of approximately 180 saigas clearly visible with winter coats against dark background.

Financing of the surveys constitutes a limitation on what is carried out. While in the past surveys were financed by the Soviet state, changes in economic circumstances have meant less funds available for conservation work. Today, the aerial surveys are financed by the '*Okhotzooprom*,' the state owned organisation for the protection of saigas, and carried out by the Institute of Zoology on a contractual basis. The renting of a plane is the most expensive part of the surveying, constituting 80-90%.

4.2 Flight practices

Each flight has two observers on board, one on the right-hand side, the other on the left. Each observer searches an area of 1 km which is estimated through experience, as they do not use streamers on the wing struts. When a group of saigas is seen, the number of individuals within the group, and the time it was detected are recorded. After the flight, the two observers will compare their notes and identify which groups are double counts. The observers will generally communicate verbally during the flight to ensure that only one observer will record a given group.

When it is thought that a large aggregation of saiga has been spotted, the plane begins flying in parallel transects, attempting to criss-cross the entire aggregation. Generally a width of 10km is chosen between transects, so with a total area of vision of 2km from the plane (1km either side), this means that the plane should cover 20% of the area of extrapolation. If the width is increased to 15km, then the area covered is 13.3%. Deciding how long to fly on a transect is decided arbitrarily but is usually if no animals are spotted for 2km.

The flight paths are marked by recording the direction the plane fly in and times at which the plane direction changed. The ground speed is assumed to be constant at 120km/hr (although some years have been at 160km/hr). After the flight, the observer uses a compass and ruler to draw the flight path on the map, using the time taken between changes in flight path direction to establish the distance travelled (i.e. 1 minute flight time is equal to 2km travelled). However, this methodology is not necessarily strict, and the observer will often use landmarks as a guide to locating flight paths (Iu. Grachev, personal communication).

4.3 Recording the counts

Unlike standard methods, the census zone is not identified before the survey begins. Instead the area into which counts are extrapolation is selected after the survey by tracing around the outline of the saiga sightings (see Figure 4.2) which is supposed to mark a saiga concentration.

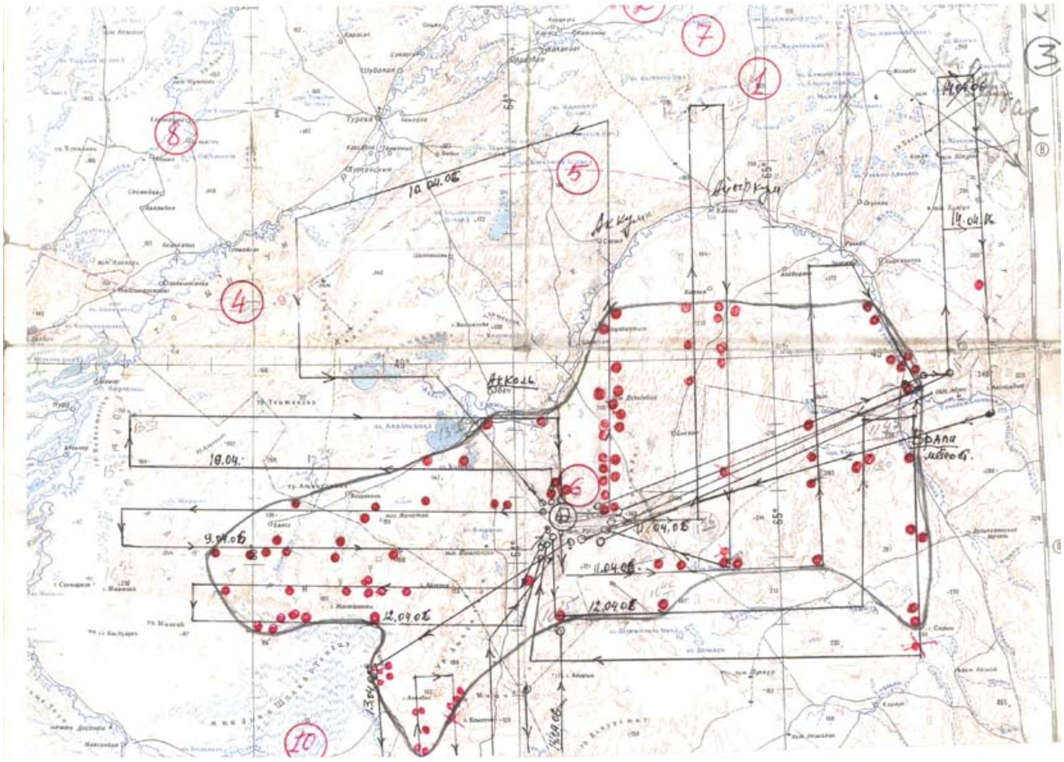


Figure 4.2 Map showing the saiga sightings in Betpak-dala 2006. Saiga sightings recorded by dots. Pencil lines in straight lines delineate flight paths. Rough pencil outline of red dots indicates the final area chosen for extrapolation.

The sightings of saiga are marked on the map much in the same way as the flight paths. Once the flight path has been drawn onto the map, the observer uses the time of each recorded group to work out at what point along the line the group was spotted, and marks the spot. There is little emphasis on accuracy of the location of the marks, and as 1mm represents 1 km and each mark is roughly 2mm, the locations of the groups are very vague indications.

Other problems exist in that the map simply contains marks without reference to how many individuals were seen. This makes it difficult to account for all the sightings. In my case, as I was attempting to locate every sighting on the map, obtaining this data involved spending a considerable amount of time (a full day’s work per population, in some cases) with one of the scientists who carried out the survey, who would indicate which sighting referred to a particular mark on the map. Often, however, what had been drawn on the map did not always accurately reflect the original records (e.g. some sightings had not been recorded on the map, while some marks on the map were not accounted for in the notebooks).

4.4 Estimating the population from the aerial surveys

The estimation of area and animal density is obtained from the maps mentioned above. The scientist inspects the maps visually and draws onto the map the areas that are assumed to be a saiga concentration (see picture 4.2). This involves joining the outer sightings in pencil. The total area within those outer sightings is the area into which the results from the aerial surveys are extrapolated. Once the area for the extrapolation is identified, the size of the area is calculated by tracing over the outline on graph paper of grid size of $1mm^2$.

The sample zone, or the area that was searched, is calculated by multiplying the total strip width (in this case 2km) by the distance flown within the extrapolation area. The density of animals is calculated by dividing the number of animals seen by the area of the sample zone. This density is then multiplied by the total area in the extrapolation zone.

Population estimates have not always been by aerial survey alone. In 2002, practically all of the counts from Betpak-dala and Ural came from ground counts, despite full aerial surveys conducted that year.

5. Methods

5.1 Analysis of the data

The data available was that of direct counts of animal herd sizes as seen from two observers on either side of the plane. Eight separate datasets were available; 6 from the Ustiurt plateau and 1 of each from Betpak-dala and Ural.

Year	Population	Period of survey
1990	Ustiurt	5-15th April
1998	Ustiurt	April, dates unknown
2002	Ustiurt	4-8th June
2004	Ustiurt	9-16th April
2005	Ustiurt	12-19th April
2006	Ustiurt	12-18th April
2006	Betpak-dala	6-15th April
2006	Ural	25-30th April

Table 5.1 The aerial survey data available for analysis

These data included the population, date of survey and exact and approximate herd sizes. Other information present in some of the datasets included time of observation, number of males, females and calves observed, the direction of the flight path, and for 2006, a photocopy of the map flight path on a 1:100,000 scale map. For the purpose of the presentation of results for this report, the following shorthand is used to refer to the populations: Ustiurt is written as "Ust," Betpak-dala as "BPD," while Ural remains "Ural."

Also available were the official reports containing summaries of the population censuses from 1989 to 2006, known as an "*otchot*". These are prepared by Institute of Zoology Almaty for the government of Kazakhstan. These contained the official estimates of the censuses, and how these figures were arrived at by showing:

- the length of transect flown through areas of saiga concentration;
- the area (km^2) that was searched within the saiga concentration;
- the number of saigas seen;
- the average density for that area;
- the total area into which numbers were extrapolated; and
- the total number of saigas presumed in that area.

Where surveys were carried out by vehicle this was generally included but not always. Total flying hours were available for all the datasets except 2004. This data was analysed for trends in population dynamics and assessment techniques.

The data from the datasets and the official reports was examined in brief to identify possible changes in population distribution, herd size or survey techniques that may have an impact on population assessment.

5.2 Identifying possible sources of bias

The next step was to identify and evaluate the relative importance of the potential sources of errors and biases in the current aerial survey practices in Kazakhstan. These are summarised in Figure 4.1. Three main sources were identified from the literature review:

- errors in counting;
- erroneous survey technique; and
- random sampling variation.

Errors in counting involve the failure to accurately enumerate the animals within that observer's area of search. Visibility bias is certain to be a major source of error and occurs as a result of factors reducing sightability (see section 2.4 above).

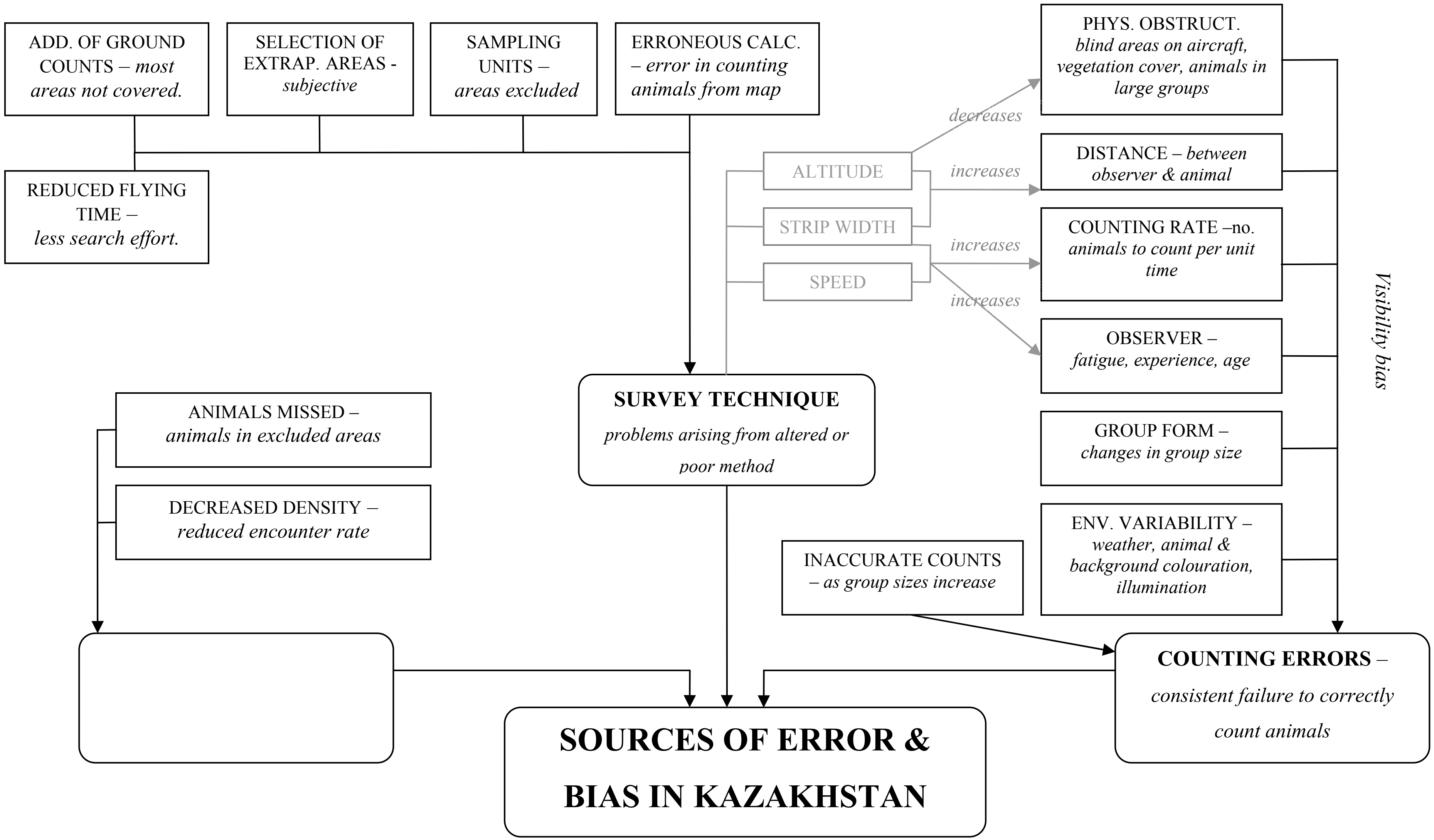


Figure 5.1 Sources of error and bias in population estimation of saiga in Kazakhstan

The relative importance of these three sources of error is uncertain. It is clear from the literature that counting errors will have a very significant impact on the estimates, introducing a negative bias. Visibility bias is frequently quoted as the most serious issue in aerial survey counts (Cook & Jacobson, 1979). The strip widths used are substantially higher than those quoted in the literature, frequently 250 metres or less. The kilometre width on each side of the plane means that each observer has a maximum of 30 seconds to survey 1 km^2 (at 120km/hr) compared to 2½ minutes for a strip of 200m. This increases the amount of eye movement required by the observer and can cause fatigue. Coupled with this is the effect of distance on counts. This is quite clearly demonstrated in Figure 5.2.

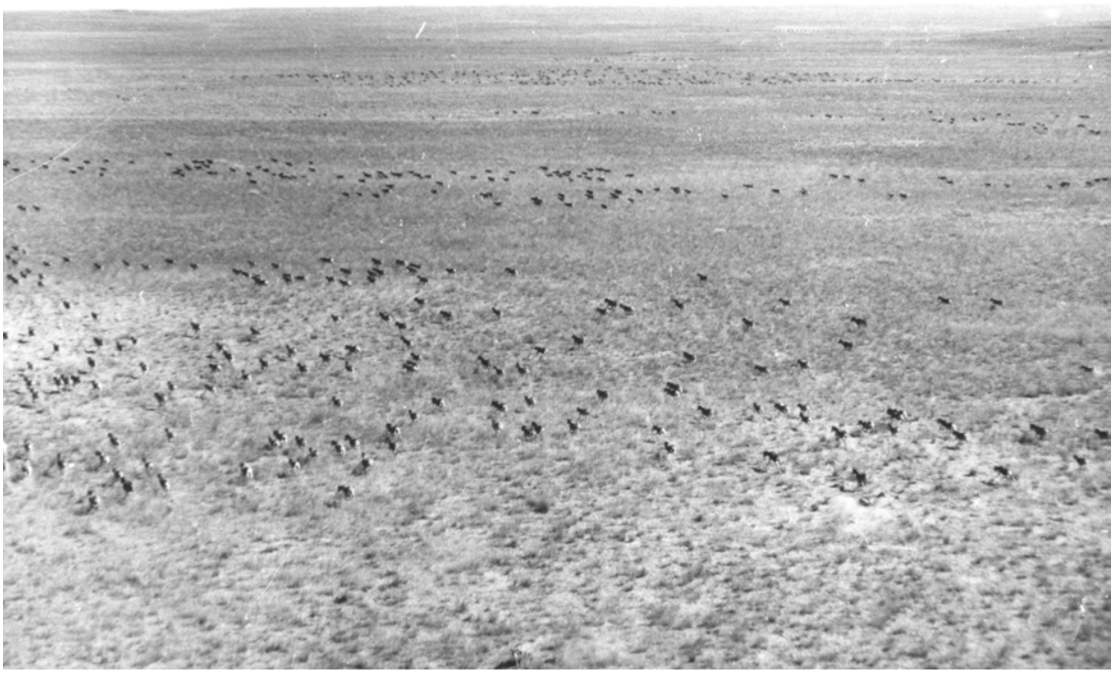


Figure 5.2 An example of reduced visibility with increased distance from the observer. Loose aggregations of approximately 150, 110 and possibly 160 individuals with increasing distance from observer. (From the Institute of Zoology, Almaty).

Another important influence on sightability identified in the literature is the size of the group. It has been well documented how increases in group size increase the probability that the group will be detected (Drummer & McDonald, 1987; Samuel *et al.*, 1987). This is of particular importance for saiga as mean group size appears to be changing.

Related to group size is the inaccurate counting of larger groups. Norton-Griffiths (unpublished data) shows that accurate counting breaks down with groups over 15 individuals, with group numbers rounded off to the closest multiple of 5 or 10. This is a significant problem with animals that can occur in thousands such as saiga and can add significant degree of uncertainty as to the accuracy of the estimates.

This thesis will look at the effect that these factors, may be having on population estimates because of their overall importance and because of their potential to have changed in recent years. However, it is important to note the other factors that may also be having an effect.

Random variation affects the spatial distribution of the animals and the confidence limits of the estimate. The confidence intervals of the data are calculated as described below (see section 5.3).

Survey technique could be having affecting the counts. Strip width and flight speed have not always been constant throughout the years, which will affect the bias. Shorter strip widths of 250m were experimented with between 1989 and 1991 although not consistently. In one survey in 1993 in Betpak-dala a strip width of 2km on either side was used, while a strip width closer to 0.4 km appeared to be used in Ustiurt that same year. In 1999, the strip width of 750m was used. Speed has varied throughout the years with some years carried out at 160 km/hr (1991, 1998, and 2004) and others at 120 km/hr (2006).

5.3 Identifying 95% confidence intervals

It is necessary to have an indication of the precision of the survey data in order to assess how much variation there may be if the survey on the same population was repeated. This was done by calculating the 95% confidence intervals using bootstrapping. Bootstrapping is a method of calculating the sampling distribution of an estimator by sampling with replacement from the data (Crawley, 2005). In this case, the sampling process was repeated 10,000 times. The question it attempts to ask is if the surveys observe all the animals within their sample area, what is the likely range of the estimates. The 95% confidence intervals are obtained by extracting the 2.5% and 97.5% quantile ranges at the extreme high and low end of the estimates.

The confidence intervals estimated in this way are likely to be overestimates, i.e. higher levels of error than is probably the case. This is because bootstrapping samples from the data with equal probability of picking any group. In reality it is likely that very large groups (for example 1000 and over) have a greater chance of being located than small groups. In fact, it is possible that very large herds are almost certain to be located due to local information. However, the methods used in Kazakhstan assume equal probability of detecting groups i.e. if an aggregation of 5000 individuals is detected in an area where 20% was sampled, then it is assumed that there were 5 such aggregations in total with in the total area. Therefore this method reflects the assumptions made in the methods.

5.4 Correcting the data for biases

The observed data were used to obtain what should be a more realistic reflection of the numbers present. Computation was carried out in R version 2.3.1 (R Development Core Team 2006). The factors included in the model were limited to those that are likely to most impact or have changed over recent years as mentioned above. These were taken to be

- the effect distance on detectability;
- the effect of group size on detectability;

- counting errors associated with groups of increasing size.

No herds were assigned distances underneath the plane to a distance of 50m from the line to take account of the blind spot underneath the aircraft. This meant that the visibility of smaller groups was often less than 100% at the nearest point of search.

It is assumed that no herds are detected further away than *w*, the truncation distance, of 1km. This is taken from the methods produced by the Institute of Zoology, Almaty as the approximate limit of visibility for the Kazakhstan steppe conditions (Grachev, 2004). In reality visibility will vary, with animals occasionally counted outside this distance if conditions are good (Iu. Grachev, personal communication). These inaccuracies will not be considered at the present study and are likely to be small in respect of the other errors that exist.

A detection curve had to be assumed in the absence of distances recorded from saiga surveys. A reversed logistic curve was used as an approximate model for detection. It was selected due to the presence of a 'shoulder' representing certainty of detection which can be extended for larger groups and its ease in manipulation for assigning different probabilities for various groups sizes.

$$p = 1 - \frac{\exp(a + bx)}{1 + \exp(a + bx)} \qquad (1)$$

where p is the probability of detecting an animal at distance *x*, and *a* and *b* are shape parameters. The degree of shoulder is determined by the point of inflection, *i*, of the curve. This is included in the function as *x* – *i*.

The occurrence of animals in groups was dealt with in a different way than Buckland *et al.* (1993) who recommend a detection curve to represent mean group size, where the density of individuals is estimated by multiplying the number of groups within a specified area by the mean group size. This is subject to error when animals occur in groups of very variable size. Also, as the probability of sighting a group is related to its group size as well as distance from the line, the observed count is likely to contain a higher proportion of larger groups, thus biasing the mean group size estimate, i.e. size bias (Drummer & McDonald, 1987).

Size bias was dealt with in the model by setting a separate detection curve for each group size that occurred. To do this, one detection curve was selected for individual animals and another for the smallest group size that is deemed to be consistently detected at 1km distance from the aircraft. This latter was taken to be 1000 animals as a reasonable guess based on judgement from aerial photographs but the true number is not known. Individual curves for intermediate group sizes were determined by linear regression between these two points by altering the point of inflection of the curve.

$$i = mg + c, \tag{2}$$

where i is the point of inflection, m is the slope of the line between inflection points of 1 and 1,000, c is the constant of the line and g is the number of individuals within the specified group. This follows that the detection probabilities of a group is equal to the sum of the detection probabilities of the individuals within that group. This is possibly a simplistic representation of detection function as the interaction may not always be linear. Closely aggregated groups may conceal individuals, while groups in straight lines may increase the probability of detection.

Distance detection curves from aerial surveys for pronghorn (*Antilocapra americana*) (Guenzel, 1997) and marsh deer (*Blastocerus dichotomus*) (Andriolo *et al.*, 2005) were used as guidelines from which to estimate a curve for saiga. Pronghorn are a similar size to saiga and live in similar habitat, open grasslands, brushland and desert. Marsh deer are also a similar appearance though live in longer grass than saiga. The selected detection function is shown below.

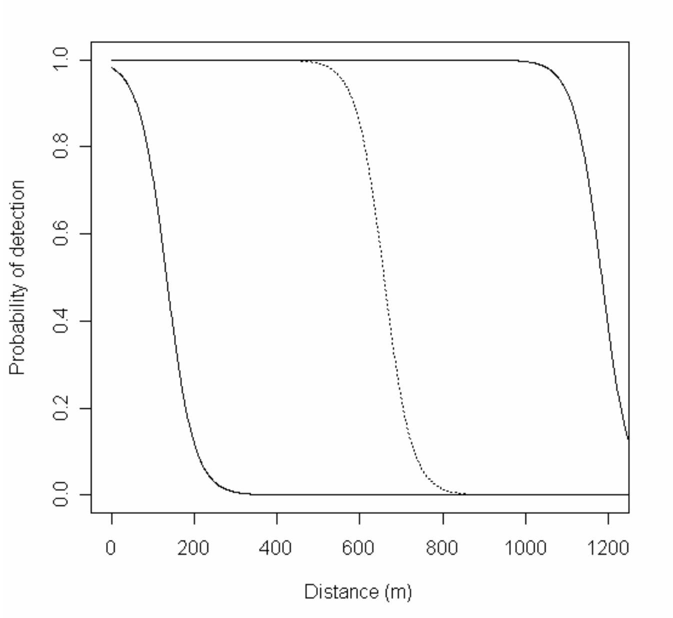


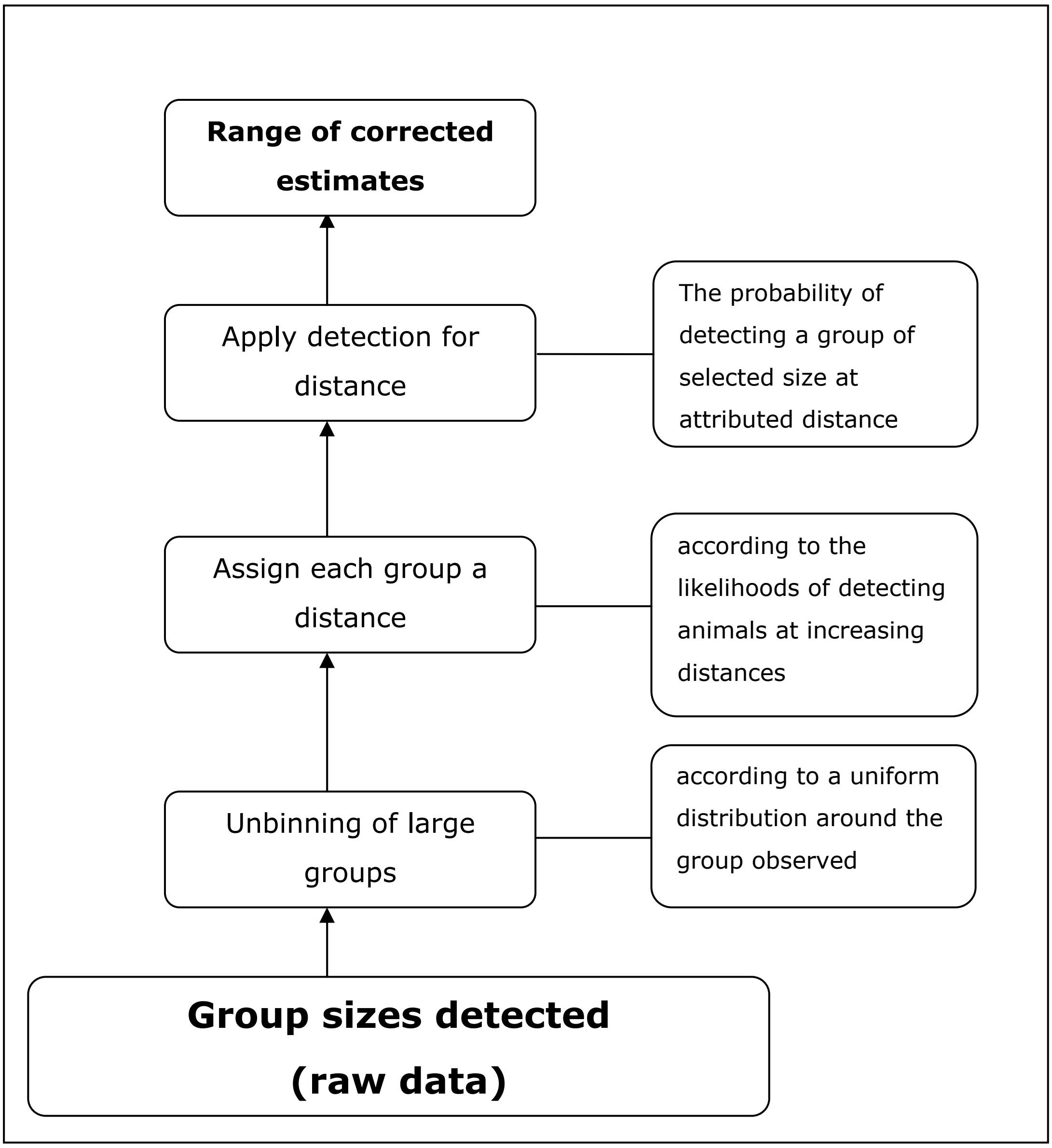
Figure 5.3 Detection curves for groups of different sizes. Full lines indicate groups of 1 and 1,000 from left to right respectively, dotted line represents a detection curve for group of 500.

5.5 Running the model

The model selects each sighting from the data individually. If the number is a multiple of 1000, 100 or 10, it is assumed it has been artificially binned by the observer. The sighting is therefore changed to a random number from a uniform distribution which is plus or minus half the value of that multiple. E.g. a group size of 2,000 may be changed to a number from 1,500 to 2,500. A uniform rather than a normal distribution around the original number was chosen as there is no biological reason to expect that herd sizes will be distributed around the multiples mentioned above.

The group is then assigned a distance from 0 to 1000m. Account was taken of the fact that the data will contain more groups closer to the aircraft than further away, and that this will also depend on the group size. Thus the model reads the group size, calculates the distance detection curve for that group size, and attributed a distance. The random sampler in R, when assigning distance classes to the groups, did so according to the area under the curve for that distance. Thus a distance class of 25 would have a much higher probability than 925. The detection curve is then applied to the group to find the likely number of groups of that size that are missed. This is achieved by dividing the probability of detecting a group at distance *x*, into the group size. Thus if there is a probability of detecting a group size of 0.5, then, the model will predict two such groups. The model was run 1000 times per dataset, providing a range of possible corrected estimates.

Figure 5. Flow diagram of model to correct for biases



5.6 Testing assumptions

In order to see what affect the choice of detection curve had on the estimates, two other detection curves were selected and the same model was run for 1000 times on each dataset.

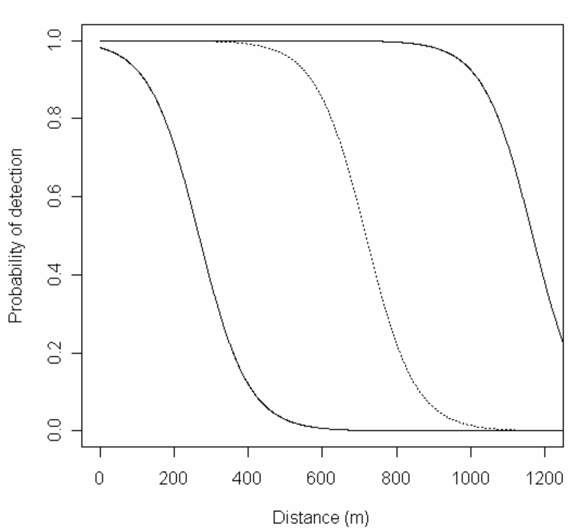


Figure 5.5 Detection curve with higher probability of detection. Full lines indicate groups of 1 and 1,000 from left to right respectively, dotted line represents a detection curve for group of 500.

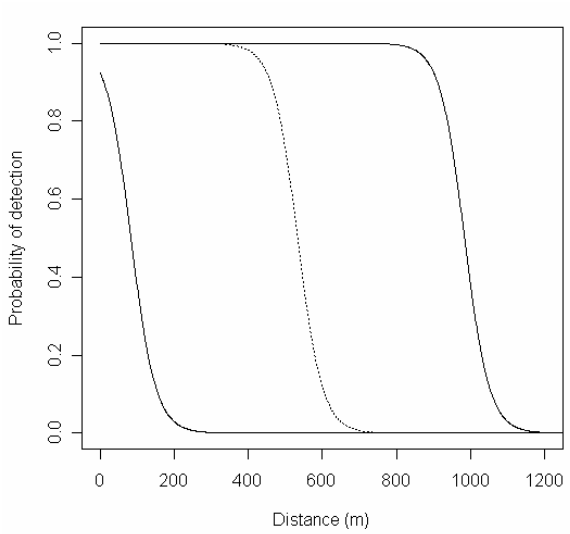


Figure 5.6. Detection curve with lower probability of detection. Full lines indicate groups of 1 and 1,000 from left to right respectively, dotted line represents a detection curve for group of 500.

6. Results

6.1 Analysis of the supplied data

The total number of animals seen during aerial surveys has increased consistently since 2003, almost matching the rate in increase of the population estimates.

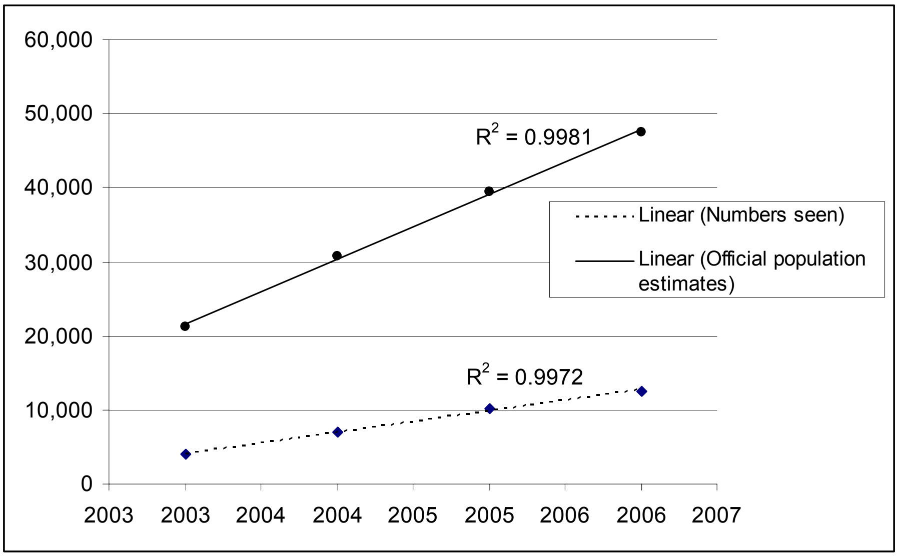


Figure 6.1 The trend in the official population estimates and the numbers seen since 2003 in all populations in Kazakhstan. R^2 close to 1 reflects a very constant rate of increase.

Between 2003 and 2005, all populations increased. Between 2005 and 2006, Betpak-dala and Ural populations reported increases, but Ustiurt reported a decline.

The reduction in saiga numbers since 1998 has caused changes in the patterns of saiga forming groups. Figure 6.2 shows the proportion of herds of different sizes from the available data, in groups sizes of 1-50, 51-500 and greater than 500. It includes data by Fadeev & Sludskii (1982) for the month of April, taken from data during the 1970s, when populations were high. Their data shows that almost 40% of herds were made up of more than 500 individuals, and 25% of the herd were between 51 and 500. This is considerably higher than that observed in the available datasets, which showed a much lower proportion of large herd sizes.

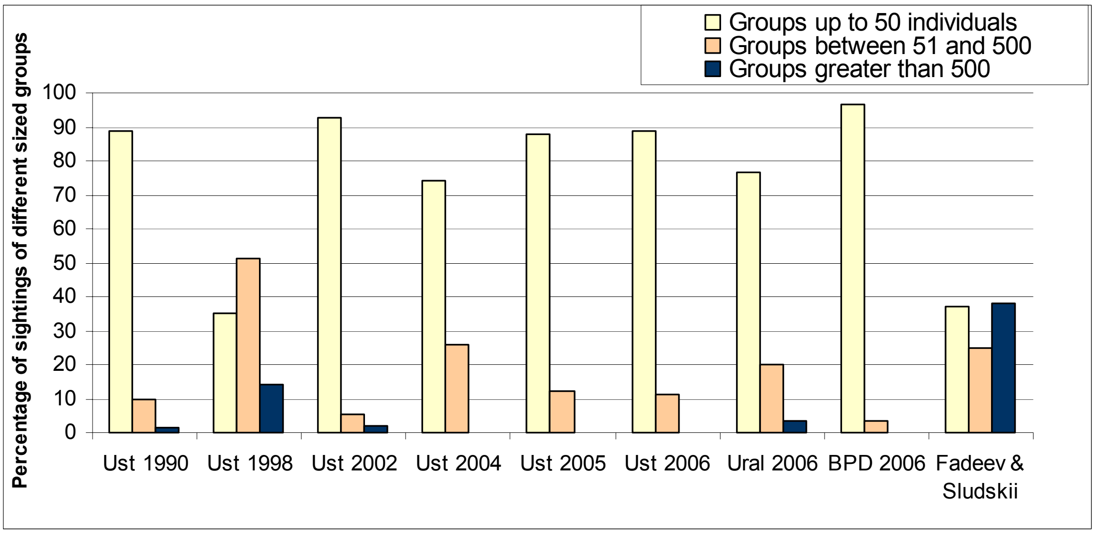


Figure 6.2 Proportion of herds of different sizes in Kazakhstan, for the years with available data. Included is data from Fadeev & Sludskii (1982) for the proportion of herds in the month of April from the 1970s.

One would have expected the data for the 1990s to have been similar to that of the 1970s as populations were high on both occasions. However, 1990 has a very low proportion of larger herds with the vast majority containing 1-50 individuals. 1998 shows the largest aggregations in the 1990s, with 64% of herds containing more than 50 individuals.

The proportion of the population that is in various group sizes, shown in Figure 6.3, reveals more marked changes between the 1990s and the post population crash years.

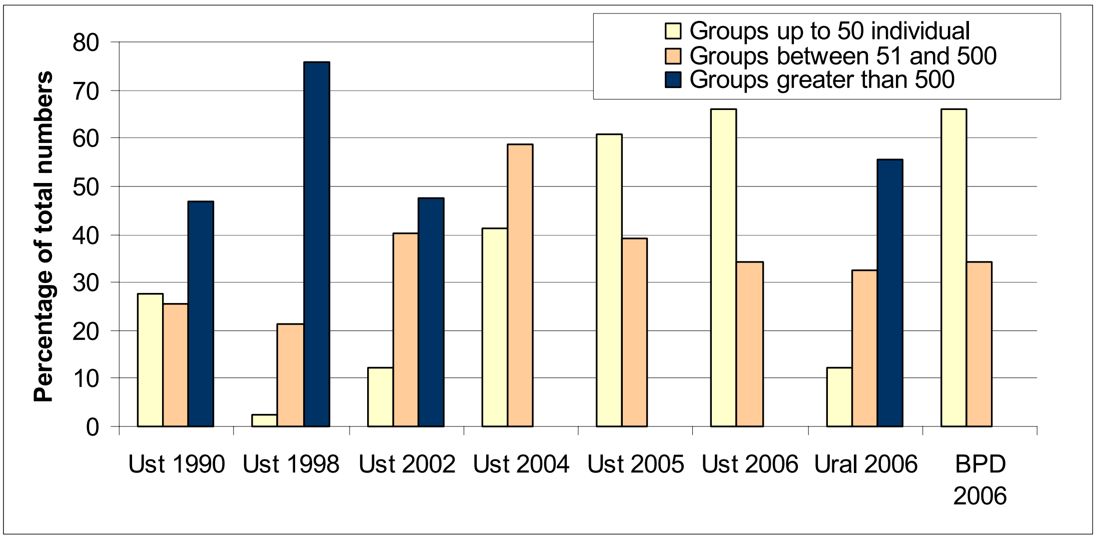


Figure 6.3 The proportion of the animals observed present in groups of different sizes

The graphs reveal that even in the cases of Ustiurt 2002 and Ural 2006, where overall numbers where low, approximately 50% of the observed animals were made up of one aggregation. In Ustiurt in recent years the proportion of animals found in larger herds has been steadily decreasing. Maximum herd sizes have also been falling (Figure 6.4).

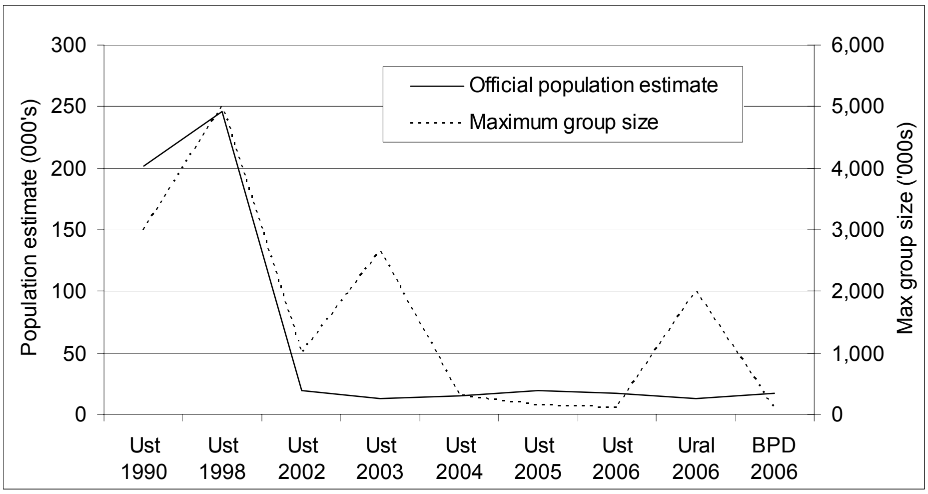


Figure 6.4 Trends in total population and maximum group sizes for the available data.

This graph shows the falling maximum group size in the Ustiurt population since 1998. The Ustiurt 2002 survey was carried in June, when the aggregations are presumed to be broken up (Bekenov *et al.*, 1998), thus it is interesting that an aggregation as large as 1,000 individuals was spotted. From 2003 to 2006 in Ustiurt there has been a consistent decrease in the maximum group sizes, from over 2,000 individuals in 2003 to 100 in 2006. This is concurrent with a slight increase in the numbers observed in Ustiurt (although in 2006 similar total numbers were observed as 2003).

The density in which saigas occur also appears to have gone down. Graph 6.5 shows the highest density in a saiga concentration per year. It shows densities have fallen for all populations and that the Ural population has shown consistently higher densities than the other two. In 2006, the highest density in Ural was 70 animals per km^2, compared to 2 and 1.3 animals per km^2 in Ustiurt and Betpak-dala respectively.

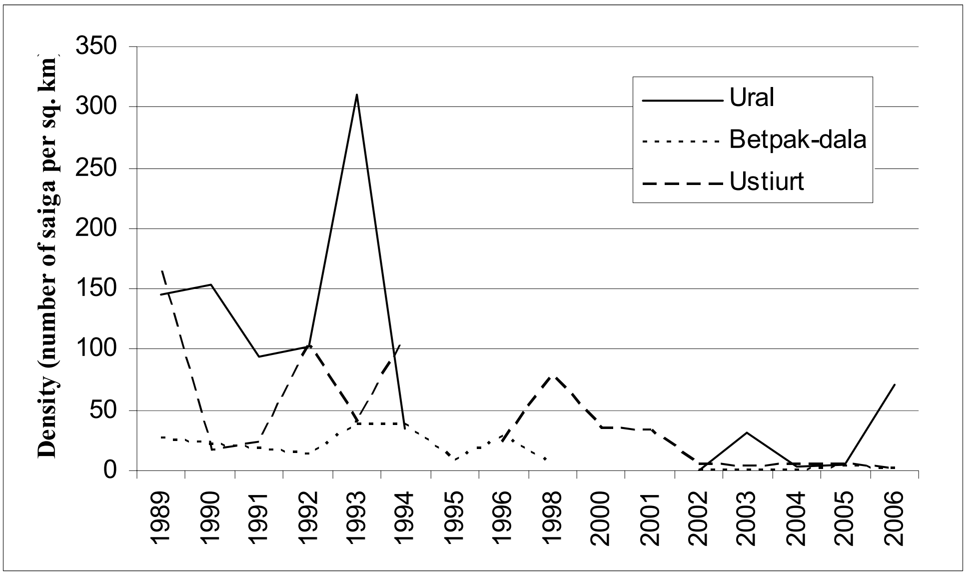


Figure 6.5 Maximum densities of saiga concentrations per year

The distance flown was available for all datasets except Ustiurt 2004, as well as for the years 1989 to 1992 from the *otchots*. Flying time dropped in 1992, and in 2006 the total flying time was less than half of what it had been in 1990 and 1991. Graph 6.6 shows distance flown of the datasets along with the encounter rate of saiga group sighting. A sighting was taken to mean any reporting of a saiga group, whether an individual or a herd of 1000 individuals.

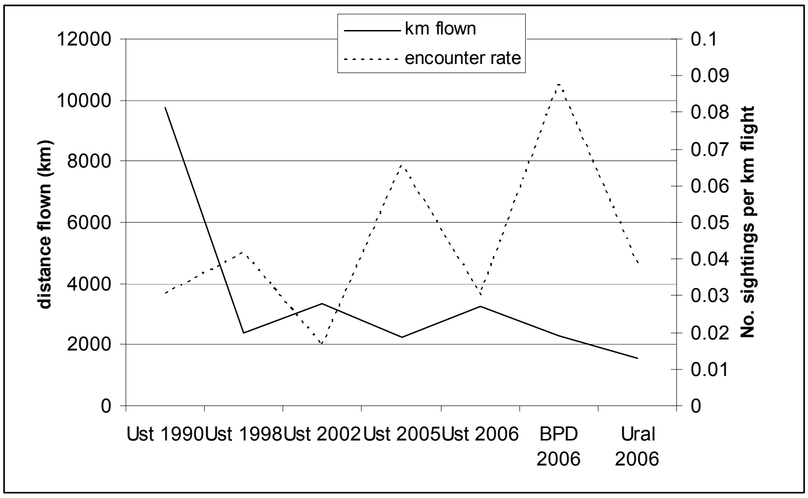


Figure 6.6. Distance flown (km) and the encounter rate of saiga sightings.

While distances flown have been cut, the number of sightings has fluctuated. Thus the encounter rate for saiga herds has not changed significantly in Ustiurt, or has perhaps increased. However, the average size of herd per sighting is decreasing. For Betpak-dala, the high encounter rate may be explained by the fragmented nature of the population. The maximum herd size was 86, with a median group size of 11 indicating that animals are not aggregating as they are in the other populations.

6.2 Confidence intervals

The confidence intervals for the data where calculated by bootstrapping as described in section 5.3.

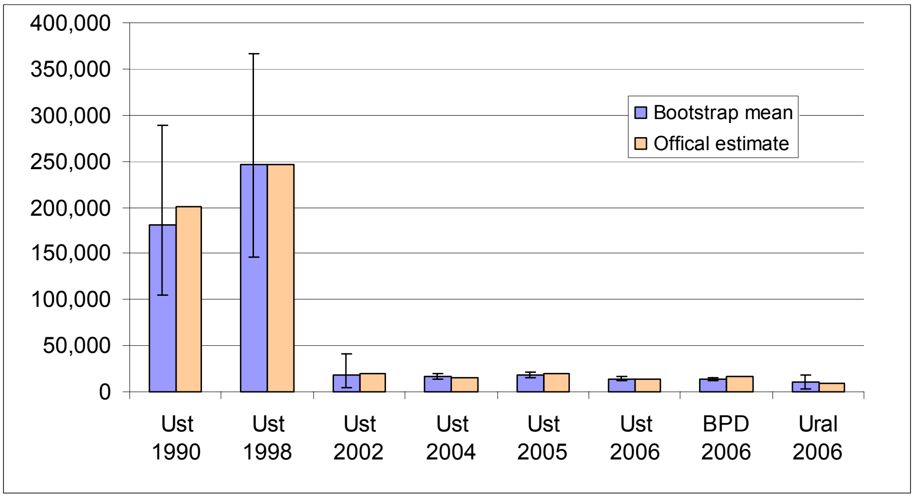


Figure 6.7 The estimation of 95% confidence intervals and mean population estimate from 10,000 replicates

(a) Confidence intervals and bootstrap results from all years

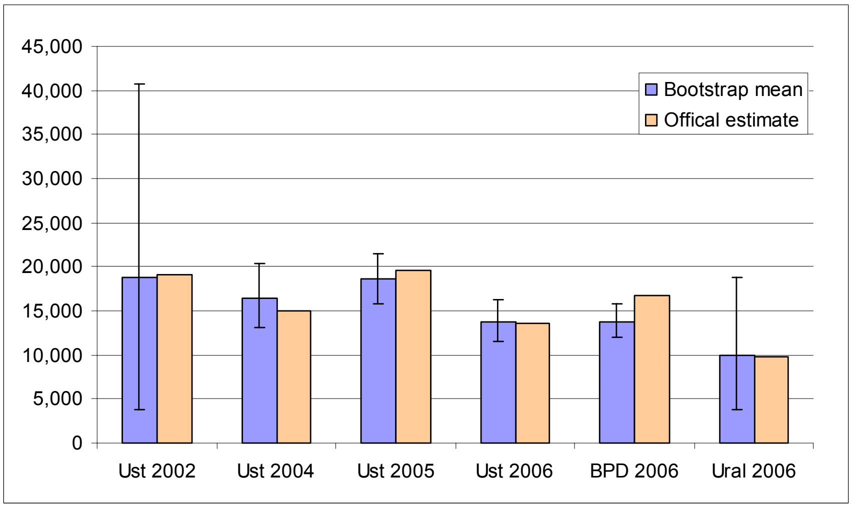


Figure 6.7 (b) Continued Confidence intervals and bootstrap results from 2002 to 2006, enlarged.

These graphs show the possible outcome if the estimates were carried out multiple times. Error bars show the 95% confidence intervals. The confidence intervals are largest for those populations that contain large groups such as Ustiurt 1990, 1998, 2002 and Ural 2006. Particularly high were Ustiurt 2002 and Ural 2006 where a large proportion of the population came from one or two large groups; -80/+117% for Ustiurt

2002 and -62/+88% for Ural 2006. This shows the importance of locating the larger herds particularly in low years.

6.3 Correcting the data for biases

The model is designed to give an indication of the effect of missing individuals due to distance. It is affected by the size of the groups, with larger groups having a greater chance of detection. It also includes the degree of uncertainty due to the binning of larger herds. It was run 1000 times for each dataset and the mean, median and 95% confidence intervals calculated. The model produced 1000 estimates of frequency of various corrected population estimates. The results were compared with the official estimate along with the 95% confidence intervals from the bootstrapping.

6.3.1 Comparison of official estimate with model estimates

The results show a great deal of variation in the range of estimates for all populations. The official estimates are closer to the corrected estimates in years where a high proportion of the population is in large groups.

	Ust 1990	Ust 1998	Ust 2002	Ust 2004	Ust 2005	Ust 2006	BPD 2006	Ural 2006
2.50%	91	99	115	72	74	43	65	97
97.50%	18	53	25	10	15	13	11	25

Table 6.1 Table showing the what percentage the official estimate constitutes of the 2.5% and 97.5% of the model estimates, using the original model.

The results show that only the official estimate from Ustiurt 2002 falls within the 95% confidence intervals of the model. The official estimates from Ustiurt 1990 & 1998, and Ural 2006 account for more than 90% of the lower confidence interval of the model. All these years had a high proportion of the individuals occurring in large groups. Ustiurt 2006 showed the lowest detection rate with only 43% of the lower interval and 13% of the higher interval.

When you consider the median and the mean of the corrected estimates 1998, the Ustiurt 1998 estimate is closest to the corrected estimates. It accounts for 71% of the mean corrected estimate and 91% of the median meaning that on 1 out of 2 occasions, the official estimate would account for at least 91% of the actual population. The median was considered a more reliable reflection of the corrected estimates as the mean is distorted by the presence of outliers. Ustiurt 2006 was the still the lowest with only 36% of the median indicating a very high negative bias.

	Ust 1990	Ust 1998	Ust 2002	Ust 2004	Ust 2005	Ust 2006	BPD 2006	Ural 2006
% of mean	57	71	60	32	40	26	31	52
% of median	74	91	84	55	54	36	47	82

Table 6.2 Table showing the percentage the official estimate constitutes of the mean and median of the corrected estimates (using the original model).

Despite this, all years showed substantial variation in the range of results. For Ustiurt 1998, the official estimate may account for between 99 and 53% of the corrected estimates, meaning up to 47% of the animals could be missed. This increased for the other years where group sizes were smaller.

Changing the detection curve did not have a major impact on the corrected estimates. An examination of the tables below shows that the official estimate constitutes a similar proportion of the corrected estimates as the original model. Ustiurt 2002 was still the only official estimate to be within the 95% confidence intervals of the corrected estimate. For the lower detection model, there was reduced detection of the three populations with the smallest groups sizes, Ustiurt 2005, Ustiurt 2006 and Betpak-dala 2006.

	Ust 1990	Ust 1998	Ust 2002	Ust 2004	Ust 2005	Ust 2006	BPD 2006	Ural 2006
2.5%	93	97	116	73	77	75	64	97
97.5%	21	41	30	13	12	8	12	23

Table 6.3 Table showing the percentage the official estimate constitutes of the 2.5% and 97.5% intervals of the higher detection model

	Ust 1990	Ust 1998	Ust 2002	Ust 2004	Ust 2005	Ust 2006	BPD 2006	Ural 2006
2.5%	91	98	115	73	56	56	47	89
97.5%	21	51	29	12	7	6	5	21

Table 6.4 Table showing the percentage the official estimate constitutes of the 2.5% and 97.5% of the lower detection model.

6.3.2 Graphical output from the model

The following histograms show the results from the model for each dataset. They depict the range of population estimates on the x-axis. The y-axis represents the frequency at which population estimates were predicted, expressed as percentage frequency.

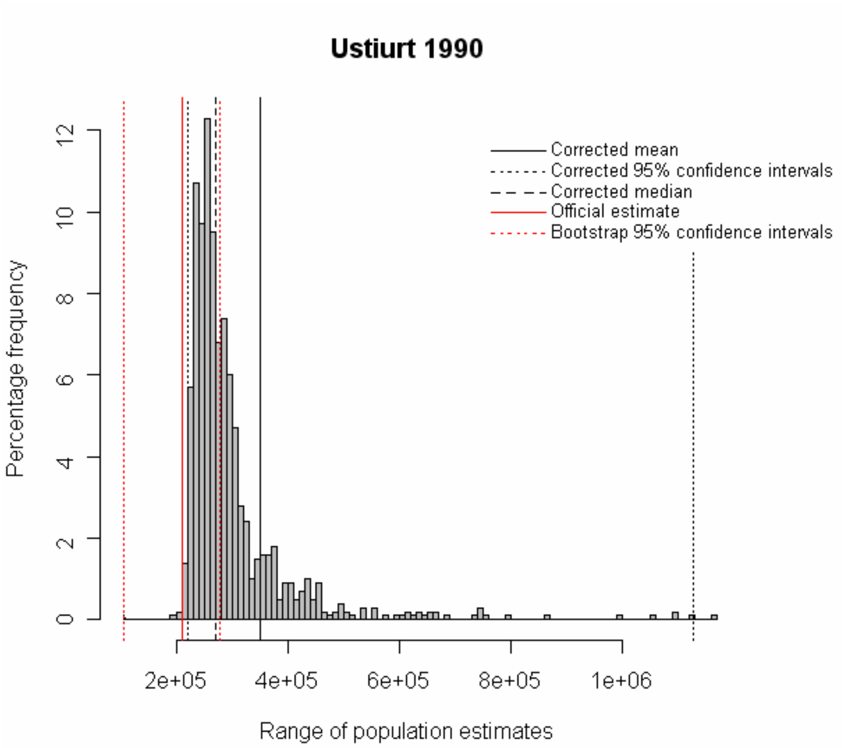


Figure 6.8 Range of corrected population estimates for Ustiurt 1990.

Figure 6.8 shows that the official estimate is close to the 95% confidence intervals of the corrected estimates. The bootstrap confidence intervals account for over 50% of the corrected estimates.

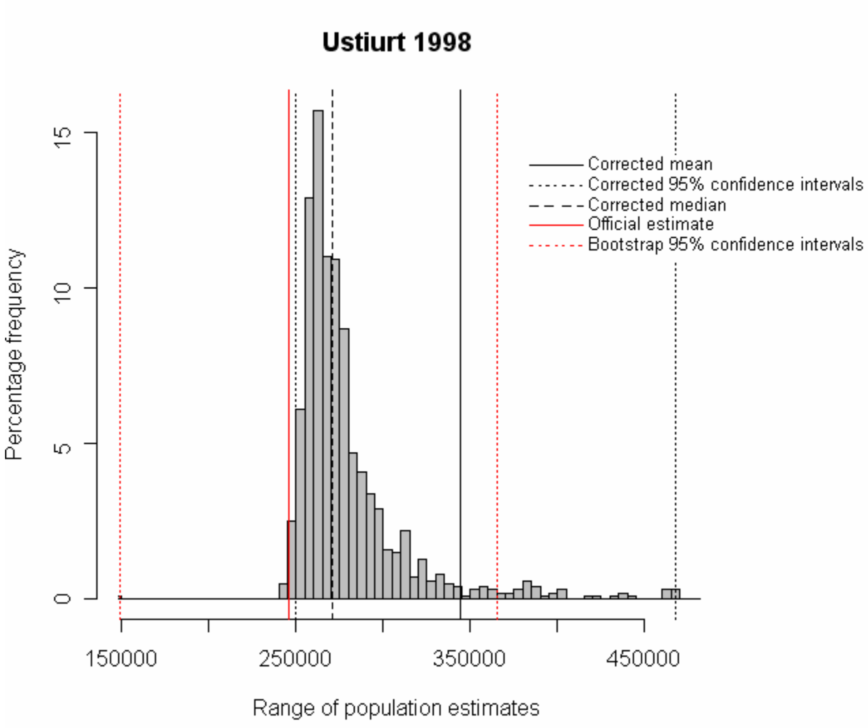


Figure 6.9 Range of corrected population estimates for Ustiurt 1998.

Figure 6.9 shows that for 1998, the upper confidence intervals of the estimates cover the majority of the corrected estimates.

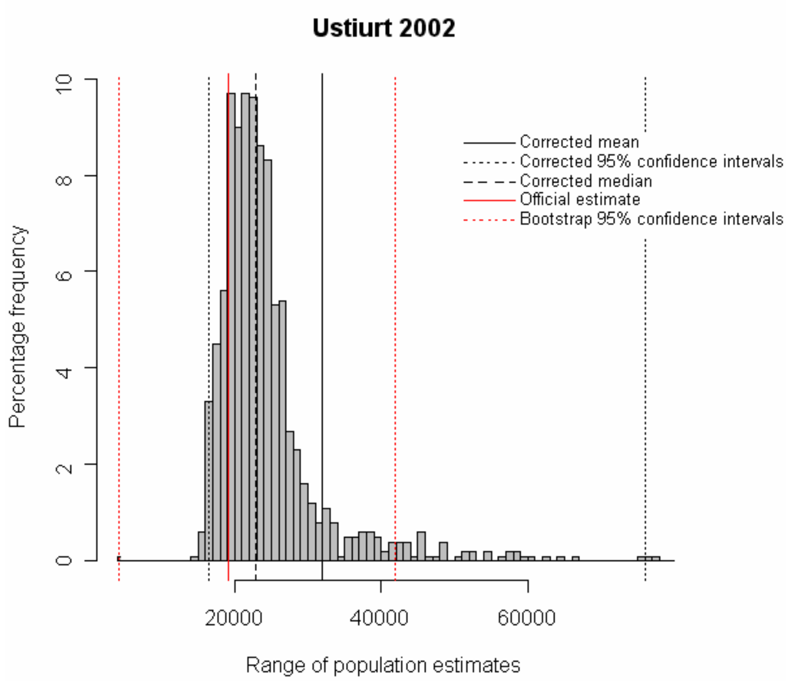


Figure 6.10 Range of corrected population estimates for Ustiurt 2002

Ustiurt 2002 was the only population in which the official estimate falls within the 95% confidence intervals of the corrected estimates.

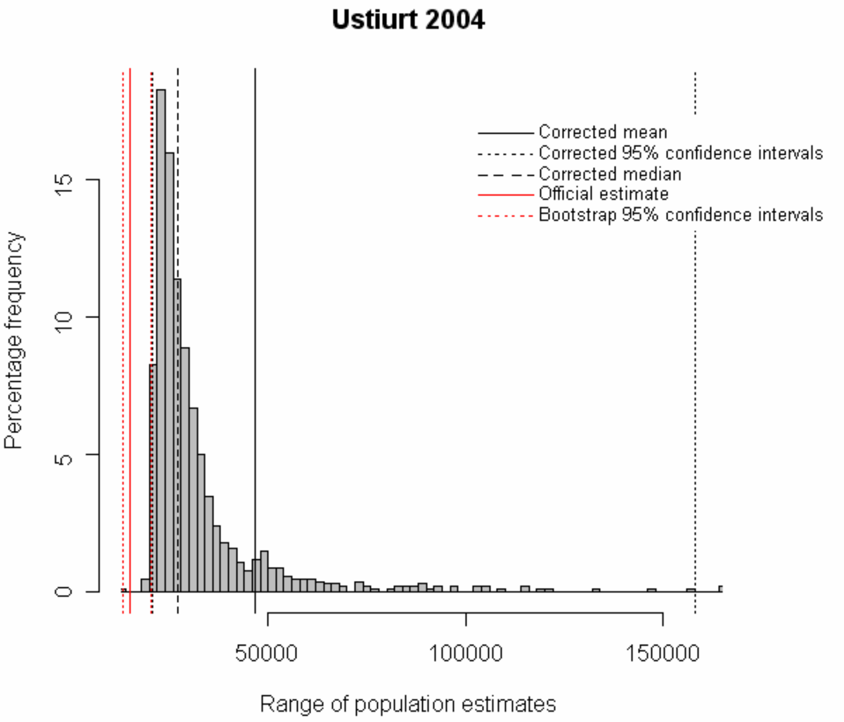


Figure 6.11 Range of corrected estimates for Ustiurt 2004.

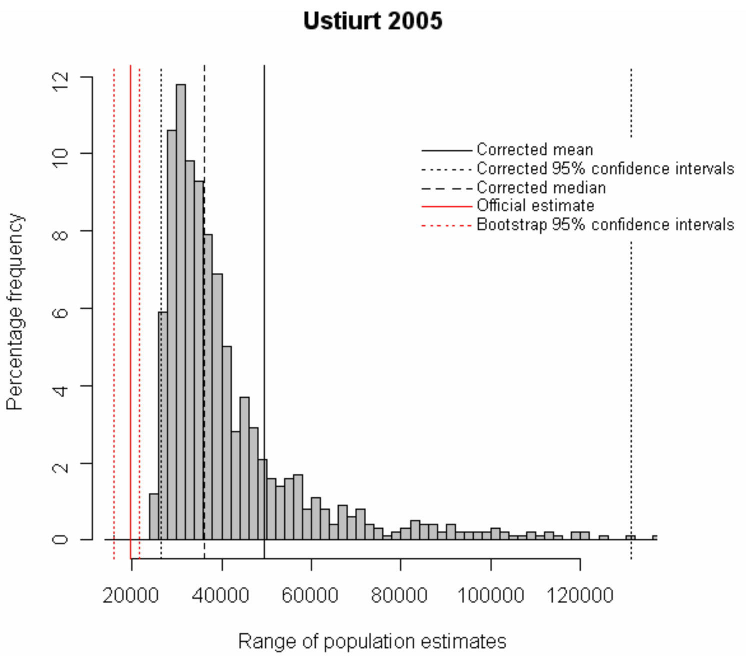


Figure 6.12 Range of corrected estimates for Ustiurt 2005.

For Ustiurt 2005, the official estimate is only 74% of the lower confidence interval of the corrected estimates.

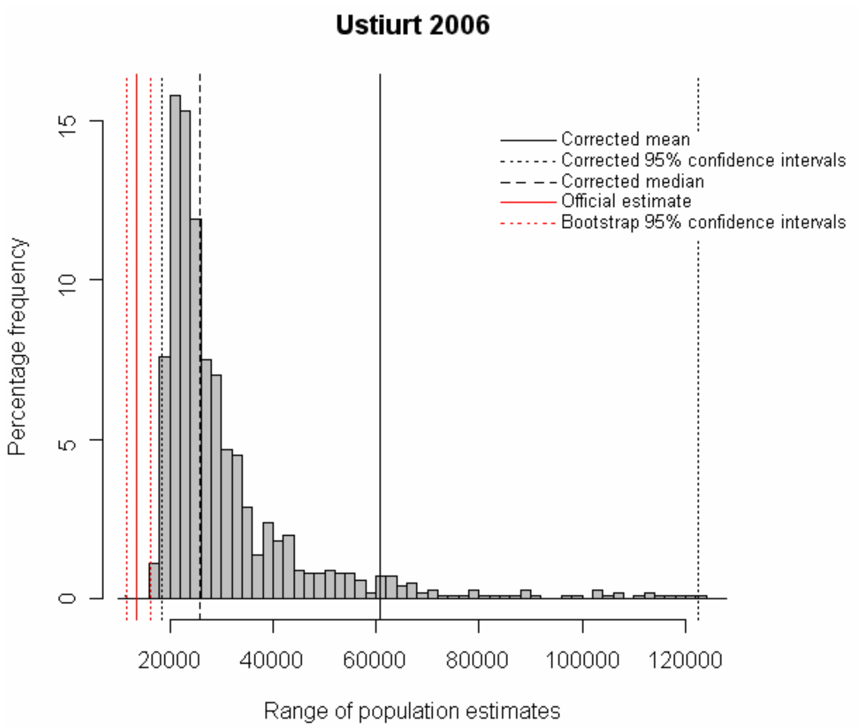


Figure 6.13 Range of corrected estimates for Ustiurt 2006.

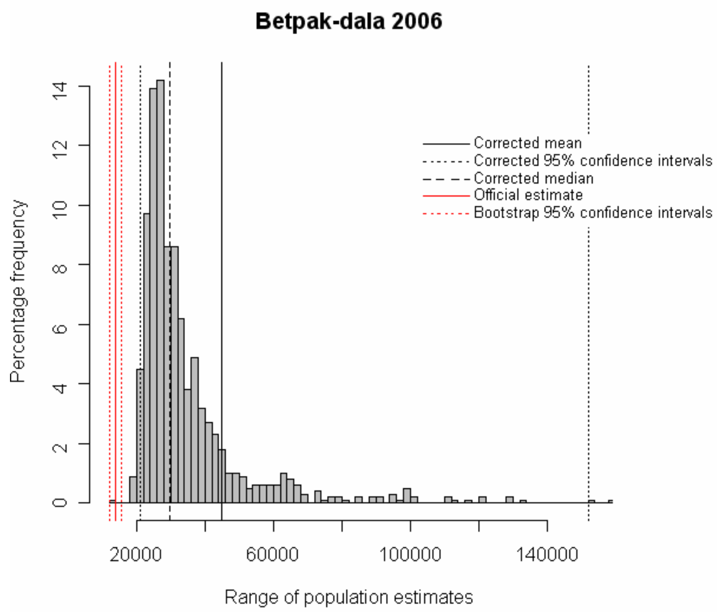


Figure 6.14 The range of corrected population estimates for Betpak-dala.

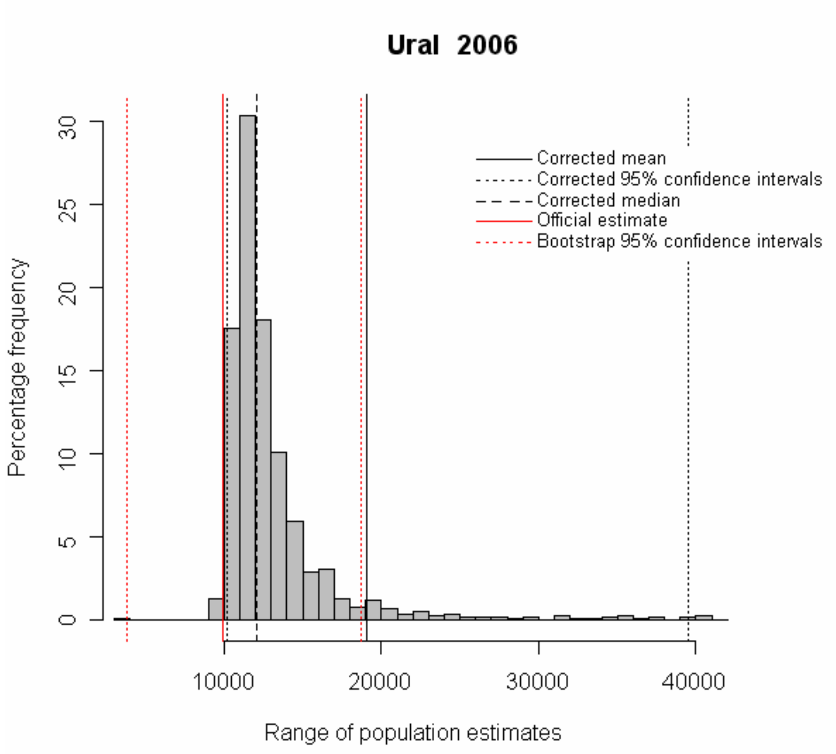


Figure 6.15 Range of corrected population estimates for Ural 2006.

The official estimate of Ural 2006 is 97% of the lower confidence interval for the corrected estimate and 82% of the corrected median.

7. Discussion

7.1 Analysis of the data

Examination of the data revealed some surprising results. Despite the population reporting overall increases since 2003, the maximum group size in Ustiurt has consistently fallen every year. This is at odds with the intuitive reasoning that a recovering population would return to larger aggregations. Encounter rates, for the data that was available, appear not to have changed significantly since 1998. The number of sightings has remained fairly constant, but herds are becoming smaller.

All three populations display different characteristics and thus may have to be treated differently in surveying. Betpak-dala has occurred in the lowest densities of the three populations and tended to more spread out (see Figure 7.1). Ural on the other hand tends to occur in smaller and more dense groups.

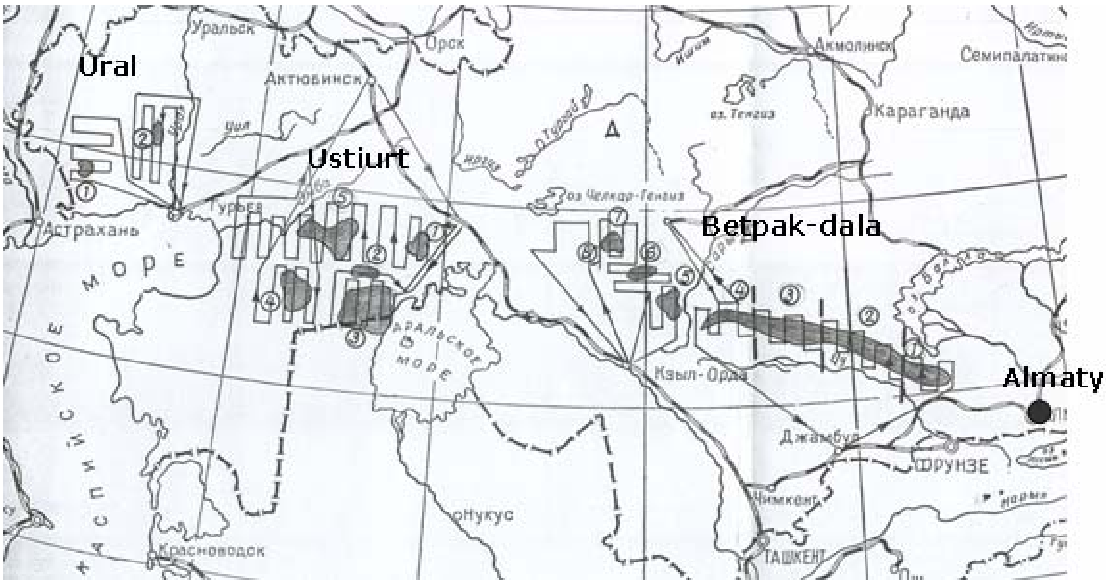


Figure 7.1 Map showing flight paths and saiga concentrations (shaded areas) in Kazakhstan in 1990. (Source: 1990 *otchot*, Institute of Zoology, Almaty).

7.2 Correcting for biases

The model showed very low rates of detection that may seem implausible at first. For Ustiurt 2006, the model predicts that at least 74% of the animals present within the observer's field of search will be missed in 1 out of 2 occasions, and 87 % missed in 1 out of 20. For Betpak-dala, it predicts 53% of the animals present will be missed in 1 out of 2 occasions and 89% in 1 out of 20. Even populations where a large proportion of the animals were in big groups, such as Ustiurt 2002, in 1 out of 20 occasions it predicts at least 75% of the population to be missed.

The literature suggests that very high numbers of animals can be missed during aerial surveys. LeResche & Rausch (1974) reported that for quadrat surveys of moose (*Alces alces*) experienced observers counted only 68% of the animals and inexperienced observers counted 43%. Quadrat surveys have the advantage over transects that the aircraft can divert from its course to accurately count herds. Norton-Griffiths (personal communication) selects strip widths of just 150m either side of plane for mammals in Kenya, and accepts that 20% of the animals are missed. Thus for strip widths of 1km, it is possible such large proportions of the population are being missed. However, in lower densities observers are probably better at detecting all the groups present than in a high density population, due to reduced eye movement and fatigue. Thus it is possible that the model over estimates the negative bias in years of lower densities (2002 to 2006).

The model only accounts for animals missed during an aerial survey, due to distance from the aircraft. As such, the corrected estimates inevitably show higher numbers that the official estimates. A look at Figure 4.1 will reveal that the model only addresses a part of the potential errors and biases that are probably affecting estimates in Kazakhstan. It does not include animals that are missed as a result of excluding areas from the survey.

While the model predicts that there are more animals present in Kazakhstan the official estimates report, there is also the possibility that the extrapolation of large group sizes of perhaps 1,000 or over will almost certainly be detected due to local information and size. Also the experience and knowledge of the scientists must be taken into account. Through knowledge of saigas' movements in response to various factors such as weather and vegetation preferences (see section 3.3 above), aerial surveys can hone in on areas with a higher probability of saiga presence.

This may be the case for Ural 2006 for example, which found group of 2,000 and 1,300 individuals occurred in a very small area, 140km^2. These were extrapolated to add an extra 3,300 individuals into the estimate which itself was only 9,850 from the aerial surveys. This problem is more likely to affect good years such as 1998, where most of the population occurred in groups over 1,000 suggesting that perhaps extrapolating these very large groups would be overestimating the population.

7.3 Critique of current population assessment techniques in Kazakhstan

The errors and biases that are likely affecting counts in Kazakhstan are substantial. The methods, developed in the 1950s for a particular set of conditions have remained virtually the same, failing to take account of developments and improvements to aerial survey techniques. No acknowledgement is made of any errors that could be associated with the counts, nor of any of the changes in saiga behaviour throughout the years. Large extrapolations are made without attributing confidence intervals expressing the degree of repeatability of the surveys.

The methods are based on the assumption that saiga form large migratory herds which contain the bulk of the population and thus large sections of area are excluded from consideration in the official estimates. This may have worked well when the biology was such that only an insignificant proportion of the population did not occur in an aggregation. However, it can be seen from the data that these aggregations are probably no longer occurring, particularly in Betpak-dala and Ustiurt. Group sizes may be constrained by the low population densities due to a reduced encounter frequency (Krause & Ruxton, 2002) and thus there may be more, smaller groups spread out over a greater distance.

The challenge in aerial surveying is not to eliminate bias but to keep it constant so that trends can be measured. In recent years, since the numbers have become so low, observers are no longer restricting counts to the 1km strip band and are counting all animals they can see (Iu. Grachev, personal communication). Grachev (2004) describes 1km as approximately the limit of visibility for observations in this conditions. Thus the assumption is made that visibility is perfect up to 1km and then falls to zero.

7.4 Assessment of the population recovery in Kazakhstan

The increases in saiga population seem biologically unlikely. A possible explanation is that numbers did not actually fall as low as was recorded. In Betpak-dala in 2003, the results from the aerial survey were misplaced, and the results had to be fabricated. This was the year of lowest recorded saiga populations in Betpak-dala, with only 165 animals reported seen. The saiga population in Kazakhstan was reported to have increased by almost 50% between 2003 and 2004. The change in the Betpak-dala population between these years accounted for half of this increase. Thus a significant part of the increase between the years is due to an artificially low estimate for the year 2003.

It should also be noted that for some years, only half the territory was covered by survey. Rather than take the estimate as a minimum, the numbers calculated for the survey area was simply multiplied by two. This causes an unknown error in the results.

Unfortunately detailed data was not available for Betpak-dala and Ural for the years before 2006. These populations have shown steady recoveries, and examination of the group size distribution could give an invaluable insight into the causes for the reported increase. Ustiurt, for which data was available has shown a decrease in 2006 on 2005 numbers. However, what is interesting is the steady decrease in group sizes since 2003 despite a reported increase in the population since 2003. The model has thus predicted an increase in negative bias for correcting the estimate for Ustiurt 2006 to a median value of 37,000 individuals compared to 13,500 calculated from the aerial survey. The reduction of group sizes would appear to indicate a population under stress.

Another explanation is the addition of ground counts to the aerial surveys without questioning the validity of doing so. In 2006, 15% of the estimate resulted from animals seen during vehicle counts being added on to the aerial survey estimates. The reasoning was that the counts came from an area that had not been covered in the aerial surveys. This was done late in September when the official reports had already been published and was adjusted in time for a major meeting of the Signatories of the Memorandum of Understanding on saiga. It is quite possible that these were not even carried out at the same time as the aerial surveys and thus could be double counts.

The power to detect a change in population is difficult to estimate without data from all populations. However, the model shows a great deal of variability in the possible estimates due to the fall-off in detection with distance. Based on Ustiurt, the changes in population reported in the last 4 years would not be possible to detect.

7.5 Recommendations for improvements to the methods and further work

Simple improvements to the current methods could be made. To begin with, all data from the surveys should be recorded digitally on a spreadsheet immediately after the survey to be made available for analysis. Currently the detail for most of the surveys exists in messy scrap books belonging to the various observers, intelligible only to themselves. All the detail that is in digital form has been used in this project. Digital photography should be used on all herds greater than 15 individuals. The time is automatically recorded and autofocus will mean that photography will not be time consuming. The animals spotted on transects should be recorded as pertaining to that transect. In this way, if each transect is treated as a sample unit, confidence intervals can be worked out for a particular saiga concentration. Extremely useful would be the use of a global positioning system (GPS) to record every sighting. This would give invaluable information on the distribution of herds and the tendency of saigas to aggregate. The scientists may take some persuading in this matter as it tends to slow down counting but they appear reasonably open to the suggestion (Iu. Grachev, personal communication).

In the longer term, a study needs to be carried out to determine whether saigas are still forming aggregations during the migratory period but simply in lower densities and animals rarely occur outside these aggregations (the assumption that is used by the methods today) or whether they are more evenly distributed out in the landscape. This could be done by attempting to cover the entire suspected range of saigas at that time by a combination of ground and aerial counts. If the latter is the case, then they would be better advised to apply standard techniques and divide the entire range into sample zones which are sampled at random (Norton-Griffiths, 1978; Caughley, 1977).

Visibility bias has to be considered in the population estimates. As densities are low, it would appear to be wasteful of sightings to simply reduce strip width to 150 or 200m. Therefore an attempt should made to use line transect methods using 4 or 5 grouped distance classes. It is unlikely to be popular amongst scientists in Kazakhstan as previous attempts to use markers on the wing struts was abandoned due to excessive banking of the aircraft in the high winds of the steppe. However, as long as observers do not attempt to correct for banking themselves and consistently assign distances according to the markers, then the positive and negative counts as a result of banking will cancel each other out (Caughley, 1974).

The model constructed only takes into account visibility bias, thus it will inevitably predict a higher population estimate. A model is needed that takes into account the spatial distribution of herds and the probabilities of locating larger herds.

8. Conclusions

The data that was available for analysis was 8 datasets containing the details from the aerial surveys, 6 from the population of Ustiurt and one from each Betpak-dala and Ural. Also available was information from the official reports which summaries the main findings of the population censuses. The report found that maximum aggregations in the Ustiurt population have been steadily decreasing since 2003. This is despite 2003 being the lowest recorded population number for Ustiurt since the population recovered in the 1920s. It is unclear if this decrease is due to a continued fall in population that is not being detected or if the pattern of aggregation has simply changed.

As many biases as possible that may be affecting the population estimates in Kazakhstan were identified through a literature review and from gaining knowledge of the population estimate methods currently in use. It was reasoned that the most significant biases that may be affecting the trends in saiga population estimates were the effect of missing animals with distance from the observer and the change in saigas herd forming properties during the time of aerial survey. A model was designed to attempt to correct for these biases. Results show a very variable range of corrected estimates for all populations. In cases where a higher proportion of animal were in large groups, this bias was reduced. The model predicts that for Ustiurt 2006, as much as 87% could be missed as a result of distance. Also identified as a major bias is the failure to cover the entire range of the saiga distribution. 15% of the 2006 estimate came from ground counts from areas not covered in the aerial survey. Thus the current estimates are likely to be significant underestimates of the actual population. A possible explanation for the large increases is the underestimation of the numbers in 2003 due to mislaying of survey results.

Distance sampling methods are recommended on a trial basis to correct for the fall in detection due to distance. Further modelling work is recommended to take into account the spatial distribution of herds and the probability of locating larger aggregations.

References:

Andriolo, A., Piovezan, U., Rodrigues Paranhos da Costa, M.J., Laake, J. & Barbanti Duarte, J.M. (2005) Aerial line transect survey to estimate abundance of marsh deer (*Blastocerus dichotomus*)(Illiger, 1815). *Brazilian Archives of Biology and Technology*, **48**(5), 807-814.

Bayliss, P. & Yeomans, K.M. (1989) Correcting bias in aerial survey population estimates of feral livestock in Northern Australia using the double-count technique. *Journal of Applied Ecology*, **26**, 925-933.

Bekenov, A.B., Grachev, Iu.A. & Milner-Gulland, E.J. (1998) The ecology and management of the Saiga antelope in Kazakhstan. *Mammal Review*, **28**, 1-52.

Buckland, S.T., Anderson, D.R., Burnham, K.P. & Laake, J.L. (1993). *Distance Sampling: Estimating Abundance of Biological Populations*. Chapman & Hall, London. 446pp.

Caughley, G. (1974) Bias in aerial survey. *Journal of Wildlife Management*. **38** (4), 921-933.

Caughley, G. (1977) Sampling in aerial survey. *Journal of Wildlife Management*. **41**(4), 605-615.

Caughley, G. & Grice, D. (1982) A correctin factor for counting emus from the air, and its application to counts in Western Australia. *Australian Wildlife Research*, **9**, 253-59.

Cook, D.R. & Jacobson, J.O. (1979) A design for estimating visibility bias in aerial surveys. Biometrics, **35**, 735-742.

CMS (2006) First meeting of the signatories to the memorandum of understanding concerning conservation, restoration and sustainable use of the saiga antelope (*Saiga tartarica tartarica*): Overview Report. Almaty, Kazakhstan.

Crawley, M.J (2005) *Statistics: An introduction using R*. John Wiley & Sons Ltd.

Douglas-Hamilton, I., Hillman, A.K.K. & Moss, C.J. (1981) (eds.) Low-level aerial survey techniques. ILCA Monograph. Report International workshop 6-11 November, Nairobi Kenya.

Drummer, T.D. & McDonald, L.L. (1987) Size bias in line transect sampling. *Biometrics*, **43**, 13-21.

Grachev, Iu.A. (2004) Saiga. In: *Metodi uchota osnovnikh okhotniche-promislobikh I redkikh vidov zhivotnikh Kazakhstana* (Fundamental methods of assessment for hunted and rare species of animals in Kazakhstan), Institute of Zoology, Almaty.

Grachev, Iu.A. & Bekenov, A.B. (1993) The present state of Saiga populations in Kazakhstan. In: *Zoologischeskoe issledovania v Kazakhstane* (Zoological research in Kazakhstan), Part 2, 165-189. [Quoted in Bekenov *et al.*, 1998]

Graham, A. & Bell, R. (1969) Factors influencing the countability of animals. *East African Agricultural and Forestry Journal*, **34** (special issue), 38-43.

Guenzel, R.J. (1997). *Estimating Pronghorn Abundance Using Aerial Line Transect Sampling.* Wyoming Game and Fish Department, Cheyenne. 176pp. Available at http://www.ruwpa.st-and.ac.uk/distance.book/pronghorn.html

Jolly, G.M. (1969a) Sampling methods for aerial censuses of wildlife populations. *East African Agricultural and Forestry Journal*, **34** (special issue), 46-49.

Jolly, G.M. (1969b) The treatment of errors in aerial counts of wildlife populations. *East African Agricultural and Forestry Journal*, **34** (special issue), 50-55.

Kholodova, M.V., Milner-Gulland, E.J., Easton, A.J., Amgalan, L., Arylov, Iu., Bekenov, A., Grachev, Iu.A., Lushchekina & A.A., Ryder, O. (2006) Population genetics of the critically endangered saiga antelope. *Oryx* **40**, 103-107.

Krause, J. & Ruxton, G.D. (2002) *Living in Groups*. Oxford Series in Ecology and Evolution. Oxford University Press.

Kühl, A. (2003) Saiga antelope community-based conservation – why and for whom? MSc Thesis, Imperial College, London.

Lundervold, M. (2001) Infectious diseases of Saiga antelopes and domestic livestock in Kazakhstan. PhD Thesis, University of Warwick, UK.

Milner-Gulland. E.J., Kholodova, M.V., Bekenov, A., Bukreeva, O.M., Grachev, Iu.A., Amagalan, L. & Lushchekina, A.A. (2001) Dramatic declines in Saiga antelope populations. *Oryx* **35**(4), 340-345.

Milner-Gulland, E.J. (1994) A population model for the management of the Saiga antelope. *Journal of Applied Ecology*, **31**, 25-39.

Milner-Gulland, E.J., Kholodova, M.V., Bekenov, A.B., Bukreeva, O.M., Grachev, Iu.A., Amgalan, L. & Lushchekina, A.A. (2001) Dramatic declines in saiga antelope populations. *Oryx*, **35**, 340-345.

Milner-Gulland, E.J., Bukreeva, O.M., Coulson, T.N., Lushchekina, A.A., Kholodova, M.V., Bekenov, A.B., Grachev, Iu.A. (2003) Reproductive collapse in saiga antelope harems. *Nature* **422**, 135.

Norton-Griffiths, M. (1978) Counting Animals. Handbook No. 1, 2nd edition. African Wildlife Leadership Foundation, Nairobi, Kenya. Available at www.iucn.org/themes/Ssc/sgs/AfESG/tools/pdfs/man_ctgani_en.pdf. [Accessed on 9 October, 2006].

Olsen, K.A., Fuller, T.K., Schaller, G.B., Odondhuu, D. & Murray, M.G. (2005) Estimating the population density of Mongolian gazelles *Procapra gutturosa* by driving long-distance transects. *Oryx*. **39**(2), 164-169.

Otto, M.C. & Pollock, K.H. (2002) Size bias in Line Transect Sampling: A Field Test. *Biometrics*, **46**, 239-245.

Quang, P.X. & Lanctot, R.B. (1991) A line transect model for aerial surveys. *Biometrics*, **47**, 1089-1102.

LeResche, R.E. & Rausch, R.A. (1974) Accuracy and precision of aerial moose censusing. *Journal of Wildlife Management*. **38**(2), 175-182.

Samuel, M.D. & Pollock K.H. (1981) Correction of visibility bias in aerial surveys where animals occur in groups. *Journal of Wildlife Management*. **45**(4), 993-997.

Samuel, M.D., Garton, E.O., Schlegel, M.W. & Garson, R.G. (1987) Visibility bias during aerial surveys of elk in Northcentral Idaho. *Journal of Wildlife Management*. **51**(3), 622-630.

Siniff, D.B. & Skoog, D.O. (1964) Aerial censusing of caribou using stratified random sampling. *Journal of Wildlife Management*, **28**(2), 391-401.

Sludskii, A.A. (1955) The Saiga in Kazakhstan. *Trudi Instituta Zoologii AN KazSSR* [Proceedings of the Zoological Institute of the Kazakhstan Academy of Sciences], **17**, 24-143.

Sokolov, V.E. & Zhirnov, L.V. (eds) (1998). *The saiga: phylogeny, systematics, ecology, conservation and use.* Russian Academy of Sciences, Moscow, Russia.

Southwell, C. (1996) Bias in aerial survey of feral goats in the rangelands of western Australia. *Rangelands Journal*, **18**(1), 99-103.

Steinhorst, R.K. & Samuel, M.D. (1989) Sightability adjustment methods for aerial surveys of wildlife populations. *Biometrics* 425, 415-425.

Sutherland, W.J. (1996) ed. *Ecological census techniques: a handbook*. Sutherland, W.J. "Mammals". Cambridge University Press.

Thomas, L., Laake, J.L., Derry, J.F., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Strindberg, S., Hedley, S.L., Burt, M.L., Marques, F.F.C., Pollared, J.H. & Fewster, R.M (1998). Distance 3.5. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

Vereschagin, N.K. (1975) The species composition and geographical range of Ungulates during the Qaternary Era. In: *Koputnye fauny SSSR* [Ungulates of the USSR.], 7-9. Moscow, USSR. (Cited in Bekenov *et al.* 1998).

Thomas, L., Buckland, S.T., Burnham, K.P., Anderson, D.R., Laake, J.L., Borchers, D.L. & Strindberg, S. (2002) *Distance sampling*. In Encyclopedia of Environmetrics. John Wiley & Sons, Chichester.

Wikipedia, (last modified 30 September 2006). Kazakhstan. Available at http://en.wikipedia.org/wiki/Kazakhstan. Accessed 1st October 2006.