Chapter 1: Pastoralism in Kazakhstan and the Impacts of Recent Agricultural Reforms

1.1 Geographical and Botanical background

Most of Kazakhstan is relatively flat and covered by treeless steppe, semi-desert and desert vegetation. It is characterised by hot summers and severe winters, during which the temperature may drop as low as -40°C. In the south and east of the country are the Tien Shan and Altai mountain ranges, rising to 7000 and 4000 metres respectively, and sources of valuable alpine pastures.

Figures 1.1 and 1.2 are maps of the administrative and geographical regions of the country. The administrative regions shown are called *oblasts* which are sub-divided into *raions* (not shown). In the non-mountainous areas of Kazakhstan there are three main ecological zones described by Soviet botanists (for example Kirichenko 1980 and Zhambakin 1995), whose differences in rainfall, snow cover, and vegetation type have all been important in the history of livestock farming in Kazakhstan. These zones are shown in Figure 1.2 and are described below. Photographs of typical vegetation in the desert and semi-desert zones are shown in Chapter 3 (Figures 3.3 and 3.4).

The steppe zone in which rainfall is above 300 mm per year is to be found mainly in the *oblasts* of Kostanai, Kokchetav, North Kazakhstan, and Pavlodar. These areas consist of pastures on black or chestnut soils dominated by grasses such as *Stipa lessinga, S. capillata, S. sareptana, Festuca valesica*, *Poa*, and *Agropyron* species. However much of this zone was ploughed up during the virgin lands campaign in the 1950s, and is not now a major livestock rearing area. Since the 1950s the major pastoral zones have increasingly been in the semi-desert and desert regions.

The semi-desert zone typically has a rainfall of 200-250 mm per year. This zone includes parts of East Kazakhstan *oblast*, most of Akmola, Karaganda, and Semipalatinsk *oblasts*, and northern Aktiubinsk and Dzhezkazgan *oblasts* (Zhambakin

1995). These areas also contain associations of *Stipa* and *Festuca* species. However there are also to be found many areas dominated by *Artemesia* species, particularly on '*solonets*' soils. These are soils in depressions, which, due to the accumulation and subsequent evaporation of water, become salinized. The lower layers of the soil harden into columnar units which are impervious to water (Mately 1994a). Few grasses can survive on these soils, due to their high salt content, and associations tend to be dominated by *Artemesia pauciflora, Artemesia terrae-albae*, and *Atriplex cana*. Otherwise, the soil in this zone and in the desert zone consists of brown or grey-brown desert soils, or sandy soils, which are not suitable for agriculture.

The desert zone comprises roughly those areas having less than 200 mm rainfall. This is the area south of about 47 degrees north. The northern desert zone has boundaries which are shown on Figure 1.2 in bold (from Kirichenko 1980). This region is of particular interest in this study. It is characterised by flat land on clay soils, and to the north is dominated by *Artemesia* species such as *Artemesia terrae-albae* and *Artemesia turanica*. Further south and east, towards the river Chu and Lake Balkhash, and on the Ustiurt plateau between the Aral and Caspian seas, are communities dominated by saltworts, xerophytic species such as *Anabasis salsa*, *Salsola orientalis*, *Atriplex cana*, and *Salsola arbusciliformis.*

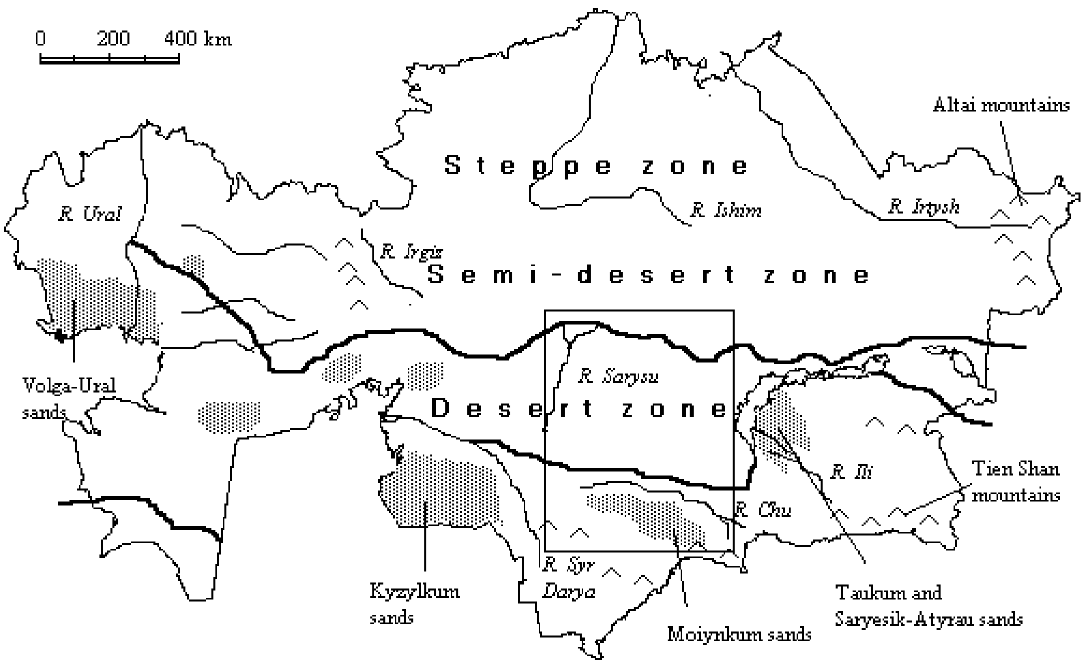
South of the rivers Chu and Syr Darya and Lake Balkhash are three of the major sand deserts of Kazakhstan, the Moiynkum, Kyzylkum, and Taukum deserts (see Figure 1.2). These are characterised by shrubby vegetation such as *Haloxylon* and *Calligonum* species growing on dunes. However, the mix of species varies widely between the deserts.

The foothills and alpine pastures of the Tien Shan mountains have been used for livestock rearing throughout Kazakh history. The foothills have higher rainfall and better soils than the neighbouring desert regions, and are even used in some areas for grain production.

Figure 1.1: Administrative regions (oblasts) of Kazakhstan.

Snow cover in the semi-desert zone exists between November and March and has an average depth of 25-35 cm. In the steppe zone it is higher. Animals cannot obtain food under snow when the depth averages 35-40 cm, or 20 cm when the snow is dense (Sludskii 1963). Therefore, the steppe and semi-desert regions cannot be used as winter pastures if supplementary fodder is not available. Traditionally the sand deserts, with their low snowfall and shrubby vegetation, were used as winter pasture. Those that have dunes are particularly suited to this as on the south slopes of the dunes the snow melts quickly. The northern desert (*Artemesia* and saltwort pastures) the semi desert regions, and foothills of the Tien Shan were used as autumn and spring pastures, and the pastures of the steppe region or mountains for summer pasture. These are generalisations, and changes in pasture use through time is one of the main themes of this chapter.

Figure 1.2: Physical map of Kazakhstan including vegetation zones. *The bold line running across the centre of the country shows the boundaries of the northern desert zone, characterised by clay soils. The box shows the study area, described in section 1.4. Sandy deserts are shown as stippled areas.*



1.2 History of pastoralism in Kazakhstan

1.2.1 The Kazakh people

The Kazakhs are a turkic people who have probably lived in the area occupied by present day Kazakhstan since the early 16th century (Olcott 1995). At that time, the empire of the Kazakhs stretched from the Tien Shan mountains to present day Tobolsk in Siberia. Subsequently their territory was reduced, and the eastern part of the country became part of the Zhungarian empire until the 1750s when their conquerors, the Oyrats, were defeated by the Manchu Chinese. Between 1731 and 1742 the Kazakhs asked the Russian Tsar for protection against the Oyrats, and this was used as an invitation to annex Kazakh territory. Russian incursions started to eat into the summer pasture areas of the Kazakh population, and the first settlement of the Kazakh population began. By the 1870s most of what is now Kazakhstan was officially under Russian administration, and by the first world war 3 million Europeans had settled there (Olcott 1995). The process of immigration of other nationalities continued throughout the socialist period, until in 1970 only 32% of the population were Kazakh. In the late 1980s the population of Kazakhstan was 41.9%

Kazakh and 37% Russian, the remaining population consisting of mainly of Ukrainians, Uzbeks and Tatars (*Goskomstat* 1987).

The proportion of Kazakhs has increased since the country gained independence in 1991 due to a higher birth rate, and the emigration of Russians who fear a reduction in opportunities for non-Kazakh speakers under the new government. Even throughout the Soviet period almost all pastoralism in the country was conducted by ethnic Kazakhs, cultivation being dominated by Russian settlers, Germans, and Ukrainians.

1.2.2 Pastoralism before 1917

As has been discussed above, the ecosystems of Kazakhstan are generally harsh, with low rainfall, and crucially, the effective elimination of a large part of the pasture in winter due to snow cover. Therefore, in order to be able to stay south of the snow line in winter, whilst benefiting from good summer pastures in the north, Kazakhs were highly migratory, and migrations could span up to 700km in the desert and steppe regions. Before Russia took an interest in the country, the Kazakhs were purely pastoralists, practising no agriculture or hay production at all. They thus did not have any supplementary feed for their animals (Matley 1994a), and stock numbers were strongly influenced by climate.

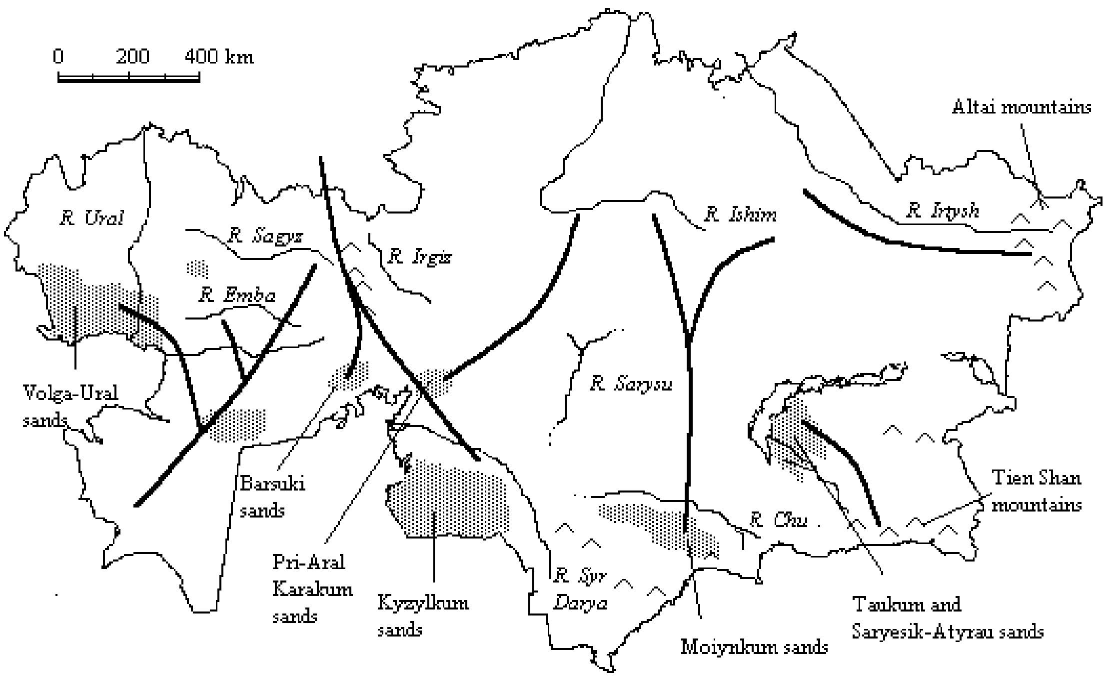
Particularly disastrous were *dhzu*ts. This is a Kazakh term which refers both to conditions under which melting snow re-freezes to form an icy layer covering the grass, and to snow falls much higher than average (Fadeev and Sludskii 1982). *Dzhuts* could cause entire herds to die of starvation. For example, in the winter of 1789-1880 in Turgai *oblast* over 40% of stock died due to *dhzut*, and a decade later up to 95% died in the Kazalinsk area (Zhambakin 1995). There is also some evidence to suggest that livestock populations were affected by drought. In 1928 for example one quarter of the livestock numbers in south and west of Kazakhstan died due to drought (Channon and Channon 1990). The effects of drought and *dzhut* on livestock are discussed in more detail in Chapter 2 of this thesis.

Some of the major migration routes are shown in Figure 1.3. They were partitioned between three major tribes, or 'hordes', known as the Great, Little, and Middle Hordes. According to references in Zhambakin (1995) and Olcott (1995), the Middle and Great Hordes wintered along the river Chu and in the Moiynkum desert, moving to the summer pastures along the River Ishim. Members of the Middle Horde also occupied pastures in the east of Kazakhstan, spending summer in the Altai mountains, and winter along the river Irtysh. The Great Horde controlled pastures in the Tien Shan mountains, to which some of them would go in the summer from the Moiynkum or Taukum deserts.

The Little Horde spent winter along the Syr Darya river or in the Pri-Aral Karakum or Barsuki sands, moving in the summer to just south of Orenburg, outside the boundaries of modern Kazakhstan. One group also spent winter along the shores of the Caspian sea, and summer in the basins of the Emba and Sagyz rivers. These migrations were not fixed, however, and depended from year to year on climatic conditions. For example if there was drought in the summer territory of one horde, it might move further north, or into the territory of another horde (Zhambakin 1995). This flexibility of migration was one of the first things to disappear with the coming of Europeans to Kazakhstan.

According to references in Olcott (1995), the average family in the middle horde had 120 sheep or goats, 30-50 horses, 15-20 cattle, and a few camels. Families would have spent the winter and migrated in groups of 30-40 yurts (known as *auls*), each consisting of a few extended families, although in summer these would split into smaller groups.

Figure 1.3: Major seasonal migrations of the Kazakhs in the 15th Century. *Stippled regions show pastures on sandy desert soils.*



As the Kazakh grazing lands were appropriated by the Tsar, migratory movements of the Kazakh people declined both in distance and frequency. Perhaps the greatest changes wrought by the Russian 'invasion' occurred in the 50 years leading up to the Russian revolution (Olcott 1995). The Steppe Act of 1891 effectively claimed all the Kazakh lands for the crown, and Kazakhs in many areas had to pay rent on land in order to use it (Zhambakin 1995). In Aktiubinsk *oblast* at the end of the 19th Century, Kazakhs were already moving only 20-40 km from their winter pastures, and in South Kazakhstan *oblast* the majority of the population were sedentarised by 1908 (Zhambakin 1995). By 1917 almost ¾ of the population had some form of permanent winter quarters, and some had brick structures for animals and humans (Olcott 1995). This was probably partly aided by the introduction of the scythe, which allowed them to cut and store hay for the winter (Matley 1994b).

The Russian invasion also had effects on the type of livestock kept and wealth distribution among Kazakhs. Small livestock for subsistence became less common, and by the revolution their percentage of the overall Kazakh herd had dropped from 90% to 50%, being replaced by cattle, which were bred for profit. This led to large inequalities in Kazakh society. The average herd size dropped from 150 animals per household, to 26 in 1915, and in that year only 5% of the population owned more than 50 head (Olcott 1995).

There was a crash in stock numbers during the first world war (which is illustrated in Figure 1.4) and many people, as well as animals, died of famine. This was due to the fact that many of the areas used to grow winter fodder became battlegrounds, or were abandoned. During the twenties the size of the national herd increased back up to its pre-war level, but by the end of the decade, half of all Kazakh households still owned less than 5 animals (Olcott 1995).

1.2.3 Pastoralism in the socialist period

After 1930 settlement became more deliberately enforced upon the population in the form of collectivisation. This resulted again in huge famines as livestock died of hunger or were shot to avoid collectivisation. Over 80% of the Kazakh herd was lost (see Figure 1.4) and over one million Kazakhs died (Olcott 1995). The failure of sedentarisation of nomads was officially recognised by the 1940s and the system was adapted to allow for a limited form of nomadism which continued within the context of the state farms until the early 1990s.

(i) Farm structures

Under the Soviet system, farms were of two types, *kolkhoz* (collective farm) and *sovkhoz* (state farm). The former were farms owned by their members, who had to deliver an assigned amount of produce to the state every year. Any surplus was to be used for sowing, after which members received their shares calculated on the basis of ‘workdays’ which they had put in for the *kolkhoz*. *Sovkhozes* were state enterprises in which each worker had a wage paid by the state, with bonuses if the state quota was exceeded. In the 1950s many *kolkhoz*es were converted to *sovkhoz*es, as these tended to be regarded more favourably by the government. *Sovkhozes* were large farms, containing, at their peak in the 1980’s, an average of 540 workers and their families (*Gosokomstat* 1988). Each had a school, hospital, social facilities, vets, accountants, technicians, and agricultural experts as well as workers such as shepherds who were more directly involved in pastoral activities.

Although most livestock were state owned, people were allowed limited numbers of private stock and small garden plots, the production from which was sold to residents of urban areas in special farmers markets, or even to the state. This became more important in the 1980s, when limits to owning animals privately were abolished, and the importance of personal plots to meeting production targets, and in increasing living standards was officially recognised (Podol'skii and Ivanov 1984). By 1988, individually owned produce provided Kazakhstan with 30.9% of its meat, 43% of its milk, and 30% of its eggs (Werner 1994).

(ii) Organisation of land

After collectivisation in the 1930s, enormous areas of arid pasture in Central and South-eastern Kazakhstan were left without livestock for long periods of time. The newly created *sovkhoz*es had strictly defined boundaries, and there was no stock movement outside of these. In the 1940s the numbers of animals started to increase, and in the winter of 1941-42 the driving of cattle and sheep to pastures remote from the farm itself began. In March 1942 the communist party passed a resolution to increase the numbers of stock, and this included provision for the use of remote pastures on state reserve land. The Moiynkum desert started to be used again in this period, as winter pasture for farms in Dzhambyl *oblast* (Alimaev *et al.* 1986). During the 1950s, the best summer pastures in the steppe regions were ploughed up for grain production, and so any expansion of the livestock sector had to occur in the other vegetation zones.

In the 1960s 155 specialised sheep raising *sovkhoz*es were created on state reserve land in the semi-desert and desert regions, with a stock of 50,000-60,000 sheep each (Asanov and Alimaev 1990). Wells were sunk and water was extracted by pump where the water table was deep, or even brought in by tanker, so opening up new areas for grazing. At this time the state was aiming for sheep numbers to reach 50 million in Kazakhstan. The pastures which therefore would have formerly been used briefly during migratory periods started to be used for months at a time, and movement in some areas started to contract again as the new *sovkhozes* blocked the migration routes.

Migration, although primarily conducted on horseback, benefited from considerable technical support. Families could use tractors to help transport their yurts and food, and were supplied with petrol for well pumps. In some areas of Kazakhstan water tankers went along too as the stock sometimes migrated across waterless zones (for example stock in Almaty *oblast* which migrated from the mountains to the Taukum desert on the shores of Lake Balkhash (see Figure 1.3). Vets would visit the shepherds during the summer months, and in certain areas trucks would bring fresh food supplies to shepherds and their families once a month. Those members of the shepherd's families who had to remain at the village (e.g. children of school age) were fed by the *sovkhoz* during the summer. Through these efforts the Soviets managed to make use of even the remotest pastures, and to reach a high of livestock numbers in the mid 1980s of 36 million sheep, double the number of 1916 (Figure 1.4) whilst at the same time living standards and opportunities for pastoralists improved.

Stock movement patterns in the later socialist period (after 1960) can be divided into two major types:

Type 1: Long distance migrations across ecological zones. These usually involved movements to pastures on state reserve land remote from the *sovkhoz*, in other *raions*, *oblasts*, or even other republics. These migrations were often several hundred kilometres in length.

Type 2 : Short distance migrations which should probably be better labelled as movements, occurring within the farm territory, and which did not always entail a move with each season. These were between about 10 and 120 km in length and were usually within one ecological zone.

The long distance migrations were mainly from farms in the south situated between a good winter site such as a sandy desert and a good summer pasture such as Sary Arka or the Tien Shan mountains. They would generally involve mass movements of hundreds of thousands of animals from entire *raions*.

The short distance migrations occurred mainly on farms further north in the semi-desert zone, in which each individual *sovkhoz* would be split into units of seasonal land use. On some of the new farms built in the 1960s, stock could be on the same pasture for three seasons, (autumn-winter-spring, or spring-summer-autumn), movement often constituting simply rotations between adjacent wells. According to Zhambakin (1995), such grazing regimes lead to pasture degradation.

The difference between the two types of movement was never clear cut, and even in the more northerly *oblasts*, if significant amounts of particularly useful pastures existed, such as those on sands, or along rivers, these would be set aside as state reserve land, and used by several farms from the area who would drive animals there on a seasonal basis. Conversely, in southern areas some farms stopped sending their animals north in the summer, and they thus stayed on the autumn-spring pasture for the summer also. According to I. Alimaev (pers. comm.) such practises were particularly damaging.

To summarise, during the Soviet period, and especially after the 1960s, the whole of Kazakhstan was partitioned into a patchwork of units, each with its land use and type defined by the state. Each farm, and indeed each herd was allocated grazing locations for each season. Shepherds took no decisions all as to where they went with the animals in their charge. All decisions were taken by the farm management. However, upon closer inspection it can be seen that some of the longer migrations which remained followed routes of earlier movements of traditional times. For example, the migrations from the Moiynkum desert, Kyzylkum desert, and Syr Darya river towards the summer pastures near the River Ishim (see Figure 1.3) survived in a shortened form. In both cases stock did not go so far as before, as the former summer pastures were taken up by new farms and stock which stayed all year round in those areas, barring migrations from southern farms.

Figure 1.4: Numbers of sheep, horses, and cattle in Kazakhstan during the 20th Century. *Source: Goskomstat 1984, 1985, 1987, Mately 1994b.*

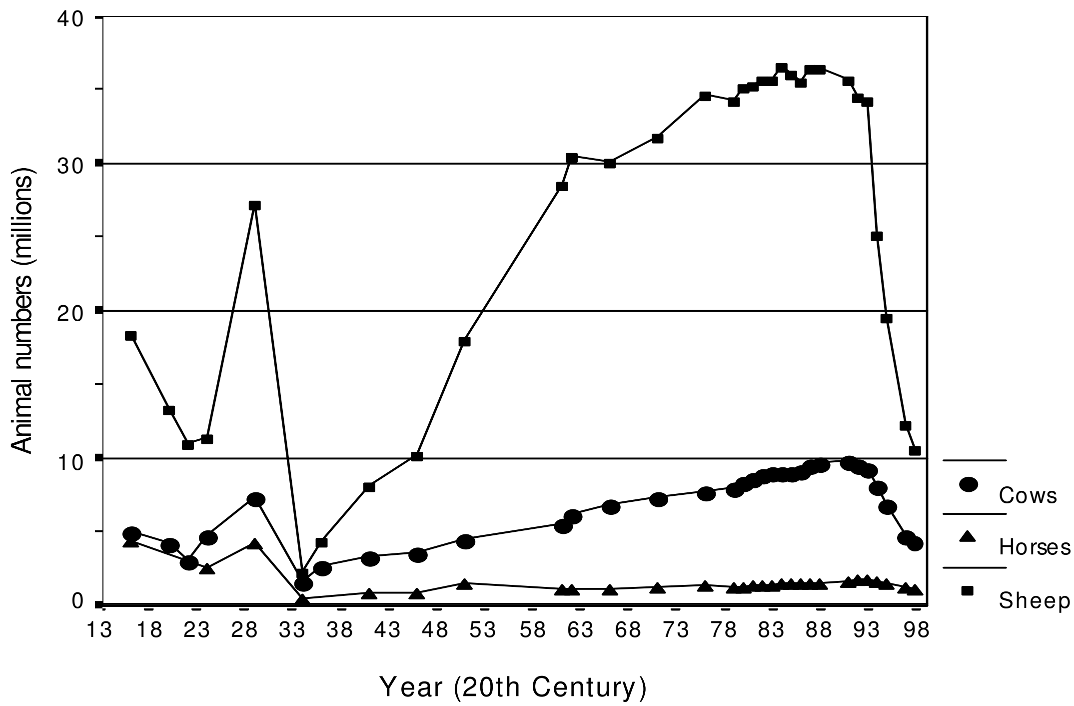


Figure 1.4 graphically illustrates the changes which have occurred in livestock farming over the 20th Century. The drops in numbers due to the first world war and collectivisation can be clearly seen, as can the large increase in numbers over the 1980s. The most spectacular drop however occurs between 1994 and 1998. This drop is the main impact of agricultural reform since independence, and is discussed in the next section.

1.3 Agricultural Reform

1.3.1 The process of reform

Agricultural reform started as early as 1987 with the introduction of the contract system enabling families or larger groups to make contracts with the state farms which would buy their produce for a set price. At this time the limits to ownership of private stock were abolished. However, although some individuals had started to take advantage of these reforms (Asanov and Alimaev 1990) there was not time for the effects to become widespread in Kazakhstan before the Soviet Union collapsed, and a much more radical form of privatisation was implemented in which the state played no role in subsidising farms, nor in marketing their produce. The program of transferral of farms from state to private enterprises began in 1993, and had been completed by the end of 1996.

Prior to privatisation, the state committee for privatisation assessed the value of farm property, taking into account debt, inflation, and depreciation, and established a standard property share for each member of the farm (Asian Development Bank, 1996b). Similarly, a land and asset share per farm member was determined based on a number of factors. There were various methods of deciding upon the size of these land shares, all of which were designed by central government. According to interviews conducted with the farm administration during this study, it was up to the *raion* authorities to decide which method to use. For example two methods were observed during fieldwork. One of these was to award members coefficients according to how long they had worked there, which was then converted into hectares or assets. Another method awarded coefficients depending on the person's role, for example a farm worker would receive a higher coefficient than a housewife or a child. In some cases certain assets were distributed as standard shares, the same amount for every adult. The size of the shares were calculated based on the sum of the coefficients of all household members.

The farm management was supposed to conduct an informal consultative process to try to establish a consensus on the structure of the new type of farming entity and the allocation of property and land shares. Several types of collective farm structures were formed, for example Joint Stock Companies, Production Co-operatives and Small Enterprises, all of which closely resembled the structure of a *sovkhoz*. Whichever form was chosen, however, workers wishing to leave the farm and form independent smaller farming units have the legal right to redeem their land share certificates for demarcated land plots. They should also receive some share of the farm assets such as stock or access to machinery. The resulting independent units are designated as *kristianski khozyaistva* (peasant farms), but they will be referred to here as private farms. Such farmers who are leaving collective farms or re-organised state-owned agricultural enterprises, should normally be granted land out of the property of the former *sovkhoz* of which they were a member, the registered value of which must be at the enterprise's average level (articles 77 and 79, Republic of Kazakhstan Civil Code 1995). The terms of land tenure are described below.

1.3.2 Land tenure

Before 1995, all land was owned by the state, and so permanent rights to use land for a particular purpose did not exist. This discouraged investment in land. However, the civil code introduced in early 1995 introduced the concept of land ownership, although only for certain categories of land use.

Below are the terms and conditions of land use of different categories of land by the new collectives and peasant farmers:

Ownership - only for personal supplementary farming, *dacha* (country house) construction, and residential homes.

Permanent use - (article 40, Republic of Kazakhstan Civil Code 1995) these rights may be bequeathed, bought and sold by non-state users for prices decided by the two parties. However this is not the same as ownership because the land may be reclaimed by the government. This land is available to non-state organisations engaged in farming activities i.e. Production Co-operatives, and private farms. It is subject a tax levied per hectare, and dependant on the quality of land. According to the Asian Development Bank (1996a) the tax varied in 1995 between 0.25 and 25 *tenge*/ha (*tenge* is the Kazakh currency, and at this point in time 68 *tenge* were equal to 1 $US.

Temporary use - land in the state land reserve may be leased for 1-3 or 3-99 years (articles 41, 101, 102 of the 1995 civil code). It is not granted as a land share to private farmers leaving collectives, and must be applied for separately.

All land rights are granted for a specific purpose, and if this is not fulfilled the government may take back the land. The government may also repossess land if it is used in gross violation of regulations concerning sustainable use or if use of the land causes a vital decrease in soil fertility or significant damage to the environment (articles 9,103,104 of 1995 civil code). Whether this would ever be carried out in practice remains to be seen.

<u>*Land for migration of animals*</u> - Article 80 of the Republic of Kazakhstan Civil Code (1995) stipulates that each *oblast* will grant permanent land plots set aside for the driving of stock to and from summer pastures. This indicates that the government of Kazakhstan envisage migration as a component of pastoralism which is important and likely to continue. The article also states that it will be the task of the users to equip these tracks with wells, and to drive the animals through the areas within deadlines required by veterinary regulations. Article 50 stipulates that *oblast* or *raion* administrations can also create temporary stock driving tracks for seasonal use so that migration can continue. However, these must be with the agreement of private owners on whose land the track is to lie, and the owners of stock must bear responsibility for losses inflicted when driving cattle along the track.

1.3.3 Animal ownership

From the point of view of ownership, all livestock are now classified as belonging to one of the following structures:

- Co-operative structures
- Private farms
- Households

Co-operatives and private farms have been defined above. Household animals are those which belong to individual families who might be engaged in working for a co-operative but which also have animals of their own at home. The same applies to animals belonging to families which no longer work for a co-operative but which have not registered as private farmers, or animals belonging to people who have never been directly involved in farming. For example, many farm workers such as teachers or accountants had a few cows to ensure a constant milk supply. These animals should be registered with the *Selsoviet* (village council) if they are to be sold, as they can only receive an officially approved veterinary certificate in this way. Registering them, however means that they are eligible to be taxed.

1.4 Fieldwork and choice of study area

1.4.1 The study area

The study was conducted in 1997 and 1998 in Betpak-dala, an area of clay desert covering much of central Kazakhstan, the sandy desert of Moiynkum, and semi-desert areas to the north of Betpak-dala. The area includes much of Dzhezkazgan *oblast*, plus the northern *raions* of Dzhambyl and South Kazakhstan *oblasts* (Figure 1.5).

The area was chosen for a variety of reasons:

- Firstly it is an area in which pastoralism is the dominant agricultural activity. The farms studied were predominantly sheep raising farms on land where agriculture is difficult (north) or impossible (south).

- Within this area both the type 1 (long) and type 2 (short) migrations described in section 1.2.3 occurred. The study area is the site of one of the most enduring long migrations in Kazakhstan, one which continued through both the period of Russian colonisation, and the socialist era (Zhambakin 1995). Stock originally wintered in the Moiynkum desert, and spent summer in the steppe pastures of Karaganda *oblast* the rest of the year being spent crossing the clay desert of Betpak-dala. In Soviet times the migration was shorter, as new farms were established in the region of the former summer pastures and in much of northern Dzhezkazgan *oblast*. On these new farms shorter (or type 2) migrations took place, animals moving short distances within the farm boundaries or to designated seasonal pastures nearby.

These grazing patterns can be seen in Figure 1.6, and are discussed in more detail in the next section.

- Parts of the study area had, according to Soviet literature, suffered from overstocking, and much of the work in the following Chapters of this thesis is concerned with this topic.

- The availability of biomass and climate data for parts of the study area from both meteorological stations and the Institute of Botany (see Chapter 3) also made it a particularly interesting choice for the research in this thesis.

- The study *oblasts* are home to one of the three populations of saiga antelope in Kazakhstan. The saiga is the most numerous wild ungulate in Kazakhstan and in the study area follows roughly the same migration routes as were once followed by domestic animals. Because of this the effects of climate on its population are probably similar to those on domestic animals before the introduction of winter fodder and shelter. This is examined in Chapter 2 of this thesis.

- The reform process had progressed differently in the different *oblasts* of the study area. In Dzhambyl and South Kazakhstan *oblasts*, as in most areas of Kazakhstan, some form of collective structure still existed on most farms in 1997, but in Dzhezkazgan *oblast*, which was used as an early 'experiment' in privatisation, all the assets were distributed to individuals almost immediately. This made it a very interesting indicator of the way the rest of Kazakhstan may be heading.

- The study *raions* are generally far from Almaty, and so do not have the influence of the large markets of the capital.

Precipitation in the study area varies between extremes of 80 and 200mm per year in the central and southern regions, and is slightly higher towards the north. In the south the precipitation peak is in winter, whilst in the north it is in summer (see Chapter 3).

The average temperature is about 23°C degrees in July, sometimes reaching 40°C in the daytime, and -15°C in February, reaching -40°C degrees occasionally.

To summarise, the area spans several ecological zones corresponding to different seasonal pastures. It contains farms engaged in both large scale and small scale stock movements in the Soviet period, and which in the late 1990s were at different stages of reform. The locations within the study area which were actually visited reflected these differences. As will be described further in the methods section, farms visited were mainly along two transects within the study area. The first transect visited was in the south, along the river Chu. The second was along the road between Dzhezkazgan and Karaganda, and the farms visited here are shown individually in Figure 1.6. Some farms were also visited in the far north of the study area (Tengiz *raion*, Karaganda *oblast)* as a pilot study. All the farms had small numbers of cows, horses, and in the south, camels also. The sheep breed was mostly the local Edilbay, a kind of fat tailed sheep, although other breeds observed were Angora, Karakol, Red Steppe, and Kazakh white headed. The characteristics of the study areas are summarised in Table 1.1. More detailed descriptions of the actual farms visited are given in the following sections.

Figure 1.5: The administrative districts (raions) in the study area.

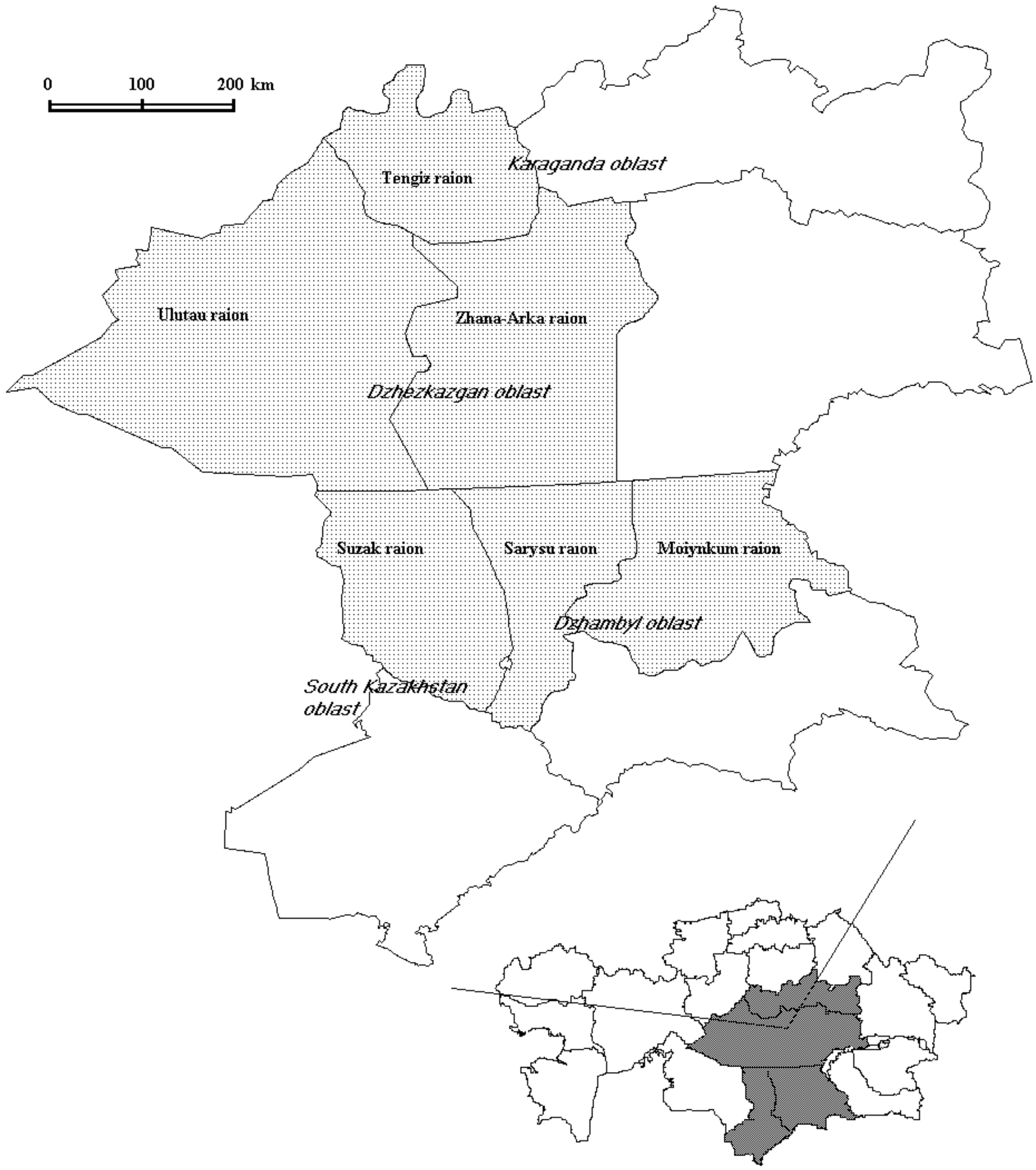


Figure 1.6: Land use types and stock migration in the study area.

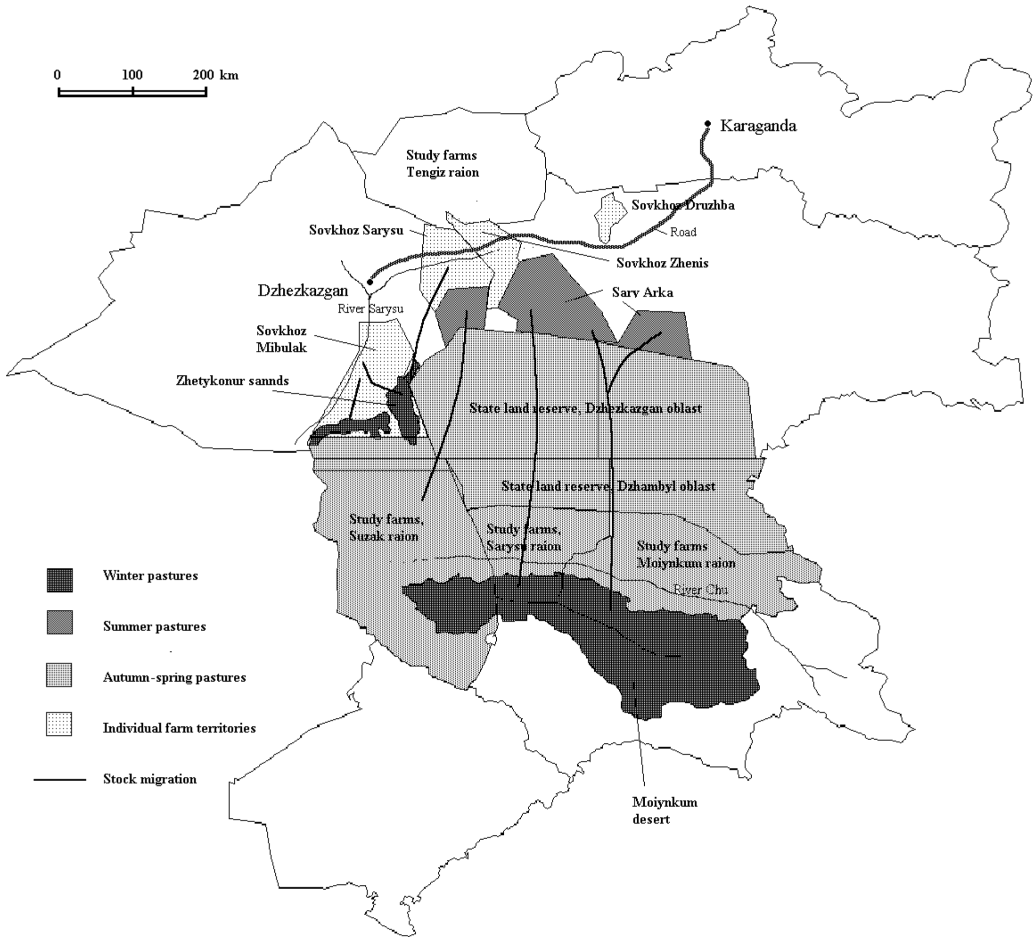


Table 1.1: Summary of study raions.

Area	***Raion***	***Oblast***	**Location**	**Dominant vegetation**	**Farm structure**
Pilot study	Tengiz	Karaganda	North of Betpak-dala	Border of semi-desert and steppe zone:*Stipa, Festuca, Artemesia* spp.	Mostly collective
Southern transect	Moiynkum, Sarysu, Suzak	Dzhambyl and South Kazakhstan	Southern Betpak-dala along river Chu	Northern desert zone (clay desert): *Haloxylon, Artemesia, Salsola* spp.	Mostly collective
Northern transect	Ulutau, Zhana-arkin	Dzhezkazgan	Northern Betpak-dala	Semi-desert zone: *Artemesia, Stipa* spp.	Private farm, household

1.4.2 Methods

There were two main approaches used in this study:

(i) Collection of official statistics for all farms in the study *raions*
(ii) Visits to sub-sections of these farms to gain a deeper understanding of processes involved in privatisation through interviews with inhabitants.

(i) Collection of official statistics

At *oblast* or *raion* centres (the main town in each region or district) statistics and/or maps were available for some or all of the following (depending on the *raion):*

- The structures existing on each farm (number and membership of registered private farms and collectives).
- Numbers of stock, private and collective
- Migration of animals
- Area of each farm and of each land use type within it (hay land, winter pasture etc.)
- Number of wells

These statistics were collected at *raion* centres for all farms in the study *raions* except in Tengiz *raion*, where they were collected on the farms themselves. The statistics were available from various institutions such as regional branches of the State Statistical Agency and various government agencies and management authorities such as the Kazakh State Institute for Land Planning and Land Use (*Kazgiprozem*), and offices responsible for water provision and livestock. The visits to these institutions involved not only the collection of statistics but also interviews with key informants on general trends of stocking patterns (past and present) in each *raion*, local policy on reform, and changes in land use.

The accuracy of the statistics collected depends on whether they are for collective or private structures. In the time of the Soviet Union, a ceiling was placed on the number of private stock, and so people would under-report the numbers of private stock which they had in official surveys. Although this system no longer exists, there is now a tax on each head of livestock and therefore a continuing incentive to under-report.

Goskomstat told us that *raion* statistical offices are responsible for conducting random unannounced checks on private stock numbers, although whether these actually occur is unclear. On every collective farm which was visited there was an accountant who still kept extremely detailed records on collective stock numbers by age, deaths, births, how many were bartered or bought, how much fodder was available etc. This would imply that the figures for collective stock at least are accurate. Numbers of collective stock quoted on farms generally corresponded to those published by statistical offices.

In an assessment of the existing statistical system in the agricultural sector the Asian Development Bank (1996d) notes that coverage of statistics on former state farms and co-operatives by *Goskomstat* (known since 1997 as the State Statistical Agency) remains good. However such entities only accounted for 30% of the country's agricultural production in 1996. The smaller independent peasant farms, household plots, and *dachas* accounted for 70% of production in 1997-1998, and are unlikely to be well recorded.

The visits to farms described in the next section were conducted in part to check some of the information given in the statistics. For example, information given on stock movements may have still referred to stock movements as they were during the Soviet period, and it seemed likely from the beginning that the numbers given for registered private farmers far underestimated the numbers of people who were actually working for themselves.

(ii) Visits to farms and interviews

The objective of this study was to gain an broad understanding of how the reforms described in section 1.3 were progressing in reality, and of their effects on land use and stock distribution. Therefore, for the most part the methods used were qualitative, and interviews were not conducted with the aim of making quantitative statements about the results of privatisation, although in many cases it was useful to compare the results of interviews with official statistics. These methods were chosen because at the beginning of this study information about the reforms and their implementation was extremely limited, and information about their effects was virtually absent.

Therefore, a quantitative study (survey by questionnaire) would have been inappropriate as there would have been no way of designing the questions. A survey type approach also means that important information on the processes involved may be missed (Patton 1990). The approaches used are described in more detail below for each of the main areas visited (see Table 1.1) along with a description of the farms visited in each area. In all cases an emphasis was put on understanding systems both before and after the reforms so that comparisons could be made.

- *Preliminary fieldwork*

In the spring and early summer of 1997 two short trips were run as pilot studies. The first was a reconnaissance trip to visit shepherds in Sary Arka, and the second was a visit to four farms in Tengiz *raion* (Karaganda *oblast*). These trips were to remote areas and were possible courtesy of the Institute of Zoology who were running a field trip to count Saiga Antelope into the areas in which the shepherds were interviewed, and the hunting organisation of Karaganda *oblast* who offered transport to visit farms in that region. Sary Arka was found to be mostly empty. However five shepherds coming from Dzhambyl and Chimkent *oblasts* were interviewed, questions mainly focusing on the ownership of the animals in their care (private or collective), stock movement, and the level of dependency of the shepherd on the collectives from which they came.

The farms in Tengiz *raion* (still collectives) were visited for 1 or 2 days each to gather statistics and conduct interviews with vets, agronomists and directors in order to gain a general idea of the running of the *sovkhoz*, grazing patterns, animal husbandry, and marketing.

- *Southern transect*

Nine farms were visited along the transect in August 1997. These included three farms in Suzak *raion*, all five farms in Sarysu *raion* north of the river Chu, and one farm in Moiynkum *raion*. These farms are shown in Figure 1.7. This Figure is taken from an actual map of land organisation (*Kazgiprozem* 1992) and illustrates the complexity and detail of the Soviet organisation of grazing. Each of the study farms had an area of grazing in the Moiynkum desert, and an area just to the north. The long thin areas between farms in Sarysu *raion* are migration tracks.

The farms along the River Chu were chosen because they were all engaged in the Moiynkum - Sary Arka migration, and include areas which were overgrazed according to the literature (see Chapter 2). The subset visited were located along the road running from Zhuantobe eastwards (Figure 1.7). All the farms along this road were visited as far as Ulan bel' at which point it was felt that a general picture of the situation (which at that point was very similar from farm to farm) had been gained.

On these farms interviews were conducted with the administration, technicians, agronomists and with a small number of shepherds to look at general processes on the farms. No more than 2-3 days were spent on any of them and the information collected focused on farm organisation, stock numbers, movements, and marketing of animals on the collective level. The shepherds interviewed earlier in the year, in Sary Arka, came from two of these farms (Chu and Zhailma).

- *Northern transect*

When the northern transect was visited in the summer of 1998 there were few collective structures left, and thus the focus was put on understanding individual decision making. A qualitative approach based on interviews and observation was used, resembling that used by Thwaites *et al.* (1998) in their analysis of grazing systems in farms in Inner Mongolia. Such an approach necessitates the use of individual case studies, and four farms were chosen in Dzhezkazgan *oblast*, periods of between five days and three weeks being spent on each. On these farms interviews were conducted with the former administration and technical staff as in other areas, however the research was concentrated mainly on interviewing pastoralists.

The locations of the farms are shown in Figure 1.6. Sarysu, Mibulak and Zhenis were chosen because they cover large areas, and were solely involved in extensive sheep raising. These farms are situated adjacent to the summer pasture used by the farms from the southern transect, and thus provide a contrast in grazing strategy to these areas in the same ecological zone. Druzhba was chosen as a contrast with the others as grain production was possible (although marginal) on this farm. Its main function during the Soviet period was cattle raising. *Sovkhoz* Zhenis in 1998 was still a collective and subsidised partly by the state. Therefore it was not considered representative of the general situation. However grazing patterns were investigated, and these will be discussed in Chapter 2. The other three farms were studied in more detail. Diagrams of each of these farms and simplified stock movements within them are shown in Figure 1.8 and discussed in the next section.

The different survey techniques were used mainly because on the southern farms most stock were still collective, and thus the grazing behaviour of most of the animals was determined by the collective administration. On the northern farms the situation was far more fragmented and complex. Individual decision making was the factor determining grazing patterns of all stock, necessitating the interviewing of more pastoralists.

FIGURE 1.7

Overall, taking all the areas visited, as well as interviews with the administration and technical staff of each *sovkhoz*, 43 interviews were conducted with the inhabitants; of these 26 were with members of registered private farms, 2 worked for an individual on his private farm or enterprise, 8 worked for former collectives, and 7 were unemployed and had too few animals to make a living from pastoralism.

1.4.3 Former grazing patterns in the study areas (see also Figure 1.6)

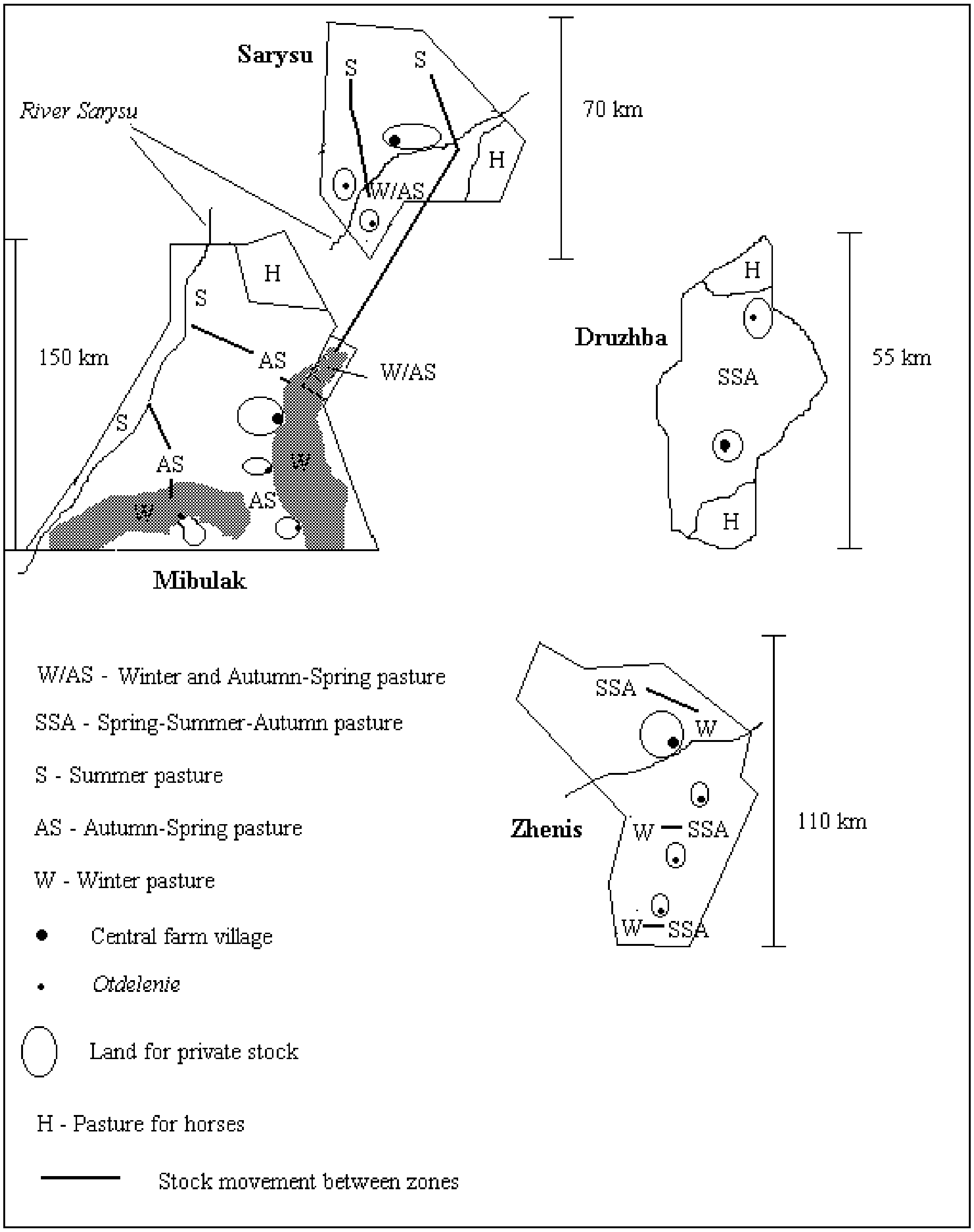
Former grazing patterns are explained in detail here so that changes outlined in following sections can be more easily put in context.

(i) Farms in Dzhezkazgan and Karaganda oblasts (Northern transect)

*Sovkhoz*es Mibulak, Sarysu, and Zhenis were split into pasture zones according to season. For example a particular zone might be designated as pasture for autumn-winter-spring, winter, summer, spring-summer-autumn, or autumn-spring pasture. These zones are shown in Figure 1.8.

Within each zone each herd was allocated a specific area of land and a number of wells. Movements consisted of those between two areas in different zones of the farm, or movements between different water sources within one pasture area, as occurred on the autumn-winter-spring pasture of *sovkhoz* Sarysu. The schema below describes grazing patterns for stock on the study *sovkhozes.* Horses were kept in the same area all year round, and cows spent the whole winter inside, and were on the pasture from late spring to early autumn only. Private animals were grazed in specially designated areas around the settlements. Each *sovkhoz* had one main settlement, and several smaller ones known as *otdelenie*.

Figure 1.8: Schematic diagrams of stock movements on case study farms.



<u>Winter (October-April)</u>: In winter shepherds lived in winter houses, or *zimovki*. A *zimovka* is generally a brick construction, and has a barn next to it where the animals are kept at night and in bad weather. The *zimovki* are usually single isolated houses, but sometimes they are clustered together at *otdelenie.* All sheep at Mibulak and most at Sarysu were allocated zones on Zhetykonur sands for winter, where the terrain consists of dunes providing protection from wind, and south facing slopes on which snow tends not to stay for so long. This had the advantage that the sheep could spend

more time eating natural pasture, and would only need supplements for about six weeks. Winter pastures not in sandy areas (for example on *sovkhoz* Zhenis or the south of *sovkhoz* Sarysu) were adjacent to summer pastures, and here the sheep would need extra fodder for 3-4 months.

Spring (lambing period) (April-May): Stock were moved from the *zimovka* to the spring pasture area. On *sovkhoz* Mibulak this was in a different zone, between the sands and the river. This way the sheep did not have to move a long distance when pregnant, but could benefit from fresh pasture (and also pasture which was never used for long, and probably free of parasites). On Sarysu the animals were moved to a different well (or to the river) a short distance (5-10km) from the *zimovka* for birthing, remaining however in the same pasture area. On Zhenis the animals were moved to the spring-summer-autumn pasture area where they would remain until October.

Summer (mid June-September, or May-September): This pasture was generally the furthest from the winter pasture, and shepherds lived in yurts or wagons at this time. On *sovkhoz* Sarysu the summer zone was in hills in the north of the *sovkhoz* territory, at Mibulak it was along the river Sarysu.

Autumn (September-October): On the study *sovkhoz*es this pasture was the same area that used for spring.

(ii) Farms in South Kazakhstan and Dzhambyl oblasts (southern transect)

The migration from these farms to Sary Arka is shown in Figure 1.6. The seasonal movements involved in this migration are described below and concerned mainly sheep. However horses and cows were also moved to Sary Arka for summer. Private stock stayed on specially designated land around the villages. Each of the 32 farms in the three study *raions* had between 20,000 and 40,000 sheep, 0 to 4,000 horses and 0 to 1000 cows in 1992.

Winter (November-March): All the farms in these *raions* had territory and *zimovki* on the Moiynkum sands for winter grazing. These sands comprise a huge area of *Haloxylon* dominated pasture, which can be eaten even when there is deep snow.

Spring (April-May): The animals were walked to the northern part of the farm in Betpak-dala for lambing (Figure 1.7). In some cases they remained there until shearing time in May.

Summer (June-September): The animals were walked to Sary Arka, a distance of 300 km. Once here the animals would remain until September, changing water point once in August.

Autumn: The move back to the winter quarters was slower. The animals stayed from mid September to November on desert pasture between Sary Arka and Moiynkum. This land was either in the state land reserve, or on the northern territory of the farm itself.

1.5 Overall results and comparison of study area with national trends

1.5.1 General patterns of reform in the study area - new structures and patterns of ownership

In the study *raions* of South Kazakhstan and Dzhambyl *oblasts* the farms had more or less kept their former structure after privatisation, although in 1996 some had split into many co-operatives, each of which resembled the former *sovkhozes*. There were up to 26 private farms on each former *sovkhoz*, but virtually all the land and most of the stock were still collective. In the *raions* studied in Dzhambyl *oblast*, only 0.2% and 4% of the pasture land had been officially given over to private farms. In the study *raion* of Karaganda *oblast* the farms visited in 1997 had also stayed as single co-operatives, and there were no more than 2 private farmers on each one.

However, within this system individuals were not totally reliant on the *sovkhoz*. The shepherds interviewed in Sary Arka took their own animals with them also, and in winter would go as far as Chimkent or Dzhambyl to market them. The benefits of staying in the co-operatives varied from farm to farm. For those still employed these included payment in stock, flour, some provision of winter feed for private stock, although this depended on the state of the collective farm, and access to machinery, which they would probably not have if they went private.

It was hypothesised that for the shepherds the continued use of *sovkhoz* inputs could help them to continue to build up their own stock numbers, however all those interviewed who still worked for collectives said that since 1992 they had fewer animals of their own.

Because of the drop in stock numbers after 1994, many shepherds were laid off. For example, at sovkhoz Zhailma (Sarysu *raion*), the number of shepherds employed by the collective dropped from 51 to 15, yet there were only two private farms. One of the shepherds interviewed in 1997 in Sary Arka was a member of a Joint Stock Company. He had been made redundant, however he maintained the right to use a *zimovka* and wells to pasture his own animals and, although he had to pay for hay land, he paid nothing for use of collective pasture, and still had his shares, indicating that he would receive dividends in the unlikely event that the farm made a profit. Under these conditions shepherds have nothing to gain by starting a private farm. We were told however that many of the shepherds who lost their jobs had simply left.

There were also more negative reasons for staying in collectives. Although the land given out to each individual should represent the average land value of the *sovkhoz* territory (Civil Code 1995), in reality those leaving the collective first received in general the worst land. Kerven *et a1.* (1998) and R. Shreeves (pers. comm.), working in Almaty *oblast* have found that people have not been leaving collectives because many had been persuaded to give their land shares to the director, who often held substantial control over inputs such as fodder and fuel. These would then have to be negotiated for by private farmers, meaning that there would be little advantage in leaving.

According to the Asian Development Bank (1996b) the trend of staying in collectives is a national one. In Kazakhstan, farmers who received land and property share certificates as part of the farm privatisation process almost universally contributed those shares to the charter capital of newly formed farm enterprises. However, as already mentioned, Dzhezkazgan *oblast* was a special case, an experimental *oblast* in which privatisation had been started much earlier. In the two *raions* of Dzhezkazgan *oblast* studied, only one farm (Zhenis) had retained its collective structure, and this was a decision by the local authorities as the farm had been used for sheep breeding. On all the other farms the only official structure in existence was that of the private farm.

Figure 1.9 illustrates how the policy in Dzhezkazgan *oblast* meant that more animals passed into the hands of private farmers. The main periods of transfer of animals seem to be in 1992 and 1995, especially in the case of Ulutau *raion*, However after these periods animal numbers decline, suggesting that private farmers, as well as collective directors, were not managing to maintain their stocks. The reasons for this are discussed in the following section on animal numbers.

Table 1.2 shows sheep in private farms or households as a proportion of total numbers, and also shows what proportion of sheep are held by registered private farms.

Figure 1.9: Numbers of sheep in private farms or households, 1991-1998 for five raions in the study area. *Ulutau and Zhana-arkin raions are in Dzhezkazgan oblast.* *Source: Dzhambyl and Karaganda statisticheskye upravlenya [statistical offices].*

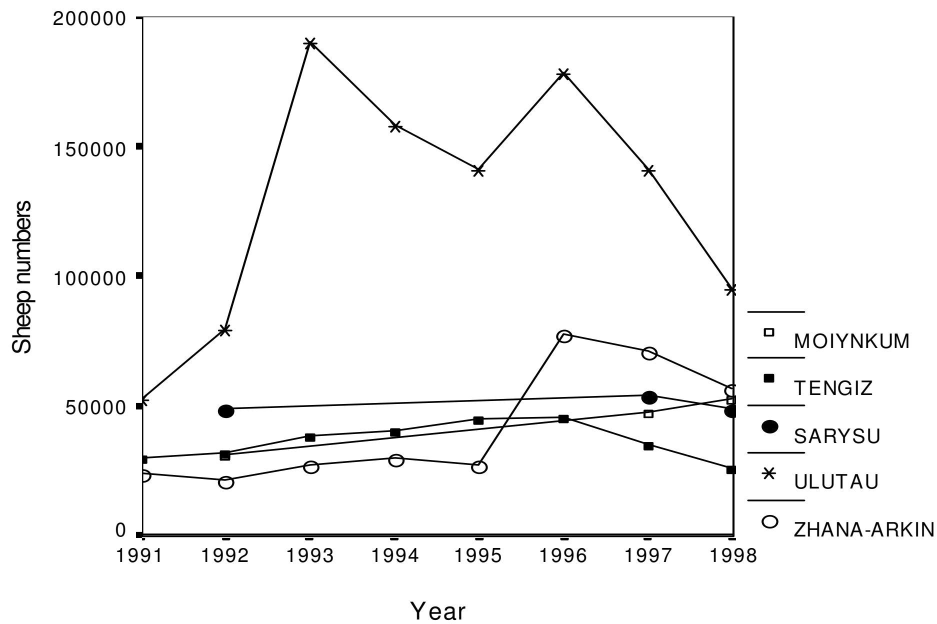


Table 1.2: Sheep ownership by sector in five study raions in 1998.
Source: Dzhambyl and Karaganda statisticheskye upravleniya [statistical offices].

Raion	**Sarysu**	**Moiynkum**	**Ulutau**	**Zhana-arkin**	**Tengiz**
All sheep	82499	77919	95988	87000	74281
All sheep in households or private farms as percent of total numbers	59%	68%	99%	65%	35%
Private farms as % of all non-collective ownership	6%	3%	77%	23%	3%
% sheep in collective enterprises	41%	32%	1%	35%	65%

This suggests that the bulk of sheep are now held in households, and not in private farms or collective enterprises. Only in one *raion*, Ulutau (in Dzhezkazgan *oblast*) were most in the private farm structure. In 1998 in Kazakhstan as a whole, of the 11 million sheep remaining after the 1994 crash, 17% were still collective, 10% were owned by private farmers, and the remainder were sheep owned by individual households.

Another question which arises from these statistics is how equally were stock distributed amongst the population? This will be discussed in detail in the context of the case study farms, however the official statistics can also give an idea. These were gathered for all the private farms in the two *raions* which had a substantial number of private farms, Ulutau and Zhana-arkin, and are summarised in Table 1.3.

Table 1.3: Distribution of animals among private farmers in Ulutau and Zhana-arkin raions. *Source: Karaganda statisticheskoe upravlenie [statistical office].*

Raion	**Ulutau**	**Zhana-arkin**
Number private farms	896	560
Number having no animals	315 (35%)	102 (18%)
Number having less than 100 sheep	678 (75%)	468 (83%)
Number having more than 1000 sheep	6 (less than 0.01%)	0

From Table 1.3 it becomes apparent that, however the stock may have been distributed originally, by 1998 most private farms had less than 100 sheep, (although some of these may rely on crops or cattle raising), and very few indeed have what could be described as commercially viable flocks. However these figures must be regarded with suspicion as people may well have reported a loss of all animals to escape taxation. The question of distribution of stock will be returned to on case study farms in section 1.6.

1.5.2 Inputs and markets

State procurement of wool and meat completely ceased between 1991 and early 1995, and there were no emerging markets to replace it. Russia had previously imported 30% of Kazakhstan's agricultural produce, but this market collapsed. The economy came to rely solely on barter, even where large amounts of goods were concerned. Farm managers were put in a situation in which they needed to pay their workers and buy petrol, coal for heating, spare parts and winter feed, all of which lost their subsidies in 1993. They bought these items by bartering away their animals. The farms in the study areas could not afford to send their animals to meat factories due to transport costs (they had to be transported live as the *sovkhoz*es were not authorised to slaughter animals), and the low prices paid. Therefore the most common form of selling stock was via traders (middlemen) who came to the farm, or even to yurts in the summer pasture, and exchanged goods for stock. This was a fairly random process, and tended not to be organised in advance. These traders often came from China, or even from Uzbekistan. Agreements were occasionally set up with companies in towns, such as a coal company in Karaganda for example, to exchange collective stock in return for a commodity. The companies would use the animals in lieu of wages to pay their own workers.

For private farmers problems were found to be similar, though on a smaller scale. They would exchange sheep for onions or flour, and hoped to sell the wool they had stocked up to passing tradesmen. Wool was being stockpiled on many of the farms in all three of the study regions because it was impossible to sell, most sheep being of the fat tail breed, whose wool is virtually worthless on the world market. Most pastoralists, including those still working for the collectives, marketed a few of their own animals every year. They would drive them to *oblast* centres such as Chimkent, Dzhambyl, and Dzhezkazgan, which often meant a journey of several hundred kilometres.

Winter feed became a major issue and collectives or individuals who could not grow it themselves were at a major disadvantage. The lack of supplies of *kombikorm*, the grain based winter feed which had been used in Soviet times, meant that most animals were fed only on hay during the winter. According to Wright (1999) ewes in Kazakhstan which are fed on concentrate and hay over winter have birth rates at least 15% higher than those fed on hay alone.

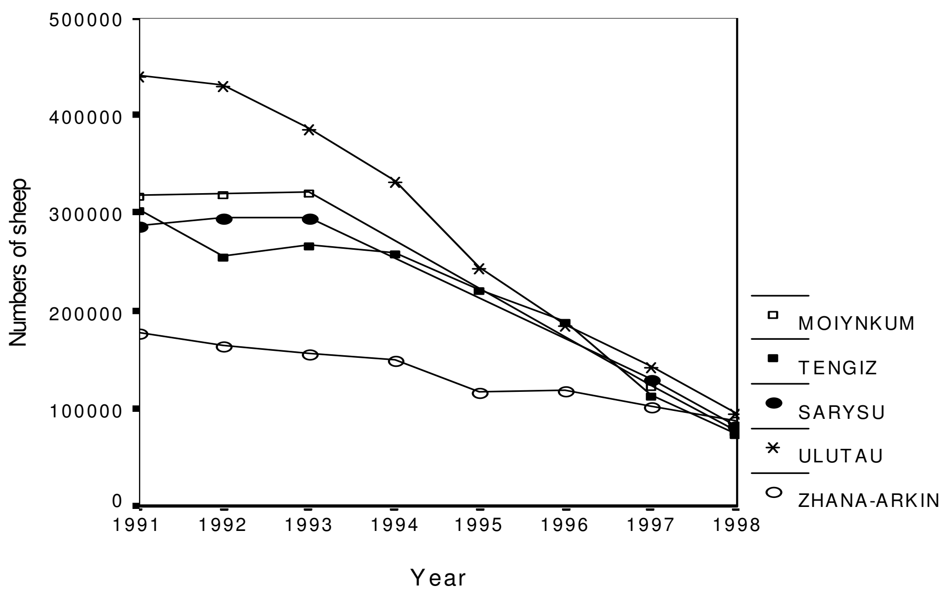
1.5.3 Drop in animal numbers

The result of the lack of inputs and markets has been a huge drop in stock numbers. Between 1989 and 1999, sheep numbers dropped nationally by 70% (see Figure 1.4). This is shown for five of the study *raions* (data for Suzak *raion* was not available) in Figure 1.10.

In Sarysu, Moiynkum, and Suzak *raions* total horse numbers fell by 71%, cows by 90%, and sheep by 69%, numbers of the latter going from over a million to 300,000. Numbers of private sheep rose very little (Figure 1.8) however, numbers of private cows and horses rose by 80% and 127% respectively in Moiynkum, Sarysu and Suzak *raions,* reflecting the higher value of these animals to their owners.

The decrease in numbers was due not only to the bartering of animals, but also to lack of winter feed. Here farms in the northern steppe regions and in the south both had problems. In the north, although the pasture was suitable for cutting, and grain could be grown, they had no seed or spare parts for the machines. The area of sown land on these farms generally dropped over this period. *Sovkhoz* Arshelin in Tengiz *raion* lost 5000 sheep to starvation in the winter of 1996-97. The southern farms had better access to good natural pasture in winter. However they also had less possibility to produce winter fodder themselves as grain growing was impossible, and the pasture was generally not suitable for hay production.

Figure 1.10: Drop in total sheep numbers in five study raions. *Source: Dzhambyl and Karaganda statisticheskye upravleniya [statistical offices].*



1.5.4 Land tenure and migration

The numbers of sheep going to Sary Arka from the two *raions* studied in Dzhambyl *oblast* fell from about 600,000 to less than 50,000 between 1992 and 1998. The animals were spending winter in Moiynkum desert much as before, but were spending summer at wells on the former spring-autumn pasture on the *sovkhoz* territory not far from the *sovkhoz* village. The farms which continued to send shepherds into Sary

Arka in 1997 did not have more stock than other farms, and in fact two of them had conspicuously less stock than the others. Overall, of 71 farms in Dzhambyl *oblast* using land in Sary Arka in the early 1980s, it was found that only five were still going in 1997 (with greatly reduced numbers of stock), and of the 9 farms in Suzak *raion* in South Kazakhstan *oblast* who used to go, only one (Chu) went in 1997. In Dzhezkazgan *oblast*, of the private farmers who had been allocated land plots in different seasonal pastures many were not using them at all, pasturing their animals on common land around the farm, or were just using winter pasture all year round. This is discussed in more detail in section 1.6.

For private farmers, both official and non-official, access to pasture land was not a problem because at the time of the study there were few stock and a lot of land. However access to land for growing winter feed was more competitive. On farms where this land was shared out, those with machinery tended to buy it or lease it from those without, and Kerven *et al.* (1998) have noted that in cases where farmers leave co-operatives, they do not always receive the hay land to which they is entitled, and instead have to pay the director a large proportion of the harvest in return for using the collective hay land.

1.5.5 The rural economy in general

In general the impact of privatisation on the rural economy has been disastrous. There are virtually no sources of cash and most people have too few animals to barter them for goods. In the study area the only sources of employment are the bigger farmers who have access to capital, machinery, and many animals. These are extremely few, and indeed only one was observed to be employing people for monetary wages, others mainly taking on relatives. Electricity is often cut off as people can no longer pay for it, but those who have no animals must rely on electric cooking stoves as the only available fuel on the steppe is dung. Schools and hospitals are working with cut staff, or in some cases have been torn down and the materials taken away by the farm population. Rural to urban migration is increasing. In Tengiz *raion* for example the numbers of families on the four farms visited dropped from 1036 to 670 (by 36%) between 1992 and 1996. In South Kazakhstan and Dzhambyl *oblasts* the number of families dropped by 17 % on farms for which data were available.

Although the government of Kazakhstan did launch a small credit scheme, the Agricultural Support Fund, in 1995, it reached only a tiny percentage of private farmers. For example in Dzhambyl *oblast* only 55 private farmers out of 1711 received loans in 1996, and most of the money allocated to the Fund was never distributed (Asian Development Bank 1996c). This was partly due to the fact that most business plans submitted were deemed to be unrealistic. Other problems are that agricultural incomes may be taxed up to 50% (Asian Development Bank 1996c), and that the co-operatives have inherited the debts left over from the state structures. One farm in Dzhambyl *oblast* claimed to have debts to the value of £16,000! Under such conditions, and with a lack of a government policy on agriculture, the future is bleak for pastoralism in these remote regions of Kazakhstan.

1.6 Case studies of farms in Dzhezkazgan *oblast*

1.6.1 Distribution of assets on the study farms

On *sovkhozes* Sarysu, Mibulak and Druzhba the privatisation process started in 1992 when people were offered the chance to buy stock and equipment at very low prices. People were 'encouraged', but not forced to leave. Credit was available, and at this point on *sovkhoz* Sarysu 17 private farms were formed. Those farmers which had left in 1992 were among the most successful of those interviewed. They used credit to buy tractors, animals, *zimovki*, and other equipment.

Some of the interviewees gave reasons why relatively few people started their own enterprise in 1992:

- They were worried that they would inherit the debts of the farm
- They were told that the land would not be theirs, and that the government could take it back at any time

- They were told that they would have to pay many taxes
- They did not have the experience to start up their own farm
- They did not have enough money to buy anything from the *sovkhoz* and were afraid of taking credit.

On *sovkhozes* Sarysu and Mibulak detailed pictures of the processes involved in asset distribution were gained. These are described below:

(i) Sovkhoz Mibulak

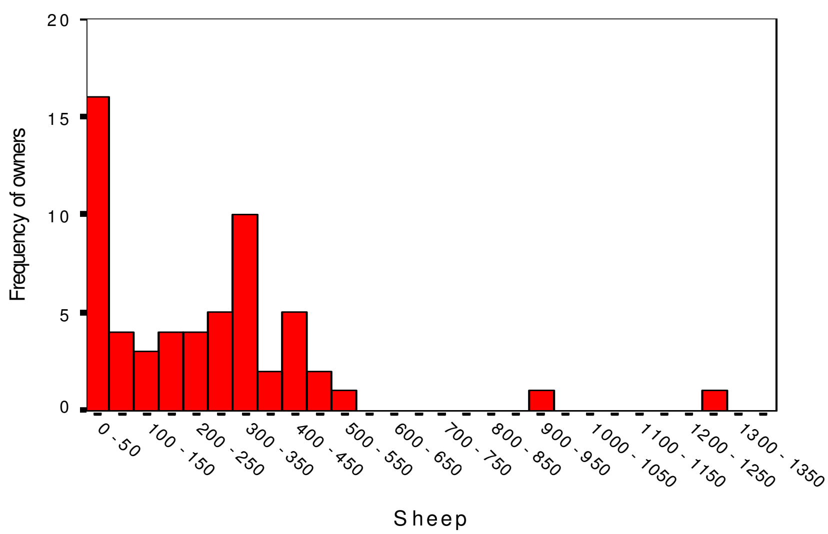
Mibulak had 60,000 sheep in the 1980s. The contract system came into force in 1989. At this time two families took out contracts and were thus able to acquire tractors very cheaply, as well as livestock. In 1992 assets were divided on paper, but most were not given out until 1995 when 58 private farms were formed. In this year the *sovkhoz* had 19000 sheep, 462 horses, and 20 cows left to distribute, the rest having been bartered away for goods or used to pay workers. The livestock assets were immediately distributed to all *sovkhoz* members, but other assets were only distributed to those starting a private farm. The number of years worked was converted into *tenge*, and values were put on the assets to be distributed. 35% of each individual's share was received as livestock, and the rest as *sovkhoz* equipment, buildings, or wells. An example is shown in Table 1.4. From this it can be seen that an individual cannot gain much in assets given the number of man years needed. Therefore it was expected that most private farms would consist of extended families or groups of families. In most cases the receipt of assets according to man years was probably largely theoretical because many of the installations such as *zimovki*, barns, and wells were abandoned due to lack of stock and so were there for the taking by anyone able to use them.

Table 1.4: An example of the assets distributed to one private farmer on sovkhoz Mibulak.

Price (*tenge*)	Man years	Asset
81261	30	house
157639	58	barn
185815	68	yurt
25639	9	generator
15937	6	*zimovka*
416601	154	wagon
113303	42	deep well (pump)
52650	20	shaft well (bucket)

By 1998 over 20 of the private farms on Mibulak had folded. There were 12000 sheep left, and the frequency distribution of ownership among registered private farmers on the farm was already extremely skewed. This distribution is shown in Figure 1.11.

Figure 1.11: Frequency distribution of sheep ownership on sovkhoz Mibulak. *Source: Karaganda statisticheskoe upravlenie [statistical office].*



(ii) Sovkhoz Sarysu

On *sovkhoz* Sarysu in 1994 it was decided that the machinery should not be distributed as assets. An association was formed to pool machinery, which was then hired out to members. This association was also formed to market goods produced by members, such as wool and meat. Therefore the only people on the farm who owned their own tractors were those who bought them in 1992, and those who had come from other farms (14 families moved to Sarysu from a neighbouring *sovkhoz*).

The fact that some families had been allocated stock during the period of the contract system and in 1992, plus the losses through mass barter deals that occurred whilst some collective structure was still in place, meant that there were not many animals left in 1994. At this time the stock were allocated based on social connection rather than being given out in the manner described in the land law. Such problems of corruption and an associated unfair distribution of assets have also been reported by Kerven *et al.* (1998) in Almaty *oblast* where head shepherds, agronomists and other people of high standing received the bulk of the assets. We were told that of the 718 adults on the *sovkhoz* who had the right to receive stock only half received any at all.

At the time of the study structures on the farm included two small enterprises making hay, each employing about 10 people, and an association for machinery and marketing. This association, and the largest private farm 'Sarysu', employing 40 people, were both run by the same person. This concentration of capital and animals in the hands of few people can be seen in the frequency distribution of stock ownership in Figures 1.12 and 1.13. These figures are from official and interview data respectively. The official data show a similar distribution to the data gathered in interviews, the differences being that the official data are for animal numbers per private farm, whilst the interview data were taken per household. These do not always amount to the same thing, some private farms consisting of several households, and therefore in effect the stock are slightly more equally distributed than is apparent from official data.

Figure 1.12: Frequency distribution of sheep ownership on sovkhoz Sarysu from official data. *Source: Karaganda statisticheskoe upravlenie [statistical office].*

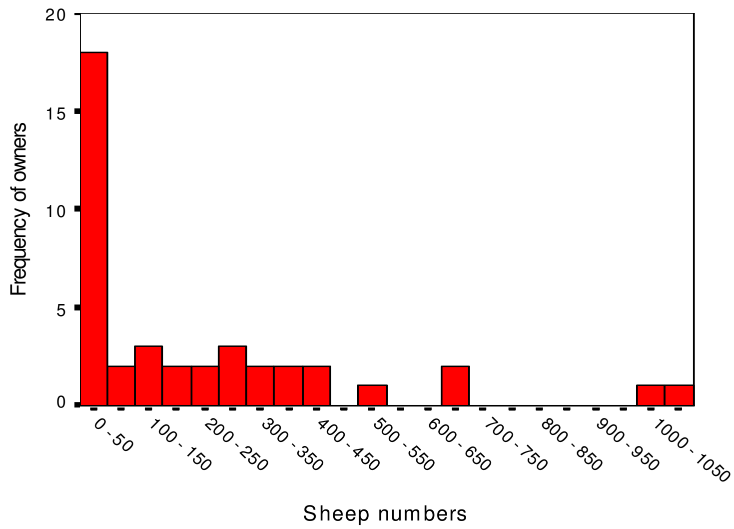
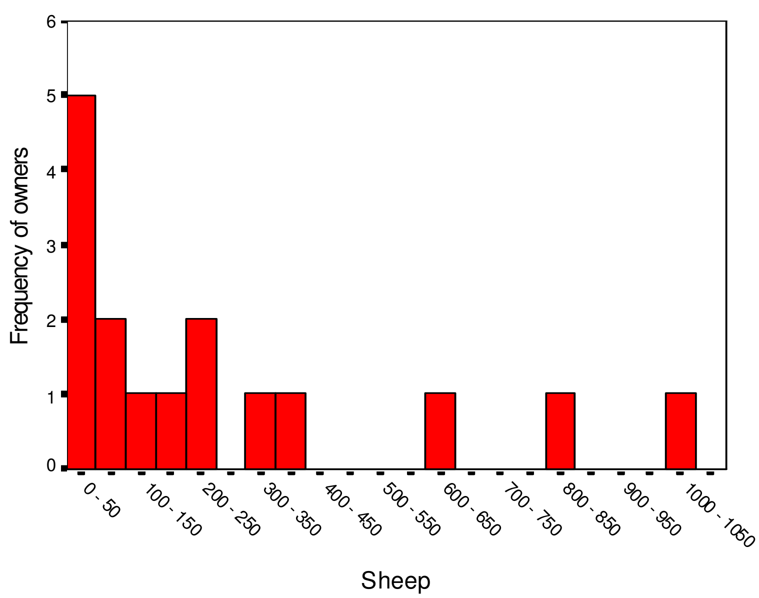


Figure 1.13: Frequency distribution of sheep ownership on sovkhoz Sarysu from interview data.



At Sarysu, of the eight families interviewed who stated how many sheep they had received in 1992, four in 1998 had less (in some cases substantially less) and four had the same or more. Families who had received no stock at all from the *sovkhoz* often had none left even if they had had a few of their own to start with. Of the 47 private farms officially existing, only 20 were still functioning in 1998. Reasons cited for the loss of animals were as follows:

- The animals (especially sheep) were needed as a source of meat.
- They were often slaughtered for special occasions. For example, for a marriage, normally 30 sheep would be given.
- Stock were bartered for goods. In 1995-1996 flour cost 2 sheep per sack, and onions 1 sheep per sack, and interviewees mentioned that during this period they lost many animals.

It should be noted that the distributions shown in Figures 1.11 to 1.13 concern only those who had registered as private farmers (a minority). The rest of the farm population tended to have even fewer animals. In summary, the biggest category of people on the two farms studied were those who did not have enough animals or capital to start a private farm, or those who started one but by 1998 had no animals left.

1.6.2 Winter feed

In Soviet times, *kombikorm,* a high quality fodder, was produced on Sarysu farm from grain brought in from other regions. There were also a number of hay making brigades who cut hay on the *liman* (rich irrigated hay land along the river). From 1992 to 1997 all the hay land was owned by the *raion*, and was cut by 2 former hay brigades, which had stayed together more or less under the same structure. These sold hay to people for 1800 *tenge* per tonne.

All interviewees gave their stock some kind of supplementary feed over winter. Three shepherds (one at Mibulak and two at Sarysu) who fed their sheep on hay only gave information on how much they provided and for how long. One of the shepherds from Sarysu did not migrate to the sands and provided a minimum of 2kg hay per day per sheep for 4 months (120 days) in winter. Therefore 1 sheep cost 432 *tenge* per year to feed. As an adult sheep was worth (in 1998) a maximum of 3000 *tenge*, selling one enabled the farmer to buy enough hay for 7 sheep. The two shepherds using the Zheykonur sands (one from Sarysu and one from Mibulak) both stated that sheep on the sands in winter would need to be fed hay for up to 6 weeks, which would cost only 151 *tenge* per year.

On *sovkhoz* Sarysu, in 1998 every adult on the farm received 9ha of *liman*, so that a typical family would end up with 40-80ha. However, as most people, particularly those who had not set up a private farm, did not have access to a tractor to cut the hay, they could not use their shares. These people 'gave' or sold their hay shares back to the brigades, which had become small enterprises, or to other farmers with tractors. For example the owner of private farm 'Sarysu' had access to machinery (as he ran the machinery association) and acquired the *liman* shares of 227 people. His workers would cut the hay and then sell it back to the people whose land it had been. The fact that winter feed production is in the hands of a few people had a substantial effect on the inequality of stock distribution. As most people did not have any money, they paid for their hay in sheep, and this has meant for example that the owner of private farm 'Sarysu', (and over 1000ha of hay land), was able to amass a substantial number of animals. He employed 3 shepherds to look after them.

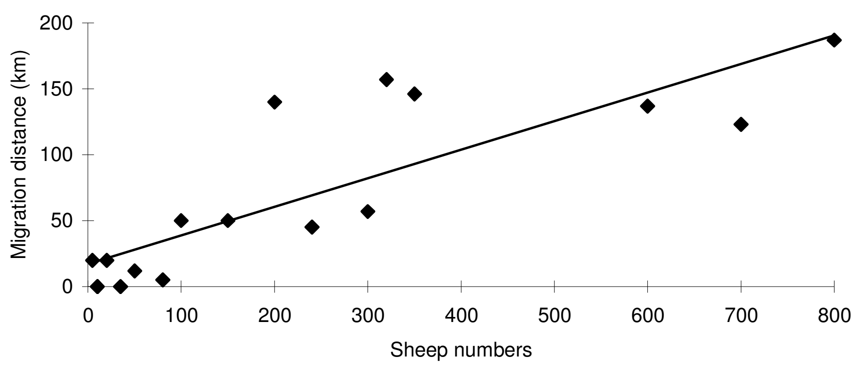
At Druzhba the pasture was of higher quality, being more dominated by grasses, and hay could be cut anywhere, not just on *liman*. At Mibulak winter feed was also less of a problem because Zhetykonur sands are much closer to the *sovkhoz* settlements. However, sheep still needed enough hay for about a month and this had to be bought as the pasture was unsuitable for hay cutting. The *liman* was 40-100 km away from most people's permanent dwellings, and so it was not economical to cut hay there. A small number of farmers purchased grain for winter feed, but at 5500 *tenge* per tonne this was too expensive for most.

1.6.3 Land use patterns and stock movement.

The frequency distributions of animals seen in section 1.6.1 highlight a major reason for the decrease in livestock mobility in Kazakhstan. There is a direct relationship between the numbers of sheep owned by people, and the distance they are prepared to travel. This is shown for one of the former *sovkohzes*, Sarysu, in Figure 1.14. Those farmers with 300 or more sheep tended to continue to make the journey to distant winter pastures on Zhetykonur sands, but those with fewer usually moved a shorter distance or did not move at all. Stock numbers govern not only the distance moved, but also the number of movements in a year. For example, on *sovkhoz* Mibulak two interviewees who had 150 and 300 sheep were conducting simple summer-winter migrations, and two who had 700 and 1000 sheep were still conducting the full 4 season migration.

A lack of animals is, however, not the only reason why mobility has decreased, and grazing strategies among different types of farmer are discussed in more detail below.

Figure 1.14: The relationship between sheep numbers owned by private farmers, and migration distances between winter and summer pastures on sovkhoz Sarysu.
*(R^2 = 0.7***)*



There are two emerging types of independent livestock owner in Kazakhstan. The first and smaller group is made up of those who have relatively high stock numbers, and access to a *zimovka*, barns, and wells, either as assets received on registration, or because they are simply unused and available. They have stable or increasing numbers of animals, and their farms could be described as commercial enterprises (Kerven 1999). The largest category is made up of those who did not receive or acquire enough animals or capital to start a viable private farm, or those who started one but lost their animals very quickly. These shepherds are basically subsistence farmers, selling a few animals from time to time.

The difference between the two types of farmer is characterised by stock numbers. In Dzhezkazgan *oblast*, due to low meat prices and distances to markets, even flocks of 150 sheep were considered to be small, and non-viable as the basis for a commercial enterprise. However Kerven (1999b) has found that in Almaty *oblast* the transition from subsistence to commercial farmer can be made at flock sizes of fifty. Here we look at the behaviour of these two kinds of farmer in Dzhezkazgan *oblast*.

(i) Those with more than 150 sheep

In Dzhezkazgan *oblast* most people in this situation were registered as private farmers, and therefore had received specific areas of land for their animals. On Sarysu and Mibulak, of the 22 interviews undertaken, 17 were with members of official private farms, all of whom had received in 1992 or 1994, a *zimovka* with a well, some spring (lambing) pasture with a well, and summer pasture with access to water (a well, spring or river). On Druzhba, the cows were inside for much of the year, and out on the pasture for summer. They were not moved between different areas as on the other farms, and therefore people received just one pasture share.

The amounts of pasture received by private farms on Sarysu and Mibulak varied substantially, between 500 and 1800ha according to official records (Karaganda *Zemliustroistvo* 1998). On Druzhba, a much smaller farm, each private farm had an average of 195 ha of ploughed land, and 330 ha of pasture. The information about ploughed land is likely to be fairly accurate as those asked were able to quote exactly how many hectares they had. However the pasture information for all three farms is probably of limited value. This is because all respondents who grazed stock on the summer pasture said that they took their animals a minimum of 3km from their water point in any direction, as there was enough land not to be limited by anything other than distances from the water. Therefore they would effectively use about 2800 ha of pasture. In the official records only one family came close to owning this amount. A practical reason for owning a low number of hectares of pasture on paper was that tax was paid per hectare of land owned on paper rather than per hectare of land actually used.

One finding which was noted on all the farms studied was that many people were either not using their land at all, or had swapped it for other land so as to reduce migration distances. For example, on Druzhba there were 100 private farms registered, each with both ploughed land and pasture. It was found, however, that of these, only 7 were actually using their pasture land for grazing animals. Everyone else pastured all their animals on the common land in summer, and either used their pasture share for cutting hay for these animals for the winter, or did not use it at all. Two such families were interviewed, and explained that grain production was much more profitable than stock production (despite the fact that zero yields can be expected every 6-7 years) and that it was not worth their while to move out onto the steppe and live in yurts.

On this farm, therefore, whereas in 1990 there were 3000 cows on summer pasture in herds of 200, in 1998 there were 6 or 7 herds of 20-80 cows and horses out on the summer pasture, and the rest were grazed around the two villages. There did not seem to a shortage of land or wells for grazing, as each family asked said that they had received the land that they wanted and that they did not know how many hectares of grazing land they had because it was ‘not important’.

On *sovkhoz* Sarysu, of those six farmers interviewed who had been migrating to the sands since 1994, three had swapped their winter shares for others which were unused and closer to the *sovkhoz* centre. For two of these this shortened their migration distance from 120km to just 20km, and one was planning to move *zimovka* again, bringing his migration distance down to 15km. The other three farmers, who migrated to the sands before, continued to do so. Overall on the winter territory of Sarysu, where there used to be about 20 herds in Soviet times, there remained 7 in 1998. The summer pastures in the north of the *sovkhoz* remained totally empty in 1998. Shepherds stayed in the south of the *sovkhoz* in summer to be nearer the villages, either moving to spring and autumn areas, or staying at *zimovki* all year round if they had very few animals.

It would seem that the benefits of the snow free winter pastures, or the productive summer pasture were outweighed by the costs of getting the animals there. Many farmers did not have access to transport, or even if they did they did not have the money for petrol for the vehicle or for the well pumps. Even the richest farmers with access to all these necessities were often choosing not to go to distant pastures, and either swapped distant shares for those nearer the farm, or ignored registration and used abandoned areas as near to the farm as possible. This was due to a number of factors, which are discussed below:

- *Access to services and markets*

It must be remembered that, for all their faults, the state farms in many ways facilitated stock mobility. The marketing of animals was conducted by the state and winter feed production was taken care of by specialised brigades. Children of shepherds could stay at boarding school free of charge whilst their parents were away. Families would often spend the whole summer several hundred kilometres from the nearest town, but were supplied with goods by trucks from the *sovkhoz*. Since reform all these services were discontinued. In the study area shepherds preferred to be near farm centres in order to have access to links to town, both for marketing, and for obtaining goods and services.

- *Stock theft*

With the increasing isolation of those few shepherds migrating to distant pastures, and the increase of crime in Kazakhstan, many people are scared of moving far with their animals. There were reports of stock theft, and indeed this was the major reason why well-off farmers have stopped moving to distant pastures in Almaty *oblast* (Kerven *et al.* 1998).

- *Lack of Labour*

In places where de-collectivisation was complete, hay brigades were broken up and hay land distributed. Several farmers on *sovkhoz*es Sarysu and Mibulak with access to the equipment to cut hay themselves sometimes mentioned that the summer pastures were too far from the hay land that was available to be able to make use of both. On Druzhba moving animals to summer pasture was sometimes sacrificed for spending more time on grain production (either for direct sale, or for winter fodder).

This was not the case, however for the largest private farm which, comprising 12 families, was able to do both.

In both Soviet and traditional times, the costs and risks of migration were offset by the large numbers of animals moved. As previously stated, in the pre-Soviet era Kazakhs would have moved in groups of 20-30 families, pooling their livestock together (Olcott 1995). In Soviet times, in the case of the Moiynkum to Sary Arka migration huge numbers of animals would have been on the move together, and the maintenance of wells and other infrastructure was financed by the state. In post-Soviet Kazakhstan private farmers have found themselves very much on their own, and the economies of scale which once supported migration have disappeared.

(ii) Those with less than 150 sheep

Those people having very low numbers of animals were either private farmers who had lost most of their stock, or families who never received enough animals to make it worth registering as private farmers. These families tended to graze their stock on common land around the village in summer for which a tax must be paid. This included horses, because milking mares had to be kept in the village during the day to be milked every two hours. In winter the cows and sheep were kept indoors most of the time, and the horses were sent out further from the village (normally about 15-20 km). Most farms had special common land set aside for horses.

The system for grazing household sheep usually involved about ten families taking turns to pasture all their sheep as one flock, whilst for horses each group of families shared the price of a shepherd, who took them out every day, or even in some cases lived permanently in the steppe in winter, when the horses were pastured a long way from the farm. Few people on any of the farms paid established shepherds to pasture their sheep elsewhere, as half their lambs would be taken as payment. Due to this system, the majority of stock remaining on the farms were clustered into small areas around settlements. Those people with an intermediate number of animals (about 100-150) also did not move pasture at all during the year, however they were normally based at a *zimovka* all year round rather than on the village.

1.6.4 Problems for non-pastoralists

Many of the inhabitants of the *sovkhoz*es had never been involved in farming during the Soviet period. These included teachers, nurses, veterinary staff, accountants, and cleaners. Such people, who mostly lived in the central village, had never had many animals and had little expertise in animal husbandry. These people either became labourers in the small enterprises or larger private farms, or they lived off their own animals. Because they lived on the central village it was not possible to keep more than around 50 sheep due to the lack of barns, and therefore it was not possible to support a family for very long without some extra source of income.

Horses and cows cannot be killed in summer as the meat goes off before it can be eaten, so they were usually killed in January. In summer, therefore, the day to day meat requirements of many families were often met by hunting saiga antelope. In Soviet times this antelope was well managed, and hunted mostly by professionals with strict quotas (Milner-Gulland, 1994). Poaching was strictly controlled. However, this system has mostly broken down. Inspectors are poorly paid and often corrupt, and borders have opened for trade with China, where there is demand for Saiga horn as medicine. Most young men on *sovkhoz* Sarysu had access to a motorbike, and went hunting at least 2-3 times a week. Saiga meat was also a source of income for many women who sold it in the town of Dzhezkazgan. In winter the saiga move south, so this is a seasonal trade. Box 1 is a case study of a typical non-pastoralist family on *sovkhoz* Sarysu in 1998.

The situation described in Box 1 is typical and things are even worse in Mibulak which is more isolated from Dzhezkazgan, meaning that it is hard for people to go to town to sell or buy goods. The goal of most people we interviewed who did not have private farms (and many who did) was to leave the *sovkhoz* and go to the town. However, this is virtually impossible as houses in the countryside are worth nothing, and they have no way of raising money to buy a flat in town.

Box 1. In the time of the Soviet Union Myrbek was a vet and his wife, Gulzhamal, was a nurse. By 1998, they were both without work. They had 5 cows (2 of which gave milk) and 5 sheep. They needed money to buy hay for their animals in the winter as they did not have a tractor to cut hay themselves. They also needed to buy clothes, school books, tea, sugar, onions, and enough flour to make bread and pasta. They did not have enough animals to be able to sell any, and besides they needed the cows for meat in winter. Virtually their entire income came from small businesses run by Gylzhamal. She bought saiga on the *sovkhoz* to sell in Dzhezkazgan. For each saiga she made a profit of about 200-300 *tenge* (about $3), and she sold three or four per week. If she was caught she would in theory face huge fines, but hunting inspectors were few and far between. In Dzhezkazgan she bought spirit and tobacco and sold it on the *sovkhoz*.

1.7 Summary and Conclusions

The main result of the agricultural reform in the livestock sector has been a catastrophic crash in livestock numbers. This is because state subsidies on inputs such as feed and petrol were removed, whilst at the same time farms were privatised meaning that farm workers ceased to receive salaries from the state. The sudden collapse in the availability of money and inputs meant that animals were bartered away for essential items by both collectives and individuals.

Although most people at the time of the study chose to stay in collective structures, these were mostly in debt and increasingly unable to pay or otherwise support their workers. E. Morgan (pers. comm.) notes that since 1997 the collective structures on the farms along the River Chu have started to dissolve, and people are generally farming for themselves. However they have not registered as private farmers, probably because of a fear of taxes, and heavy bureaucracy.

Where farm assets were distributed, the process was characterised for the most part by widespread confusion about how the law should be interpreted. This was often taken advantage of by the administration. The resulting inequitable distribution of assets combined with the loss of stock through barter meant that most families have few animals and no access to farm equipment or fuel for cutting winter feed, running wells, or transporting stock to market.

There is a lack of expertise in animal husbandry among non-shepherds, but there are no other employment opportunities open to them other than poaching wildlife. All the new farming entities have great difficulties in marketing their stock or its products. This is because of transport difficulties, lack of experience, and low prices for basic produce such as wool. There is a lack of access to credit or training to improve the situation, and there are few community institutions for finding solutions to marketing or supply problems perhaps due to a long history of top-down management. These factors have lead to high levels of poverty and despair, and rural to urban migration.
The value of migration has historically been as a way of maximising livestock production by allowing the most efficient use of the semi-arid rangelands of Kazakhstan. However, the economies of scale and cheap inputs which made it possible during the socialist period no longer exist. In order for private farmers to be able to conduct long distance migrations today, they must have access to a *zimovka*, a barn, and a vehicle. They need to have enough animals to make migration both necessary, and worth the cost. The wells both in seasonal pastures, and on migration routes, must be maintained, especially deep wells with pumps, for which farmers would also need to supply petrol. They also need enough labour at their disposal to produce winter feed, market animals, and maintain all the assets needed to support the migration. At present these conditions apply to very few individuals in Kazakhstan, and the longer remote pastures remain empty, the less likely it is that they will be used again in the near future as much of the infrastructure has already fallen into disrepair.

Chapter 2: Overstocking and land degradation in Kazakhstan

During the Soviet period, Kazakhstan's farming systems were criticised by Soviet scientists, who suggested that overstocking had occurred, causing land degradation and a loss of animal productivity. The objective of this chapter is to look at the evidence, both in literature and from data, for and against these suggestions. The approach taken is to determine whether, and under what conditions, stocking rates might have exceeded carrying capacity.

Before this question can be tackled, it is important to discuss exactly what is meant by overstocking, as its meaning depends very much on how we define carrying capacity. Therefore in the first part of this chapter the literature on the concept of carrying capacity and its applicability to semi-arid areas of Kazakhstan is discussed. Indeed, we will see that before the Russians influenced Kazakh livestock farming, carrying capacity was not always an appropriate concept, as animal numbers were limited by factors other than forage quantity and thus were not density dependent.

The next section reviews the literature on land degradation, and details the effects of overstocking on the rangelands of Kazakhstan. The evidence that density started to play a role in limiting animal productivity during the Soviet period is examined, using statistics on animal numbers, health and outputs from the livestock sector.

The second half of the chapter looks at the *measurement* of carrying capacity. The Soviet literature on the subject for Kazakh pastures is critically examined, and the availability of information needed for its calculation is discussed. Data available for *sovkhozes* in the study area (which had been suffering from degradation according to the literature) are analysed with information on grazing systems on those farms in order to determine what the offtakes by animals on these pastures might have been, and what the effects of this were with reference to literature on the effects of grazing on these pastures.

2.1 Defining Carrying Capacity

The concept of carrying capacity (CC) is generally used to mean the number of animals which can be supported on a sustainable basis by food resources in a defined area. However such a definition is operationally meaningless, and a number of authors have been very critical of the fact that carrying capacity is rarely properly defined, or simply cannot be realistically applied by managers (Bartels *et al.* 1993, Behnke and Abel 1996, Hjort 1981).

Bartels *et al.* (1993) have conducted a review of the carrying capacity concept in the context of domestic livestock. The authors list 12 very different definitions from the literature of the past thirty years. They recommend that a useful definition of carrying capacity must include a definition of the production objective, acceptable resource condition, and time frame. These are discussed below:

2.1.1 Production objective

There are two main classes of definition of carrying capacity: ecological and economic. Ecological carrying capacity (K) has been defined in various ways by different authors. A recent definition is 'the mean population density of a species that can be supported by its environment in the absence of human interference' (Milner-Gulland and Mace 1998). Economic carrying capacity is defined according to the objectives of livestock farmers who may be trying to maximise stock numbers per hectare, yield per animal, or yield per hectare depending on their situation.

For example, in Behnke and Scoones (1993) it is suggested that the sustainable meat offtake rate is greatest at the stocking density at which recruitment is highest. This point usually lies at 1/2 to 3/4 of biological carrying capacity. It is not possible to take off a certain proportion of animals for meat and still maintain a stable population at carrying capacity, and therefore the population will stabilise at a point below K. However, this is not the only way of defining the economic carrying capacity. For example, for pastoralists in many parts of Africa maximum meat offtake is not an objective. For reasons of long term food security and the value of animals as wealth, their management objective is to own as many head of cattle as possible (Behnke and Abel 1996).

Behnke and Abel (1996) note that commercial farmers are highly unlikely to keep animals numbers at or below the density at which feed starts to limit productivity per animal because stocking densities keeping animals at peak condition are unlikely to match the aggregate output of more heavily stocked areas. Between this very low stocking density, and the biological stocking density there will be an profit CC and a yield CC, called maximum profit MP, and maximum yield MY by the authors. MY represents the maximum aggregate output per unit area, and MP the maximum profit, the level of which will be determined by input and output prices. Wilson and Macleod (1991) have stressed the importance of prices in determining the economic CC. Seligman *et al.* (1989) have noted that in Israel there was a variation of about 40% in the optimum economic stocking rate depending on the level of prices, variable, and fixed costs. The higher the relative proportion of fixed costs, the higher the optimum stocking rate for MP.

2.1.2 Resource condition

In any definition of carrying capacity, an acceptable condition of the range vegetation should be stated below which it is considered to have an adverse effect on the production objective. Of course this will depend on the definition of the production objective. In rangelands managed for livestock production, a change in species composition is not important, provided it does not result in the replacement of palatable by non-palatable species, and thus in a reduction in animal productivity. A reduction in vegetation biomass may be more severe. However an important point about decisions on acceptable resource condition, is that if the criteria are very rigid, then in very variable climates very low stocking rates may have to be accepted. This so called 'conservative stocking rate' implies that the numbers of stock will be kept below the number that would be supported in the worst years, so that under drought conditions there would be no decrease in stock numbers or damage to the rangeland. This might be a management strategy for those trying to minimise risk, and who have a secure land tenure. However, it is perhaps not the most efficient use of the rangeland, especially for those whose goals are to maximise animal numbers, because biomass is under-utilised in good years. Strategies which may allow higher stocking rates include the provision of extra feed for livestock in the harshest periods of the year, migration with stock to wherever the best pastures happen to be at any given time, and culling of stock to sell the meat before the drought deepens too much. The latter solution relies on flexible and reliable markets which can soak up sudden influxes of produce.

Alternatively for those farmers who have little access to inputs, but whose goal is to maximise stock numbers, the strategy commonly used is simply to allow boom and bust situations, letting livestock numbers build up and then crash in drought years without any form of control. Such situations are commonly seen in Africa, and have long been criticised as being unsustainable and irrational. However, they mirror the behaviour of wild populations, and Scoones (1993) and Biot (1995) have suggested that it may, in the long term, be the best strategy for the pastoralist in that it is better to have numbers of animals above the 'worst case' carrying capacity as these are a store of wealth for the bad years. The problem then in such systems, is to define what really constitutes 'irreparable damage' to the rangeland, in other words to understand how resilient the system in question is over the time scale of interest.

Our concept of carrying capacity therefore is determined not only by the production objective, but by whether the rangeland in question can be described as an equilibrium system, sometimes perturbed by droughts, or as a system showing non-equilibrium dynamics characterised by large fluctuations in biomass levels from one year to the next, with corresponding fluctuations in livestock numbers (Ellis *et al.* 1993). Shepherd and Caughley (1987) suggest that where the coefficient of variation of rainfall exceeds about 30% then the long term performance of a system is better characterised in terms of its variability than by measures of mean values. Caughley (1987), in models of Kangaroo population dynamics, has demonstrated that there is an inverse relationship between population size and rainfall variation arising from the lags in reproduction rates whereby animals recover more slowly than forage production. In the study area rainfall variability is low, having coefficients of variation of between 34% in the south and 25% in the north (see Table 5.2 for full list of coefficients of variation by site). Systems described as non-equilibrial in the literature tend to have much higher coefficients of variation (e.g. 45% in Australia (Caughly 1987), 60% in Turkana, Kenya (Ellis *et al.* 1995)). This suggests that rangelands in the study area could be described as an equilibrium system. However, as will become clear in this chapter, livestock numbers in pre-Soviet Kazakhstan were regulated by snow depth in winter rather by biomass itself. Therefore at this time, despite the low biomass variability, livestock numbers may never have been high enough to have reached a density dependant equilibrium with the vegetation. Since the introduction of winter feed this may have changed, although biomass levels would only have likely to have affected stock numbers in the growing season when other feed was not provided. This is one of the themes investigated in this chapter.

2.1.3 Time frame

Definitions of carrying capacity which have a yearly time frame do not take into account possible feedback effects of vegetation degradation on grazing in future years. For example, a rangeland dominated by perennial plants rather than annuals may be more susceptible to overgrazing, as a high removal of biomass in one year will have an effect on the following year's biomass. The removal of biomass may also lead to long term effects on soil. For example, in winter, a certain vegetation cover may be essential to prevent soil blowing away. If this cover is reduced, then forage production would be affected in the future, but this would be very difficult to measure. These factors may mean that long term carrying capacity is lower than would otherwise be expected, as the animals will destroy their environment before they die of starvation. Climate variability, discussed above, should also influence the choice of a meaningful time frame. For example, what are the frequencies of good and bad years? What are the effects of these on prices of both inputs and outputs in following years?

2.1.4 Other factors

Many other factors influence carrying capacity. These include the distribution of water, intake by wild herbivores, and non-livestock demands such as wood collection and tourism. Bartels *et al.* (1993) note that most definitions of carrying capacity rely on a unique population of livestock associated with a defined area for a specific period of time, with one decision maker, be it a person, group, or state. These conditions are the exception rather than the rule, however as we will see, most of them are met for the case of Soviet Kazakhstan.

2.2 Factors limiting numbers of ungulates relying solely on natural pastures

The idea of a carrying capacity may often be inappropriate because it may not actually be fodder resources which are limiting numbers. Here we look at the factors which regulate numbers of wild ungulates and domestic ungulates with no access to winter fodder, as would have been the case for traditional Kazakh pastoralists. We will see that in some cases such conditions have returned to Kazakhstan in the late 1990s.

Many of the studies mentioned in part 2.1 are for Sub-Saharan Africa or Australia, tropical regions where temperatures are never limiting for vegetation growth, but where annual rainfall is extremely variable. Kazakhstan has very different ecological conditions, with harsh winters and low coefficients of variation of annual rainfall Below, the evidence for the limiting effects of both severe winters (*dzhut*) and drought is presented.

2.2.1 Dzhut

Dzhut, as mentioned in Chapter 1, is a Kazakh term referring to conditions under which melting snow re-freezes to form an icy layer covering the grass, or to unusually heavy snow falls (Zhambakin 1995, Fadeev and Sludskii 1982). Animals cannot obtain food under snow when the depth is much over 30cm, or 20 cm when the snow is dense (Sludskii 1963), so such falls would qualify as *dzhuts*.

Dzhuts occur every 3-4 years in Kazakhstan, and severe cases causing high stock mortality occurred every 10-12 years before winter fodder provision became significant (Sludskii 1963). The same author suggests that often stock numbers would take roughly 10 years to recover from these events, leading to 'boom and bust' fluctuations of 10-12 years regulated by *dzhuts*. One example given in Sludskii (1963) is of the *dzhut* of 1879 in which 48% of stock died in central Kazakhstan. Figures available for Turgai *oblast* show the recovery period (Table 2.1). There were mild *dzhuts* in 1881-1882 and 1888-1889 which probably retarded recovery. The next severe *dzhut* after the period shown in Table 2.1 occurred in 1891-1892 which caused stock numbers to crash once again, this time by 32%.

Table 2.1: Recovery of stock numbers in Turgai oblast after the dzhut of 1879-1880. *Source: Sludskii 1963.*

Year	Stock numbers
1879	3662737
1881	1788623
1885	2110677
1890	3313865

The end of subsidies on winter feed has led to the localised reappearance of such disasters in Kazakhstan. In fieldwork conducted for this study several farms reported losing large numbers of stock in short periods for this reason, as the supplies of winter feed had ceased. In particular one *sovkhoz* in Karaganda *oblast* lost 5000 sheep, and another in South Kazakhstan *oblast* lost 30,000 sheep, both in a single winter. This is a particularly severe problem when one considers that of the 697 specialised sheep raising *sovkhozes* and *kolkhozes* in the country, even during the Soviet period, when machinery was available, 450 could not produce grain, and 98 could not even produce hay (Zhambakin 1995).

2.2.2 Drought

There is little in the literature on the effects of drought on stock mortality or productivity. There is information on one mass mortality event in 1928, when drought caused the deaths of one quarter of all stock in the south and west of the country (Channon and Channon 1990). Also, Sludskii (1963) notes that the effects of *dzhuts* can be considerably worsened by a preceding drought year as the vegetation is shorter, and harder to reach under the snow. Given the lack of literature on the subject of drought and domestic livestock, it is interesting to take a look at the behaviour of wild nomadic herding species in the steppe, to see if wild animals are affected by rainfall fluctuations.

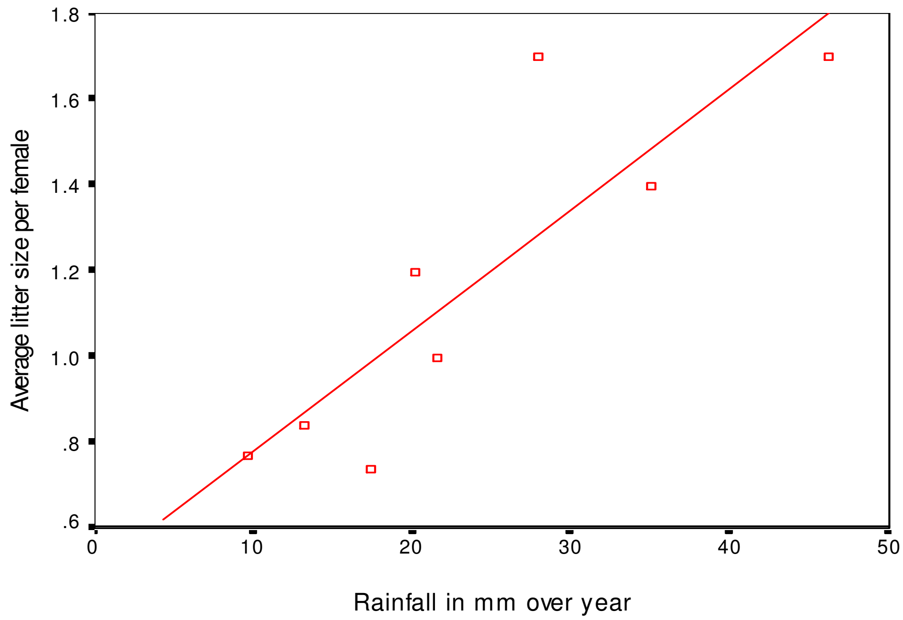
2.2.3 Effects of climatic factors on the Saiga Antelope (Saiga tatarica)

The saiga antelope is the only wild ungulate found in large numbers in Kazakhstan, and is similar in size to sheep. It is of interest to this thesis as one of the aims of the INTAS project (see Introduction) was to look at possible effects of degradation on both wild and domestic ungulates. There are three populations: Ural, Ustiurt, and Betpak-dala. The Betpak-dala population was 240,000 strong in 1996 (Bekenov *et al.* 1998), and has similar seasonal movements to domestic animals before (and to a more limited extent, during) the Soviet period. The animals spend winter in the south of Betpak-dala or the Moiynkum desert, and the summer further north in Karaganda *oblast*. The literature on saiga antelope has mostly been collated in a monograph (Bekenov *et al.* 1998). According to this, Saiga antelope populations undergo periodic crashes during which up to 40% of the population may die. These crashes are mainly caused by *dzhuts*. For example the Betpak-dala population was reduced by 20% in the winter of 1976-77 and by 37% in 1985-86, and in fact references in Bekenov *et al.* (1996) suggest that *dzhuts* were one of the main causes of the saiga's reduction in range in the early twentieth century. Other causes of mass mortality are diseases such as *Pasturella* which reduced the Ural population from 150,000 to 40,000 in 1984. However, there is no evidence in the literature that lack of water or vegetation has catastrophic effects on saiga populations, although there is evidence that it causes higher infertility and embryo reabsorption (Fadeev and Sludskii 1982).

Saiga may have 1 or 2 young depending on age and condition. Rashek (1963) collected data on saiga litter sizes for a population of saiga on Barsa Kelm'es Island in the Aral Sea. These data are plotted against rainfall in the year before the births (Figure 2.1).

The data suggest that litter size is affected by rainfall, and thus by vegetation growth. However on such an island migration is not possible, which is not a realistic situation for the other populations of saiga, nor for domestic animals under the traditional system.

Figure 2.1: The relationship between rainfall and litter size for saiga antelope living on Barsa Kel'mes Island, 1956-1964. *Source: Rashek 1963. R^2 = 0.74**.*



Fadeev and Sludskii (1982) suggest that in free-ranging population of saiga drought has strong effects on nutrition, general condition of the animal, fertility, development of calves, and length of lactation. The authors state that in Kazakhstan drought years occur quite frequently, and can cause raised mortality of calves. According to data in Fadeev and Sludskii (1982), 1976 was the third drought year in a row, resulting in infertility in young females of 31.8%, and embryo reabsorption of 31% (figures in a normal year would be 7.7% and 3.4% respectively). Adults were affected to a lesser extent. Overall, including all age groups, the number of embryos per female fell from an average of 1.5, to 1, and lactation finished 1 - 1.5 months earlier than usual. The authors do not specify in which region of Kazakhstan this drought took place, however in Betpak-dala in the two years before the spring of 1976, rainfall was 80% and 70% of average.

The effects of drought on saiga fecundity in the study area were investigated for this thesis. The Institute of Zoology, Almaty collected data on numbers of embryos per female saiga in February, for the three separate populations during the 1980s and 90s. The embryo information exists for the Betpak-dala population for a total of 9 years, all of which coincide with availability of rainfall data for the region, and 7 of which coincide with the availability of satellite data from which indices related to vegetation quantity can be derived (see Chapter 4 for a description of these data). The number of animals sampled over the 9 years for Betpak-dala were 381 adults and 164 juveniles, an average of 42.3 and 18.2 individuals per year respectively.

The females normally conceive in December, and give birth in April or May. As poor nutrition can cause both infertility and embryo reabsorption, embryo number depends on nutrition both before and after conception, but probably depends most on conditions in the autumn-winter range in the clay deserts and the Moiynkum sand desert as this is where they spend the periods just before conception and during gestation.

Regressions were performed between annual rainfall and embryo number in the following February, both for the summer range and winter range, using average rainfall data from meteorological stations in these two areas (the positions of these stations are shown in Figure 3.2). For the winter range, the average rainfall values of stations Tasty, Ulan bel', Betpak-dala, and Tiuken were used. For the summer range, the stations used were Koktas and Berlik. There were no significant relationships between annual rainfall occurring in either range, and adult or juvenile embryo number.

The satellite data were available in the form of the Normalised Difference Vegetation Index (NDVI) and were also used in this analysis. The data is described fully in Chapter 4. The average NDVI over a circle of radius 72km around each meteorological station was found for each ten day period between March and October. These were then summed to create figures for NDVI summed over the growing season. The average of these figures was found for the four stations in the autumn-winter range, and two stations in the summer range of the antelope). The average summed NDVIs for the two groups of stations were regressed against average embryo number in the following year (n=7). Again there were no significant relationships between any of the variables.

It therefore appears that saiga fecundity is either not affected by rainfall, or that the data set is too short to show any relationships. Coulson *et al.* (1999) have used the same embryo data to test whether the likelihood that an animal will produce twins is dependent on density of saiga, or winter temperatures. They used a generalised linear model with binomial error structure and binomial indicator equal to the number of individuals that were fecund. This was probably a more sensitive method than that used here which took population means only. They found relationships between the likelihood of twinning in adults, and both of the independent variables. Particularly surprising is the implication that the fecundity of saiga is density dependent. This is because during the nine year period of the embryo data saiga numbers fluctuated from 210,000 to 500,000. At the same time sheep numbers stood at 1.3 million, and cattle at 600,000 in Dzhezkazgan and Karaganda *oblasts* alone, which do not comprise the whole range of the Betpak-dala saiga population. It is difficult to believe that in the face of such high stock numbers that fluctuations in saiga numbers could affect their access to forage, particularly when saiga are so mobile. However density dependence may not have its effect through simple forage biomass but through other factors such as predation, disease, or the predictability of finding resources. For example in *dzhut* years, those key resources such as larger shrubs may be limiting, and through this density dependance may be important.

Here we have looked only at fecundity of saiga. Saether (1997) has discussed factors regulating ungulate populations and suggests density dependant mortality outside the breeding season may be very important in many of them. He also stresses that longer datasets are much more likely to provide evidence for density dependence than short ones such as the data set used here. Mortality has not been studied here and in particular the study of mortality at different times of the year in relation to population size would certainly go a long way to answering the question of the importance of density dependence. However such data does not exist at present.

Overall, from the analysis conducted here, it would appear that, compared to other factors, forage biomass is not a major factor limiting numbers of the saiga antelope, but we cannot say that its effects are negligible.

To summarise, it would appear that the major factor limiting numbers of ungulates living on natural pastures is *dzhut*, both in the frequency with which they occur, and in the magnitude of the mortality caused. The effects of drought on ungulate mortality or fecundity are still unclear, and need further research. However it seems reasonable to conclude that drought is not a major cause of adult mortality, and is more likely to affect fertility and calf survival.

2.3 Land degradation, and limits to production in the Soviet era

With the introduction of the collective farm system described in Chapter 1, winter feed constraints were virtually eliminated, and stock numbers increased to reach new, higher levels. It is at this time that availability of fodder in summer or autumn may have had more of a part to play in limiting stock production. In section 2.1 some of the essential elements of any definition of carrying capacity were discussed. It should be easier to come to a workable definition of carrying capacity for Soviet Kazakhstan than for most rangelands because there was one decision maker, the state, and the production objective was simply to maximise production (meat or milk output) per hectare. This was often expressed in both target animal numbers, and in target meat or milk production, suggesting that these were synonymous for planners. The most important point about this system is that the objective was not maximum output within certain economic constraints, but simply maximum output. Therefore costs of inputs such as good quality grain feed for winter, and petrol for machinery such as tractors and well pumps, were probably not a barrier to production. According to the schema proposed by Behnke and Abel (1996), and discussed in part 2.1, the stocking rate in Soviet Kazakhstan would have been at MY, maximum yield. However, the national target of 50 million sheep was never reached, so something was limiting production. Soviet scientists suggest that it was because for much of the semi-arid regions of Kazakhstan, the biological carrying capacity had been reached. That is to say that damage to plants was occurring which was having a feedback effect on production. Rangeland degradation and its effects on productivity are discussed in the next two sections.

2.3.1 Literature on Rangeland degradation in the Soviet Era

According to Kharin and Kiriltseva (1988), Babaev and Kharin (1992), and Gieldyieva and Viesiliova (1992), 60% of the area of arid and semi-arid Kazakhstan is affected by degradation in some way. These authors blame animal production as the chief cause of this. This could be interpreted to mean that by the end of the Soviet period, Kazakhstan's rangelands were in a state of crisis. However it is worth looking at the evidence more closely in order to gain a more detailed and subtle picture of the degradation or otherwise of Kazakhstan's pastures.

One of the main pieces of evidence which has been quoted to illustrate land degradation is a map of degradation intensity in arid regions of Central Asia, compiled at the Institute of Deserts (Babaev 1985). The authors used data from previous research, questionnaires, and satellite images to classify the degradation into 5 classes: none, weak, moderate, severe, and very severe. At moderate levels or above there is some decrease in vegetation production. A copy of this map was obtained on a scale of 1:2 500 000. It is described in Kharin and Kiriltseva (1988) and Kharin *et al.* (1986). To classify each land area the authors measured the following aspects:

Vegetation state - current plant productivity as a percentage of potential.

Wind erosion - presence of deflation scars, sod cover.

Water erosion - percentage of bare soil, number of rills and gullies per km.

Desertification caused by activities such as construction and quarrying - disturbance of vegetation (% of total area).

Salinisation of irrigated lands - cotton yields, position of salt in soil horizon

Figure 2.2

For each area, the degradation index assigned was calculated from a summed value of all the above indices.

There is no description, in any of the papers cited, of the methodologies used to measure any of the above indices of land degradation, the only information given was the fact that satellite images were used. The effects of animals on the environment were measured and included on the map. The stocking load was defined in Kharin and Kiriltseva (1988) as “the ratio of the actual load on the rangelands compared to the potentially possible load", 0-66% of possible was considered low, 66-100% moderate, 100-200 strong, and >200 very strong. The methods used to calculate potential stocking loads are discussed in section 2.4.

According to Kharin *et al.* (1986) the most widespread type of desertification in Kazakhstan is degradation of vegetation cover. The description of the vegetation changes which define the different vegetation classes on the map imply that for these scientists, 'desertification' or 'degradation' (both words are used), in fact means any change from what is considered to be the 'normal' vegetation type for the region, although this is not defined. For example, the 'slight' desertification class means a slight change in plant species composition. Moderate degradation 'involves the presence of more or less stable associations that have been productive for long periods but still include weed species'.

On the desertification map, only the categories of severe and highly severe degradation are cited as having low productivities and high proportions of non-palatable species. Highly severe degradation is defined as an irreversible change in the vegetation, and in the study area only exists in the southern part of the Moiynkum desert. It is difficult to say from the map, however, whether this severe degradation is around wells and settlements only, or whether it really involves the whole of the area shaded on the map. The part of the map showing the study area is shown in Figure 2.3.

Other literature on land degradation comes mostly from workers at the Institute of Pasture and Fodder, Almaty, and in some cases is contradictory to the map in Figure 2.2. According to these workers degradation in Kazakhstan began in the 1960s. At this time, as outlined in Chapter 1 (section 1.2.3) 155 specialised sheep raising *sovkhozes* were created on state reserve land, with a stock of 50,000-60,000 sheep each (Asanov and Alimaev 1990). All the *sovkhozes* studied for this thesis were among this group. They were situated in areas which had formerly been used either for driving through of stock or for longer periods in spring and autumn. Some of the new *sovkhozes* blocked migratory routes. For example, stock from Dzhambyl and South Kazakhstan *oblasts* would formerly have spent summer in Karaganda *oblast* (Zhambakin 1995), however after the 1960s this migration contracted due to the establishment of new farms in Karaganda *oblast*, and the stock only went as far as northern Dzhezkazgan *oblast* (Figure 1.6). Some stopped going altogether (I. Alimaev pers. comm.).

The pastures which therefore would have formerly been used briefly during migratory periods started to be used for months at a time. For example most of the land on *sovkhoz* Zhenis, founded in the 1960s, was used in spring, summer, and autumn. According to Alimaev *et al.* (1986) after this period problems with water supply in remote areas were experienced, and the frequency of pasture changes was reduced. Nomadic camps in the spring time became fewer. Farms which had winter pasture on sands, and which moved their large herds to areas adjoining the sands for lambing were obliged to keep their animals on the sands, in some cases until the end of shearing (mid June). According to the *raion* statistical offices of Dzhambyl *oblast*, the numbers of animals going to remote summer pastures in Dzhezkazgan *oblast* from there had already dropped substantially in the early 80s, because of water problems, and some animals were also spending summer on what had previously been autumn and spring pastures. According to Asanov and Alimaev (1990) the plants on this 3 season pasture were not given the chance to grow up or go to seed, and the yield dropped to 100 - 200kg/ha over all areas, regardless of rainfall (normally they would be expected to reach 500kg/ha given average rainfalls). Figures given for yields were almost half of what is ecologically possible. These problems were compounded by the ploughing up of the best summer pastures in the 1950s, which increased reliance on the semi-arid pastures.

The types of species composition change caused by various grazing levels are described in Kirichenko (1980). The author describes how pasture dominated by *Artemesia terrae-albae* and *Haloxylon* species is particularly sensitive to grazing, these species being replaced progressively by edible annuals such as *Ceratocarpus utriculosis* and *Alyssum desertorum*, and then inedible annuals such as *Peganum tataricum*, and *Atriplex tataricum.* The average biomass in the growing season drops from 483 kg/ha to 100 kg/ha. Kirichenko (1980) notes that ecosystems dominated by *Anabasis salsa*, *Salsola arbusciliformis*, and *Atriplex cana* are relatively resistant to grazing.

Dzhanpeisov *et al.* (1990) however, suggest that the *Artemesia-Salsola* dominated pastures of autumn-spring pastures of Betpak-dala are relatively resistant to erosion. Severely trampled areas apparently experience a change in species, being overtaken by *Atriplex cana* and *Anabasis salsa*, but this only occurs in small areas around temporary camps. According to these authors, and as is suggested by Babaev and Kharin (1991), pastures on sandy soil, such as the Moiynkum desert, which are dominated by *Calligonum, Artemesia, Haloxylon* and grass species, are often severely degraded. In these areas, land around wells was severely deflated and coverage dropped from 30-50% to 10-15%. This was due to the high concentration of animals around *zimovki*. The authors conclude that in the Moiynkum desert erosion processes had reached threatening dimensions: "soil cover complex along cattle trails, near winter camps, and temporary pasture corrals, near watering places, and in the region of sheep shearing and dipping stations is usually completely destroyed and strongly deflated. (This) worsens the landscape, ecological, and economic conditions in the region".

Zonov (1974) conducted a study on the effects of land use on vegetation and soils in the north of Betpak-dala. He remarks that since 1950s land use of Betpak-dala had gone from simple driving through of animals to use of pastures for up to 30 days in spring and autumn by *sovkhozes* of Dzhambyl and South Kazakhstan *oblasts*. The communities discussed are characterised by *Artemesia terrae-albae*, *Salsola arbusciliformis,* and *Ceratoides* spp. According to the author, the cover of healthy vegetation in these communities is 40%, humus content of the soil should be 0.5-0.7% with 20-24 tonnes organic material per hectare. These figures drop for degraded regions, and the soil structure also changes. For example, around migration routes, cover drops to 30% or 10-15% around barns and water points where organic content drops to 10 tonnes/ha. Annual species take over, such as *Ceratocarpus arenarius, C. orthoceras, Lepidium* spp*,* and *Acroptilien repens.* Zonov also mentions erosion on Zhetykonur sands (see Figure 1.6) which he says are affected around *zimovki*. These sands are the winter grazing areas for two of the *sovkhozes* studied in detail, *sovkhoz* Sarysu, and *sovkhoz* Mibulak.

Overall there is contradictory information regarding degradation. All sources, however agree that the Moiynkum desert has suffered severe degradation

(Dzhanpeisov *et al.* (1990); Zhambakin (1995); Babaev (1985)). I. Alimaev (pers. comm.) has stated that the pastures on farms in Suzak, Sarysu, and Moiynkum *raions*, and the state land reserve immediately north in Dzhambyl *oblast* (see Figure 1.6) are degraded. This is because they are traditionally autumn-spring pastures, which have been used for longer and longer periods since the 1960s. The south of this area, along the river Chu, has also been described as degraded by Babaev (1985), and E. Rachkovskaya (pers. comm.). Central Betpak-dala (state land reserve) is apparently in good condition (I. Alimaev, pers. comm., L. Stogova pers. comm., Babaev, 1985), although local degradation has been described by Zonov (1974) and Dzhanpeisov *et al.* (1990). Some of the new *sovkhozes* in the north of Betpak-dala and semi-desert zones, which use the same pastures for three seasons have been described as degraded according to Zhambakin (1995).

In summary, the two types of pastures which tend to be degraded are winter pastures on sands where there is a high density of animals, and clay desert pastures which are used for spring, summer, and autumn where the prolongation of even moderate grazing causes degradation. According to Asanov and Alimaev (1990), degradation had begun to affect the productivity of the livestock sector, causing increased mortality and lower birth rates. This suggests that the vegetation was limiting stock production per animal, and this is investigated in the next section.

2.3.2 Effects of land degradation on production objectives

Birth and death rates of sheep for the whole country and for the *oblasts* of interest were obtained from *Goskomstat* (The state statistical agency). These figures were compiled for each farm by the administration and sent to *raion* and *oblast* centres so that averages could be calculated at district and regional levels.

There are likely to be two sources of error in these data: firstly directors may have lied directly to disguise shortcomings of the farms for which they were responsible. Secondly, in the case of death rates, those sheep which were weak may have been slaughtered, meaning that they would be missing from the death rate statistics, which were supposed to include only deaths from natural causes. Both of these errors would mean that death rate statistics may be underestimates.

The data for birth and death rates were plotted together with data on stock numbers, in order to determine whether these indices did indicate that the livestock sector was experiencing problems. The results are shown in Figure 2.3.

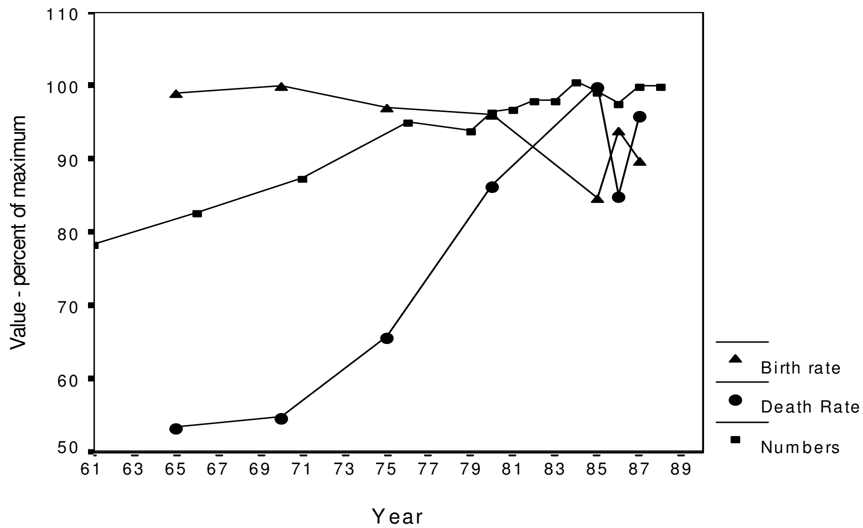
The graphs in Figure 2.3 show a strong increase in death rates, and a less marked decrease in birth rates with stock numbers. There is a significant positive correlation between death rates and numbers (R^2 is 0.72**), although the relationship is not significant for birth rates. There is, of course no proof that increasing death rates are due to rising numbers. They could also be due to disease or some other factor.

One point which is interesting to note from Figure 2.3a is that in 1986 a small drop in stock numbers of 2% coincides with increases in birth rate of 11% and decreases in death rate of 15% compared with figures for 1985. The livestock numbers are for the first of January of each year, whilst the death and birth rate numbers refer to deaths and births during the course of the year. Therefore the decrease in stock numbers would in fact have occurred during 1985, a year with extremely high death rates and low birth rates. The cause of these is unknown, however, rainfall data from 5 meteorological stations show that in the desert zone the years from 1982 to 1986 were very dry, rainfall being between 75% and 93% of average over all the five stations in that zone. 1984 was very dry in both the desert and semi-desert zones, and in that year none of the stations across the two zones had rainfalls above 80% of average. Long term rainfall data is presented in graphical form in Figure 4.1 of Chapter 4. The geographical position of the meteorological stations is shown in Chapter 3 (Figure 3.2). Rainfall data presented in Ellis and Lee (2000) for Almaty *oblast* and the Balkhash basin suggests that these years were dry there also, so it seems as if it was a general phenomenon for the southern half of Kazakhstan, the major zone of sheep rearing.

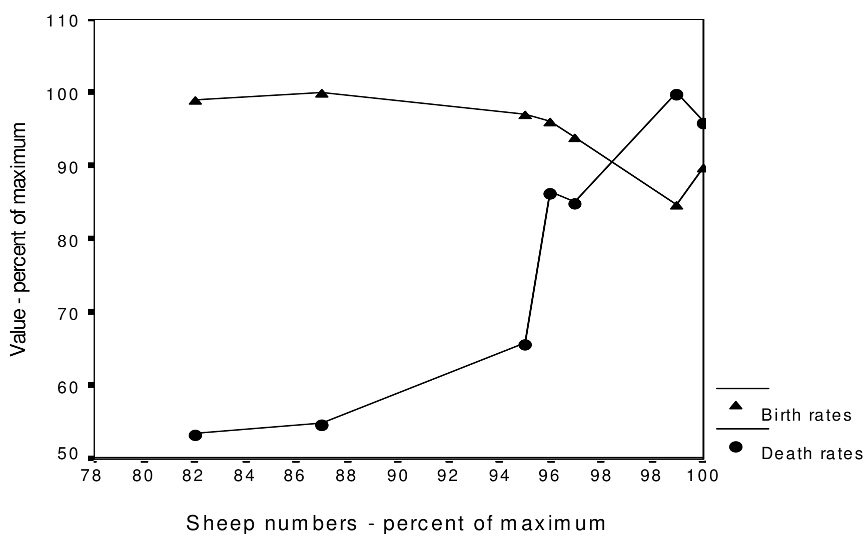
Figure 2.3: Changes in sheep numbers, birth, and death rates in Kazakhstan, 1960-1988. *Source: Goskomstat 1984, 1985, 1987.*
(a) Numbers, birth, and death rates plotted against year. (b) Birth and death rates plotted against numbers. All figures are plotted as percentages of maximum value for

comparison, Actual maxima as follows: birth rate 98 per 100 ewes, death rate 7.3%, numbers 36.6 million.

(a)



(b)



It is possible therefore that a sequence of drought years combined with high and rising stock numbers caused the particularly sharp rise in death rates and drop in birth rates seen over the early 1980s, and that in 1986 this was enough to depress sheep numbers. This is tenuous evidence indeed for any dependence of sheep numbers on density or rainfall, however it is evident that in the second half of the 1980s something was stopping the increase in sheep numbers which had been continuing since the 1930s.

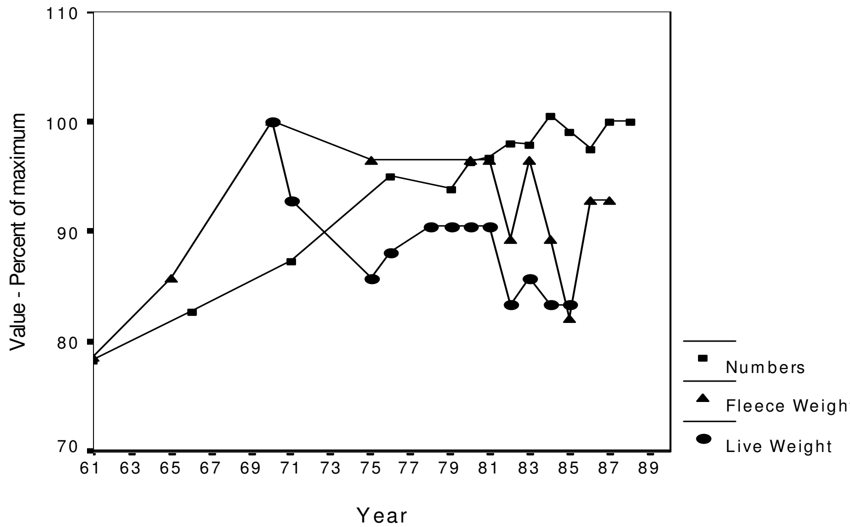
The possible errors mentioned above associated with the birth and death rate data would imply that the declining birth rates and increasing death rates seen here may have, in reality, been more severe than is apparent from the data. However they do not change the overall conclusions.

In order to further investigate the effects of sheep numbers on productivity, data on stock live weight and fleece weight were also plotted against year and numbers (Figure 2.4). Liveweight is strongly related to nutritional status (AFRC 1993, Elsen *et al.* 1988). Fleece growth is also affected by nutrition (AFRC 1993) and fleece wieght been related, in lactating ewes, to herbage allowance in controlled experiments (Rattray *et al.* 1982).

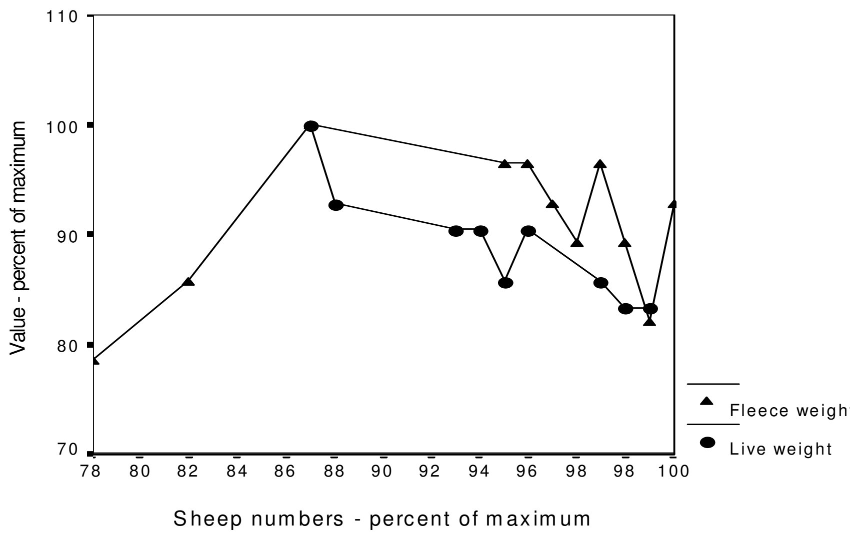
Although the live weight data were only available from 1970 onwards, it can be seen that both this factor and fleece weight show a general decline since the early 1970s. The regression between fleece weight and numbers had an R^2 value of 0.61***. That between live weight and numbers was also significant (R^2 was 0.85***). The sharp decline in live weight between 1981 and 1982, and its continued depression for the next few years can be clearly seen in Figure 2.4, and could be due to the low rainfall of this period.

Figure 2.4: Changes in sheep numbers, live weight, and fleece weight in Kazakhstan, 1960-1988. *Source: Goskomstat 1984, 1985, 1987.*
(a) Numbers, live weight and fleece weight plotted against year. (b) Live weight and fleece weight plotted against numbers. All figures are plotted as percentages of maximum value for comparison, Actual maxima are as follows: live weight 42kg, fleece weight 2.8kg, numbers 36.6 million.

(a)



(b)



Sheep live weight data were also available by *oblast* from 1970 to 1985. As sheep weight varies between *oblast* and analysis of covariance was performed on the data from all four *oblasts*, putting in sheep number as a covariate, and *oblast* as a factor. There was no interaction between sheep number and *oblast* (F=0.627 NS) meaning that the data for all four factors showed the same behaviour. According to the subsequent analysis of covariance, both the factor *oblast* and sheep number were related to sheep weight, live weight decreasing with sheep number, as expected. The total number of data points was 38. The F values and their significances for the two variables are shown below:

Oblast: F=11.59 DF=3 P=0.000

Sheep number: F= 25.9 DF=1 P=0.000

The variance of the factor variable is equal across groups (Levenes test of homogeneity of variances) F = 1.4 P=0.242.

Therefore, sheep number is a significant predictor of sheep weight, taking between-*oblast* differences into account and we can say that the study area as a whole follows national trends.

We have seen so far that sheep condition tended to worsen over the 1970s and 1980s However, this is not necessarily disastrous as far as production is concerned. Behnke and Abel (1996) and Wilson and Macleod (1991) have pointed out that at high densities of animals, competition for forage will often mean an increase in mortality and fall in birth rates. However it does not necessarily follow that there is a decrease in production *per hectare*, nor does it follow that rangeland degradation is resulting from these high densities. Figures 2.5 and 2.6 below show how in Kazakhstan as a whole, and in Dzhezkazgan *oblast*, during the time that birth and death rates were increasing, meat production was increasing with stock numbers, and did not show a decrease even when numbers were at their highest. Here total stock numbers are shown (as livestock units) rather than sheep numbers, because the meat production statistics were available only as lumped statistics for all meat types.

In both Kazakhstan and Dzhezkazgan *oblast* productivity rose with stock numbers until 1992. At this point there was a sharp drop in meat production, together with a small drop in sheep numbers. Whilst it is true that there was a severe drought in 1991, the main reason for the decrease in production was probably due to reduced domestic demand in this period resulting from declining real wages, and the fact that export of meat to other parts of the former Soviet Union suffered a large decrease (World Bank 1994). The rise in meat production after this probably corresponds to the increased slaughter of animals leading to the stock crash of 1994 - 1995.

It appears therefore that the high stock numbers were not limiting production per hectare, both throughout Kazakhstan, and in Dzhezkazgan *oblast*. However, the increase in meat production comes to a temporary halt from 1982 to 1985 in Kazakhstan as a whole, coinciding with the drops in numbers and live weight, and fleece weight described above. This pattern is not seen for Dzhezkazgan *oblast*, however data for the years 1982 and 1985 are missing. This slowdown in production could have been linked to the poor condition of the livestock at this time, however it could also have been linked to other factors such as policy, and demand for meat.

Figure 2.5: Changes in livestock numbers and meat production in Kazakhstan, 1960-1997. *Source: Goskomstat 1984, 1985, 1987, 1996. One livestock unit is equivalent to one horse, one cow, or 10 sheep.*

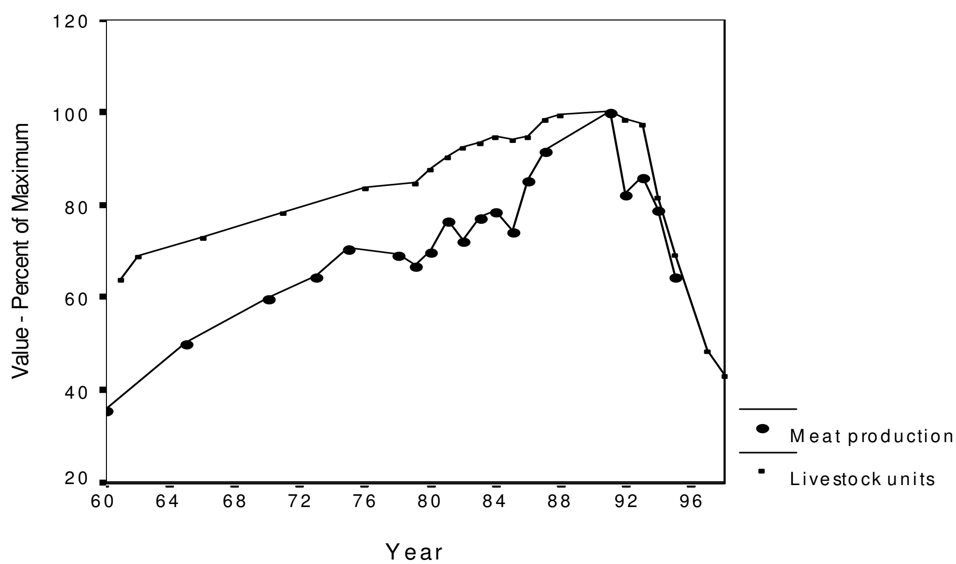
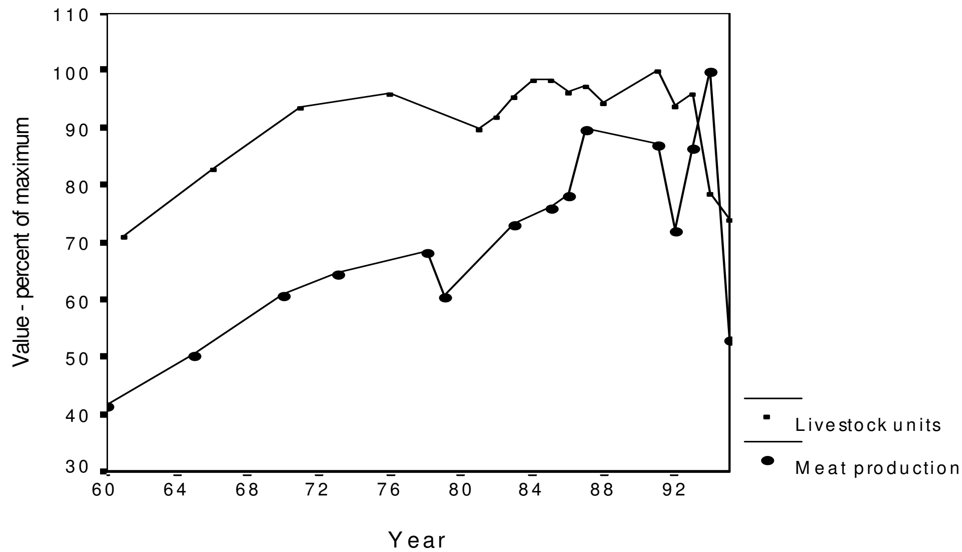


Figure 2.6: Changes in livestock numbers and meat production in Dzhezkazgan oblast 1960-1995. *Source: Goskomstat 1984, 1985, 1987, 1996.*



Despite the reports of overgrazing, and provided that the data from *Goskomstat* are accurate (which for collective stock at least is probably a reasonable assumption), it appears that the stocking rate in Soviet Kazakhstan probably did not exceed MY, that required to produce the maximum yield. Therefore in this sense carrying capacity was not exceeded. However, stock numbers were only at very high levels for a few years, and given the negative effects on animal condition, it is possible that feedback effects on meat productivity would have occurred had the stocking rates of the late 1980s been maintained for a longer period. In the next section we look at carrying capacity, not in terms of effects on animal production, but in terms of effects on the pasture.

2.4 Carrying capacity and stocking rates for regions in the study area

2.4.1 Measuring carrying capacity

In section 2.1 definitions of carrying capacity were discussed. In the above section, the evidence for overstocking with respect to animal production CC was analysed. We can also define carrying capacity as that number of animals (which in the study area means sheep), which can be supported on an area of pasture for the season of use without reducing plant productivity in future seasons, and in this section we look at the evidence for overstocking from this point of view. We start by looking at how carrying capacity is measured in the field. Methods from the literature are discussed and compared with their Soviet equivalents.

A range of methods for calculating carrying capacity are discussed in the literature, but there are two major approaches (Muir and McClaren 1997):

1. Range condition - This is an assessment of the real state of the vegetation in the grazed area compared to some expected or desirable state, given climate and soils (Frost and Smith 1991).

2. Forage inventory methods - these methods require knowledge of the amount of forage available, animal intake, and the amount of forage plants which can be eaten without damage to the plant - the proper use factor. Such methods have been used to predict carrying capacity many studies, for example De Leeuw *et al.* (1993) and Sweet (1996).

The first method is desirable because it does not involve the risky estimate of many unknown factors. It relies simply on observation. However, it is not be possible to use this method to predict the effects of theoretical stocking rates without information from grazed and ungrazed reference sites of the same vegetation type. It is possible to carry out controlled grazing experiments (Zhambakin 1995), but these are expensive, especially as they must be long term in order to study effects on vegetation productivity several years down the line. Also, such experiments will be valid only for the particular vegetation and animal types with which they were conducted, and results are unlikely to apply to other situations.

The second method involves the estimation of many factors, small differences in which may lead to estimates of carrying capacity which differ by several orders of magnitude. For example, the area of pasture available is not simply defined, as the amount actually used by animals will depend on the distribution of water, distribution of vegetation types, and 'special resources' such as river banks, which may provide high amounts of forage at particular times of the year (Scoones 1992). Vegetation yields may be extremely variable between years, and so available forage resources should be estimated for good and bad years, and in different periods of the year, as die off in dry periods reduces the available forage (De Leeuw *et al.* 1993). Proper use factors are often fairly arbitrary, and yet the decision to use a proper use factor of 30% or 45% for example, will double or halve the calculated CC (Bartels *et al.* 1993). Accurate estimations of daily intake by animals are difficult to obtain as these depend on many characteristics of the animals themselves and of the pasture. Also, the type of vegetation selected will affect both intake itself, and the future forage value of the pasture. In some situations shepherds also have access to other feed resources such as crop residues or stored hay for their animals, resources which may, in certain seasons, be more important than range vegetation.

Bartels *et al.* (1993) conclude that for sub-Saharan Africa, the concept of carrying capacity is meaningless due to the above problems, and should be abandoned. However, in Kazakhstan during the Soviet period, herds were of a specific size, and were kept in defined areas in each season, areas which did not change according to yearly climate fluctuations. Each herd usually had one water source (a well) at any given time of the year, and those seasons or situations in which feed supplements were given are well documented. Perhaps the reasons why such rigidly structured grazing systems existed (or were possible) include not only the Soviet system itself, with its emphasis on centralised control, but the fact that Kazakhstan's rangelands are at equilibrium. In other words, due to the low coefficient of variation of rainfall, forage production is predictable enough to mean that once the influence of *dzhut* is eliminated by winter fodder, animal production is likely to be limited only by the area of land with access to water, and by density, which makes estimation of carrying capacity much easier. However as we will see, some of the factors needed for its estimation, such as proper use factors and intake prove as intractable as they have been in other areas of the world.

There is much in the Soviet literature on carrying capacity in Kazakhstan. Indeed it was calculated for many pastures types for different seasons, and recommendations made as to ideal number of 'sheep days' per hectare which would produce the most beneficial effects on pasture and sheep productivity. One sheep day is the grazing pressure produced by one sheep on one hectare of land in one day.

Grazing experiments to determine the effects of different stocking loads have been carried out by members of the Institute of Pasture and Fodder (Almaty), and some are described in Zhambakin (1995). These look not only at the effect of stocking loads, but on the effects of different grazing regimes and rotational strategies. From such experiments so called 'coefficients of use' were determined for each season, corresponding to the proper use factors of western range science. These grazing experiments are described in more detail in the section on proper use factors (2.4.2 (iii)).

Forage inventory methods were also used, and are described in Asanov *et al.* (1994).

The formula used for carrying capacity, in terms of the number of sheep days per hectare is (source Asanov *et al.* 1994):

$$C = \frac{B\,E\,P}{I\,D} \qquad \mathbf{(2.2)}$$

Where:

C = Carrying Capacity in sheep days/ha
B = Biomass of air dried matter of edible species kg/ ha
E = Edibility in "feed units" (digestible matter as a proportion of the total)
P = "Coefficient of use" this is equivalent to a proper use factor
I = Intake per sheep per day in feed units.
D = Numbers of days of grazing period.

Feed units are equivalent to digestible matter as a proportion of total dry matter available (Ospanova 1996) and are discussed further in section 2.4.2 (iv) on forage quality.

From this equation carrying capacity estimates were obtained such as those given in Table 2.2.

Table 2.2: Estimated carrying capacities for a number of pasture types in sheep days per hectare. *The number of hectares which would be needed for one herd of 1000 sheep in one month on such pasture is given in brackets. Source: Asanov et al. 1994.*

Association	Spring	Summer	Autumn
Salsola arbusciliformis, *Artemesia* spp.	131 (229)	58 (517)	24 (1250)
Atriplex cana, *Artemesia pauciflora*	130 (230)	65 (461)	72 (416)
Anabasis salsa	35 (857)	36 (833)	22 (1363)
Artemesia terrae-albae, annuals	92 (326)	101 (297)	49 (612)
Ceratoides papposa, grasses	109 (275)	114 (263)	74 (405)

Such carrying capacities, together with real stocking rates, were among the data used to make the map of desertification of arid areas of the USSR (Babaev 1985) which was discussed in section 2.3.1., and therefore it is important to understand exactly how the elements of the carrying capacity equation, such as proper use factors and animal intake, were estimated. Overall the elements needed for the calculation of carrying capacity and its comparison with real stocking rates can be summarised under the following headings:

(i) Herbivore density and distribution in space and time
(ii) Biomass yield and quality
(iii) Proper use factors for each pasture type
(iv) Intake per animal per day

In the next section we examine the availability and quality of the information available to estimate the above parameters for *sovkhozes* in the study region. Example areas are then chosen to represent winter or three season (spring-summer-autumn) pastures, the two major types suffering from degradation according to the literature. In section 2.5 stocking rates and carrying capacities are estimated for these example areas to see whether overstocking would have been predicted using such forage inventory methods.

2.4.2 Data for the estimation of carrying capacity

(i) Herbivore density and distribution

Domestic herbivore density is relatively easy to obtain for Soviet Kazakhstan as animals were kept in specific areas in the vicinity of water holes. Statistics are available for each *sovkhoz* on the numbers of these herbivores around each well, and for the amount of land which is in walking distance of a water hole. There was no flexibility or free choice by individual shepherds, which simplifies very much the situation from the point of view of carrying capacity. For example, on *sovkhoz* Zhenis herd sizes were all 800-900 animals, and there was one herd per well for summer, and one for winter. The situation was similar for *sovkhoz* Sarysu except that there was also a separate well for spring grazing, and the winter pasture areas were much larger. The statistics are available in the form of maps, which show, for each herd of sheep, the location and size of the pasture allocated to that herd in each season. Wells, *zimovki*, and migration routes are also marked.

The distance that animals are likely to travel from water holes is discussed in Asanov *et al.* (1994). According to this author, the distance used from a well is determined by the type of animal, productivity of pasture, and organisation of pasturing. The authors estimates that for a herd of 800 sheep, acceptable (or required) distances from wells ranged from 1.5 to 4.2 km depending on pasture quality. In interviews conducted for this study, shepherds generally estimated that they took their sheep 3 km from a water point in summer, but that more was possible in other seasons. *Kazgiprozem* (1981) in a report on *sovkhoz* Zhenis state that sheep moved a maximum of 4 km from wells. Therefore 3 km seems to be reasonable as a conservative estimate.

(ii) Biomass yield and productivity

Biomass yield is the above-ground non-woody plant matter at a particular point in time. Such data exist for many areas of Kazakhstan. Productivity is the amount of biomass produced by a plant in the growing season, and includes matter removed by grazing animals. For example, plants may have a low biomass yield at a given moment in time, but still be highly productive over time. This high productivity would go unnoticed if animal intake was not taken into account.

One problem which affects all estimates of carrying capacity is that the effects of grazing on productivity are complex, and may be positive in some cases. A well known study by McNaughton (1979) shows that grazing increased plant productivity in the Serengeti National Park, and it would appear that the same is true for Kazakhstan. For example Abaturov (1979) measured vegetation removal by sousliks (*Citella pygmaeus*) and marmots (*Marmota bobac*) in the Northern Caspian region and the Ukrainian steppes, and found that grazing had no negative effects on productivity. Sousliks removed about 20% of the available biomass, and marmots between 20 and 40%. This removal of photosynthetic material did not impair the rate of growth, and there was even a slight increase in productivity under grazing by marmots.

The same conclusion has been reached by workers at the Institute of Pasture and Fodder, whose 20 year grazing experiments with sheep are outlined in Zhambakin (1995). The results of these experiments are discussed in section 2.4.2 (iii). Some of the results are shown in Table 2.5. They show that maximum yields on moderately grazed pasture are higher than those on ungrazed pasture by 10% in wet years, and 20% in dry years, under single season grazing regimes.

Biomass yield data are available on a 10 daily basis from 1967 to 1997 for six meteorological stations in the study area (see Chapter 3, Figure 3.2). For the Northern desert zone (Betpak-dala), there exists a more detailed data set available for 1958-1961 for five different pasture types. These data and their collection are described in detail in Chapter 3, where they were used to gain an idea of the expected minima, maxima, and average yields expected in different parts of the study area.
Botanical data are also available for individual *sovkhozes* from reports and maps conducted by the Kazakhstan State Institute for Land Planning (*Kazgiprozem*). Botanical maps were acquired for three farms: Sarysu, Zhenis, and Druzhba. In Soviet rangeland science vegetation associations were all assigned numbers according to their species composition. The map guide gives details on some or all of the following for each map: species composition of each vegetation association, its

height, minimum and maximum yield in spring, summer, autumn and winter, and its digestibility in feed units. Unfortunately, for each type, the species composition was not expressed quantitatively, i.e. the dominant species was given, plus the presence of other species. Therefore for the purposes of this study, it was assumed that each type consisted simply of the dominant species.

On the botanical maps, the farms are divided into polygons according to vegetation type. For each polygon was given :

a. The area of the polygon in hectares
b. The vegetation associations present in that polygon
c. The percentage of the polygon covered by each association

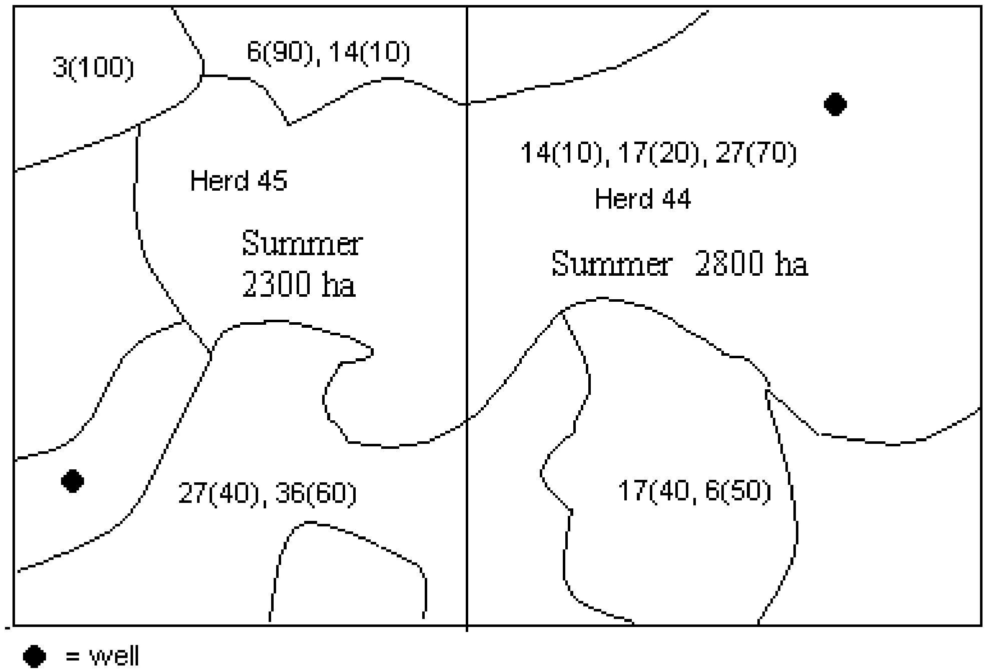
An example is shown in Figure 2.7.

One doubt which arises from the scrutiny of such a map is whether the boundaries between each grazing area ever had any basis in reality. However the areas given (average 2300ha) normally roughly correspond to a grazing distance of 3 km from each well (2800 ha) so the size of the areas, if not their exact location relative to one another, are probably more or less accurate.

For the grazing area allocated to each herd in a certain season, the area covered by each polygon (representing a weighted combination of vegetation types) can be calculated, and the overall average vegetation composition and yield of each area can be determined. This was carried out for four example herds on *sovkhoz* Sarysu, for each season. For example, the minimum and maximum yields expected from each polygon were found from the weighted averages of the different associations.
The weighted averages for the polygons were then found. The four herds were chosen to be representative of the different grazing patterns present on the farm. Two of them spent spring, winter and autumn on the sands (off the farm itself) and summer in the north east of the farm. The other two herds spent spring, winter and autumn in the south of the farm territory and summer in the north west of the farm. These grazing patterns are shown in Chapter 1, Figure 1.8.

Figure 2.7: Example of the spatial forage information available for sovkhozes. *The rectangular areas represent grazing areas for a particular herd in a certain season, in this case, herds 44 and 45 in summer. The curved lines enclose polygons*

representing combinations of vegetation associations. For example 6(90) means that 90% of that polygons area is covered by vegetation association number 6.



The average, minimum and maximum yields for the average of four herd areas are shown in Table 2.3 with data from Koktas meteorological station (again minimum, maximum, and average), which was only 70km to the east. These areas can be considered typical of the semi-desert zone.

Table 2.3: Sources of data for estimating biomass yields over the year in Northern Dzhezkazgan oblast. *The Min-Max biomass per grazing area refers to the minimum and maximum yields obtained if we average over all the vegetation types in an area of 2300 ha (the average area available for each herd).*

Koktas meteorological station			***Sovkhoz* Sarysu botanical map**	
Month	Average biomass	Min-Max biomass	Season	Min-Max biomass per grazing area
April	2.2		Spring	

May	2.9	1.8 - 6.9		2.0-4.9
June	6.5	4.1 - 8.6	Summer	3.3 - 7.1
July	5.6	3.3 - 9.7		
August	5	3.0 - 8.0		
September	4.3	2.9 - 6		
October	3.7	2 - 5.5	Autumn	2.75 - 5.0
Winter			Winter	2.0 - 4.1

The biomass calculated for the grazing areas in the different seasons falls within the bounds of that recorded at Koktas meteorological station. Therefore we now have a good idea of biomass variability between years and over the seasons of interest.

The above data are for the semi-desert zone. Data for the desert zone were available in more detail, and are examined in Chapter 3.

(iii) Coefficient of use

Coefficients of use are the Soviet equivalent of proper use factors, and are defined as the offtake which can be sustained by the pasture without reducing its productivity in future seasons. A number of these are shown in Table 2.4.

Table 2.4: Proper use factors from Soviet literature.

Vegetation type	**Proper use factor**	**Source**
Semi-shrub spring	75%	Kirichenko 1980
Semi shrub summer	60%	Kirichenko 1980
Semi shrub autumn	55%	Kirichenko 1980
Atriplex cana, Artemesia pauciflora	50-70% (1 season)	Zhambakin 1995
Artemesia pauciflora	50-60% (1 season)	Zhambakin 1995
Stipa, Festuca spp.	60-70%	Zhambakin 1995

The figures in Table 2.4 are much higher than Western figures for perennial grasslands, which are usually between 30 and 45% (De Leeuw *et al.* 1993). This is possibly because they are for specific seasons. According to Zhambakin (1995) proper use factors are only valid in conjunction with 'sound grazing practice'. This can be seen by looking at how they were calculated:

Some of these proper use factors were calculated from the results of grazing experiments conducted by the Institute of Pasture and Fodder, and described in Zhambakin (1995). For example different stocking loads (corresponding to pasture removal of 20-40%, 50-70%, 75-90%) were tried on pasture comprised of annual species, *Artemesia terrae-albae*, and *Salsola orientalis.* Stocking intensities which lead to over 70% removal of biomass from the perennial species tended to have serious effects on their growth and reproduction. At moderate grazing levels the effects depended on the species; some, such as *Salsola rigida*, being much more sought after than others such as *Artemesia terrae-albae* and *Ceratoides papposa*. However the proper use factors for pastures were conceived to take into account damage to the most palatable species.

The results of moderate offtakes (50-70%) were also compared under different grazing systems (Table 2.5). Under a rotational grazing system the experimental area was divided into three parts, so that the sheep spent each season in a new area. This was compared with a control area of the same size which was not split into parts, and grazing continued from April to October on the same area of pasture. On the control area biomass was 10% to 20% lower than it would have been had the pasture been grazed under a rotational system. However such prolonged three season grazing still did not have negative effects on productivity when compared with ungrazed areas.

A fourth area was studied (not shown in Table 2.5) which was subject to 'system-less grazing'. On this pasture grazing started at the end of February and continued into October. This had much more harmful effects on the pasture, yields dropping to 35 - 45% of the biomass of the ungrazed area. However the authors do not give the stocking loads on this area so it is difficult to say if the deleterious effects on the pasture are due to grazing in early spring, or due to overstocking. However the authors conclude that such early commencement of grazing is one of the major reasons for pasture degradation in Kazakhstan.

Table 2.5: Results of grazing experiments conducted by the Institute of Pasture 1970-1990. *Source: Zhambakin 1995.*

Regime	**Seasons**	**Offtake (%)**	**yield DM kg/ha (wet year)**	**yield DM kg/ha (dry year)**
No grazing		0	648	519
rotational	1 season each area	50-70 (100-120 sheep days)	711	633
prolonged grazing	three seasons	50-70 (100-120 sheep days)	642	559

(iv) Consumption of biomass per animal

This is a factor for which the estimates given by Soviet scientists are very different from those from Western range science. According to Asanov *et al.* (1994), sheep intake is determined only by requirement. For example, a sheep needs a certain number of MJ per day to survive, and it will eat to satisfy this need. Following this logic, the higher the digestibility of the forage, the less of it the sheep will need to consume.

Therefore it was assumed that the sheep intake would be enough to fulfil its requirements, so that a sheep would eat more pasture in winter, and less in spring, as is evident from Table 2.6.

Table 2.6: Estimates of daily sheep intake from Soviet literature.

Intake (kg DM /day)	**Sheep type**	**Pasture type**	**Source**
1.8-2.6	Adult Karakul	general, spring-summer	Tamme and Balaban quoted in Asanov *et al.* (1994)
2.6-3.0	Adult Karakul	general, autumn-winter	Tamme and Balaban quoted in Asanov *et al.* (1994)

3.7-4.5	80kg	*Artemesia, Artemesia-Stipa*	Larin quoted in Asanov *et al.* (1994)
2.2-2.6	40kg	*Artemesia, Artemesia-Stipa*	Larin quoted in Asanov *et al.* (1994)
2.5	general	general	Kirichenko 1980

Many livestock intakes used to calculate carrying capacity in Western literature are also based on requirement (De Leeuw *et al.* 1993, Sweet 1996). For example the FAO (1984) suggest that daily maintenance requirements of livestock are 2 percent of live weight per day. Short (1987) used the following relationship:

$60\text{-}80 g/kg^{0.75}/day$ This is raised to 0.75 in order to estimate metabolic weight.

For a sheep weighing 40kg this corresponds to: 954g - 1272 g per day.
For a sheep weighing 60kg this corresponds to: 1285 - 1680 g per day

These estimates are very general, however more accurate estimates are possible using equations provided by the AFRC (1993) among others, which take into account not only weight, but the reproductive status of the animal, weight gain objectives, and movement allowances.

The above estimates for intake from Western literature are about half those of Soviet ones, and it is clear that the choice of estimate will lead to a 2 fold difference in herd offtake estimates, and thus in carrying capacity. However both groups of estimate assume that the sheep is fulfilling exactly its requirement, they are describing *potential intake*.

Potential intake is the maximum intake possible by a particular animal, and depends on size, stage of growth, and lactation of that animal. Relative or actual intake for a given sheep depends on features of the pasture such as height, digestibility, and biomass. The factors affecting intake are reviewed below:

- *Biomass yield*

This can be measured as a simple feeding response - the biomass of food intake changing simply as a function of standing biomass of forage. For example animals may have a lower intake because as biomass declines they simply cannot eat enough in the time available to them.

Both Short (1987) and Elsen (1988) have compared feed responses of sheep from data or models of different authors. Generally the response takes the form of an inverted exponential curve (Noy-Meir 1975), with a asymptote at maximum intake (or maximum weight gain). The asymptotes occurred between biomass levels of 200-600kg/ha on *Chenopod* shrubland (references in Short 1987), and at yields of more than 1500kg/ha on sown clover pastures (Allden 1961, Willoughby 1959).

- *Food quality*

Food quality corresponds to the *digestibility* of the vegetation, the amount which can be absorbed into the gut, the rest being voided as faeces. Low food quality (high amounts of fibre and low protein) slows the passage of food through the gut, and therefore depresses intake. Freer (1981) notes a number of studies showing that the volume of intake increases linearly with increasing digestibility. Sometimes this relationship can be attributed to particular chemical constituents of the forage. For example Ridder and Bremen (1993) found that digestibility of annual plants in the African Sahel decreases at nitrogen levels of less then 25g/kg DM. The effect of such relationships on intake was examined by Short (1987), who found that an increase in the amount of nitrogen in the diet from 1 to 2 percent of dry weight produces an increase in food consumption in both sheep and kangaroos, of 35-40%.

Feed quality is therefore a major issue when predicting sheep intake, so it is worth taking a look at Soviet methods of measuring this factor.

Forage availability and sheep intake are often given in feed units. This is equivalent to the weight of digestible material in the forage. Typical forage values in feed units can be found in Ospanova (1996) for all steppe plants, at various stages over the growing season.

The way in which these were calculated is as follows: samples from all common steppe species (nearly 600 in all) were collected from different *oblasts* in Kazakhstan in each season (and sometimes in every month). The plants were analysed for contents of fat, protein, cellulose, nitrogen free extractive, and ash (no calorific value). Each of these constituents was given a coefficient of digestion, and therefore the digestibility of the plant as a whole could be worked out from its constituents. The digestible plant matter was expressed in feed units in proportions of a kg. An example is given in Table 2.7.

Table 2.7: Calculation of feed units from plant constituents. *Source: Ospanova 1996.*

	Protein	**fat**	**cellulose**	**nitrogen - free extractives**
Weight in g/kg of dry matter	117.8	24.1	316.0	458.8
Coefficient of digestion (%)	64	53	60	68
Digestible matter	75.4	12.8	189.6	309.9

The sum of digestible matter per kg is therefore calculated as follows:

$$75.4 + 12.8 + 189.6 + 309.9 = 590g \qquad \textbf{(2.3)}$$

In Soviet range science, sheep requirements were often expressed in terms of feed units, 1 sheep needing 1.2 FU per day (Zhambakin 1995). This corresponds to 1.2 kg of digestible matter per day. From this it easy to see why on winter pastures, where digestibility averages at 40-50%, estimates of intake would have been 3 kg per sheep per day.

Estimates for digestible matter requirements are based on estimates of energy requirements. According to Ospanova (1996), energy per kilogram of dry plant matter is calculated from digestibility of that matter. The one difference is that the fat component is multiplied by 2.25 because it gives 2.25 times more energy per gram than the other plant constituents. Therefore if these data are to be used to calculate energy, the sum of the digestible matter will be given as 603.7g. The weight of digestible energy can be converted to joules through a simple transformation:

Following Ospanova (1996), one gram of digestible food gives 18.46 kJ of energy. Of the energy available after digestion only about 84% of this is metabolised. The resulting energy available is expressed in Energetic Feed Units (EFU), each equivalent to 10,000 kJ. For example, our sample above having 603.7g of digestible matter per kilogram has an energy content of:

$$18.46\ kJ \times 603.7 = 11144.3\ KJ \qquad \textbf{(2.4)}$$

of which the following are metabolisable:

$$11144.3\ kJ \times 0.84 = 9361.2\ kJ\ or\ 0.94\ EFU \qquad \textbf{(2.5)}$$

EFUs should be multiplied by 10 to convert them to mega joules (MJ), the SI unit used internationally for metabolisable energy. If such results are compared with the results obtained for the same pasture with equations used by MAFF (1975) (given in a note at the end of Appendix 1), the answer is different by only 6%, suggesting that Western and Soviet methods for calculating fodder energy content are comparable.

The 1.2 feed unit requirement per sheep per day thus converts to 18 MJ per day. AFRC (1993) equations for the requirements of a mature lactating ewe weighing 40kg kept outdoors and gaining zero weight per day give between 12.44 and 19.91 MJ per day depending on milk output. However, this is a maximum requirement. Such ewes when pregnant for example, would require 6.38 MJ/day at 14 weeks, and 8.9 MJ/day at 20 weeks, roughly half their requirements when lactating, and much lower than the general Soviet estimate.

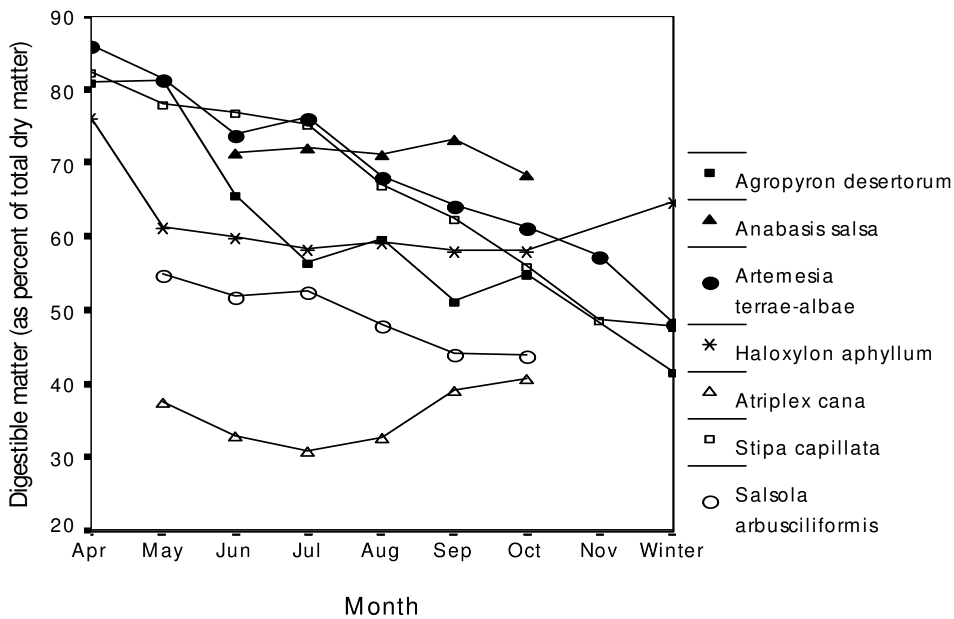
The tables in Ospanova (1996) are an extremely useful resource, as from them pasture quality in all areas of Kazakhstan can be calculated if the species composition is known. Such information can also tell us a lot about the value of different pastures in different seasons. From the data of Ospanova (1996) we can examine the nutritive quality of different steppe plants, and these are shown for some example species in Figure 2.8.

Figure 2.8 shows the digestibilities and energy values of a selection of steppe and desert plants over the year. It can be seen that the two graphs are very similar. This is to be expected given that energy is calculated from digestible matter and fat content. However, *Stipa capillata* has relatively high energy content for its digestibility, whilst *Anabasis salsa* has a relatively low energy content.

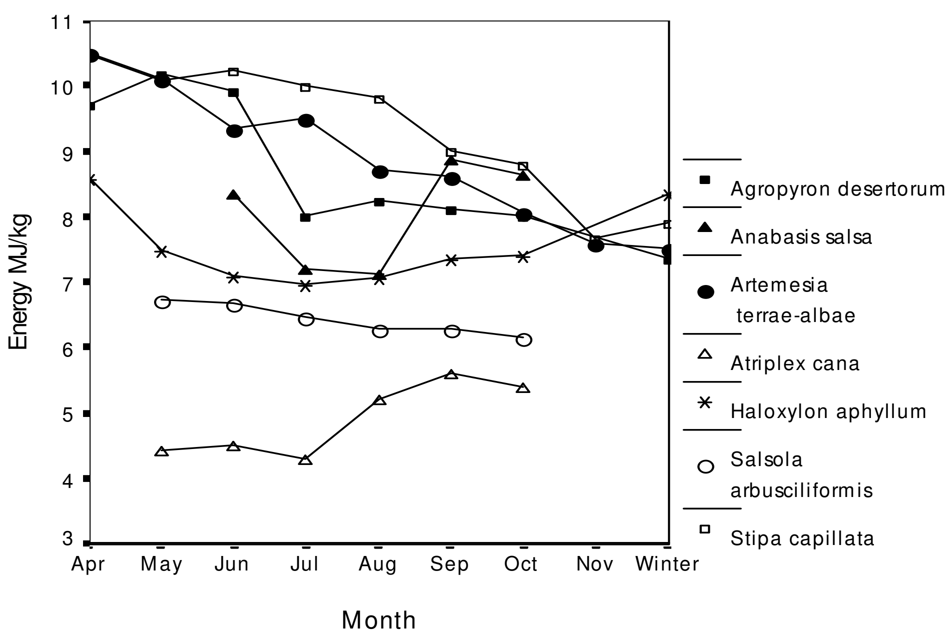
It was not possible to show a large number of plants on the graphs, however common species of *Artemesia* such as *A. pauciflora* and *A. sublessingiana* show patterns similar to that of *A. terrae-albae* (shown on the graph). *Festuca valesica* and *Stipa sareptana,* important components of the semi-desert and steppe zones, exhibit patterns similar to that of *Stipa capillata* (shown).

Figure 2.8: Digestibility and Energy contents of various steppe plant species over the year*. Source: Ospanova 1996. (a) Digestibility (b) Energy content.*

(a)



(b)



In spring and summer, those plants having the highest energy contents per unit weight are *Stipa capillata and S. sareptana, Festuca valesica, Artemesia terrae-albae,* and *A. Pauciflora.* The advantages of moving north in spring to areas dominated by these species can therefore be clearly seen.

Atriplex cana, Salsola arbusciliformis, Anabasis salsa, and *Haloxylon* species have low energy values. These are typical of dryer and more salty areas. Towards winter, however the absolute edibility of the latter of these two plants rises. The value of *Haloxylon* species as winter fodder is therefore due not only to their shrubby morphology, but also because they have high digestibilities at that time of year. *Anabasis* is small, and is not generally eaten when there is snow cover, even by horses (Ospanova 1996). Those plants with the highest protein contents (not shown) are the *Artemesia* spp., *Haloxylon* spp., and *Anabasis salsa*.

- *Selective grazing and changes in species composition*

Selective grazing can be extremely important to the herbivore feeding response: White (1983) has studied foraging patterns and their multiplier effects on productivity of northern ungulates. He has found that selective feeding which makes only very small changes in quality or amount of food intake may have much larger effects on animal production. Therefore the overall or average biomass and nitrogen content of the food is not necessarily indicative of forage quality. Scoones (1995) cites forage selection as the reason why potential carrying capacity of cattle in Zimbabwe is higher than official recommendations. He found that "Cattle populations are able to persist at high levels because of the availability of 'key resource' patches that provide forage at particular times of the year, and because of the ability to move adaptively between different portions of the landscape". Ridder and Bremen (1993) found that the nitrogen content of forage actually consumed by animals was always higher than the average nitrogen content of the pasture itself, however high that average may be. For this reason estimates of sheep intake based on the average digestibility of the pasture are likely to be underestimates. In the northern desert zone for example, annual species are always consumed first, followed by *Artemesia*, and then *Salsola* species (Zhambakin 1995). Preferences may vary between species, and this may lead to beneficial associations of herbivores (Short 1987, Gwynne and Bell 1968).

Digestibility and energy are not the only factors regulating forage selection by sheep. Some of the plant species mentioned above are not eaten at certain times of the year due to the accumulation of toxins or ash. For example, *Stipa sareptana* (very widespread) is harmful to sheep after flowering in June, as is *Stipa capillata*, which can cause skin and wool loss (*Kazgiprozem* 1988). *Artemesia terrae-albae*, *A. pauciflora*, *A. Lercheana*, and *A. turanica* and are not preferred forage species in summer, due to a build up of ether oils (Kirichenko 1980), and cows avoid *Artemesia terrae-albae* totally during this season (Ospanova 1996).

- *Vegetation structure*

It has been noted above that sheep intake plotted against pasture biomass plateaus off at very different levels according to the pasture. The differences between intake on Chenopod rangeland, which plateaus at a pasture biomass of 200-600kg/ha (Short 1987) and intake on sown temperate pastures which reaches an asymptote at biomasses of between 1700 and 2000kg/ha (Allden 1962, Willoughby 1959) are particularly striking. According to Short (1987) these differences are due to pasture structure. On the Australian rangelands the forage is tall and sparse, whilst on temperate pastures, it is short and dense, lowering intake rate, and making selection of green vegetation more difficult. Black and Kenney (1984) showed that at high herbage availabilities, the intake rates of sheep were several times higher when grazing tall sparse pastures than short dense ones.

Allden and Whittaker (1970) showed that tiller length is more related to plant intake than is actual biomass/ha, maximum intake being reached at a plant height of 20cm. Arnold (1975) found that food intake of sheep grazing pasture of *Phalaris tuberosa* and *Trifolium subterraneum* was depressed at leaf lengths below 10cm, and fell to 50% of maximum at lengths of 2.5cm. In some models (Freer 1997) pasture height is the major determinant of sheep intake along with digestibility, pasture biomass having a negligible effect (see Appendix 1).

- *Amount of Leguminous plants in pasture*

It is generally agreed that intake of leguminous plants by grazing animals is greater than that for grasses of the same digestibility. As is noted below, they also increase the efficiency of pasture use. An increase in the proportion of legumes from 0 to 30% can produce a 25% increase in weight gain (Freer *et al.* 1997).

- *Animal dependent factors*

Potential, or maximum intake is proportional to the mature size of the sheep breed type, its stage of development as it grows towards its mature size, and its condition. The first of these is known as the Standard Reference Weight (SRW) which is the live weight (excluding fleece and conceptus) of a ewe when skeletal development is complete, and condition score is in the middle of the range. The Normal Weight (NW) is the weight of an animal of a certain age in average condition. The actual weight (AW) is the real weight of the sheep, and may also be expressed as RW or weight relative to the normal weight. A sheep having high relative weight would be fatter than average for that age or frame size, and a low relative weight would apply to an animal weighing less than NW.

Most models to predict sheep intake reviewed in Elsen *et al.* (1988) predicted that the higher the NW or SRW of the sheep, the higher the intake. However the effects of changes in relative weight vary greatly between models. For example, for a given pasture availability and quality, a change in relative weight of -25% causes the intakes to drop, stay the same, or increase depending on the model! This depends whether the authors assume that at low relative weights the sheep have a greater intake capacity because they have to get themselves back up to normal weight, or whether they assume that thinner animals have a smaller rumen capacity, meaning that intake is lower. There is evidence for both effects in the literature, but there is not room to go into detail here.

During lactation, potential intake increases to an extent that depends on the stage of lactation, the potential yield of milk and the number of young, an increase which is related to changes in rumen capacity (Finlayson *et al.* 1992). The intake increases associated with lactation can be substantial. Arnold and Dudzinski (1967) showed that digestible organic matter intake increases by 40-45% in lactating ewes compared to dry ewes.

- *Summary of factors controlling intake*

This review has suggested that factors controlling sheep intake are numerous. The important question to ask is, given these different factors, what are the boundaries within which we can expect sheep intake to fall? The reason for asking this question is that here the aim is to look at whether overstocking would have been likely to occur on some of the study farms given knowledge about the grazing systems on those farms. Therefore, it is important to have estimates of minima, maxima, and 'likely' offtakes per sheep per day.

Elsen *et al.* (1988) reviewed 11 models, each of which predicts sheep intake according to a number (but not all) of the factors mentioned above. On good pasture with a non-limiting biomass of 2000kg per ha, and a high digestibility (77%), the average predicted offtake from the models for a sheep weighing 60kg, was 1.4kg DM/day. This dropped steeply with decreasing digestibility. In fact only one of the models reviewed predicted that sheep intake would ever exceed 2kg DM/day, under any circumstances. Compared to this Soviet estimates, averaging 2.5-3kg, appear to be extremely high indeed, and in some cases predict offtakes which are three times higher than those expected from Western estimates.

The reasons for this are probably as follows:

- Soviet predictions of sheep intake are based solely on the sheep's daily requirement of digestible matter.
- The required intake predicted from average pasture digestibility will be too high, as the digestibility of the biomass actually eaten is always higher than the average pasture digestibility.
- The digestible matter requirement is based on energy requirements which would correspond (according to AFRC 1993) to those of ewes under the demanding conditions of lactation, and so is in fact a maximum requirement. For most of the year sheep would need half this amount.

For the estimation and investigation of carrying capacities, intake should be predicted according to specific characteristics of both the pasture and the sheep. Such an exercise is carried out in Appendix 1. Here, a model predicting sheep intake is tested using parameters which apply to one test pasture (winter pasture on Zhetykonur sands). The maximum intake predicted from this model for a sheep weighing 40 kg on this pasture was 1 kg per day. The Soviet estimate on such a pasture would be 2.6 kg (Table 2.6). The effect of this difference on the analysis of carrying capacity and stocking rates will become apparent in the next section.

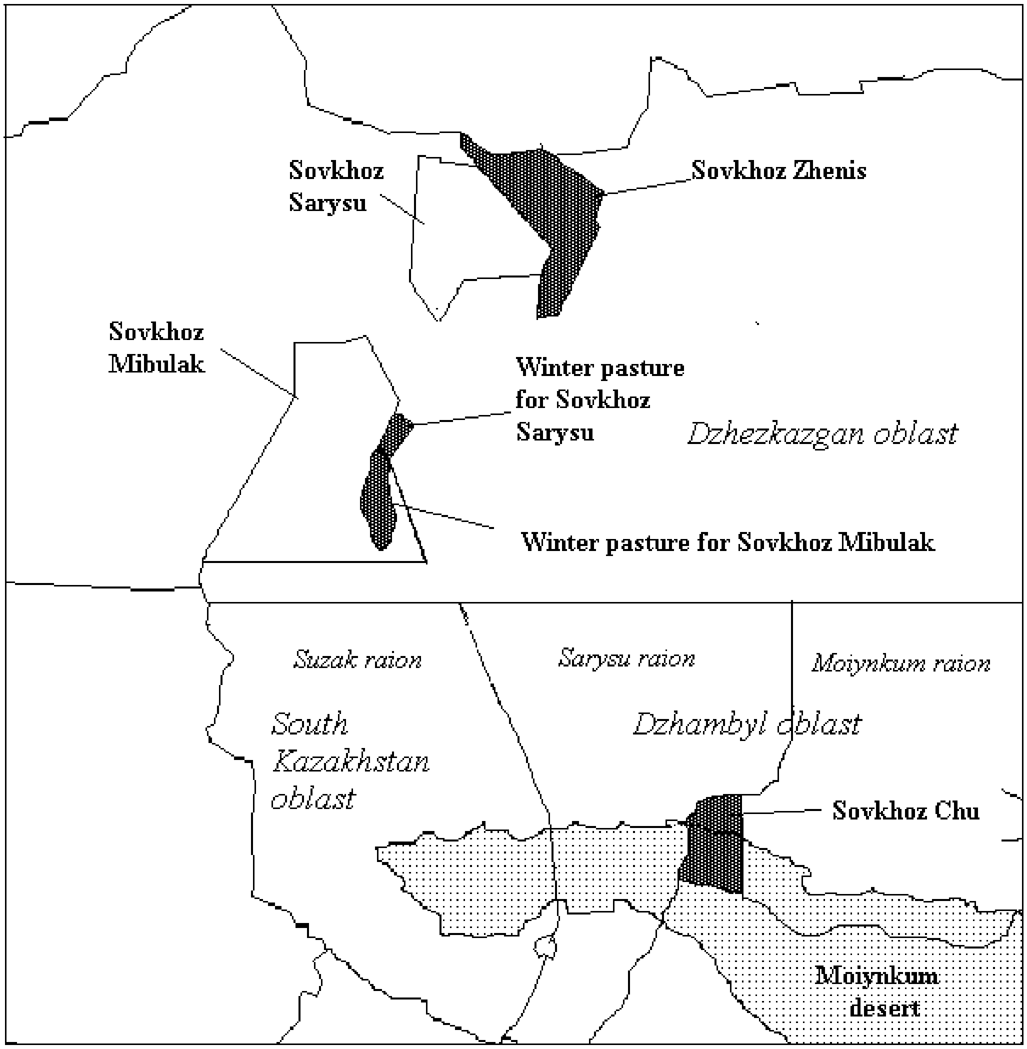
2.5: Comparisons of stocking rates and carrying capacities in the study area

In this section case studies of specific farms are used to compare likely offtakes by herds of sheep and forage availability on seasonal pastures during the Soviet period. The aim is to see if those areas where offtakes were highest correspond to those described as degraded in the literature.

2.5.1 Description of areas and observed state during fieldwork

The examples discussed here were chosen to represent those pasture types which had been described as degraded in the literature. Those chosen in Dzhezkazkgan *oblast* were visited with scientists from the Institute of Botany in 1998. For each area (except the Moiynkum desert) detailed information on stocking rates and vegetation yields (minimum, maximum, and average) were available. The areas chosen are indicated on the map of land degradation in Figure 2.2, and are shown here in Figure 2.9.

Figure 2.9: Map showing the position of example grazing areas within the study area *(dark shading).*



The Zhetykonur sands, winter pasture for *sovkhozes* Sarysu and Mibulak, was severely degraded according to Babaev (1985), especially around *zimovki* (Zonov 1974). The summer pasture of *sovkhoz* Sarysu was used only for one season (130 days), separate pasture areas being available for spring and autumn, whilst on neighbouring *sovkhoz* Zhenis it was used for three seasons (170-200 days) leading to degradation (Zhambakin 1995). The offtakes resulting from such three season grazing in this semi-desert zone are estimated below.

In the study area, the region which had apparently suffered from the most degradation was the Moiynkum sands. The information on pastures available for this region was rather sparse. However, a stock map of one farm having territory in the region, *sovkhoz* Chu (at Ulan bel' village, Moiynkum *raion*) was available, and stocking rates here were examined and compared to pasture availability.

The autumn-spring pastures along the river Chu were supposedly highly degraded (Babaev 1985, E. Rachovskaya pers. comm.). The case study of *sovkhoz* Chu is also used to study effects of high stocking rates in these areas. Since 1994, movement to summer pastures ceased entirely, leading to three season grazing of the *Artemesia-Salsola* pastures on all farms. The possible effects of this are also investigated with respect to forage resources.

Zhetykonur sands was visited with members of the Institute of Botany during an expedition to collect spectral ground data from steppe and desert plants in June 1998 (see Chapter 4). At this time much of the pasture had not been grazed for four years, and according to these workers the biomass compositions and yields were characteristic of those expected from healthy pasture in this area (L. Stogova pers. comm.). Areas in which vegetation cover was visibly degraded (denuded dunes) were observed only in one place, around the village of Akkense, an *otdelenie* of *sovkhoz* Mibulak (Figure 2.10a). Such areas are more likely to suffer from overstocking as this is where the inhabitants' personal stock were kept. These animals graze all year round, and have a certain area of land set aside for them, which supposedly is enough to support the numbers involved. However, it is likely that the numbers of private animals were much higher than those given in *Kazgiprozem* reports due to under-reporting. Denudation was also observed around the central village *sovkhoz* Zhenis (Figure 2.10b) but was not observed around other villages or *zimovki* of this *sovkhoz,* nor of *sovkhoz* Sarysu, although the areas along the river banks on these two farms are reported to be slightly overgrazed (*Kazgiprozem* 1981, 1988).
It was not possible to visit the Moiynkum sands or pastures along the river Chu during the botanical expedition of 1998, as these zones were closed during this period due to efforts to control the drug trade in this area.
Figure 2.10

2.5.2 Stocking rates and pasture in each study area

(i) Winter pasture on Zhetykonur sands (sovkhozes Sarysu and Mibulak)

This pasture area is located in the northern part of a sandy massif which is approximately 100 km long and 20 km wide. The vegetation is quite different from that of the surrounding clay desert, and is dominated by *Poa pratensis, Agropyron desertorum*, *A. fragile, Artemesia marschalliania* and *A. albicurata* (a photograph of this area is shown in Chapter 3, Figure 3.4).

According to interviews undertaken on *sovkhozes* Mibulak and Sarysu, the grazing period on Zhetykonur sands would have been from some point in November until early April, which is about 150 days. Of this time, much would have been spent indoors. According to Asanov *et al.* (1994) on winter pasture in that climate zone, between 85 and 95 days would have been spent outside, and 65-80 days would have been spent inside. This is similar to the answers given by shepherds in interviews, who said that they would only need to feed their animals on hay for two months of the year. According to *Kazgiprozem* (1988) on *sovkhoz* Sarysu average herd sizes were 750 head, and each had an area of winter pasture about 2300ha in size according to the *sovkhoz* map of pasture and wells. On *sovkhoz* Mibulak (*Kazgiprozem* 1985) each herd comprised 800 animals, and had about 2900 ha of winter pasture. Such figures for former herd sizes were also quoted in interviews.

During the winter there is little natural reduction in biomass. It tends to have reached a minimum by December and remains level due to the extreme cold. The minimum and maximum biomass yields of the vegetation in typical areas of the winter pasture were calculated from data in the botanical survey of *sovkhoz* Sarysu (*Kazgiprozem* 1988) as described in section 2.4.2 (ii). This gives an idea of the forage resources available in good and bad years. In this example minimum biomass is used (200kg per hectare) as the situation of interest is the worst case one.

These yields were also used as inputs into a model developed by Freer *et al.* (1997) to predict sheep intake, along with many other factors describing both the pasture, and the sheep. This is described in full, with a sensitivity analysis, in Appendix 2. Given the information known about the pasture and the sheep, the maximum intake was predicted to be 1kg per day (the prediction given the most probable set of parameters was in fact 0.88kg per day).

According to these figures, a herd of 750 animals will eat 67.5 tonnes of dry matter in the three months of grazing, which is 14.6 % of the total forage available. In some cases two herds were kept at the same *zimovka*, so that sheep numbers would have been 1500 head. This would have brought up the pasture offtake to 30%. However this is still very low given the proper use factors normally quoted by Soviet scientists. The elements of the grazing system, and predicted offtakes are summarised in Table 2.8.

Table 2.8: Pasture and stocking information for winter pasture on Zhetykonur sands. *The example here is for sovkhoz Sarysu.*

Variable	Estimate	Source
Herd size	750	*Kazgiprozem* (1988), interviews
Area per herd (ha)	2300	*Kazgiprozem* (1988)
Area per sheep (ha)	3.1	
Grazing period (days)	90	Asanov *et al.* (1994), interviews
Max Offtake per sheep/day (kg)	1	Freer *et al.* (1997) (Appendix 2)
Offtake per herd /month (tonnes)	22.5	
Offtake per herd in grazing period	67.5	
Min Biomass/ha (kg)	200	*Kazgiprozem* (1988)
Total forage available (tonnes)	460	
Total offtake by herd over grazing period (% of available forage)	14	

(ii) Spring-summer-autumn pasture in the semi-desert zone (sovkhoz Zhenis)

The vegetation on this pasture is mostly dominated by *Artemesia terrae-albae*, *A. lercheana, Atriplex cana, Stipa* and *Festuca* species. Here again we look at the worst possible grazing scenarios in order to see in what circumstances the offtake would have been too high. This case is not as simple as the above for winter pasture, as from May to October there are die-off processes occurring whose effects are much more significant than those occurring in winter.

The grazing period on this farm was from the 1st May to the 15th October, corresponding to 175 days (*Kazgiprozem* 1981). During this time the stock would have been on pasture only, with no access to other feeds or crop residues. Biomass changes considerably during this time period due to vegetation die off. Minimum biomass values for each month were taken from the data of Koktas meteorological station (Table 2.3). These were adjusted for each month for offtake in previous months.

Intake was taken to be 1.4 kg per day per sheep. This was the average of predictions of 9 models (in Elsen 1988) for sheep weighing 50kg (12 kg heavier than the average for Zhenis), on good pasture with 75% digestibility (probably unrealistic after May). Such an intake also corresponds to that the upper limit of an intake for a sheep weighing 50kg described by Short (1987), and therefore is almost certainly an overestimate. The offtake for the whole herd in each month is taken as: 1.4 kg x 900 sheep x 30 days = 37.8 tonnes. The information available for this pasture is summarised in Table 2.9.

Table 2.9: Pasture and stocking information for spring-summer-autumn pasture on sovkhoz Zhenis.

Variable	Estimate	Source
Herd size	900	*Kazgiprozem* (1981)
Area per herd (ha)	2800	
Area per sheep (ha)	3.1	
Grazing period	1 May - 15 Oct (170 days)	*Kazgiprozem* (1981)
Offtake per sheep/day (kg)	1.4	Elsen *et al.* (1988), Freer *et al.* (1997), Short (1987)
Offtake per herd/month (tonnes)	37.8	
Biomass	Calculated per month - See Table 2.10	Koktas Meteorological station, *Kazgiprozem* (1988)

Table 2.10 shows the expected forage availability and offtake around one well, in each month, for a year in which biomass is low (minima of 30 years data from Koktas meteorological station). The expected offtakes are shown in percent of available forage, each herd having access to about 2800 ha of pasture in this season.

The amount of pasture removed by the end of the growing season is not simply the sum of offtakes in preceding months, as in this case, vegetation loss would be counted twice, once as offtake, and once as die-off. The offtakes in previous months are therefore corrected for die-off by reducing them at each time step by the amount which would be expected to have been lost calculated from the ratio of vegetation available in a given month, to that of the month before. This does not apply to the first time step from May to June, as vegetation was still increasing at this time. In May, although offtake is calculated, it is possible that in fact no vegetation reduction occurred. This is because according to Zhambakin (1995), low offtake during growth does not reduce vegetation, and indeed can cause an increase in productivity.

Table 2.10: Pasture availability and offtake over an average and a poor growing season on sovkhoz Zhenis. *Figures given for biomass are averages for each month.*

Month	**Minimum biomass (kg / ha)**		**Total resources at a 3km radius from the well (tonnes)**		**Pasture after offtake**		**Pasture removed as percent of pasture expected for that month.**	
Type of year	Poor	Av.	Poor	Av.	Poor	Av.	Poor	Av.
1. May	180	290	504	812	466.2	774.2	7.5	4.7
1. June	410	650	1148	1820	1072.4	1744.4	6.6	4.2
1. July	330	560	924	1568	855.7	1497.6	7.4	4.5
1. August	300	500	840	1400	737.4	1295.8	12.2	7.4
1. September	290	430	812	1204	672.8	1067.3	17.1	11.3
1. October	200	370	560	1036	394.8	866.8	29.5	16.3

By October of a poor year, 30% of the pasture has been removed, taking die off into account. This is about level with the Western estimates of proper use factors, but much lower than the Soviet estimates for such pasture (60-70% according to Zhambakin 1995). For a year of average rainfall, the offtake by October is 16%, easily inside all estimates of permissible levels. Due to die off, the effects of grazing on the pasture increase exponentially over the season. Therefore, moving the sheep in October, as was done on *sovkhoz* Sarysu, was probably beneficial for the animals. According to the data from the Koktas meteorological station (Chapter 3, Figure 3.15 (f)), peak biomasses of less than 500kg/ha occur in this region about once every 14 years.

It therefore seems likely that if sheep really did go up to 3km from wells, then a herd of 900 should have minimal effects on the herbage, even under prolonged grazing. If the sheep were eating 2.5kg/day, as suggested by the Soviet literature, then the figures are very different. The overall offtake in a bad year would indeed have reduced the pasture to way below the proper use factor. However, as discussed here and in Appendix 2, it seems extremely unlikely that the sheep really were eating this amount.

On *sovkhoz* Zhenis, interviews were carried out with two families in 1997. These families were still working for a co-operative, and pastured herds of 300 sheep, plus their own private animals (equivalent to the same again in stock units). They had stayed on the *zimovka* until June, only moving to summer pasture after shearing. Such practices are becoming more common in the study area, and could be destructive. This is because according to Zhambakin (1995) it is offtake before April which has the most effect on later growth and development of the plants, and normally sheep should be moved off the pasture after this time. However with ever decreasing stock numbers this is perhaps unlikely to be a problem at present.

(iii) Winter pasture in the Moiynkum desert (sovkhoz Chu)

The information available for *sovkhoz* Chu was in the form of a land use map showing stocking rates (*Kazgiprozem* 1992). No botanical map was available, and so information was very general. Zhambakin (1995) suggests that biomass levels in the desert in the winter range from 70 to 200 kg per hectare according to vegetation type. Interviews were not conducted with shepherds in this area. However according to Asanov (1994) and Zhambakin (1995) on such massifs in the desert zone the sheep would have spent only one month indoors. Here herd sizes were huge, comprising 3000 animals, yet grazing areas were only 4500 ha, giving a stocking rate of 1.5 ha per animal.

The offtake was estimated to be 1.4 kg per day per sheep. This may seem rather high for winter pasture. However the digestibility of *Haloxylon* species in winter is high (>60%), and in any case, here we are looking at cases of maximum offtake. Table 2.11 summarises the information for this pasture.

Many of the factors in Table 2.11 are only guesses. For example, it is quite possible, in the case of poor nutrition due to exhaustion of natural forage, that sheep would have been kept indoors for an increasing length of time. For example if the sheep are kept on pasture for only 100 days, or have an intake of 1kg per day, offtake over the season would fall to 30-45%. However, it is undeniable that stock densities were very high, and livestock farming probably had a greater impact in this area than in the example areas in Dzhezkazgan *oblast*, and unlike them, in the scenarios presented, offtake figures approach or exceed those which would constitute overstocking. Another factor which may be important in certain years is the presence of saiga antelope. According to Fadeev and Ivanov (1988), in their winter range, saiga herds may consume 35-44 kg/ha of forage. In *dzhut* years these animals cross the river Chu to spend the winter in the Moiynkum desert and in such situations the effects of grazing on the vegetation in this area may have been particularly severe.

However, predictions of forage shortfalls may have been exaggerated. For example, Zhambakin (1995) estimates that there is a forage availability of 100kg digestible matter per hectare in the Moiynkum desert (200kg biomass with an average digestibility of 50%). Each sheep needs 1.2 kg of digestible matter per day, and will remain on the pasture for 140 days, therefore over winter it needs 168 kg digestible matter. The stocking rate is 1.2 ha per sheep, so each sheep has 120 kg digestible matter at its disposal. Therefore, over the winter only 71 % of its needs are met by natural pasture. Western estimates of digestible matter requirements per day are between a third and half of this, and therefore if these estimates are used shortfalls in forage availability are not predicted.

Table 2.11: Pasture and stocking information for winter pasture on the Moiynkum desert.

Variable	**Estimate**	**Source**
Herd size	3000	*Kazgiprozem* 1992
Area per herd (ha)	4500	*Kazgiprozem* 1992
Area per sheep (ha)	1.5 (1.2)*	
Grazing period	120 days outdoors, 30 days indoors (mid Nov - beginning of April)	Asanov 1994 Zhambakin 1995
Offtake per	1.4	

sheep/day (kg)		
Offtake per herd/month (tonnes)	126	
Biomass	200kg / ha (maximum)	Zhambakin 1995
Offtake at 1.2 ha per sheep	83%	
Offtake at 1.5 ha per sheep	56%	

** The estimate of 1.5 ha per sheep is for Sovkhoz Chu. The average area of pasture per sheep on the desert was 1.2 ha (Zhambakin 1995).*

E. Morgan (pers. comm.) has reported that some families from *sovkhoz* Chu are now grazing their animals all year round on the Moiynkum sands. However they have fewer than 100 sheep, and a few cows and horses. There are no settlements other than isolated *zimovki* on the sands, so the problem of overstocking of personal animals around villages has not occurred.

(iv) Three season and autumn grazing in the desert zone (sovkhoz Chu)

I. Alimaev (pers. comm.) has suggested that in the 1970s and 1980s some farms in Dzhambyl and South Kazakhstan *oblasts* had stopped sending their animals into Sary Arka and instead were pasturing their animals all year round on autumn pasture on state reserve land in Dzhambyl *oblast* (see Figure 1.6). However, of the thirty farms along the river Chu for which information was collected, only 5 fell into this category. Stock from *sovkhoz* Chu continued to go to Sary Arka in summer, however stocking rates on the autumn pastures were extremely high (*Kazgiprozem* 1992). Possible effects of these stocking rates are investigated.

Since 1994 most animals which are left on the farms in this area are being pastured for three seasons on such pasture. For example E. Morgan (pers. comm.) has reported that in 1999 most stock on *sovkhoz* Chu were being pastured round the village, or in areas 50-60km north of it for three seasons, from April to October, with herd sizes of 100 to 400 sheep. Effects of such grazing regimes on the pasture are analysed first.

Such pasture in the south of Betpak-dala is dominated by *Artemesia* and saltwort species such as *Artemesia terrae-albae, A. turanica, A. pauciflora, Salsola arbusciliformis, S. rigida, Atriplex cana,* and *Anabasis salsa.* The biomass variability of these species in the desert zone (at Betpak-dala meteorological station) has been studied by Kirichenko (1966), and is explored in full in Chapter 3. The data of this author provides estimates of biomass over the growing season in good and average to poor years, in particular for the dominant pasture type, made up of *Artemesia terrae-albae* and *Salsola arbsuciliformis* associations. Data are also available from a meteorological station on the farm itself, Ulan bel'.

Table 2.12 below shows the biomass available in each month in an average and dry year (Average year 1959, dry year 1960 (Kirichenko 1966)), and the offtake by a herd of 400 sheep.

It is clear that in bad years small herds of 400 would only start removing appreciable levels of pasture in October (40%), and this is still below the maximum permissible removal suggested for autumn pasture by Kirichenko (1980), of 55%. However the poor year shown here is probably not representative of the worst situations which could occur.

Table 2.12: Results of spring-summer-autumn grazing on northern desert pastures by small herds of 400 sheep. *Biomass data from Kirichenko (1966).*

Month	Biomass (kg DM / ha)		Total resources at a 3 km radius around well (tonnes)		Cumulative offtake (tonnes)		Forage available after offtake		% offtake	
Type of year	Av.	Poor	Av.	Poor	Av.	Poor	Av.	Poor	Av.	Poor
May	630	310	1764	868	16.8	16.8	1747	851	1.0	1.9
June	310	260	868	728	25.1	30.8	842.9	697.1	2.9	4.2
July	250	140	700	392	38.6	39.9	661.3	352	5.5	10.2
August	150	101	420	283	48.7	52.1	371.3	230.7	11.6	18.4
September	100	90	280	252	59.9	67.0	220.1	185	21.4	26.6

October	90	70	252	196	75.0	80.1	176.9	155.9	29.8	40.9

A frequency distribution for peak biomass of *Artemesia-Salsola arbsuciliformis* pasture (Chapter 3, Figure 3.13 (d)) constructed from a statistical model, suggests that biomasses of less than 400 kg/ha can be expected to occur once every five years at Betpak-dala meteorological station which is about 150km north of *sovkhoz* Chu but has similar annual rainfall.

Communities dominated by *Salsola arbusciliformis* have the highest yields of all vegetation types investigated, and exist at *sovkhoz* Chu according to the biomass data. Rainfall-biomass relationships developed in Chapter 3, and long term rainfall data suggest that biomasses of less than 400 kg/ha occur roughly every six years. Data on this community presented in Belobordova (1964) and the meteorological data itself both show that peak biomass can be as low as 170 kg/ha (occurring once in 30 years). According to die off models discussed in Chapter 3, in such years, biomass would probably be below 100kg/ha by July.

At Ulan bel' meteorological station on the *sovkhoz* itself, the association measured was one of *Artemesia* species and *Ceratoides papposa*. Relationships between the biomass data and rainfall at Ulan bel' meteorological station suggested that for this vegetation type, peak yields of 200 to 250 kg/ha could be expected to occur roughly once in seven years (see Chapter 3, Figure 3.13 (b)). Therefore the 'poor' year in Table 2.12 is not as low as is possible for the *sovkhoz* in question. The biomass data from this *sovkhoz* are not consistent over individual seasons, so die-off could not be estimated, however, years when peaks are lower than those shown in Table 2.12 would probably result in overgrazing even by herds smaller than 400 sheep.

From this it is clear that only very small herds can graze on such pasture for three seasons, and certainly during Soviet times when herds were never smaller than 750 sheep, damage would probably have been considerable (for the example years given above, offtake would have been 55 and 76% for the average and poor years respectively). There is evidence that a few farms did indeed pasture their herds in this region for three seasons but it is not clear whether they changed wells during this period.

In the example ‘poor year’ in Table 2.12, if the autumn pasture was ungrazed until October, as it would have been on *sovkhoz* Chu until 1994, removal in this month by such herds would only constitute 6% of the biomass, however, on *sovkhoz* Chu the herds were much larger than this. Herds of 2800 animals were apportioned only an average of 1800 ha, or 0.64ha per sheep. If the biomass was 100 kg/ha at the start of the month, by the end such herds could have removed 68% of it. In most years biomass in October was probably lower than this. The same areas were used in spring, but in this case offtake over one month would have been 20%, or probably higher as the sheep were lactating. Of all the areas looked at here, these seem to be the most susceptible to degradation given the stocking rates described, and if such stocking rates were common on farms along the river Chu, then it is clear why such pasture was degraded, even disregarding those farms which had stopped sending stock to Sary Arka in summer.

2.5 Summary and conclusions

Before the Soviet period the factors limiting numbers of livestock and wild ungulates were similar. Foremost amongst these were *dzhuts* which caused animal numbers to fluctuate over 10 -12 year periods with crashes of 30 -70% of the population in severe years. From the evidence discussed in this chapter droughts appear, at least in wild ungulates, to cause infertility, embryo absorption, and death of calves. They do not seem to result in mass mortality of adults. The effects of drought on domestic livestock are less clear and further research is needed.

During the Soviet period, winter fodder provision eliminated limits to stock numbers imposed by *dzhuts*, and animal density rose. The effects of this on stock and pasture productivity were explored in this chapter. The increase in stocking rates over the 1970s and 1980s coincided with a decrease in sheep live weight and birth rates, and an increase in death rates. During this time meat production continued to rise, and although it faltered during the drought years of the early 1980s there is no evidence to link these two events. Therefore it appears that whilst sheep densities were affecting production per animal, they did not appear to be affecting total meat production.

There is a lot of literature on land degradation resulting from overstocking, and according to many authors, 60% of Kazakhstan's arid and semi-arid rangeland suffers from this problem. However, according to Kharin (1986), the degradation types affecting much of this area (yellow regions in Figure 2.2) were in fact described as simply as changes in vegetation composition, leading to the establishment of associations which were still productive and stable, but which probably included a greater proportion of annuals and inedible species. Whilst this might be described as degradation by botanists (e.g. Kirichenko 1980) who describe deviations from 'climax' ecosystems, it was probably not, in its first stages, a serious problem for the livestock sector and would not constitute degradation according to the definitions described in the introduction.

The sequential changes in species composition described (Kirichenko 1980, Bykov 1985,) generally take the form of an invasion of annuals such as *Alyssum desertorum*, *Ceratocarpus arenarius*, *Poa bulbosa,* and in the final stages by inedible plants, (e.g. *Anabasis aphylla, Peganum harmala).* All stages are accompanied by some loss in productivity. Some Soviet authors, such as Bykov (1985) would not classify pasture which had undergone small species changes and losses in productivity of up to 25% as overgrazed. Those final stages in which the dominant *Artemesia* was destroyed are described as serious degradation by all authors due to the loss of productivity and damage to soils such as lowering of humus and nitrogen contents (Asanov *et al.* 1992, Zonov 1974, Dzanpeisov *et al.* 1990) and reduced ability of soil to absorb and store moisture (Asanov *et al*. 1992). Such pastures needed long recovery periods of over 10 years (Bykov 1985, Kirichenko 1980, Asanov *et al.* 1992). Such degradation would certainly be serious according to our definition of land degradation as being a reduction in productivity, but it was difficult from the literature to establish its real extent.

Large decreases in biomass are described by (Kirichenko 1980, Bykov 1985, Kharin 1985, Dzhanpeisov *et al*. 1990) and occur mostly around wells and settlements (Zonov 1974, Dzhanpeisov 1990) although total denudation over large areas is said to be rare (Kharin *et al*). Deflation is observed, in sandy areas, but again this is only found close to camps and winter houses (Dzanpeisov *et al.* 1990).

The three types of pasture which appeared to be most susceptible to more serious degradation were winter pastures on sandy soil, due to high stocking densities in these areas, as well as pastures which were used for spring, summer, and autumn, and in some cases, spring-autumn pastures in the northern desert zone. Stocking rates on areas corresponding to these types were examined and pasture offtake predicted for 'worst case' situations given the available information.

It appears that even taking the worst scenarios (largest possible herd sizes, drought years, and conservative estimates of available hectarage per herd), the offtakes of winter pasture on *sovkhoz* Sarysu, or spring-summer-autumn pasture on *sovkhoz* Zhenis would have been too low to cause damage to the pasture, and this seems to be confirmed by the good condition of these pastures observed in 1998. The state reserve land in Dzhezkazgan *oblast* was only ever used for one month at a time, and there was no evidence for degradation, neither in the literature, nor from the 1998 field trip. Therefore it would appear that the rangelands in the north of the study area are in good condition.

Although damage to the plants does not seem to occur under the conditions experienced here, that does not mean that the regime was not damaging for sheep productivity. Quantities of the most digestible plant matter could have been reduced, especially on winter pastures, to levels at which intake was too low to prevent weight loss.

The winter pastures of the Moiynkum desert are the most degraded in the study area according to the literature. The information that could be gathered was scant, however, it did seem that stocking rates could have come close to those which would have caused unacceptable offtakes. The *Artemesia-Salsola* pastures of Southern Betpak-dala seem to have been very highly stocked, and even one month on such pastures in October would have resulted in vegetation damage given the stocking densities existing on *sovkhoz* Chu. From biomass data for years of low rainfall, it can be estimated that three season grazing here is only possible with flocks of 400 or fewer sheep.

One problem with trying to estimate the effects of grazing from simple offtake values is that at certain times of the year, vegetation is much more susceptible to damage than at others. For example, some of the literature described here suggests that putting stock on the spring-summer-autumn pasture in early March is much more damaging than in mid-late April. According to Zhambakin (1995), this is a major reason for land degradation in Kazakhstan. However, in the case studies here, in the examples where pasture was used for three seasons, they arrived on it in late rather than early spring, and most had separate lambing areas used only for a few weeks.

One of the points highlighted in this chapter is the variability in predicted forage availability and pasture damage caused by the estimates of sheep intake. Soviet intake estimates for sheep were more than double Western ones, and choosing an estimate of 1-1.4kg per day, rather than 2.5-3 kg per day, often makes the difference between the conclusion that stock levels are safely below CC, or way above it. Of course, the only real way to assess land degradation is to monitor pasture transformation under grazing. However, some of the dire forecasts of degradation and forage shortfalls based on stocking rates may have been exaggerated.

Given the low numbers of stock present today in Kazakhstan, overstocking seems to be an unlikely prospect for the near future. However there has been an increasing tendency to pasture animals for three seasons, or even all year round on the same pasture. This is likely to have the greatest impact on the *Artemesia*-saltwort pastures of the northern desert zone. These pastures may have peak biomasses lower than 200kg/ha, and in drought years pasture can reach critically low levels by July.

Chapter 3: The prediction of biomass from rainfall

Long term biomass data are available for various regions of Kazakhstan. These data were investigated with respect to rainfall in order to understand how variability in rainfall might affect variability in biomass production in different regions. The reasons for doing this are two fold:

1. **By looking at biomass data it is possible to analyse forage availability, and perhaps more importantly, its variability, between and within years. Such information is useful to the work in Chapter 2 of this thesis, in which carrying capacity is investigated, because it allows us to predict the frequency of occurrence of very low biomasses, when forage might be limiting.**

2. **The biomass data were taken in exclosures, and thus were ungrazed. For this reason it is interesting to look at patterns of biomass change to compare with patterns of change in NDVI (see Chapter 4), which is available over the whole of Kazakhstan. For example, a cessation of grazing over large areas, such as has happened in the last few years, might lead to an increase in NDVI. This increase would probably not occur in exclosures, which had never been grazed.**

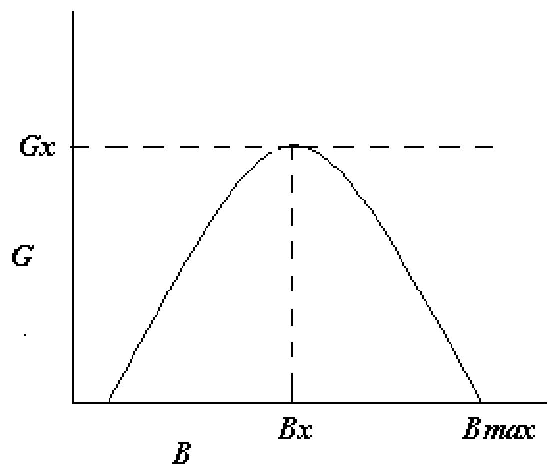
3.1 Factors affecting biomass production

The factors influencing the amount of biomass at a given time are temperature and rainfall over some period prior to the biomass measurement, and the phenology of the plants.

3.1.1 Growth of vegetation as a function of standing biomass:

Growth is assumed to be convex with a single maximum, as is shown in Figure 3.1 below (after Noy-Meir 1975). The increase in the low biomass range represents an increase in photosynthetic activity with increasing leaf area. At *Bmax* maintenance losses equal photosynthesis, and net growth is zero. This may be reached due to 'self interference effects' described by Noy-Meir to include competition and shading, or it could be due to the fact that the plant is entering the reproductive phase of its life cycle, and has therefore stopped investing in photosynthetic material.

Figure 3:1 Growth of vegetation (G) as a function of plant biomass (B). *Source: Noy-Meir 1975. Bx is the biomass at which growth is maximal, Gmax is the maximum growth rate.*



3.1.2 Vegetation responses to rainfall

Rainfall is the main factor affecting biomass production in semi-arid and arid environments and has been used as a single predictor of biomass in many temperate ecosystems (Le Houérou 1984, Murphy 1970, Sneva and Hyder 1962).

The modelling of biomass production from rainfall ranges from very simple response curve models (Robertson 1987, Sneva and Hyder 1962) to more complex models involving parameters such as evapotranspiration, soil water capacity, runoff, and crop coefficients (e.g. Bonifacio *et al.* 1993, Hobbs *et al.* 1994, Pickup, 1995). It has been suggested that actual evapotranspiration is the best single predictor of the productivity of an ecosystem because it is a combined measure of available moisture and solar energy (Rosenzweig 1968). However it was not possible to use it here as these data were not available. Therefore here rainfall has been used as the principal predictor of productivity, which is this case is defined as aerial biomass.

Le Houérou (1984) notes that over 100 studies have shown relationships between NPP (Net Primary Productivity) and annual rainfall, although these relationships usually use average annual rainfall for several sites rather than rainfall over the years for one site. Single site NPP predictions from rainfall have been constructed however. Robertson (1987) measured biomass in plots excluded from grazing every three months for four years at several sites in the Kinchega National Park in Australia. He looked at relationships between both rainfall and standing biomass, and rainfall and biomass growth. The best predictor of standing biomass was that of rainfall six months before each biomass measurement (R^2=0.7, n=19, P<0.001). Robertson also found that 97% of the variability in pasture growth measured at 3 monthly intervals could be accounted for by biomass at the beginning of each 3 month period, and rainfall during the 3 month period (statistical details not given). In this case, rainfall was the more powerful predictor, accounting for 83% of the variance when growth was regressed on it alone Rainfall predicted growth (increase over the 3 months) better than it predicted simple biomass yield.

This illustrates that, in certain cases it is possible to obtain robust predictions of biomass or biomass growth using only rainfall and biomass data such as those available for Kazakhstan. However, it must be noted that this model is for tropical grasslands, in which plant growth is not limited by radiation, and so the growth response less affected by season. In Kazakhstan, relationships between rainfall and growth would only be found between April and October, as in all other months the average temperature is below 5 degrees, the thermocline for zero growth. Although in the study by Robertson (1987), soil type was seen to have a very weak effect on the response, this may not be true for Kazakhstan. Robertson (1987) also showed that vegetation type could have an effect on overall biomass production, so that results might not be extrapolated to large areas.

Dieback would be expected to be linked, not only to a lack of rainfall, but also to the life cycle of plants. For example, many grass species start to put more resources into seeds towards the end of the growing season, and the green parts start to die back and dry off as part of the normal life cycle of the plant, independent of rainfall. This phenomenon occurs everywhere, but probably to a greater extent in Kazakhstan given the extreme seasonality of the climate.

3.2 Biomass and rainfall patterns in the study area

3.2.1 Availability of data

For the study area, or regions close to it, long term rainfall data were available for six stations. They were available for a further four stations (Turkestan, Karaganda, Balkhash, and Kyzyl-Orda) for surrounding areas. The geographical positions of these stations are shown in Figure 3.2.

Patterns of plant species distribution in the study area were described briefly in section 1.1. To generalise, at the latitude of meteorological stations Tasty and Ulan bel' the vegetation is dominated by species of saltwort such as *Anabasis*, *Atriplex* and, in particular, *Salsola* spp. *Artemesia* species such as *A. terrae-albae* and *A. turanica* are also common, and become increasingly dominant towards Betpak-dala meteorological station. Further north other *Artemesia* species appear, and become increasingly mixed with grass species north of Koktas meteorological station and in elevated areas. Figures 3.3. and 3.4 show photographs of some of the typical vegetation types in the south of the study area (desert zone) and the north of the study area (semi-desert zone). The photographs in Figure 3.3 were mostly taken south west of Betpak-dala meteorological station. Those in Figure 3.4 were taken further north, except for 3.4c which was taken on Zhetykonur sands. Although this area is in the desert zone, the sandy soils mean that the vegetation there resembles that of more northerly areas, being dominated by grass species rather than *Artemesia*.

Biomass data were available at six of the meteorological stations, whose locations and annual rainfalls are shown in Table 3.1.

Figure 3.3

Figure 3.4

Figure 3.2: Map of meteorological stations in the study area

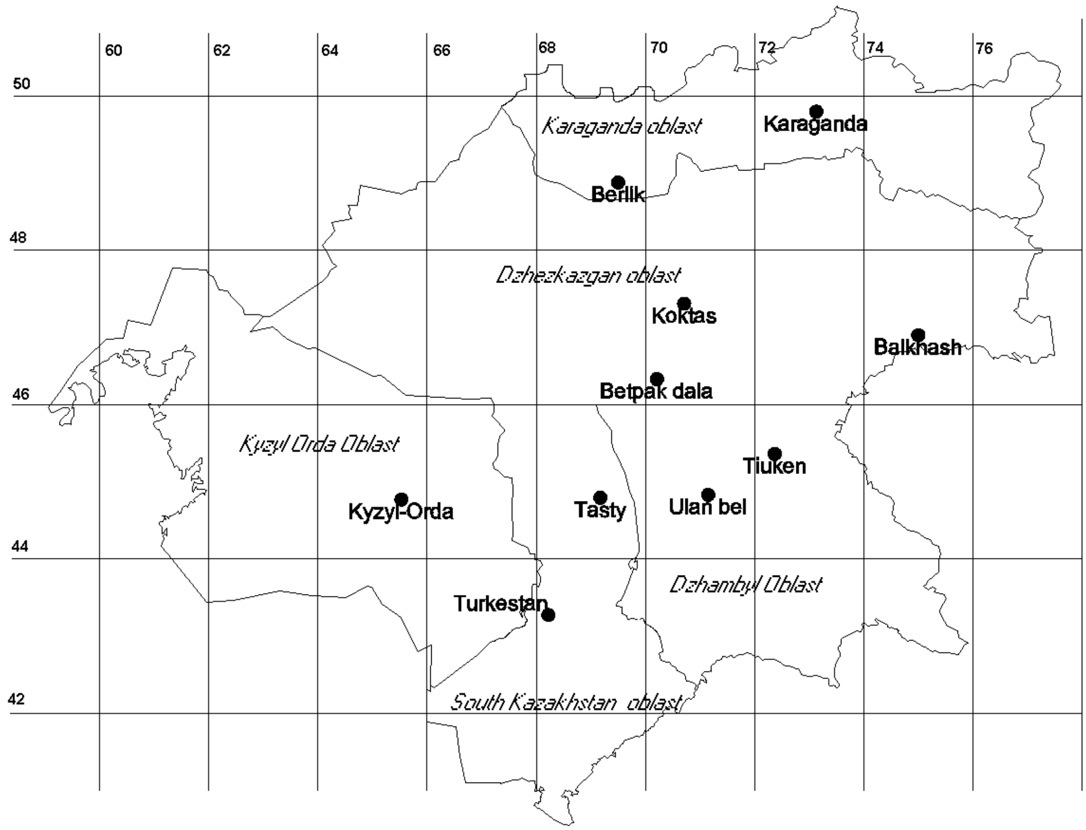


Table 3.1 : Location of meteorological stations and their average annual rainfall.
Averages are from 30 years of data, 1967 to 1997.

Station	Longitude of station	Latitude of station	Long term average rainfall (mm)
Tasty	69.17	44.79	152.9
Ulan bel'	71.14	44.82	155.6
Tiuken	72.36	45.35	142.0
Betpak -dala	70.20	46.33	152.0
Koktas	70.70	47.31	203.7
Berlik	69.49	48.88	220.2

As well as biomass data from the meteorological stations, data were also collected near Betpak-dala meteorological station in the 1950s and 1960s by Kirichenko (1966). These data, although they only exist for four years, are much more thoroughly described than the data collected at the meteorological stations, as biomass is given by species, and five different vegetation types are sampled. The data were collected between 1958 and 1961 in an area which had not been subject to grazing. Of these years, 1958 was exceptionally wet, and the others had annual rainfalls close to average. However, the spring of 1959 was very dry, resulting in low productivity, and that of 1961 was exceptionally wet, resulting in high biomass (Kirichenko 1966). Therefore over the short time period there was a wide range of winter-spring rainfall. The methodology used was to cut biomass every 20 days under four quadrats each of 1 x 2.5 m^2 for each of the five vegetation associations. In the case of shrubs and semi-shrubs only leaves and shoots of that year were cut. The biomass and rainfall data used in this chapter, and its sources, are summarised in Table 3.2.

3.2.2 Problems with biomass data from Meteorological stations

The biomass collected at the meteorological stations is supposed to be collected by workers according to the methods outlined in a manual for the study of pastoral agriculture (*Praktikum po pastbishomu khosyastvo*, Asanov *et al.* 1994). According to this, for each pasture type, biomass is cut under four quadrats 1 x 2.5m in size, placed to represent 'typical' areas of the pasture type in question. The biomass cut from shrubs and semi-shrubs is supposed to be from that year's growth only.

In reality, the data collection methods may have been quite different. The data were collected by workers at the meteorological stations, none of whom were trained scientists. The biomass was cut in permanent exclosures of 100 x 100m. Every *dekad* (Russian term for a ten day period) only 2-3 m^2 were cut from different places in the exclosure. As cutting biomass from shrubs is extremely time consuming, it is possible that branches, or even the whole shrub may be removed and weighed, leading to overestimates of biomass.

Table 3.2: Sources of biomass and rainfall data for the Betpak-dala region. *The figures given for the contribution of plant species to total biomass apply only to the dominant (first) species given.*

Source of rainfall data	**Source of biomass data**	**Region, and description of community**
Tasty Meteorological station	Tasty Meteorological station	Desert region *Artemesia terrae-albae,* Saltwort spp.
Betpak-dala Meteorological station	Betpak-dala Meteorological station	Desert region ~80-85% *Salsola arbusciliformis, Artemesia terrae-albae*
Betpak-dala Meteorological station	Kirichenko (1966) Community 1	Desert region 69-80% *Salsola arbusciliformis, Artemesia terrae-albae*
Betpak-dala Meteorological station	Kirichenko (1966) Community 2	Desert region 75-95% *Artemesia terrae-albae, A. Turanica, Salsola rigida*, grass species.
Betpak-dala Meteorological station	Kirichenko (1966) Community 3	Desert region 82-92% *Salsola arbusciliformis, Artemesia*, grass species
Betpak-dala Meteorological station	Kirichenko (1966) Community 4	Desert region 72-92% *Atriplex cana, Artemesia pauciflora*, grass species
Betpak-dala Meteorological station	Kirichenko (1966) Community 5	Desert region 84-97% *Anabasis salsa*, *Nanophyton erinaceum*
Tiuken Meteorological station	Tiuken Meteorological station	Desert region *Artemesia* spp., *Kochia prostrata, Ceratoides papposa*
Koktas Meteorological station	Koktas Meteorological station	Semi-Desert region *Artemesia* spp., *Stipa* spp.
Berlik Meteorological station	Berlik Meteorological station	Semi-Desert region *Artemesia* spp., *Stipa* spp.
Ulan bel Meteorological station	Ulan bel Meteorological station	Desert region *Artemesia terrae-albae, Salsola arbusciliformis, Ceratoides papposa.*

The meteorological station biomass data suffers from serious inconstancies in collection. At some stations, the thirty year data set suffered from sharp increases and decreases in biomass from *dekad* to *dekad*. In cases where the data were given by species, it could be seen that the species composition of areas cut in different *dekad*s of the same year, and between years, was not the same. For example in a given *dekad*, biomass from both shrubs and *Artemesia* spp. may be given as a lumped figure, whilst in following *dekad*, only *Artemesia* may be given. This gives the impression that between these two *dekad*s biomass has fallen by several orders of magnitude. This is not a problem at all the stations, but is the reason why the data from most of them could not be used at all for study on a monthly or 10 daily basis. It also means that peak biomass figures are not always consistent as the vegetation type sampled during the period of peak yields sometimes varies between years. This problem will be discussed with reference to the individual stations.

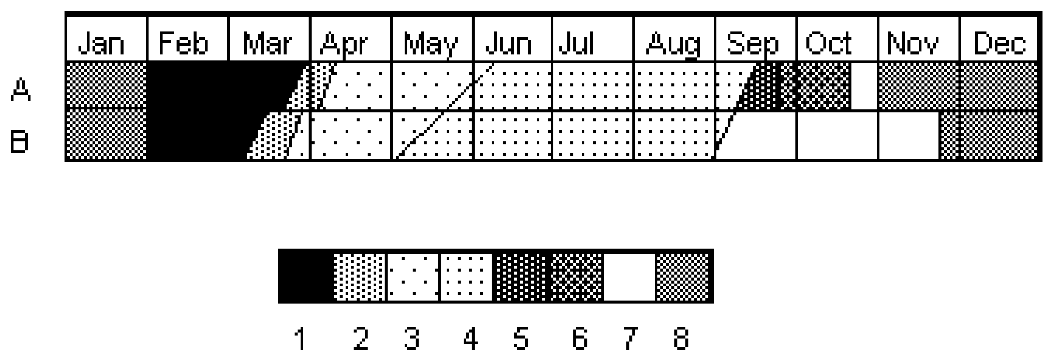
At the Betpak-dala station, the original 30 year data set collected was mostly on *Artemesia terrae-albae - Salsola arbusciliformis* pasture, however as the data were given by species, it can be seen that from 1982 onwards, biomass had been collected from *Salsola arbusciliformis* pasture only, which has a much higher biomass. The 30 year data set gave an average peak biomass of 350 kg/ha, whilst the shorter data set, form 1982 to 1996, taken on the *Salsola* pasture only, gave an average peak biomass of 670 kg/ha. The Kirichenko (1966) data set, taken over only 4 years at this station suggests an average peak biomass for the Betpak-dala area of 500 kg/ha, an average of five vegetation communities. Data from Ulan bel' suffered from large inconsistencies, but the entire 30 year data set was available by species, enabling real biomass change to be identified. For example, in some years biomass was collected in areas dominated by *Salsola arbusciliformis*. In others this species was not present at all, leading to huge and spurious fluctuations in biomass. However, as the data were given by species, it was possible to extract subsets of data that were consistent. The data from Koktas, Berlik, Tiuken, and Tasty were not given by species, and so must be suspect. Data at Berlik in particular had extremely strange patterns, biomass from 1967-1981 averaging 370 kg/ha, and from 1982-96 averaging 1018 kg/ha. For the latter time period biomass was labelled as *Artemesia-Stipa* pasture, and for the rest no species information was given. Data at Tasty from 1982 to 1997 were labelled as being *Artemesia*-saltwort pasture, but other than this there was little information given.

Most of the data were therefore used only for looking at average peak biomass over long periods of time (see Chapter 5) in the hope that, by averaging the peak over 30 years, the inconsistencies in collection would be smoothed over.

3.3 Seasonal patterns of biomass and rainfall, and the phenology of steppe plants

At least 30% of the pastures in the desert zone of the study area are dominated by *Artemesia terrae-albae* (Kirichenko 1980). According to Zhambakin (1995) this plant has a seasonal growth pattern which is shown in Figure 3.5.

Figure 3.5 Growth patterns of Artemesia terrae-albae. *Source: Zhambakin 1995.*
A = Year of high rainfall B = Year of low rainfall; 1 - No growth; 2 - Early spring growth; 3 - Growth of stems; 4 - Bud formation (no vegetation growth); 5 - Flowering; 6 - Seeding; 7 - no growth; 8 - Autumn-Winter growth.



The author notes that although the early spring growth (period 2) accounts for less than 10 percent of the eventual NPP of the plant, it is the most crucial phase, as this determines the number of shoots appearing, and thus the later growth of the plant. He also notes that in most cases accumulation of photosynthetic material is the most intense in May, and early June, but stops in the second half of June, when the leaves begin to dry out, and 60-70% of them are shed. At this time the plant puts energy into bud formation rather than vegetative growth. In some years of high or late rainfall, vegetative growth can continue into July, but this only occurs once in about 20 years.

In the case of *Salsola arbusciliformis*, the pattern of biomass accumulation is similar. The plant grows until mid May or the beginning of June and then starts to dry out, the leaves becoming yellow and falling off. There is no vegetative growth after this period, although budding, flowering, and seeding may occur in wet years. It has a very large variability in biomass, reacting swiftly to high availability in moisture. *Salsola* buds and flowers much earlier than *Artemesia terrae-albae*. It buds in May, flowers in late May-early June, has fruited by the end of June, and by autumn it has no leaves left. (Kirichenko 1980, Beloborodova 1964).

Anabasis salsa, Atriplex cana, and *Artemesia pauciflora* are found on saltier soils. The last two are often found together. *Atriplex cana* and *Anabasis salsa* have leaves all winter, which only drop off in August. They flower in July and fruit in August. Both plants dry out later than *Artemesia* species. *Artemesia pauciflora* has a phenology much like that of *Artemesia terrae-albae.* It undergoes vegetative growth until the end of May-early June, loses its leaves in July, and flowers and fruits in September-October. These plants show less variability in biomass than the others (Beloborodova 1964).

This then suggests that biomass of these communities is little affected by rainfall after May, and that it is better to try to predict peak biomass, as biomass in later months will, in any case be highly dependent on this peak. If this is the case, it is important to determine the period of the year during which rainfall effects peak biomass. Belorborodova (1964) conducted a study of soil moisture change over the year in Betpak-dala. She found that soil moisture on the first of May was dependent on rain or snow falling in autumn, winter and spring. Therefore rainfall outside this period is unlikely to have much affect on peak biomass, or indeed on biomass later in the season. The author also notes that although in general it is rainfall from October to May which contributes to soil moisture in spring, different plant species are most sensitive to rain in particular months within this period. For example *Salsola* and *Anabasis* species are more dependent on rainfall before April and May, whilst biomass of *Atriplex cana* and *Artemesia* species is affected more by rainfall in these two months. This spring rainfall is also the determining factor for the growth of annuals, which are absent in years when spring rainfall is low.

Another important point, which applies to all the dominant plants in the regions studied, is that they are perennials. Annuals, although they do exist, make up only a tiny proportion of the biomass of Kazakh pastures, the exception being degraded areas (see Chapter 2). This domination by perennials may mean that biomass in previous years may have an impact on biomass in a given year. For example, according to Kirichenko (1980), an exceedingly wet year may promote germination of *Artemesia* seeds which had lain dormant perhaps for several years. This will mean a large number of new plants appearing in that year. This may also have an impact in future years as the new plants grow and reach maturity, however, such effects were not mentioned in the literature, and Le Houérou *et al.* (1988) in a review of rainfall-biomass relationships, has found that biomass of rangelands tends not to be affected by biomass in preceding years.

3.4 Statistical relationships between biomass and rainfall

The principal aim of the work in this chapter was to find relationships between biomass and rainfall. It was hoped to establish statistical relationships for the semi-desert zone, dominated by *Artemesia, Stipa*, and *Festuca* species, and models for the desert zone, dominated by *Artemesia* and saltwort species. The aim was then to look at long term rainfall data (available in most cases for longer periods than biomass data), and to see from this how often very low or very high values of biomass might occur for each region.

Two types of model were attempted. The first used monthly data to try to fit a curve to the seasonal biomass patterns. The second type involved the prediction of NPP (annual peak biomass) from rainfall in various time periods leading up to that peak.

3.4.1 Statistical tests used in regression analyses

The regressions performed were tested for constant variability and independence of the residuals. These are basic assumptions of regression and ANOVA analyses, but often in time series data these assumptions may not be met. The following were tested for in the programme 'Microfit' (Pesaran and Pesaran 1997):

Heteroscedasticity - This is when residuals trend with the trend, i.e. the magnitude of the residual is a function of the magnitude of some variable which has not been included in the regression. Therefore models which fail this test normally have a missing predictor, or the method or accuracy of data collection may have changed over the time period in question (Sohkal and Rohlf 1995). This is tested for by regressing the squared residuals against the squared fitted values. There should be no correlation.

Serial Correlation - This is the auto-correlation of residuals. Autocorrelation affects cross correlations between variables measured in time, and thus violates the basic regression assumption of independence. For example if biomass in one year is affected by biomass in preceding years, then particularly high values may lead to high values the following years, even if the rainfall is low. In such a case the samples are not independent, and the variance may be underestimated, leading to over-estimation of the R^2 and F values and underestimation of the standard error (Gunst and Mason 1980). The Lagrange multiplier test is used in Microfit to test for this problem.

Normality - Another basic assumption of regression and ANOVA is that the residuals are normally distributed. According to Eklundh (1998), 10 day or monthly rainfall data often do not follow a normal distribution due to frequent periods of zero rainfall. Normality of the residuals is detected in Microfit using a test of skewness and kurtosis of the residuals.

Functional form - If the residuals are larger or smaller at high values of the independent variable, than at low values, a linear regression model may be inappropriate and should be replaced by some other curve shape which better describes the relationship. When a regression suffers from this problem, the R^2 value is usually underestimated. Microfit uses the Ramsey RESET test using the square of the fitted values to test for this problem.

Variable selection

Some of the regressions performed both in this chapter and Chapter 4, have several independent variables. To select the smallest group of variables which explains the maximum amount of the variability in the data (i.e. groups of variables having the minimum collinearity), a stepwise procedure was sometimes used. In this procedure predictor variables are added to the equation one by one, starting with those having the highest F statistic. If the F statistic of the overall equation is larger, and still significant to 95% upon adding this variable, then it is retained. After addition of the new variable, each predictor variable already chosen is re-evaluated and eliminated from the subset if its F statistic now fails to meet the criteria required (Gunst and Mason 1980). This re-evaluation is an advantage over the backwards remove method in which variables removed at the beginning cannot be re-tested with the smaller subset of variables later in the sequence. It is recommended as the best available technique for variable reduction by a number of authors, including Draper and Smith (1966). However, both methods have the problem of potentially converging on a local rather than global optimum.

3.4.2 Monthly biomass prediction from rainfall and lag biomass

Various monthly rainfall sums were created and regressed against biomass in *dekad* 3 of each month (because *dekad* 1 and 2 were sometimes missing) using data for each meteorological station. Sums of 2, 4, 6, 12 and 16 weeks were tried. All were non-significant. Better relationships were obtained for rainfall periods of six months or more before the biomass measurement. However the R^2 values were never higher than 0.15, and the standard errors were high. In the model by Robertson (1987), mentioned in part 3.1, rainfall predicted biomass change better than biomass itself. Therefore this was also investigated. All the regressions tried had R^2 values of less than 0.1.

The problem with these types of model is that they are trying to predict both growth and die-off. For example rainfall up to May or June would produce a high biomass, whilst rainfall in August would just slow down the die off, but probably produce little new growth. Therefore it is perhaps not surprising that the effects of rainfall detected here are quite small. Although rainfall is a very poor predictor of monthly biomass it was found to be a better predictor of yearly peak biomass (see section 3.4.4). After the peak, biomass can be predicted reasonably accurately by a die off curve, as is discussed below. This result is not surprising given the phenology of steppe plants, but the lack of monthly rainfall relationships are probably also linked to the poor quality of the biomass data.

At most meteorological stations, the monthly data were too poor to be used in rainfall-biomass models. However at Betpak-dala station the data collected by Kirichenko (1966), which was available monthly, and collected with a consistent methodology, could be used to look at change over the season, and the relative importance of die off and rainfall.

Biomass in each of the five communities was regressed against rainfall lagged one month, rainfall sums over the last three and five months, and biomass lagged 1 month. Rainfall lagged one month, and rainfall summed over the three months before the biomass measurement produced poor results. However, rainfall over the last five months produced some reasonable results (Table 3.3).

Table 3.3: Dependence of monthly biomass yield on biomass lagged 1 month, and rainfall summed over various periods before the biomass measurement for five vegetation communities:
1. *Artemesia terrae-albae, Salsola arbusciliformis*
2. *Salsola rigida, Artemesia terrae-albae*
3. *Salsola arbusciliformis, Artemesia terrae-albae*
4..*Atriplex cana, Artemesia pauciflora*
5. *Anabasis salsa*

Rainfall	**Statistic**	**1**	**2**	**3**	**4**	**5**
Lag one month DF=18	R^2	0.16	0.04	0.15	0.42	0.19
	F	3.11	0.63	3.06	12.4	4.11
	P	0.096	0.439	0.098	0.003	0.059
1-3 months DF=18	R^2	0.22	0.06	0.33	0.47	0.50
	F	4.80	1.08	8.40	15.17	17.16
	P	0.042	0.31	0.01	0.001	0.001
1-5 months DF=18	R^2	0.39	0.2	0.59	0.45	0.74
	F	10.88	4.40	24.05	13.89	48.99
	P	0.042	0.051	0.000	0.002	0.000
Biomass lag 1	R^2	0.86	0.95	0.94	0.24	0.69

DF=14	F	79	226.1	222.3	4.29	29.4
	P	0.000	0.000	0.000	0.059	0.000
Biomass lag 1 And rainfall 1-5 months Stepwise DF=14	R^2	Rainfall Eliminated	Rainfall eliminated	Rainfall Eliminated	Lag biomass eliminated	0.87
	F					25.03
	P					0.000

The Kirichenko dataset data set has only 19 data points for each vegetation community. However, there do seem to be some reasonable relationships between rainfall in the five months before the biomass measurement, and biomass.

Both rainfall and lagged biomass were regressed against biomass in a stepwise fashion (see section 3.4.1), and the results are shown in Table 3.3. For communities 1 to 3, knowledge of rainfall does not improve biomass predictions over the season, as the rainfall variable was eliminated in the stepwise regression. This is probably because the rainfall-biomass relationships produced here exist mainly because the five month rainfall sum is just an indicator of the total rainfall that year, and therefore of the general biomass level of the year. The regressions are therefore simply just showing rainfall-biomass relationships between the four years rather than over months within years.

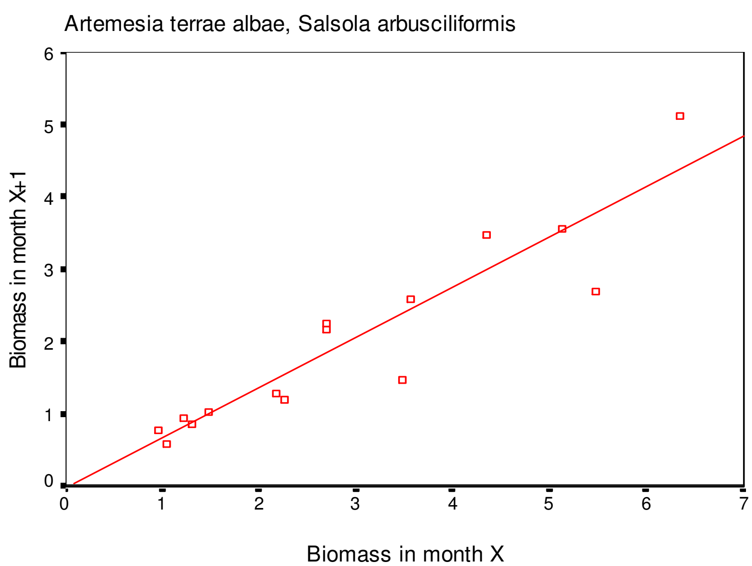
However, from Table 3.3 we can see that in the months after the peak, communities 4 and 5 do seem to be affected by rainfall, unlike in the other communities where biomass is determined by the size of the initial peak. Communities 4 and 5 are dominated by the saltworts *Atriplex cana* and *Anabasis salsa.* As explained in section 3.3 these two plant species dry out later in the season than the *Artemesia* and *Salsola* species dominating the other communities, so their growth continues on into the summer and will be more affected by rainfall in that period.

The biomass can be predicted on a monthly basis by biomass lagged one month, and generally shows a linear relationship. The graphs of vegetation die off at the individual stations (Appendix 2) show that for all the communities apart from number 4, the die off curves show similar shapes between wet and dry years, although they do have a tendency to converge, so that large differences in biomass in May or June become much smaller by September, except in exceptional years. The peak is normally in the second half of May, although it sometimes occurs in the first half of June, and in one case as late as the 24th of June.

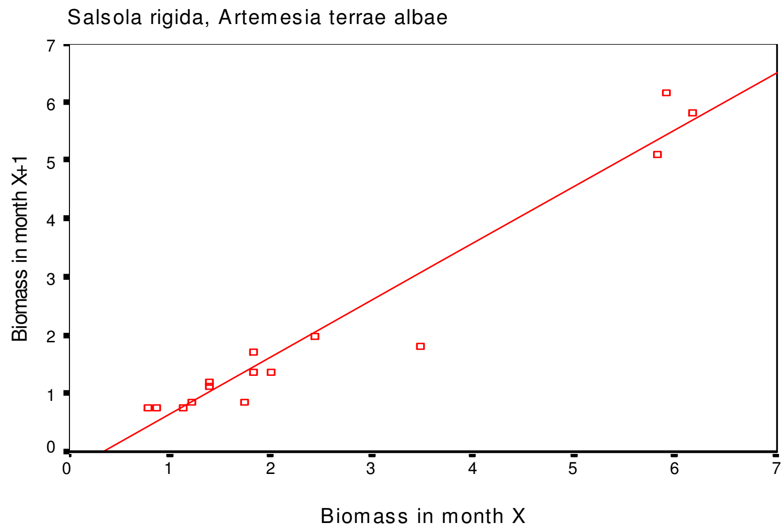
The graphs and equations for die off are shown in Figure 3.6.

Figure 3.6: Relationships between monthly biomass yield and biomass yield lag one for five vegetation types in Betpak-dala. *Where B_t is biomass at time t and B_{t-1} is biomass one month before at time t-1.*

(a) Type 1
$B_t = -0.029 + 0.693B_{t-1}$ $R^2 = 0.86$*** SE = 0.50
Significances of Chi squared values for tests on residuals: Serial correlation 0.156, Functional form 0.441, Normality 0.375, Heteroscedasticity 0.014



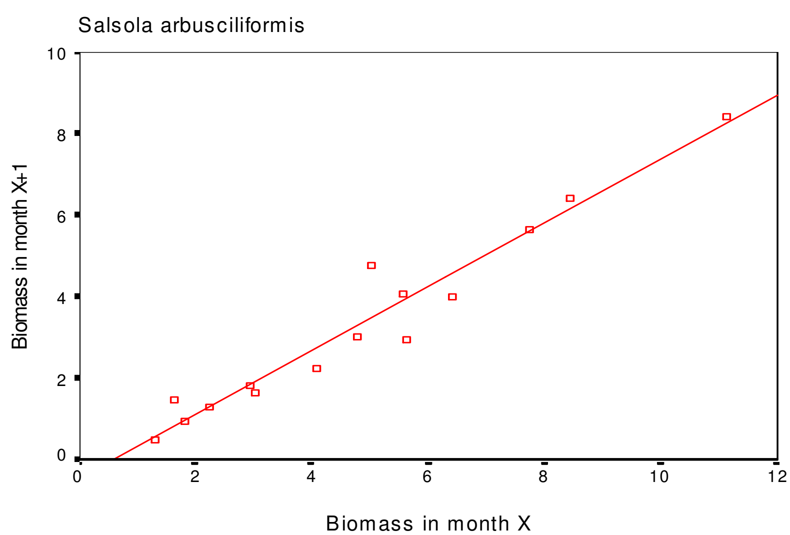
(b) Type 2
$B_t = -0.344 + 0.976B_{t-1}$ $R^2 = 0.95$*** SE = 0.461
Significances of Chi squared values for tests on residuals: Serial correlation 0.459, Functional form 0.009, Normality 0.037, Heteroscedasticity 0.475



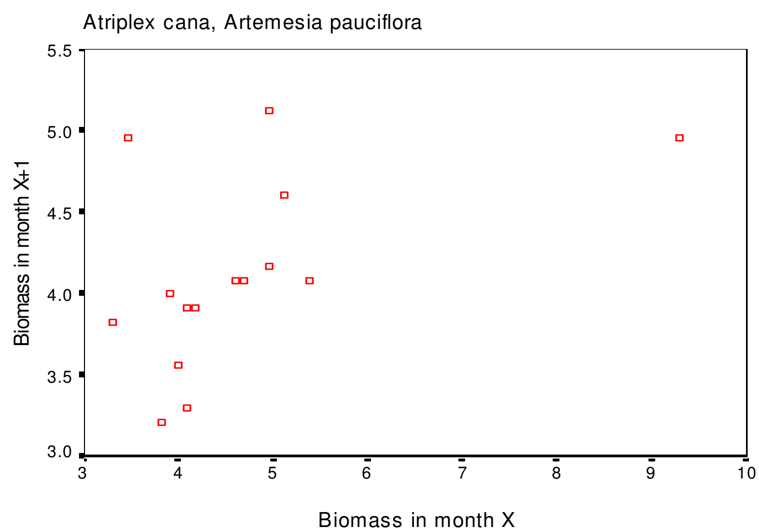
(c) Type 3

$B_t = -0.463 + 0.783B_{t-1}$ $R^2 = 0.94^{***}$ $SE = 0.5552$

Significances of Chi squared values for tests on residuals: Serial correlation 0.568, Functional form 0.404, Normality 0.488, Heteroscedasticity 0.782



(d) Type 4
$R^2 = 0.24$ *NS*



(e) Type 5
$B_t = 0.244 + 0.687B_{t-1}$ $R^2 = 0.69$*** $SE = 0.597$
Significances of Chi squared values for tests on residuals: Serial correlation 0.471, Functional form 0.358, Normality 0.002, Heteroscedasticity 0.596

As can be seen from these graphs, the relationships for all vegetation types (except type 4 where there is no relationship) are linear. Type 2 suffers from a possible problem with functional form due to a large gap in data in the middle of the range. Types 2 and 5 fail tests for normality, and type 1 shows slight heteroscedasticity. Therefore none of the relationships are perfect, and some of the problems would probably be smoothed out if more years of data had been available.

The regression equation for community 1, the most common vegetation type in the study area, was used to estimate how vegetation dies of from different peaks. This is given in Figure 3.7.

Figure 3.7: Modelled vegetation die off over the season for pasture dominated by Artemesia terrae-albae and Salsola arbusciliformis.
*B_{t+1}=-0.029+ 0.693B_t, where B=biomass in 100kg/ha and t=month, R^2=0.86***, standard error of the estimate=59 kg/ha.*

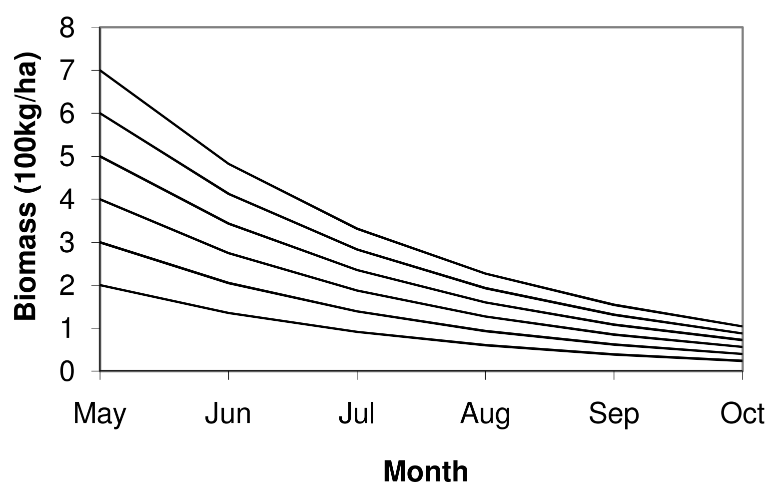


Figure 3.7 illustrates the observation (which can also be seen in the graphs showing die off for the actual data in Appendix 3), that differences in spring, be they caused by rainfall or vegetation type, become much less significant in autumn or winter.

Therefore for these pasture types, which are used for livestock in spring and autumn, rainfall will have a much greater impact on spring forage than on autumn forage availability.

3.4.3 Annual peak biomass prediction from rainfall

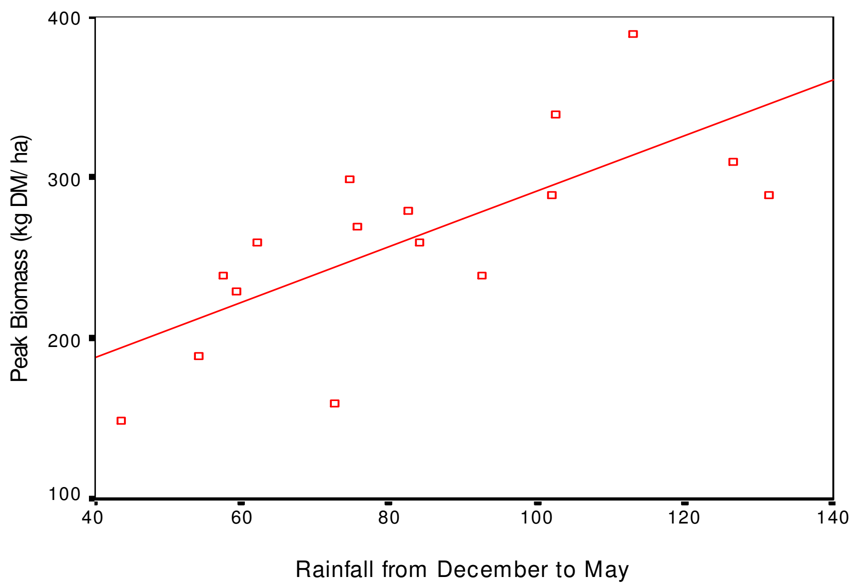
Statistical relationships between peak biomass production and rainfall were found for data from three meteorological stations in the northern desert zone. These were found at meteorological stations Tasty, Ulan bel', and Betpak-dala. For the other stations no significant relationships were found.

(i) *Tasty meteorological station*

The data for this station from 1982 to 1997 only were used as these were apparently for a single vegetation type, and so at least it could be assured that the data were from a constant mix of species, even if this mix was not described in detail. The longer data set, from 1967 to 1997 produced no significant relationships with rainfall, suggesting inconsistency in collection.

The periods tried were rainfall from April to May, March to May, February to May etc., up to October to May. The period of time over which rainfall best predicted peak biomass at this station was from December to May (Figure 3.8), R^2 values becoming progressively smaller with longer or shorter periods.

Figure 3.8: Prediction of peak biomass at Tasty as a function of rainfall from December to May. *B_p=118.6+1.7$R_{Dec\text{-}May}$ where B_p=Peak biomass and R_{decMay}=rainfall from December to May, R^2=0.522**, standard error of the estimate = 44 kg. The regression passes the tests for constant variability and independence of residuals.*

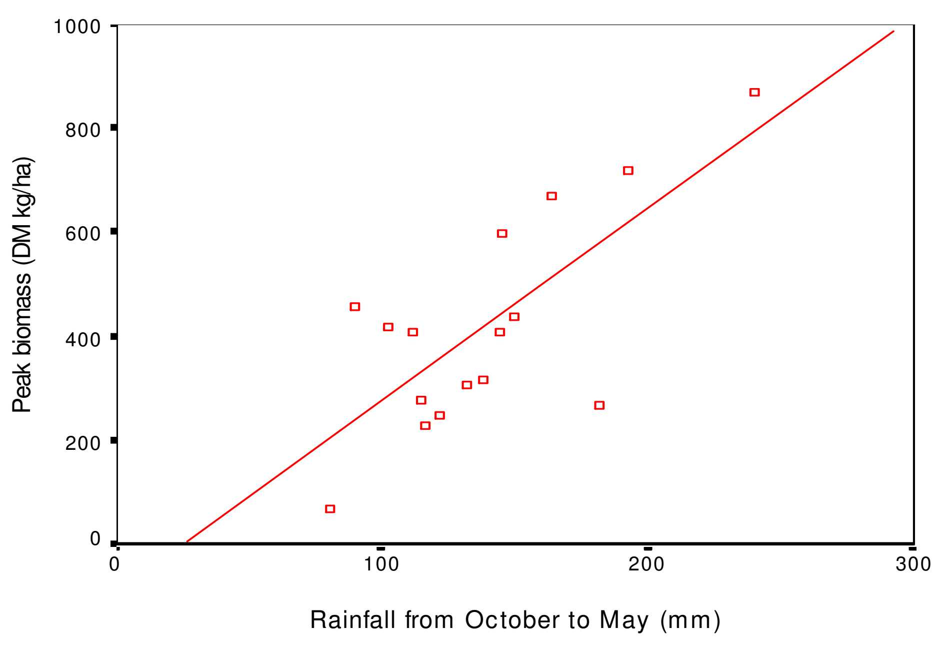


From this we can say roughly that in a dry year, with rainfall between December and May of only 50mm, peak biomass would be expected to fall between 155 and 245 kg/ha. In a good year, with 130mm between December and May, biomass would be expected to be between 295 and 385 kg/ha, according to the standard error. This is therefore a very crude model, but can give us an idea of the behaviour of this type of vegetation over the long term, and confirms that rainfall - biomass relationships do exist.

(ii) *Ulan bel' meteorological station*

This data set was available by species. From 1967 to 1984, the plants were recorded as being *Artemesia* species, *Ceratoides papposa*, and *Kochia prostrata*. From 1985 to 1992, *Salsola arbusciliformis* was cut, with a corresponding rise in biomass. From 1993 to 1996 the mixture was once again *Artemesia, Ceratoides*, and *Kochia* spp. For the purposes of the regression carried out here, the data from 1967 to 1984 only were used as this was the longest consistent dataset. Once again, multi-month rainfall sums going back from May were tested, and the best relationship was found to be between peak biomass and rainfall from October to May. The relationship is shown in Figure 3.9.

Figure 3.9 Prediction of peak biomass at Ulan bel' as a function of rainfall from October to May. *B_p=-94+3.7$R_{Oct-May}$ where B_p=Peak biomass and $R_{Oct-May}$=rainfall from October to May, R^2 = 0.53***, standard error of the estimate =146 kg. The regression passes the tests for constant variability and independence of residuals.*



The relationships at Tasty and Ulan bel' apply, of course, only to the particular vegetation types measured there, and we cannot say they represent the responses of all vegetation in these areas. This is illustrated further in the next section on Betpak-dala, for which data were available for several vegetation types.

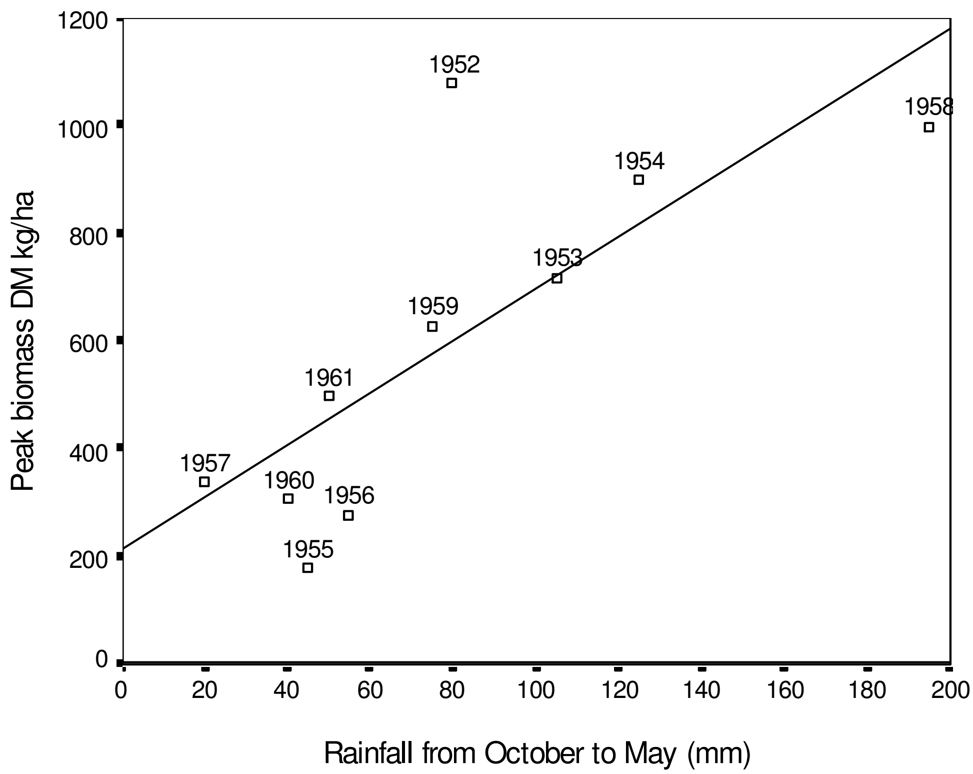
(iii) Betpak-dala meteorological station

Here the rainfall data are from Betpak-dala meteorological station, and the biomass data are of two types:

- Data from 1967-1996 collected by workers at the meteorological station. As mentioned at the beginning of the chapter this data suffers from inconsistency of collection, and only the data from 1982 to 1996 (*Salsola arbusciliformis* pasture) were used.
- Data collected by Kirichenko between 1958-1961. These data is by species, and are very detailed. The data are for 5 different vegetation communities described in Table 3.2 and which have been labelled communities 1 to 5. Communities 1 and 3 are similar in composition to the biomass collected from 1982-1996 by the workers at the meteorological station, making two comparable data sets. Data for some extra years in the 1950s is given in Beloborodova (1964), but only the peak is given, and rainfall data is only available for one specific time period. Therefore these data were not used in the analysis, but is shown separately below:

Beloborodova (1964) has shown the existence of relationships between rainfall from October to May, and peak biomass for *Salsola arbsuciliformis* dominated communities. She used data from 1958-1961 collected by Kirichenko (1980), and data from 1952 - 1957 collected by workers at Betpak-dala meteorological station for this vegetation type. The relationship is shown in Figure 3.10. For the years 1952 to 1957 rainfall data was available only as a single October to May figure, so other time periods could not be tried.

Figure 3.10: The relationship between rainfall from October to May, and peak biomass at Betpak-dala meteorological station, 1952-1961. *This graph is taken from Beloborodova 1964.* $B_p = 212 + 4.8R_{Oct\text{-}May}$ *where* B_p*=peak biomass and* $R_{Oct\text{-}May}$*=rainfall from October to May,* $R^2 = 0.595^{**}$*, standard error of the estimate = 242 kg. The regression passes the tests for constant variability and independence of residuals.*



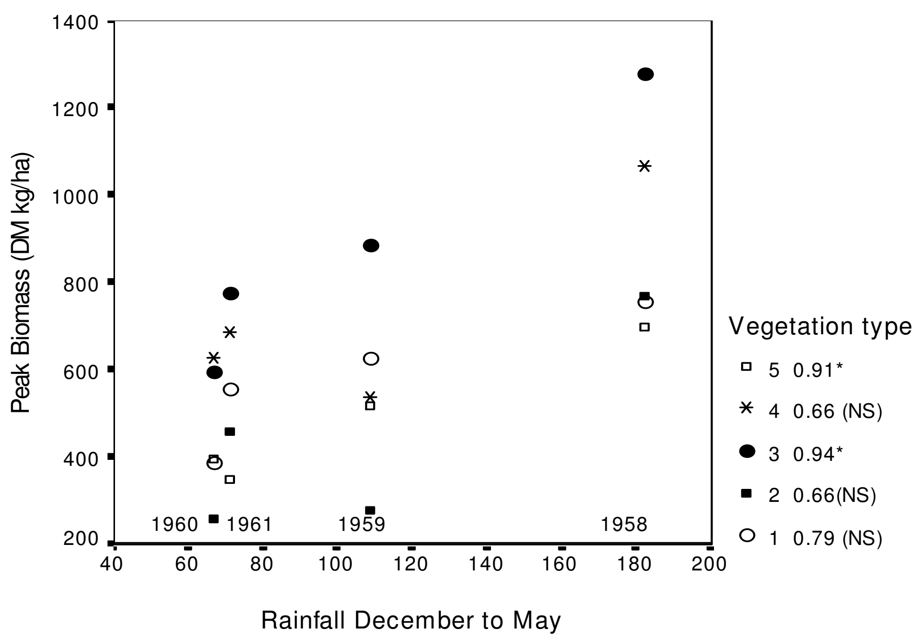
There are only four data points for the 1958-1961 data set of Kirichenko (1966), however it can be seen from Figure 3.10 that these four points cover a fairly wide range of rainfalls and biomasses when seen as part of a ten year data set. This four year data set is valuable because it includes five different associations, and thus provides us with an opportunity to compare not only variability between years, but also between pasture types.

Peak biomass was plotted against rainfall in the six months before the peak (December to May), and in the eight months before (October to May), to compare the different communities (Figure 3.11).

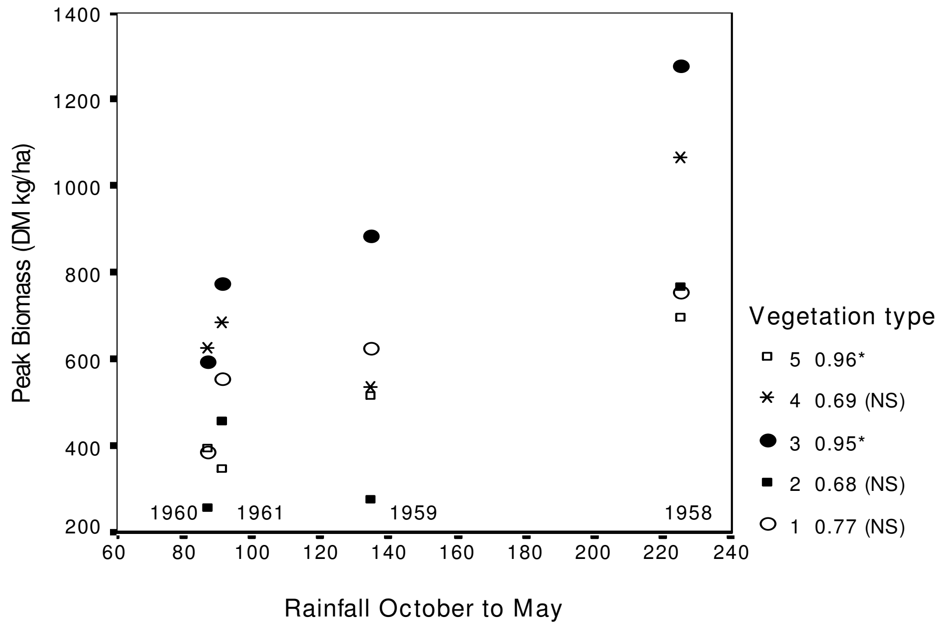
There are strong linear relationships for most of the communities, which tend to have virtually identical R^2 values for rainfall from December to May and for rainfall from October to May. However, they rely on very few data points, so the significance of the relationships is at the 95% level (communities 3 and 5) or below. For both time periods the rainfalls of 1960 and 1961 are virtually indistinguishable, however biomass is higher in 1961. This is because in that year, rainfall was concentrated in February and April, as can be seen in Figure 3.12. The relationships are reasonable for vegetation types 1, 3, and 5, and poorer for 2 and 4.

Figure 3.11: Relationships between rainfall and peak annual biomass for 5 vegetation types in Betpak-dala, 1958-1961. *Source: Kirichenko 1966.*
(a) rainfall from December to May, (b) rainfall from October to May. See Table 3.2 for a description of each vegetation type. R^2 values for relationships between rainfall and biomass are shown in legends.

(a)



(b)



Community 3 is a *Salsola arbusciliformis* dominated community (*Salsola arbusciliformis* making up between 80% and 90% of total biomass). This makes it similar to the vegetation data set for 1982 to 1996 taken at the meteorological station. Therefore two data sets exist for the same vegetation type, one with few data (Kirichenko 1980), and one with many more years of data, but which is suspected to be of poor quality (meteorological station). A rainfall-peak biomass relationship was therefore found for the meteorological station data, and then tested on the data for the years 1958-1961. The meteorological station data, although available for 30 years, was used only for 1982-1996, because before this the data was for an inconstant mixture of species, and was therefore unusable for the reasons explained at the beginning of this chapter. In this way, the reliability of both data sets could be checked.

Peak biomass at Betpak-dala for the years 1982-1996 was regressed against rainfall in different periods before the peak to see which gave the best relationship. The period producing the best result was rainfall from February to April. This was checked by running a stepwise regression with each month entered individually. The regression picked February and April ($R^2 = 0.81$***).

This was repeated for the 1958 to 1961 data for all the five communities, although the stepwise regression could not be run because there are not enough degrees of freedom. The results are shown in Figure 3.12. For the *Salsola arbusciliformis* community rainfall from February to April gave a better result than rainfall from December to May, or October to May, although for the other communities the result was worse, meaning that they have different rainfall responses. However, the results using the time period February to April are good as there is higher rainfall variability, and it is thus possible to distinguish between the data points for 1960 and 1961 which had not been possible for the December-May or October-May relationships as the rainfall was similar over these time periods in those two years.

Figure 3.12: Relationships between rainfall from February to April, and peak annual biomass for 5 vegetation types in Betpak-dala, 1958-1961*. Source: Kirichenko 1966. Vegetation type 3 is that dominated by Salsola arbusciliformis.*

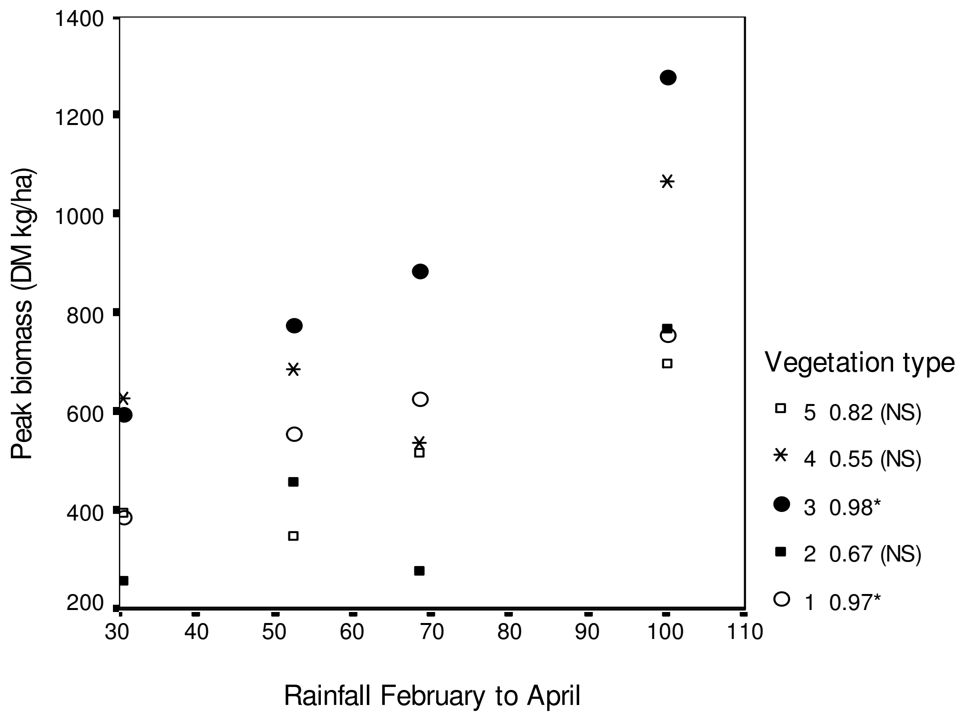


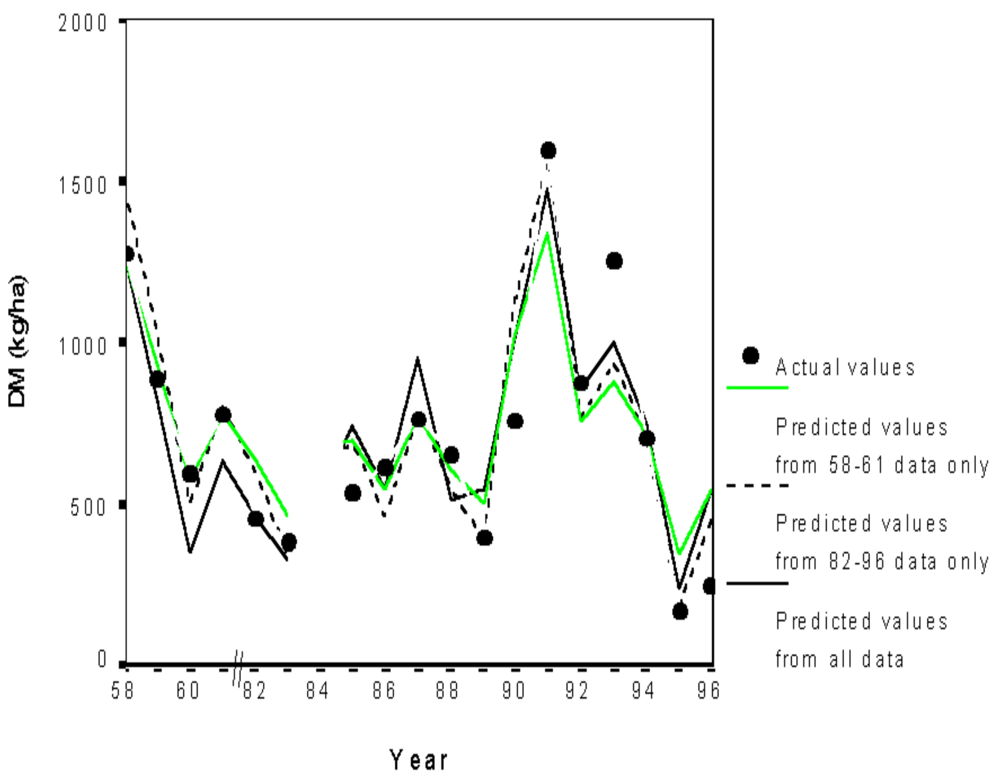
Table 3.4 shows the regression details for the prediction of peak biomass from rainfall in February to April for *Salsola arbusciliformis* dominated communities. The regressions were conducted using data collected by Kirichenko (1966) and data collected at Betpak-dala meteorological station, separately and together. The relationship obtained from the meteorological station data was improved by including the Kirichenko data.

Table 3.4: Regression results for the prediction of peak biomass from rainfall from February to April for Salsola arbusciliformis dominated communities.

Data set	rainfall data	R^2	F	Intercept	Slope
1958-1961 (Kirichenko 1966)	Feb-Apr	0.98	114**	270*	9.8**
1982 - 1996 (Betpak-dala meteorological station)	Feb-Apr	0.81	51***	69 NS	14***
Both data sets combined	Feb-Apr	0.82	74***	110 NS	12***

In order to see more clearly how well the equation for the 1982-1996 data predicted the 1958-1961 data for community 3, the predicted values were compared with actual values for the entire time series, i.e. for all data. The results are shown in Figure 3.13.

Figure 3.13: Actual and predicted values of peak biomass for communities dominated by Salsola arbusciliformis. *Actual values are from 2 data sets, one from 1958-1961(Kirichenko 1966) and one from 1982-1996 (meteorological station data).*

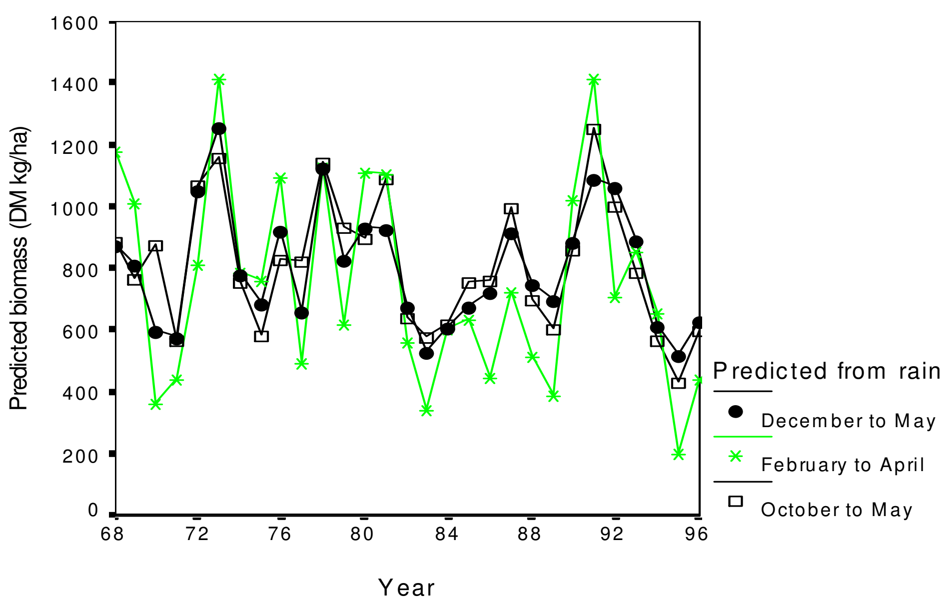


The equation which fits both data sets combined - i.e. 19 years of data is as follows:

$B_p=110 + 12R_{Feb-Apr}$ where B_p=peak biomass and $R_{Feb-Apr}$=rainfall from February to April, standard error of the estimate = 160 kg/ha. The regression does not suffer from non-random residuals.

Figure 3.14 shows that predicting biomass of this community from rainfall in the period from February to April (using the equation above) gives a greater biomass variability than predicting it from rainfall from December to May ($B_p = -11.8+7.8R_{Dec-May}$) or October to May ($B_p = 212+4.8R_{Oct-May}$). The latter two equations give virtually the same predictions.

Figure 3.14: The use of rainfall data over various periods to predict peak biomass values of Salsola arbusciliformis communities at Betpak-dala meteorological station from 1967 to 1996.



The relationships found at the stations in the desert zone are comparable with predictions of peak biomass from rainfall over the growing season in temperate North America (Sneva and Hyder 1962) which gave R^2 values ranging from 0.36 to 0.81, depending on the community.

(iv) Tiuken, Koktas, and Berlik meteorological stations

For the prediction of peak biomass, the models for these stations all had R^2 values of 0.15 or below, and none of them were significant at the 99% level or above, even though time periods ranging from 2 months to 1 year before the peak were attempted. The regressions were poor whether data from 1967-1997 or from 1982-1997 (which was apparently of constant species composition) was used.

These results further illustrate the poor quality of these data. Part of the reason for this was that different species were cut over the time period of interest.

3.5 The influence of rainfall variability and vegetation type on biomass variability

Having explored the biomass data for quality and relationships with rainfall, the question of interest is to determine how large we can expect biomass fluctuations to be, and how often very low values are likely to occur.

Table 3.5 shows the maximum and minimum biomasses of vegetation communities according to a number of data sources. The data from the meteorological stations are minima and maxima over 30 years. The *Kazgiprozem* data is for vegetation on *sovkhoz* Sarysu, and are general long term minima and maxima. The data from Kirichenko (1966) are for four years, which do not include any extremely low rainfall years. For example the lowest figure for rainfall from December to May is 68mm, and figures of less than this occurred 4 times from 1967 to 1996.

The following observations can be made from Table 3.5:

- If we look at the Kirichenko data, we can see that the response of five communities to the same rainfall (minima were recorded in 1961, maxima in 1958), can vary by several orders of magnitude. For example in the low year of 1961, different plant communities produced from 180 to 540 kg/ha of biomass, a range which is larger than that of some of the communities between low and high rainfall years. This tells us that communities in the same area have very different rainfall use efficiencies and that we can expect a large standard error for models of biomass production from rainfall over large areas comprising different communities.

- The minima are in general much more similar between vegetation types than the maxima. Over nearly all types, from all data sources, minimum yields can be expected to be between 100 and 250 kg/ha, with the only values much above this coming from the Kirichenko data which does not include very poor years.

- The problems with the data from the meteorological stations can be seen in the table, as statistics for the entire time period available are compared with subsets of apparently constant species composition. In particular the data at Berlik gives very different values depending on which time period is taken.

Table 3.5: Variability of biomass of vegetation associations according to different sources of data. *MS = meteorological station. CV = coefficient of variation.*

Data set	Vegetation type	Av	Min	Max	Range	CV
MS Tasty 82 - 97	*Artemesia,* saltwort	260	150	390	240	0.25
MS Tasty 67-97		310	150	630	480	0.30
MS Ulan bel' 67 - 97		535	230	1460	1390	-
MS Ulan bel' 67-84	*Artemesia, Ceratoides papposa*	425	230	870	800	0.47
MS Tiuken 67-97	*Artemesia, Kochia-Ceratoides papposa*	455	100	900	800	0.47
MS Betpak-dala 82-96	*Salsola arbusciliformis*	670	170	1600	1430	0.57
MS Koktas 67-97	*Artemesia, Stipa*	765	350	1300	1170	0.39
MS Berlik 82-97	*Artemesia, Stipa*	1218	970	1800	830	0.14
MS Berlik 67-97		895	240	1800	1560	-
Kazgiprozem (1988)	*Stipa* spp	-	260	810	550	
Kazgiprozem (1988)	*Festuca* spp	-	280	930	650	
Kazgiprozem (1988)	*Anabasis Salsola*	-	280	320	40	

Kazgiprozem (1988)	*Artemesia terrae-albae*	-	110	580	470	
Kirichenko (1966)	*Salsola arbusciliformis 52 - 96*	-	180	1600	1420	
Kirichenko (1966)	*Artemesia terrae-albae, Salsola arbusciliformis*	-	390	760	370	
Kirichenko (1966)	*Artemesia, Salsola rigida*	-	280	770	490	
Kirichenko (1966)	*Atriplex cana, Artemesia pauciflora*	-	540	1070	530	
Kirichenko (1966)	*Anabasis salsa*	-	350	700	350	

The maxima and minima are poor indicators of variability because they are easily affected by errors in data (especially the data from the meteorological stations). Coefficients of variation for the longer term data sets are also shown in Table 3.5, However, these are very much affected by which time period is taken. Variability is more easily illustrated by looking at frequency distributions.

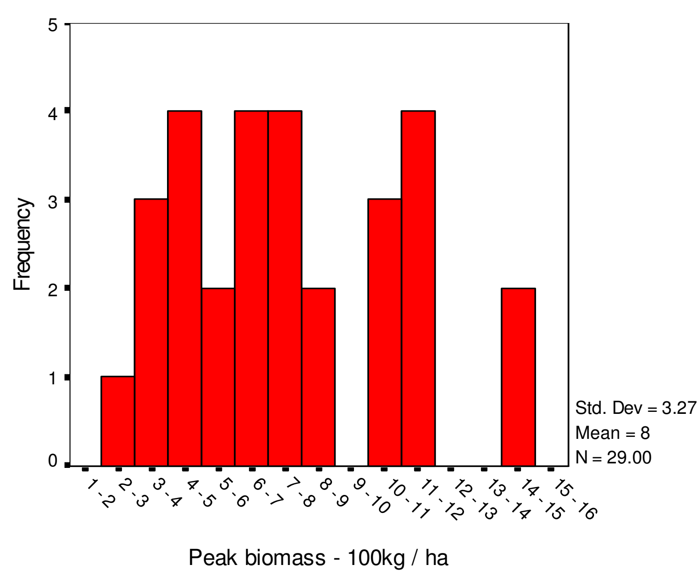
Figure 3.15 shows the predicted frequency distributions of biomass yields from rainfall from 1967 to 1996 or 1997. Most are predicted from rainfall data at the station where the biomass data was sampled. With each diagram the data source, prediction equation and regression details are given including the number of data points used to construct the statistical model. The predictions are sometimes from relationships found using the data by Kirichenko (1966), i.e. from only 4 data points. However, this was only done where the relationships were statistically significant, and in such cases the rainfall from October to May, December to May, or February to April were used depending on which period produced the best relationship (see Figures 3.11 and 3.12) All the rainfall-biomass relationships used in the predictions are those already described in this chapter.

In the case of the *Artemesia-Stipa* pasture, the histogram is constructed from the actual data values. This is because no species information was given with the data set (other than the fact that it the biomass consists of *Artemesia* and *Stipa* species). No rainfall-biomass relationships were found, so this data set is probably flawed. However it is the only long data set found which indicated variability of biomass in the semi-desert zone and which did not suffer from the very obvious inconsistencies seen at station Berlik. The fact that it corresponds roughly to maxima and minima for that zone given by *Kazgiprozem* (1988) (see Chapter 2, Table 2.3) suggests that the range at least is probably reasonable.

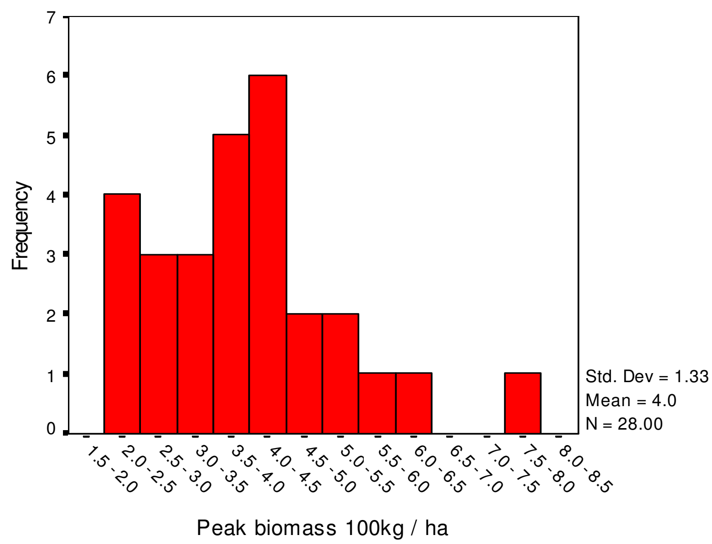
Figure 3.15: Histograms of the distribution of predicted peak biomass for various vegetation communities using rainfall data from 1967 to 1996/97.. *N=number of data points used to construct statistical model, SE=standard error of the estimate,* B_p*=peak biomass,* R_{x-y}*=rainfall from month x to month y.*

(a) *Salsola arbusciliformis*

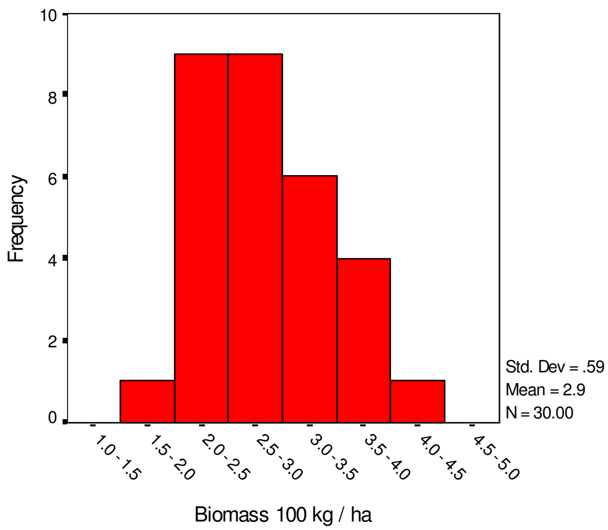
Predicted from rainfall from February to April at Betpak-dala meteorological station, $B_p=110+12R_{Feb-Apr}$, $R^2=0.82$***, *N =19, SE=160.*



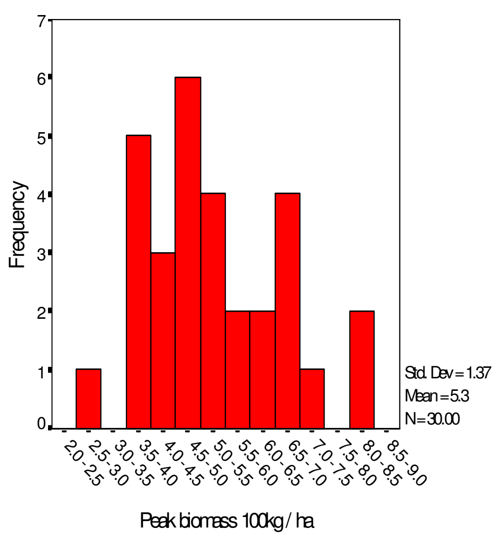
(b) Artemesia terrae-albae and Ceratoides papposa
Predicted from rainfall from October to May at Ulan bel' meteorological station,
$B_p = -94 + 3.7R_{Oct\text{-}May}$, $R^2 = 0.534$***, $N = 16$, $SE = 146$ kg.



(c) Artemesia terrae-albae and saltwort species
Predicted from rainfall from December to May at Tasty meteorological station,
$B_p = 118.6 + 1.7R_{Dec\text{-}May}$, $R^2 = 0.522$**, $N = 16$, $SE = 44$ kg.



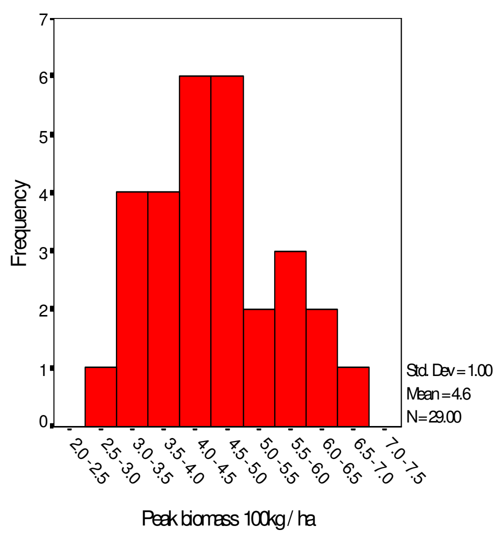
(d) Artemesia terrae-albae and Salsola arbusciliformis
Predicted from rainfall from February to April at Betpak-dala meteorological station,
B_p=257.8+5.1$R_{Feb-Apr}$, R^2=0.97, N=4, SE=33.5 kg.*



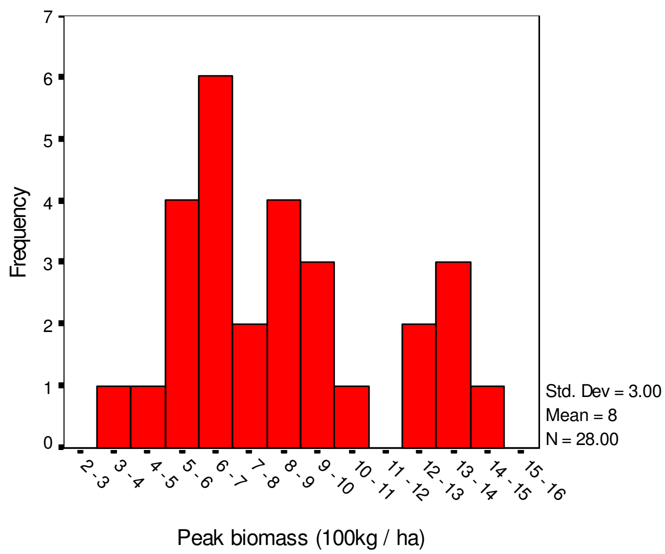
(e) *Anabasis salsa*

Predicted from rainfall from October to May at Betpak-dala meteorological station.

B_p=172.6+2.3$R_{Oct\text{-}May}$, R^2=0.96*, N=4, SE=34 kg.



(f) *Artemesia and Stipa species*
Frequency distribution of peak biomass at Koktas meteorological station.



3.6 Summary and conclusions

One of the main conclusions of this chapter is that the biomass data collected at the meteorological stations in the study area are of very poor quality, and cannot be used for looking at monthly biomass change, and in some cases even yearly change, in relation to rainfall. This is unfortunate because very few data sets of such lengths exist anywhere in the world. The reasons for the low data quality were the fact that the data collection was not carried out or supervised by the end users, and that the data were not collected for the purposes of any clearly defined analysis.

The second observation is that plant phenology is very important. For the biomass model for pastures dominated by *Salsola arbusciliformis* (Betpak-dala meteorological station, and communities 1 and 3) or *Artemesia* species (Tasty meteorological station and community 2) it was shown that rainfall has little effect on biomass yield after the peak, which is usually in late May and occasionally in June. Beyond this month standard die off curves can be constructed. Summer rainfall seemed to be more important for communities dominated by the saltworts *Anabasis salsa* and *Atriplex cana.* No models were constructed for vegetation in the semi-desert region due to the poor data quality.

Rainfall had relationships with peak biomass at Tasty, Ulan bel' and Betpak-dala meteorological stations. Regarding the data from Kirichenko (1966), both rainfall from December to May and from October to May predicted peak biomass for three of the five communities. Rainfall from February to April had a higher variability, and produced more significant results for the *Salsola arbusciliformis* and *Artemesia terrae-albae* dominated communities. Rainfall-biomass relationship for this vegetation type could be validated as two different data sets were available. It is possible, however that if very long biomass data sets could be analysed then longer rainfall time periods might be the best predictors of biomass of some of the communities. This is because soil moisture in spring is determined by rainfall from October onwards, and dry autumns are often followed by low yields in spring (Beloborodova 1964).

From rainfall data over thirty years, it was possible to construct rough predicted frequency distributions for peak biomass production of each community type, although only the model for *Salsola arbsuciliformis* could be validated. Although these would obviously be improved if more data was available on which to base the models, they do at least give an idea of the variability of biomass production.

The spatial variability in biomass in a given year is as great as the temporal variability due to rainfall for a given area. Therefore, when studying the effects of grazing on rainfall use efficiency (for example in two different areas with similar rainfalls and different grazing regimes) the vegetation type should also be taken into account, as this may be as important as the rainfall.

In this chapter biomass variability and the influence of rainfall upon it in the northern desert zone has been discussed. The second objective of this work however, was to look at trends in biomass from 1982 to 1998 to compare with the NDVI trends. Because of the poor data quality, this was not possible for most of the sites. However, Tasty and Betpak-dala meteorological stations were identified as having reasonable data over the required time period (the NDVI data is only available from 1982 onwards). The trends at these stations are compared with those of NDVI in Chapter 4.

Chapter 4: Relationships between rainfall and the Normalised Difference Vegetation Index

In this thesis so far, some areas in which land degradation was probably occurring during the Soviet period have been identified, both from literature and information on stocking rates. According to several authors (Zhambakin 1995, Kirichenko 1980, Bykov 1985), overgrazing resulted in a reduction in productivity which in some areas was of several orders of magnitude. For example Zhambakin (1995) states that the average yields in over-stocked regions of the desert zone dropped from 500-600kg/ha to 200kg/ha. In this thesis it has also been established that since 1994 domestic animal numbers have crashed, and that in most areas of Kazakhstan the stocking rates which caused damage to pastures no longer exist. Therefore some recovery of vegetation can be expected after 1994.

According to Ellis *et al.* (1999) certain pastures were already showing symptoms of recovery by 1998. For example, according to this source, semi-desert pastures in Almaty *oblast,* which had been heavily used for three seasons, saw a 20-25% increase in productivity between 1994 and 1998, and could expect full recovery within 10 years. Grazing experiments by Zhambakin (1995) described in Chapter 2 included one investigation wherein desert pasture which had previously been overgrazed was fenced off, and biomass and species composition information measured over 20 years. Here, the recovery period lasted for four years, during which time biomass went from below 300kg/ha to over 700kg/ha. The effects of rainfall over this period were not mentioned by the author, except to say that the recovered vegetation was less sensitive to rainfall fluctuations. If the claims about land degradation were true, and if they really applied to large areas, then some vegetation recovery since 1994 may be observable on satellite images. From the discussion in Chapter 2 it seems that we can expect those areas showing most vegetation increase to include desert pasture along the river Chu, and the Moiynkum desert.

The Normalised Vegetation Index (NDVI) is an index derived from satellite data which can be used as an indicator of green biomass. The advantage of using satellite data to study vegetation change is its wide spatial coverage, which allows change detection over any area of the country, in contrast to biomass data, available only at specific points. The disadvantages are that NDVI may be variously connected either with biomass, cover, or both and is thus is not a constant measure of one single factor on the ground. However the goal of the work in this chapter is not to quantitatively link NDVI to some measure of vegetation amount, but simply to look at relative NDVI change and how much this might be affected by rainfall, in order to see if the post-1994 vegetation recovery might be detectable. Problems which do affect this work however are that NDVI is heavily influenced by soil colour, and insensitive at low biomass or cover. These limitations are investigated in this chapter and errors associated with NDVI are described in section 4.1.3.

It was decided to investigate the possibility of using NDVI data from the Advanced Very High Resolution Radiometer (AVHRR) to detect vegetation recovery. The reason for using data from this particular sensor is that they are available for the whole of Kazakhstan (and indeed the world) on a daily basis from 1982 onwards. Therefore it is, in theory, possible to study NDVI change over time, in order to answer the following questions:

- Can NDVI be used to detect inter-annual variation in vegetation biomass?

- If so, does it show an increase after 1994 which is not associated with rainfall?

In Chapter three it was established that in the desert zone at least, the quantity of biomass harvested at the period of peak yield is largely a function of rainfall over winter and spring. Therefore, if NDVI is a reasonable indicator of biomass, then it should be related in some way to rainfall. In this chapter, NDVI changes over time, and the extent to which these can be explained by rainfall are examined followed by an analysis of confounding factors which reduce the sensitivity of the NDVI signal. Firstly, however, the data itself and its limitations are presented and discussed.

4.1 Satellite Data

4.1.1 The AVHRR satellite

The Tiros-N series satellites, carrying the AVHRR instrument and launched by the National Oceanic and Atmospheric Administration (NOAA), have been collecting data since 1978. They orbit the Earth every 102 minutes, and so produce 14.1 orbits per day. Because this number is not an integer, the paths of the satellite (which have a width of about 2700km) do not repeat exactly on a daily basis, although the local solar time of the satellite's passage remains constant for a given latitude. The advantages of using data from this satellite are that they are free, and are available over a relatively long time span, on a daily basis. The channels received on board the satellites used in this study are shown in Table 4.1.

Table 4.1: Wavelengths of the channels recorded by the AVHRR instrument.

Channel	Wavelength (micrometer)
1	0.58 - 0.68
2	0.73 - 1.1
3	3.55 - 3.93
4	10.3 - 11.3
5	11.5 - 12.5

The raw data collected from the satellite are not comparable temporally or spatially, due to poor georeferencing, changes in illumination geometry, and atmospheric effects among others. They therefore need to undergo several calibration and correction procedures, as is described in the next section.

4.1.2 The Normalised Difference Vegetation Index and its relationship with biomass

Vegetation absorbs much of the incoming radiation in the visible part of the spectrum (0.22-0.68µm), and reaches maximum reflectance in the near infra red channel (0.73-1.1µm) (Tucker, 1979). This near infra red is recorded by Channel 2 of the NOAA AVHRR instrument. Channel 1 records visible light reflectance between 0.58 and 0.68µm in which light is strongly absorbed by the spongy mesophyll layer of plant tissues. The contrast between the responses of the two bands can be expressed as a ratio transform, i.e. by dividing one band by the other. A normalised difference index helps reduces variation due to surface topography, sun elevation and sensor scan angle (Lillesand and Keifer 1994, Holben 1986). However, ratios do not eliminate additive effects due to atmospheric attenuation as these may have different impacts on the two wavelengths.

The NDVI is thus calculated as follows (Ch = channel):

$$NDVI = (Ch2 - Ch1) / (Ch2 + Ch1) \qquad \textbf{(4.1)}$$

Therefore NDVI is determined by the degree of absorption in the red wavelengths, which is proportional to the amount of chlorophyll, and the reflectance of infrared radiation, which is proportional to green leaf density (Tucker *et al.* 1985). It is an index which normally has a range between slightly negative values, corresponding to snow or cloud, and roughly 0.7 which corresponds to highly vegetated areas.

Among the first studies to show a relationship between NDVI and Net Primary Productivity (NPP) were those by Tucker *et al.* (1985, 1983) in the Senegalese Sahel, Prince and Tucker (1986) in Botswana, Hiernaux and Justice (1986) in Mali, and Townshend and Justice (1986) over the whole of Africa. Prince and Tucker found that NDVI was more closely related to biomass than cover (R^2 = 0.56 and 0.42 respectively), however this is not the case in all studies in the literature. Hiernaux and Justice (1986) found that end of season biomass per hectare correlated well with peak NDVI, the highest correlation coefficient which they recorded being 0.67 for 13 sites. In these studies values of less than 0.05 generally corresponded to no photosynthetic activity (Townshend and Justice 1986, Hiernaux and Justice 1986).

4.1.3 Sources of error in NDVI and comparison with other vegetation indices

The major sources of error in NDVI derived from satellite images come from the atmosphere between the sensor and the ground. For example, air particles may cause

Rayleigh scattering of light detected by the satellite, channel 1 is absorbed by ozone in the top layer of the atmosphere, whilst water vapour absorbs channel 2 radiation, altering the ratios used in NDVI calculation. Water vapour and aerosols are particularly problematic as they are highly variant in time and space, and are the atmospheric component which is hardest to correct for (Holben 1986). High amounts of water vapour cause a decrease in NDVI. Illumination and scan geometry are also important although NDVI, being a ratio, is much less affected by this than the raw channels 1 and 2. However, Singh (1988) has shown in simulation studies, that NDVI decreases at solar zenith angles larger than 30°, and extreme or spurious values may be found at values of larger than 80°, which are suggested as unusable by Holben (1986). The same author has found that scan angle may also affect the NDVI, which is maximum near the nadir.

Some of the above effects such as ozone absorption and Rayleigh scattering can be partially corrected for on daily data by applying corrective algorithms, as will be discussed in section 4.1.4. Others are corrected by compositing. Compositing is the construction of a single image from daily images over a time period (usually 10 days or one month), selecting pixels from these images according to criteria designed to reduce contamination by clouds and the atmosphere. The most common approach is simply to select the pixels with the highest NDVI over the period in question. Such composites are called Maximum Value Composites (MVCs), and the consequences of using them are described in Holben (1986). This author has found that compositing reduces the effects of changes in illumination geometry as pixels are automatically chosen from those scenes in which the satellite was close to nadir, and in which the sun angle was small. The pixels selected are also those which are least affected by cloud (which normally has a negative NDVI), and which have the lowest aerosol content. However a thermal cloud mask is usually applied afterwards as it cannot be guaranteed that over the compositing period each pixel will have a cloud free example. The time period chosen over which the composites are produced will depend on the probability that a pixel is cloudy, off nadir, or has a low sun angle.

The geographical accuracy (registration of satellite to ground co-ordinates) of the data depends on the accuracy of the location information embedded in the AVHRR data.

According to Holben (1986) the mean long track error is 4.8km, and the mean cross track error is 3.6km. This would have consequences for non-homogenous areas in which the MVC would assign high NDVI values to adjacent areas of lower NDVI.
Even after pre-processing and compositing of images, much of the variation in NDVI may not be due to vegetation change. NDVI is sensitive to differences in soil colour which may be due to moisture content or soil type. Huete (1985) found NDVI to be as sensitive to soil darkening as to plant density over partially vegetated areas. Price (1993) has shown that bare soil spectra alone may occupy the lower 30% of the usable NDVI value range between 0 and 1. This is an issue if NDVI is compared between sites with different soils or if the soil humidity changes markedly at the same site measured over time using single date images.

Perhaps the most important point about NDVI is that it measures green vegetation only. In the study area, the dominant *Artemesia* species are usually brown by July. Indeed, as mentioned in Chapter 3, *Artemesia* spp. and *Salsola arbusciliformis* plants start to lose their leaves in mid June. Those species remaining green are shrubs such as *Haloxylon* spp. and *Caragana balchasensis*. *Atriplex cana* and *Anabasis salsa* retain their leaves until August, however their greenness decreases throughout the season. Therefore in Kazakhstan, NDVI is only a good indicator of total biomass in May and June.

The consequences for this study of some of the problems discussed here are examined further in section 4.5. Other vegetation indices exist which are designed to minimise some of the problems associated with NDVI. For example the Global Environment Monitoring Index (GEMI) is less sensitive to atmospheric effects, whilst the Modified Soil-Adjusted Vegetation Index (MSAVI) is very insensitive to differences in soil type compared to NDVI (Leprieur *et al.* 1996).

The MSAVI (Qi *et al.* 1994) is a modification on SAVI, (Soil Adjusted Vegetation Index) which was introduced by Huete (1988). It is calculated as follows:

$$SAVI = (Ch1 - Ch2) / (Ch2 + Ch1) + L \qquad \textbf{(4.2)}$$

where L is a soil adjustment factor between 0 and 1. The adjustment factor L is based on measurements of cotton and range grass canopies on dark and light soils carried out in order to identify a factor that gave equal vegetation index results for both soil types. It is usually set as 0.5 for intermediate vegetation levels. L will vary with vegetation cover, for example it would be expected to be 0 if vegetation cover is 100% as soils would have no influence at all on the signal. The MSAVI replaces L with a function of Ch2 and Ch1 in order to take this into account.

GEMI (Pinty and Verstraete 1992) is designed to reduce problems produced by atmospheric variability. At low vegetation levels however it is more sensitive to the soil background than NDVI (Leprieur *et al.* 1996).

Despite the existence of other indices, NDVI was the index used in this study. There are several reasons for this. According to Ray (1994), SAVI or variants upon it should be used when the vegetation cover is below 30%, whilst at higher vegetation covers NDVI is the better index because it does not involve the use of fairly arbitrary adjustment factors like the L factor in SAVI, and is the most sensitive index to vegetation change. In section 4.7 fieldwork to compare NDVI measured on the ground with that from the satellite is described. During the course of this work (carried out in June 1998) biomass and cover measurements were taken for 27 sites representing typical desert vegetation, by members of the Institute of Botany, Almaty (see section 4.5 for a description of the methodology). The overall percentage covers measured at each site had an average, over the 27 sites, of 60% (range 35-85% cover). This therefore suggests that NDVI should be the best index to use. NDVI is well known in the literature, and its behaviour is well understood. At any rate in this case it was considered best to start with the most common index, with the possibility of recommending others in the future. Another advantage is that many pre-processed NDVI products are available. One of these is the Pathfinder dataset, which is described in the next section.

4.1.4 The Pathfinder dataset

The Pathfinder dataset is a joint project by NOAA and the National Aeronautics and Space Administration (NASA) to produce a long term data set for global change research. At the time of this analysis the data were available only from 1982-1994, and included data from the satellites NOAA-7, -9, and -11, however in late 1999 later years started to come online including data from NOAA 14. The data set and its processing is described in James and Kalluri (1994). Some of the processing procedures have implications for this study, and so they are summarised below:

(i) Navigation

The raw data used was Global Area Coverage (GAC) data with a 4x4km resolution. In this data set positional errors of several pixels are commonly found. Therefore a precision navigation system available from the University of Colorado (Baldwin and Emery 1993) was used, providing navigation accuracy to within one GAC pixel.

(ii) Radiometric calibration

First of all, the raw digital counts must be converted to radiances. This is a complex task as, although pre-flight calibration is undertaken, there is no on-board calibration for channels 1 and 2 and the sensors are known to drift after launch (Rao, 1987; Holben *et al.* 1990). In order to track sensor degradation the NOAA/NASA AVHRR calibration working group used a vegetation-free area of the southern Libyan desert as a stable calibration target for correction of the data (Rao and Chen 1995). From this gains and offsets for the conversion equation are determined. Radiances are the input for the atmospheric correction procedure.

(iii) Atmospheric correction

The atmospheric correction scheme follows the algorithm of Gordon *et al.* (1988). It is designed to correct channel 1 and 2 reflectances for ozone absorption and Rayleigh scattering.

Radiance is a measure of the amount of light reaching the sensor from the target. It is thus affected by illumination conditions as well as by properties of the target. Radiances need to be converted to reflectance values, which are ratios of the light leaving the target to light striking the target. Percent reflectances are calculated directly from the atmospherically corrected radiance by dividing them by solar irradiance corrected for ozone absorption.

(iv) Computation of NDVI

NDVI is computed as described in section 4.1.2. The data are scaled to between 3 and 253. The offset (intercept) is 128, and the gain (slope) is 0.008 for the conversion equation. Therefore the data values are calculated as follows:

$$NDVI = 0.008(x - 128) \qquad \textbf{(4.3)}$$

This gives values between -1 and 1.

(v) Binning and mapping

In order for the images to be comparable, and so that the position of geographical features or settlements can be determined on the images, they must all be converted to the same geographical projection, in this case the Interrupted Goodes Homolosine (Steinwand, 1994), with a grid size of 8x8 km.

The images are projected by a process of forward binning. Here, the location of a satellite pixel is used to locate the output bin in the grid. Between 4 and 6 pixels map to one bin, depending on how close they are to nadir. However the resulting 8km pixel value is not an average of these. Instead the value of that pixel with the maximum NDVI is chosen for the bin. In this way the pixels of the finished composites are not only temporally, but also spatially sampled maxima of NDVI values. At this stage only pixels within 42° of nadir are selected, and pixels having solar zenith angles of greater than 80% are not used because spurious NDVI values have been found for such twilight zones (Holben 1986).

(vi) Compositing

Compositing is necessary for time series analysis in order to remove cloud cover and minimise the effects of anomalies. For the pathfinder data set, 8 to 11 consecutive days of data are combined, taking the observation for each 8km bin from the date with the highest NDVI value. As previously stated, compositing also partially removes effects of directional reflectance and off nadir viewing, sun angle and shadow effects, and aerosol and water vapour (Holben 1986).

4.2 Rainfall and NDVI patterns in the study area

In this section the NDVI and rainfall data available for the study area from 1982 to 1994 are presented and compared with data used in other studies.

4.2.1 Rainfall data in the period of NDVI availability

For the study region, rainfall data were taken from the 10 meteorological stations described in Chapter 3 (Figure 3.2). In the literature on annual relationships between rainfall and NDVI, most studies involve large areas and many meteorological stations. For example, Eklundh (1998) used data from 80 stations in his study in Kenya. Prince *et al.* (1998) had meteorological data for 214 sites covering a rainfall range of 200-800mm per year. The rainfall data set for the study region of Kazakhstan has a maximum range, taking 13 years and 10 stations, of 50-486mm. Rainfall data were acquired for an additional 55 stations in Kazakhstan from the Climatic Research Unit, University of East Anglia. NDVI was also extracted for these stations, meaning that some of the investigations could be extended to larger areas of the country, although for most of these stations there were no data after 1990.

According to several studies, outside certain thresholds NDVI is no longer sensitive to rainfall variations. Nicholson *et al.* (1990) report a sensitivity of between 200 and 1200mm/year in East Africa. According to Richard and Poccard (1998) in their study of Southern Africa, sensitivity to mean annual rainfall is observed where it varies between 300 and 900mm per year, however, sensitivity to anomalies is observed only in dry areas (300 to 500mm). According to Nicholson and Farrar (1994), in Botswana, the NDVI-rainfall relationship breaks down over 500mm/year. Malo and Nicholson (1989) in a four year study using data from Niger and Mali, found that NDVI is sensitive to inter-annual variability in rainfall only below a threshold of 900-1000mm and above a threshold of 150mm.

For the study region rainfall data were available from 1967 to 1998 for most of the stations, but NDVI data were only available from 1982 to 1994. The average yearly rainfall for the period 1982-1994 compared with the longer term average is shown in Table 4.2.

Table 4.2: Rainfall averages over 30 years, and from 1982-1994 for the 10 stations in the study area. *The stations are listed in order of latitude, southernmost first.*

Station	Latitude (decimal degrees)	Average rainfall over 30 years (mm)	Average rainfall 82-94 (mm)
Turkestan	43.27	195.9	208.5
Kyzyl -Orda	44.76	128.0	180.6
Tasty	44.79	152.9	129.1
Ulan bel'	44.82	155.6	142.1
Tiuken	45.35	141.0	135.5
Betpak - dala	46.33	152.0	147.8
Balkhash	46.90	144.0	168.7
Koktas	47.31	203.7	205.8
Berlik	48.88	220.2	237.4
Karaganda	49.79	316.5	323.8

As can be seen from the above table, all the stations except one have long term average rainfalls of less than 250mm. This low rainfall potentially could be a problem when looking at NDVI-rainfall relationships.

The rainfall periods from 1967-1981 and from 1982-1994 were tested for equal variances using an F-test, and then for equal means using a two sample t-test, each group of years being regarded as a separate sample. Tasty failed the test for equal variances, and so the subsequent t-test performed on data from this station was one which did not assume equal variances. Tasty, Balkhash, and Karaganda failed the test for equal means, and Ulan bel' and Betpak-dala had small P values of 0.1. The results are shown in the Table 4.3.

Table 4.3: Results of a 2-sample t-test for means to determine whether rainfall means in the period 1967-1981 are significantly different from those in the period from 1982-1994*. Stations are listed in order of latitude, southernmost first.*

Station	**Mean rainfall (mm)**		**F test for equal variances**	**t-test for equality of means**
Time period	1967-1981	1982-1994	Value of F statistic and significance	Value of t statistic and significance (2 tailed)
Tasty	173	129	3.1*	2.4**
Ulan	168	142	0.4 NS	1.1 NS
Tiuken	157	135	2.25 NS	1.3 NS
Betpak	167	147	1.8 NS	1.18NS
Balkhash	119	169	0.8 NS	-3.5***
Koktas	208	205	0.36 NS	-2.24 NS
Berlik	224	237	0.64 NS	-6.3NS
Karaganda	285	341	0.42 NS	-2.2**

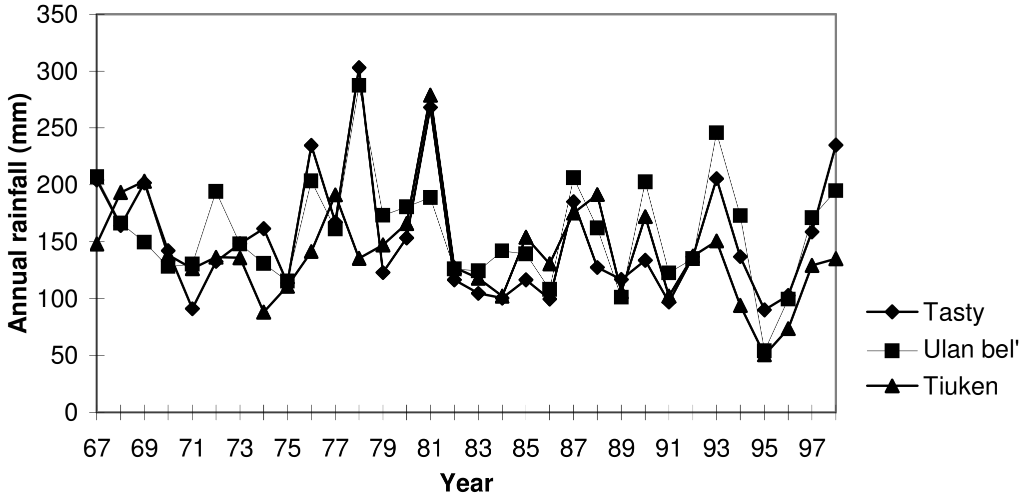
From Table 4.3 we can see that at the southern four stations, the period from 1982-1994 was dryer than previous years, but only at Tasty was this difference statistically significant. For the northern four stations the period was wetter, but this was only significant at two of the stations.

Figure 4.1 shows the rainfall data for the entire period for which it was available (1967 to 1998) for the three southernmost and three northernmost stations. From this figure, rainfall variability during the period for which NDVI data are available can be visually compared with longer term rainfall data. At stations within each region, and to a lesser extent between them, the rainfall patterns are similar over the years. This suggests that rainfall trends are not station-specific (arising from localised precipitation patterns) but are general for vegetation zones.

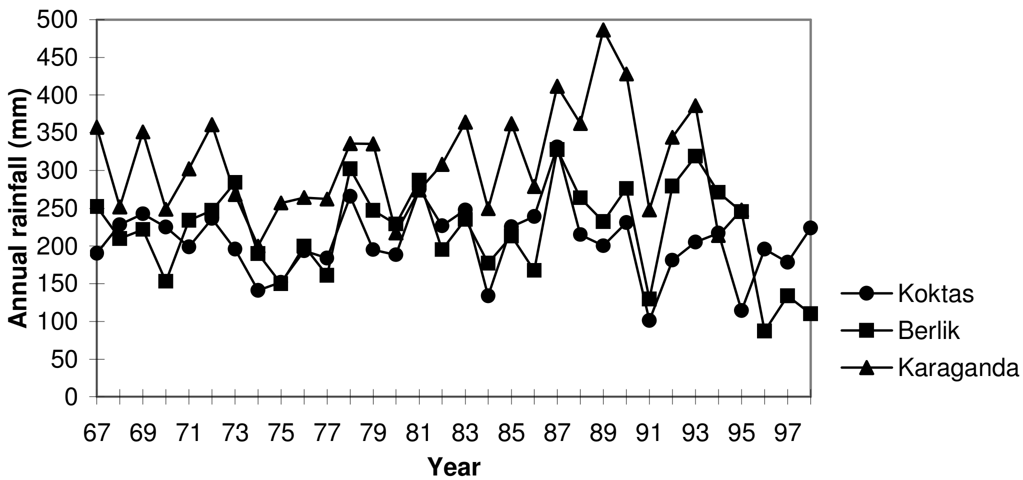
Figure 4.1: Rainfall patterns from 1967 to 1998.

(a) Three stations in the desert zone. (b) Three stations in the semi-desert zone.

(a)



(b)



The main observation is that the period for which NDVI data are available covers a wide range of rainfalls, especially in the semi-desert (northern) zone, where the lowest rainfall values (1984, 1991) and the highest (1987, 1993) of the entire period are both to be found between 1982 and 1994, and rainfall ranges from just over 100 to 350 mm at single stations. For the desert zone, it can be seen that the beginning of the period consists of several very dry years (1982 to 1986) followed by fluctuations between dry and wet years, however rainfall stays between about 100 and 225 mm. In the desert zone therefore the lack of extreme years may mean that relationships are not as strong as they might be if a longer time series could be used.

4.2.2. Extraction of NDVI and a comparison of seasonal patterns of NDVI and rainfall

Figure 4.2 shows an NDVI image (average of peak NDVI over the 13 years 1982-1994) for Kazakhstan with all the meteorological stations for which rainfall data were available marked on. One of them (Orenburg) is in fact located in Russia. On this image the increase in vegetation from the south to the north of the country can be clearly seen, and is visible also within the study area. NDVI at stations Ulan bel' and Tasty is higher than surrounding areas due to their position on the River Chu.

For each 10 day composite, NDVI was extracted for a 9 and 3 pixel radius (72km and 24km) from each station, corresponding to a block of 81 and 9 pixels respectively. The value extracted was the spatial average of NDVI for this area. Throughout this study the 9 pixel radius data is used as it gives consistently better results. This is possibly because it is an average over more vegetation types, a source of considerable variation (see Chapter 3), and also because it reduced the effects of noise (see section 4.5).

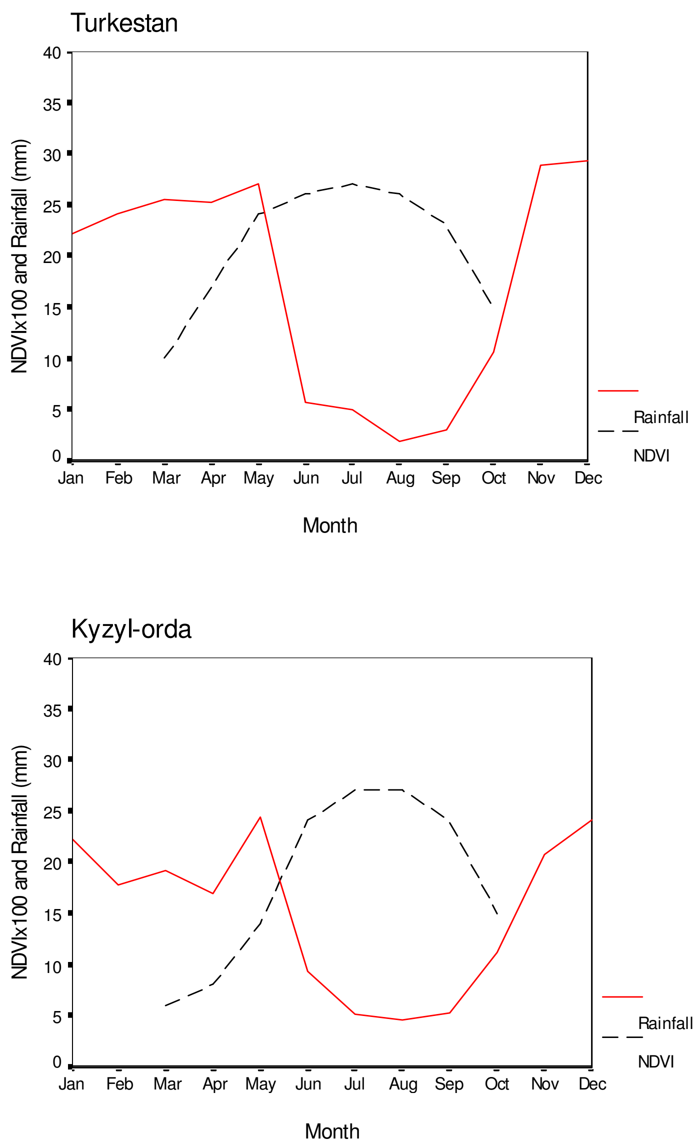
Once the data had been extracted, they were converted to monthly values so that the NDVI data actually used were all based on averages of the three 10 day maxima extracted for each month from the original data set. This is suggested by Richard and Poccard (1998) as it further reduces problems of cloud cover frequency, varying off nadir viewing angles, and solar zenith angle variations which probably still exist to some extent in 10 day composites. An average of 10 day maxima reduces one of the problems of monthly MVCs, which is that the time step of monthly data is not in fact constant. For example, during the peak to die-off period, maximum NDVI values may fall at the end of one month and beginning of the next, meaning that in effect the

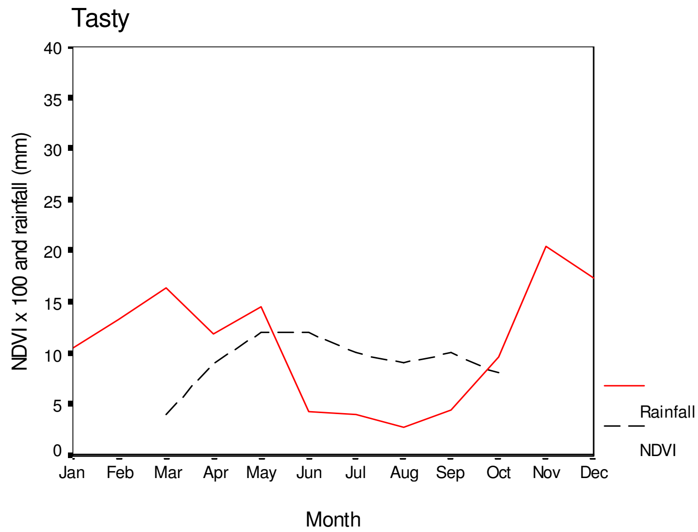
Figure 4.2

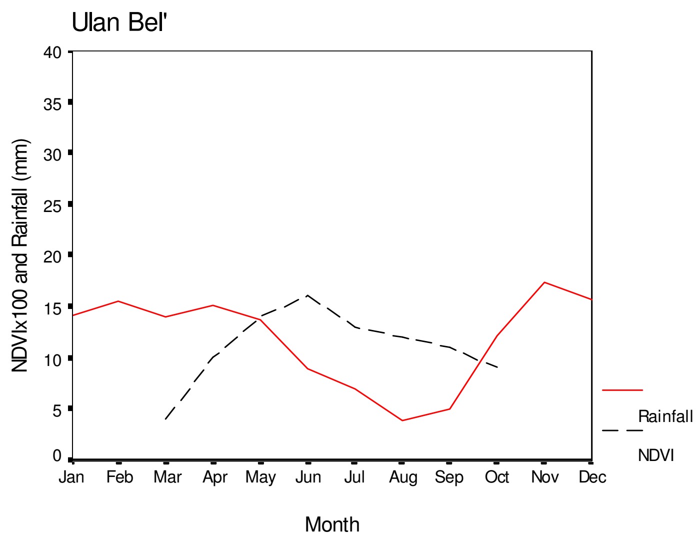
values for the two months will be virtually from the same date. Monthly means of 10 day maxima reduce this problem, and should be about 80% of the values of monthly MVC NDVI (Gutman 1989).

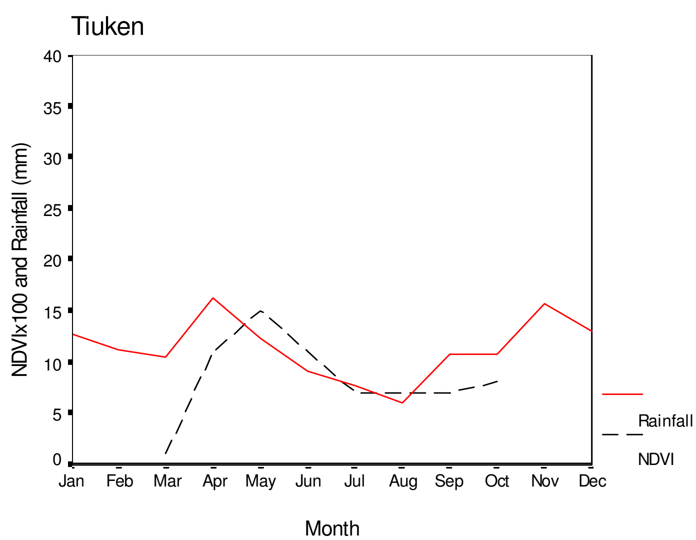
For each station, averages of rainfall and NDVI over the 13 years were found for each month, and plotted on the same graph, NDVI being multiplied by 100 so that the scales would be comparable. The resulting graphs are shown in Figure 4.3.

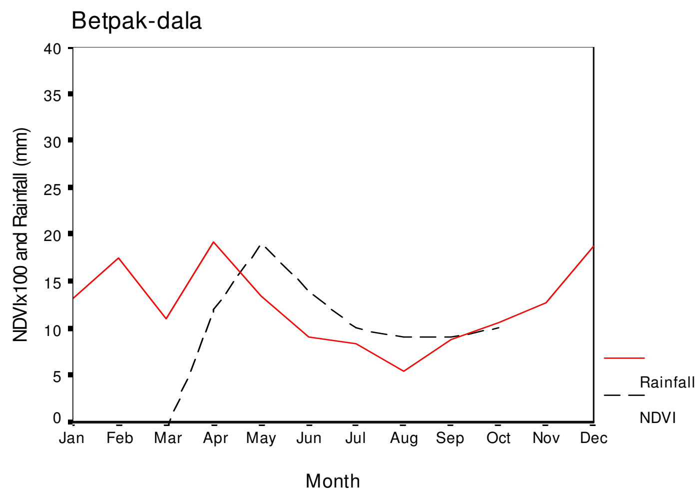
Figure 4.3: Graphs showing average monthly NDVI and Rainfall patterns for each station. *All graphs are on the same scale except for Karaganda. Rainfall units are in mm, and NDVI is multiplied by 100. The graphs are shown in order of latitude, southernmost first.*

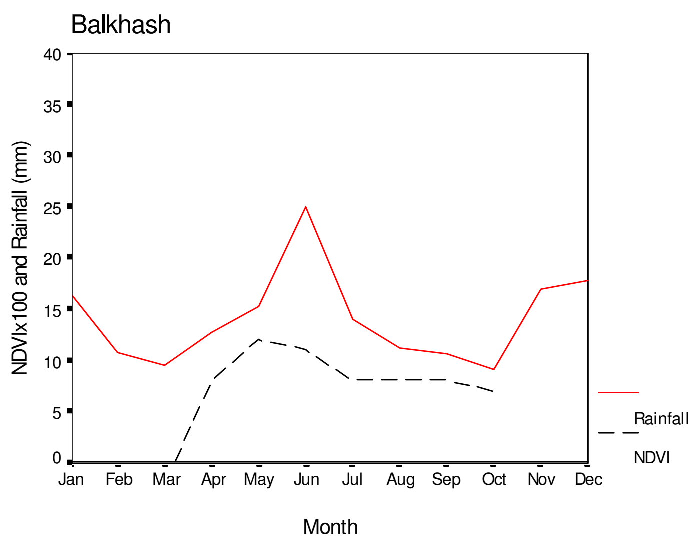


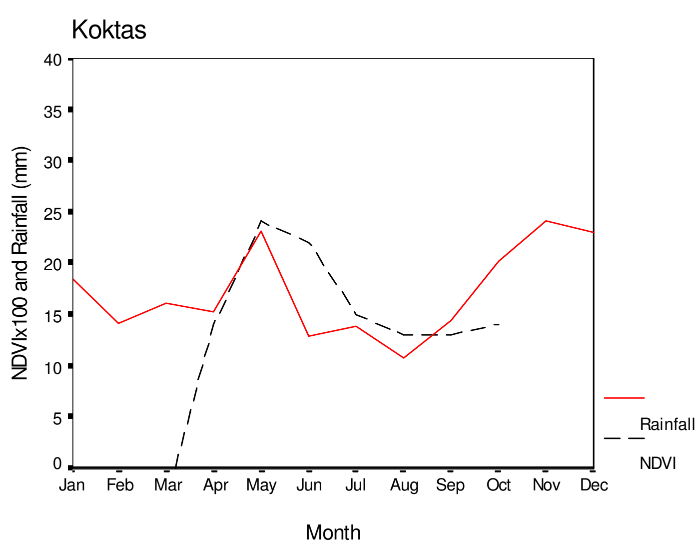

Tasty
NDVI x 100 and rainfall (mm)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Rainfall
NDVI

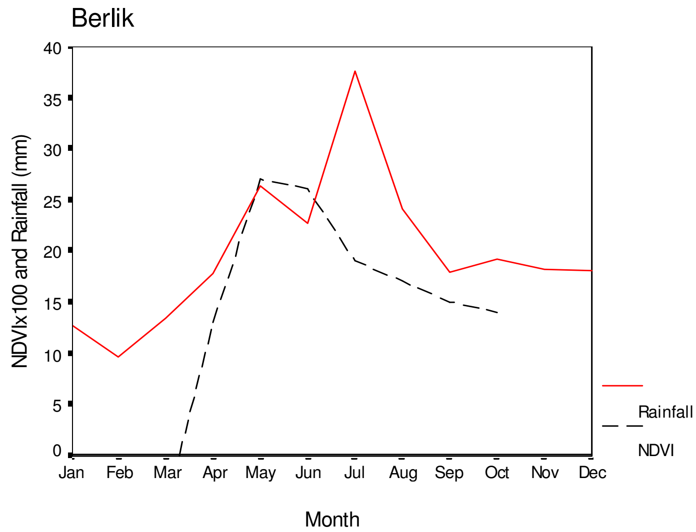

Ulan Bel'
NDVIx100 and Rainfall (mm)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Rainfall
NDVI

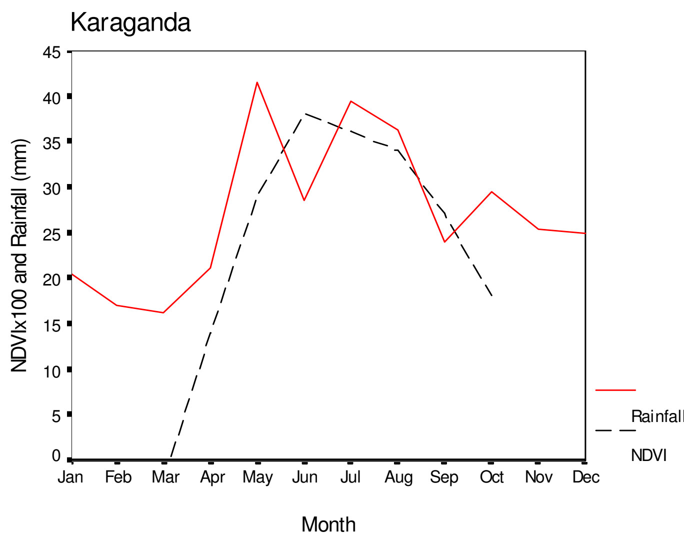

Tiuken
NDVIx100 and Rainfall (mm)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Rainfall
NDVI


Betpak-dala
NDVIx100 and Rainfall (mm)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Rainfall
NDVI


Balkhash
NDVIx100 and Rainfall (mm)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Rainfall
NDVI


Koktas
NDVIx100 and Rainfall (mm)
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Rainfall
NDVI





The general increase in NDVI with latitude visible in Figure 4.2 is also observable Figure 4.3, the exception being Balkhash, which has a very low NDVI.

Most of the more southerly stations (i.e. all except Karaganda and Berlik) have two rainfall peaks, one in April or May, and one in November. Between May and November, rainfall drops to between 10 and 0 mm per month. NDVI has a very low flat peak at Tasty and Ulan bel' in marked contrast to those at Tiuken and Betpak-dala. NDVI rises slightly again in the autumn at southerly sites.

Karaganda and Berlik (the northernmost stations) have rainfall peaks in spring and summer, a sharp drop off to October when there is again a small increase, and then lower rainfall for the rest of the year. Throughout the summer, rainfall remains higher than in the winter months, in sharp contrast to the other stations.

Kyzyl-Orda and Turkestan are anomalies. At these two stations NDVI is high and consistent all summer, only dropping off after August. This is because Kyzyl-Orda is on the Syr Darya river, and the irrigated agriculture in this region keeps the NDVI high throughout the season. Turkestan is close to the Karatau Mountains, which reach an altitude of 2000m. The data from the meteorological station are not representative of these mountains, which are the source of numerous springs, and which certainly have a higher rainfall than the plain below. Therefore these two stations were not used in further work.

The main point to note from the graphs is that the NDVI shows a similar curve between stations, although the southerly stations have a flatter peak and die-off curve which plateaus off faster than that of more northerly stations. The rainfall however, shows much more variability, having a peak in winter for the southern stations, and a peak in summer for the northern stations.

4.3 Prediction of NDVI from rainfall using time series data

In this section regression analyses are carried out between rainfall and NDVI in order to determine how well NDVI can be predicted from rainfall. These analysis were attempted on two time scales: monthly and yearly, and the results are presented separately in the following sections together with comparisons with similar studies.

4.3.1 Monthly rainfall-NDVI relationships

Nicholson and Farrar (1994), in their study of Botswana, found highest correlations between NDVI and rainfall by using multi-month rainfall values, the best correlations coming from the current month plus preceding 2 months, or from the preceding two months alone. Richard and Poccard (1998) found the same thing in their study of Southern Africa. To work out what kind of lag should be given they calculated multi-month sums, and compared these with the results using simple lags. They obtained maximum correlation coefficients of 0.75 for rainfall lagged 1 month, and 0.81 for summed rainfall over the preceding two months.

The problem in Kazakhstan, as opposed to tropical countries, is that only NDVI values from April to October can be used, because in the other months the average temperature is below 5 degrees at all stations. At this temperature, growth will be zero whatever the rainfall. In any case in these months the steppe is also covered with snow, making the NDVI meaningless. Yang *et al.* (1997) conducted a study of 2 growing seasons (1990 and 1991) in Nebraska, USA, which also has cold snowy winters. They found good correlations between bi-weekly NDVI MVCs and precipitation, with maximum R^2 values corresponding to a time lag of 5-7 weeks depending on the location of the meteorological station, and ranging from 0.54-0.74 depending on station and year. In that area, rainfall during the growing season ranges from 360-580mm, which is higher than annual precipitation in the study area. In all the studies mentioned above the relationships between monthly rainfall and NDVI were linear.

Regressions were performed on the Kazakhstan data, on each station individually for the whole time series, using various multi-month sums up to three months, and lags up to 2 months. The results are shown in Table 4.4. Some of the regressions were significant at Betpak-dala, Ulan bel', and Karaganda, with rainfall lagged one month, or summed over the two months before the NDVI measurement tending to give the best results. However, the R^2 values were very low, and is also important to remember that when so many regressions are performed, some would be expected to be significant by chance.

The analysis was repeated using the difference in NDVI (difference of one month) instead of NDVI itself. The results for Tasty (the only station for which this was tried), were non-significant. These results are similar to those for the biomass data described in Chapter three, in which it was seen that monthly or bi-monthly rainfall either did not predict biomass at all, or explained very little of the variation.

Table 4.4: R^2 values for relationships between monthly NDVI and rainfall. *The rainfall is expressed as multi-month sums and lags, rainfall in month 0 referring to the month of the NDVI measurement, 1 being the month before etc.*

Station	**0**	**0+1**	**0+1+2**	**1+2**	**0+1+2+3**	**Lag 1**	**Lag 2**
Berlik	0.02	0.06*	0.04	0.018	0.017	0.057*	0.001
Tasty	0.002	0.004	0.019	0.037	0.037	0.019	0.026
Ulan bel'	0.000	0.028	0.065*	0.117***	0.067*	0.081**	0.085**
Balkhash	0.008	0.04	0.000	0.002	0.004	0.000	0.001
Karaganda	0.028	0.180***	0.175***	0.163***	0.099	0.218***	0.019
Koktas	0.000	0.015	0.015	0.02	0.005	0.029	0.001
Betpak-dala	0.026	0.19	0.208***	0.194***	0.235***	0.212***	0.035

Overall the results for the monthly data were so poor that this avenue was not explored further, and the next section deals with attempts to predict NDVI on an annual basis.

4.3.2 Annual rainfall-NDVI relationships for the study area

The first step in the investigation of annual relationships was to summarise the NDVI as a yearly value which has some relation to net primary productivity. In the literature, typically NDVI values summed over the growing season have been used to derive indicators of total seasonal production (Prince and Tucker 1986, Tucker *et al.* 1983, 1985, Diallo *et al.* 1991), although several studies have shown that seasonal maximum NDVI may produce better correlations. For example, Fuller (1998) attempted to relate NDVI to biomass clipped at peak growing season. The biomass NPP data were most strongly related to peak NDVI for a 7 year data set, and not at all related to summed or mean annual NDVI, agreeing with Hierneaux and Justice (1986), and Hobbs (1985). In the literature there is therefore no consensus about whether peak or summed NDVI should be used, and in this study both have been tried.

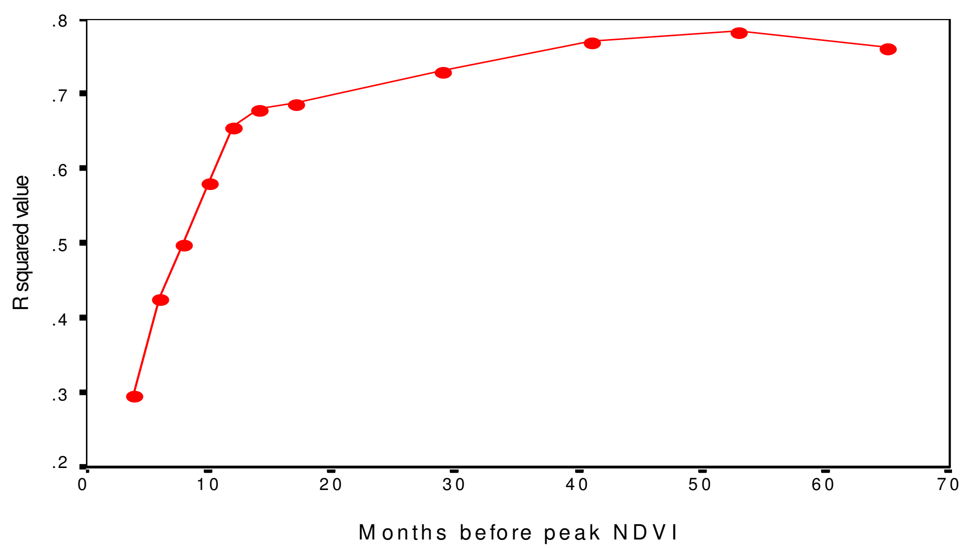
The first regressions attempted here had the aim of finding a simple relationship between rainfall and biomass for all the stations together. In the regressions below, data from 8 of the 10 available stations were used because as explained above, the stations Turkestan and Kyzyl Orda were anomalous. In most cases annual rainfall was not taken from January to December as rainfall from June to December (in the case of peak NDVI) and November and December (in the case of summed or average NDVI) would not have had any bearing on vegetation recorded by the NDVI.

(i) Peak NDVI

The first investigation was an attempt to find out over what time span rainfall had the closest relationship with peak NDVI (normally occurring at the beginning of June or end of May). The peak NDVIs used here are in fact peaks of monthly averages of 10 daily MVCs, and so inter-annual variation may be reduced if the biomass peak is short and sharp. The consequences of this are discussed in section 4.7.

Peak NDVI and rainfall were taken from 8 stations, making a total of 104 data points (as there are 13 years of satellite data). Figure 4.4 shows that the relationship increases steeply up to 12 months, and then continues to increase slowly up to a peak of four years.

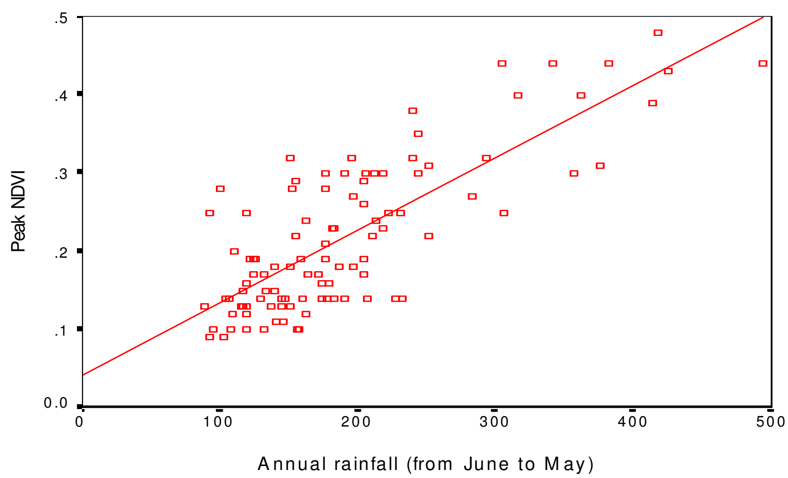
Figure 4.4: The strength of relationships between peak NDVI and different time periods of rainfall for 8 meteorological stations.



As can be seen from Figure 4.4, the most efficient rainfall value, that which explains the most variation for the least amount of information, is rainfall in the 12 or 14 months before the peak (R^2 = 0.66** and 0.68** respectively).

Figure 4.5 shows the relationship between peak NDVI and total rainfall in the previous 12 months (June to May) for the 8 stations together.

Figure 4.5: The relationship between peak NDVI and total rainfall from June to May for 8 meteorological stations in the study area. *R^2 = 0.66****



(ii) Summed NDVI

For the study region, the regression of total rainfall in the 12 months up to the end of the growing season (October year *X*-1 to September year *X*) against NDVI in year *X* summed from March to October for the 8 stations together gave an R^2 of 0.618***. To compare this with other studies, Prince *et al.* (1998) recorded an R^2 of 0.49 using summed NDVI and annual rainfall for the whole Sahel region. Hielkema *et al.* (1986) studied 12 stations over three years for Sudan, and obtained R^2 values of 0.74, 0.79, and 0.8 for various seasonal rainfall periods varying from rainfall May-July, May-August, and May-October. The rainfall variation in their study area was between long term means of 158 and over 700mm, much larger than in this study.

The results for summed NDVI were almost the same as those for Peak NDVI, the relationships improving as rainfall is taken over longer and longer periods up to four years, and giving similar R^2 values and significances. As a yearly rainfall measure, rainfall from June to May was again the best variable. This at first seems odd as NDVI is summed over the whole growing season, not just up to May, whilst rainfall periods including months after May did not improve the relationships. It could be suggested that, as was found in Chapter 3, rainfall during the summer does not in fact have much influence on biomass, and thus on summed NDVI. Also NDVI probably detects very little vegetation after June, as in most years it becomes brown very quickly.

(iii) Average NDVI

The results for this were very poor, and so this measure was abandoned. The reason is probably that a lot of the variation, which is to be found mostly at the beginning of the season, is smoothed out by this process.

(iv) Summary

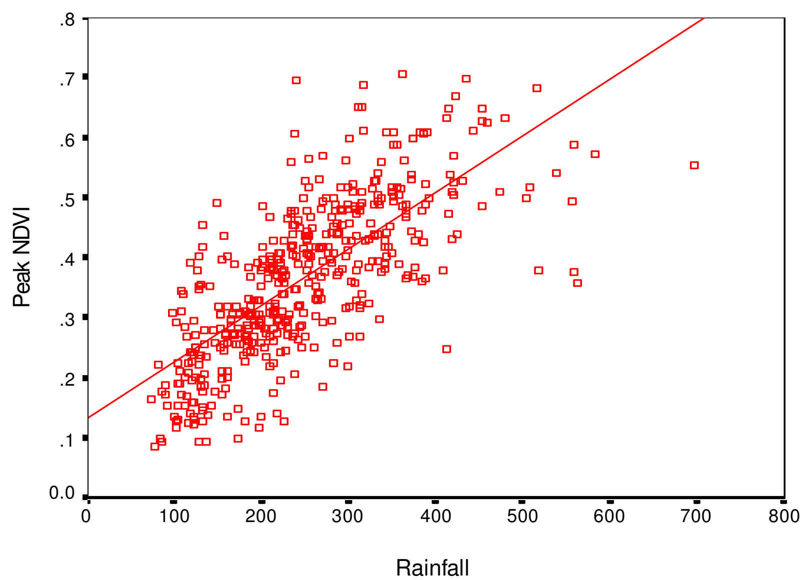
In this study, summed and peak NDVI appear to be similar indices with similar responses to rainfall, and a 12 month period seems to be the most efficient when determining both peak and summed NDVI. All the regressions conducted were linear, agreeing with most studies in the literature. Although Davenport and Nicholson (1993) found a log-linear relationship (probably reflecting a saturation response), in this study there was no sign of linear relationships being inappropriate from inspection of the regressions (see Figure 4.5).

4.3.3 Annual NDVI-rainfall relationships for the whole country

Rainfall and NDVI were available for a further 55 stations covering most *oblasts* in Kazakhstan, although the data often did not go up to 1994 as many stations closed in 1990. The positions of these stations are shown in Figure 4.2. These data were used in order to see whether a data set including a higher range of rainfall values would give similar results. On screening, it was found that the station for Almaty was anomalous, having the highest rainfall, but a relatively low biomass. This is due to its position in the Tien Shan mountains which have a very different rainfall regime from that of the other stations, and therefore data from this station were not included. The average annual rainfall at the stations ranged from 129 to 539mm per year.

When rainfall from June to May was regressed against summed NDVI, the R^2 value was 0.504***. The results for peak NDVI were similar and are shown in Figure 4.6.

Figure 4.6: The relationship between peak NDVI and annual rainfall from June to May for 64 meteorological stations in Kazakhstan. *R^2 = 0.53****.



4.3.4 Analysis of covariance on rainfall and site

It was suspected that the regressions performed to look at NDVI-rainfall relationships only pick up differences between the stations. This can be suspected from the literature. For example, Heilkema *et al.* (1986) had only three years of data, but 12 stations, and obtained better relationships than those in this study. It was considered that an analysis of covariance with station as a factor and rainfall as a covariate should tell us whether it is rainfall between or within stations which is causing the regression result. This was carried out using the data plotted in Figure 4.5, rainfall June-May and peak annual NDVI for 8 sites in the study area.

The F values and significances for the two variables are as follows:

Rainfall F =14.5 P=0.000

Site F= 27.3 P=0.000

Interaction non-significant F=1.5 P=0.177

Variances equal (Levene's test of homogeneity of variance) F= 1.2 P=0.3

This suggests that the predictive ability of rainfall in the regression has its effect both through the continuous variable of rainfall, and the between-site effects.

In summary Rainfall is a reasonable predictor of peak annual NDVI although much of the variance in this relationship can be explained by between site effects. It possible that the relevant rainfall period influencing biomass varies from site to site, meaning that simply using annual rainfall as a predictive variable produces poor models at single sites. This can be already suspected from Chapter 3, in which it was found that rainfall over a relatively short period of time in spring was the main determinant of biomass over the growing season at two sites. Also, if we are to study NDVI change through time this has to be done at single sites whose grazing histories are known. Therefore the variables affecting biomass at single sites are examined in more detail in part 4.3.5 below.

Another problem with the rainfall-NDVI relationships examined so far is that they all suffer from serial correlation. The main reason for this is that there is a strong upward trend in NDVI over the years. This is discussed in the following sections. However general problems of non-independent residuals, and attempts to resolve them, are discussed in Appendix 3.

4.3.5 Rainfall-NDVI relationships at single stations

In the literature there are few studies which look at rainfall-NDVI relationships on an annual basis for single stations because until recently the degrees of freedom were very low due to the low number of years available (usually less than 10 years of data were used in most studies in the literature). This study uses a longer data set of 13 years, so the regressions were attempted for single stations. This was considered to be useful because in order to look at NDVI change over time in relation to changes in the livestock sector, it is more useful to look at single sites rather than the study area as a whole, as each area has its particular history of land use.

Regressions were conducted using summed and peak NDVI values against rainfall in the 12 months from June to May. The results shown in Table 4.5 (column 2) confirm that one rainfall variable for the whole year is sufficient to distinguish between stations, but has little predictive value for NDVI between years for one station. Significant relationships were found for three of the eight stations, but none of the regressions were highly significant.

Table 4.5: Relationships between various independent variables and peak NDVI for single meteorological stations, 1982-1994. *The columns are numbered for subsequent reference in the text.*

1	2	3	4	5	6
Independent variable	**R^2 annual rainfall (June to May)**	**Rainfall period giving best result**	**R^2 for this period**	**R^2 annual rainfall and lagged NDVI**	**Year alone**
Tasty	0.371*	Oct-May	0.46*	0.58*	0.44*
Ulan bel'	0.62**	Aug-May	0.76***	0.7*	0.550**
Tiuken	0.00 NS	-	all < 0.1	0.586*	0.67***
Betpak-dala	0.12NS	Feb-May	0.26NS	0.4 NS	0.60**
Balkhash	0.12 NS	Jun-May	0.12 NS	0.48*	0.69***
Koktas	0.00 NS	-	all < 0.1	0.32*	0.46**
Berlik	0.15NS	Dec-May	0.17 NS	0.29NS	0.318*
Karaganda	0.396*	Dec-May	0.79***	0.27 NS	0.29*

For the biomass data (Chapter 3) it was noted that for single stations results were best if a smaller time period could be identified in which rainfall influenced peak biomass. For *Salsola arbusciliformis* pasture in Betpak-dala it was rainfall from February to April, and for Tasty it was rainfall from December to May. This was attempted for NDVI data. Columns 3 and 4 of Table 4.5 show the rainfall periods which best predicted peak NDVI at each site, and the regression results.

As can be seen from Table 4.5 the results were extremely variable, with some stations showing reasonable rainfall-NDVI relationships when certain rainfall periods are used, but most having insignificant relationships whichever period was used. The periods were chosen by using progressively longer rainfall sums from May backwards (i.e. Feb-May, Jan-May, Dec-May, …..Jun-May). This meant nine regressions per station. When so many regressions are carried out, some 1 out of 20 would be expected to be significant by chance. However, the fact that at Ulan bel' and Tasty, the two stations along the river Chu, significant results were observed, may not be due merely to chance, and it is possible that at these stations the vegetation is more responsive to rainfall than elsewhere. This will be discussed further in Chapter 5 of this thesis.

Overall, rainfall relationships with NDVI at single stations are absent or poor even when rainfall periods shorter than one year are used. An important point is that each relationship suffered from serial correlation (see Appendix 3). An attempt was made to remedy this by adding lagged NDVI and year into the regressions (columns 5 and 6 of Table 4.5). The addition of lagged NDVI as an independent variable significantly improved the relationships with annual rainfall, however the most striking result here was the effect of year. Year is the single best predictor of NDVI at all sites, and indeed also explains the reason for the effect of lagged NDVI. This is because there is a very strong trend in NDVI over the time period of study. This is discussed in section 4.4.

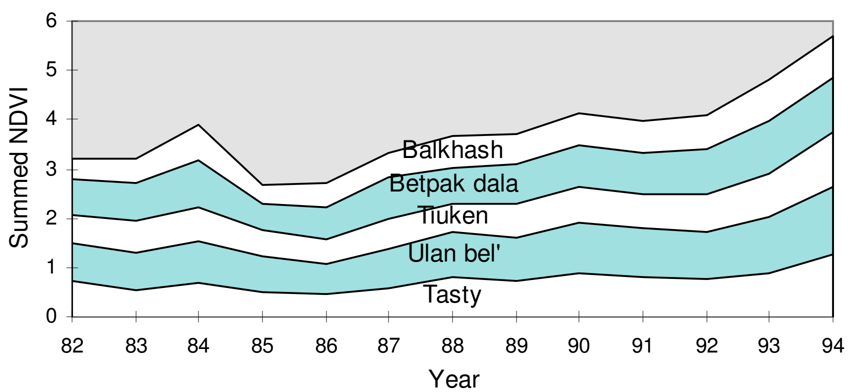
4.4 Trends in NDVI

4.4.1 Comparison of trends in NDVI and rainfall

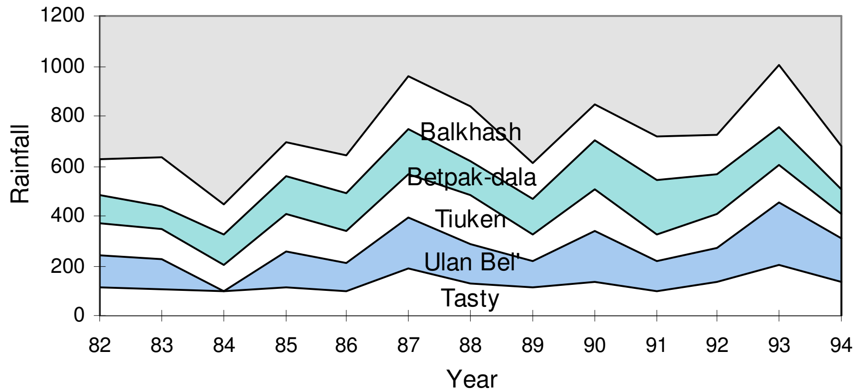
The graphs in Figures 4.7 and 4.8 illustrate the differences between annual rainfall and NDVI patterns. The sites are grouped into those in the desert zone (average annual rainfall less than 200mm per year), and those in the semi-desert zone (average rainfall greater than 200mm per year). The graphs show summed NDVI and annual rainfall (January to December). Following this, peak NDVI and other rainfall periods are examined.

Figure 4.7: Trends of NDVI and rainfall at sites in the desert zone.
***(a)** Summed NDVI, (b) Annual rainfall (January to December).*

(a)



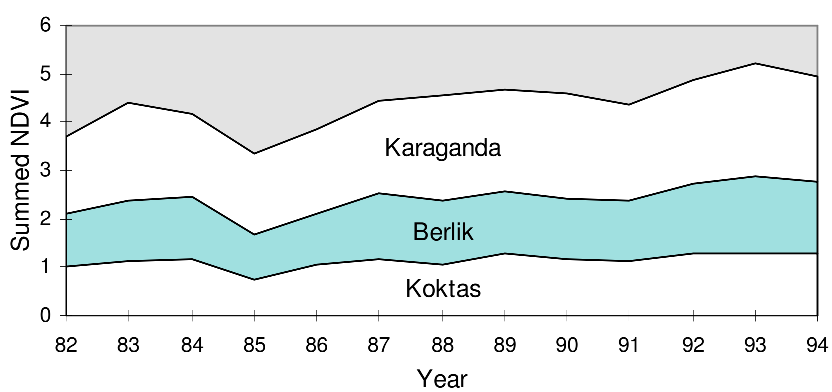
(b)



Upon examination of the data for the desert zone (Figure 4.7) it can be seen that peaks and troughs for NDVI and rainfall do not coincide, except for a peak in 1990 followed by a drop in 1991. The most noticeable troughs in the rainfall data occur in 1984, 1989, 1991, and 1994. In contrast, the lowest NDVI periods are in 1985-1986, from which time NDVI climbs year by year. Although small decreases are seen in 1989 and 1991, the sharp drop in rainfall of 1994 is not mirrored by NDVI. The periods of peak rainfall are in 1987, 1990, and 1993. The NDVI peaks are in 1984, 1990, and 1994.

Figure 4.8: Trends of NDVI and rainfall at sites in the semi-desert zone.
(a) *Summed NDVI, (b) Annual rainfall (January to December).*

(a)



(b)

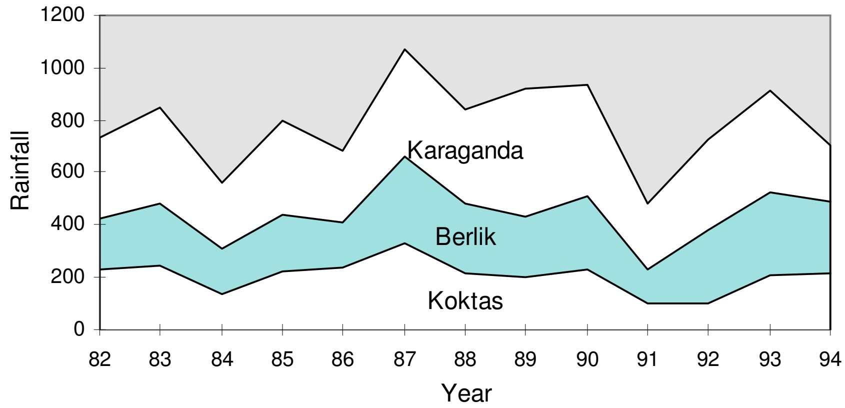


Figure 4.8 shows patterns for the semi-desert zone. Once again, there is a trough of rainfall in 1984, whilst for the NDVI, it is in 1985. The rainfall is high in 1983, 1987, and 1990, and 1993, whilst the NDVI shows peaks in 1983, 1989, and 1993. The strong rise in NDVI visible in 1994 in the desert zone does not exist at the sites in the semi-desert zone.

It is clear both from the regressions in part 4.3.5 and from the graphs above that rainfall and NDVI patterns do not coincide, and that NDVI seems to show an upward trend not seen in the rainfall data, although this is stronger for the desert area than the semi-desert area. This upward trend in average summed NDVI over the two groups of sites is significant both for the desert and semi desert zones (R^2 = 0.63*** and 0.60*** for the two zones respectively), however there is no significant rainfall trend (R^2 = 0.211 (NS) and 0.00 (NS)). The rainfall trend is also non significant if the annual rainfall figure is taken from June to May, a period which would be expected to be more closely related to NDVI.

As was discussed in Chapter 3, it appears that precipitation in winter and spring has the greatest effect on NDVI, and especially on peak NDVI. Therefore, time trends of these two variables were also investigated. The Z-scores for peak NDVI and rainfall from December to May from their 13 year norms were calculated for each station. The mean of these Z-scores for each year were found for the stations in the desert and semi-desert zones, and plotted against year. In this way, trends in stations having higher overall biomass would not be allowed to have disproportionally large effects on average values for the two zones. The resulting graphs are shown in Figures 4.9 and 4.10.

Figure 4.9: Trends of Z-scores of peak NDVI and rainfall from December to May at sites in the desert zone. *The R^2 values for the relationships of NDVI and rainfall with year are shown for each graph. (a) Peak NDVI, (b) Rainfall December-May.*

*(a) R^2 = 0.68** *(b) R^2 = 0.34****

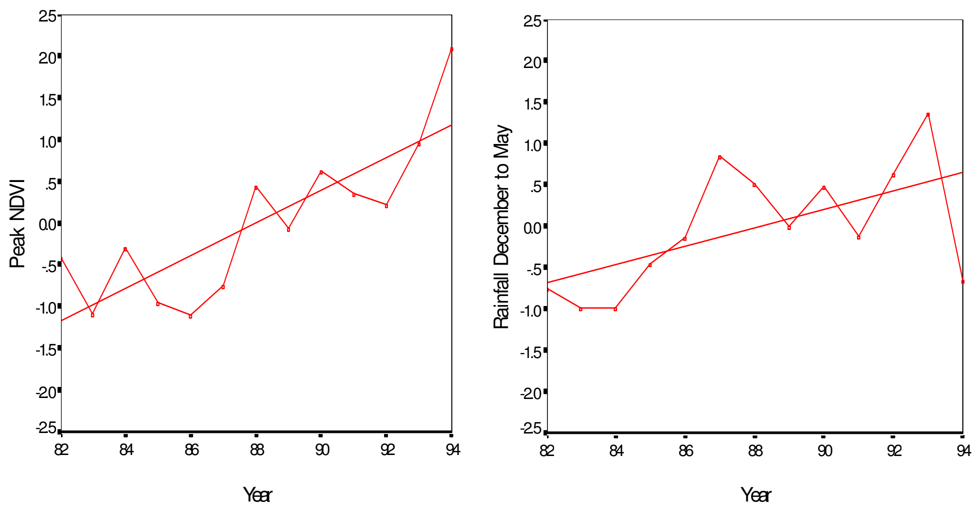


Figure 4.10: Trends of Z-scores of peak NDVI and rainfall from December to May at sites in the semi -desert zone. *The R^2 values for the relationships of NDVI and rainfall with year are shown with each graph. (a) Peak NDVI, (b) Rainfall December-May.*

*(a) R^2 = 0.42*** *(b) No relationship*

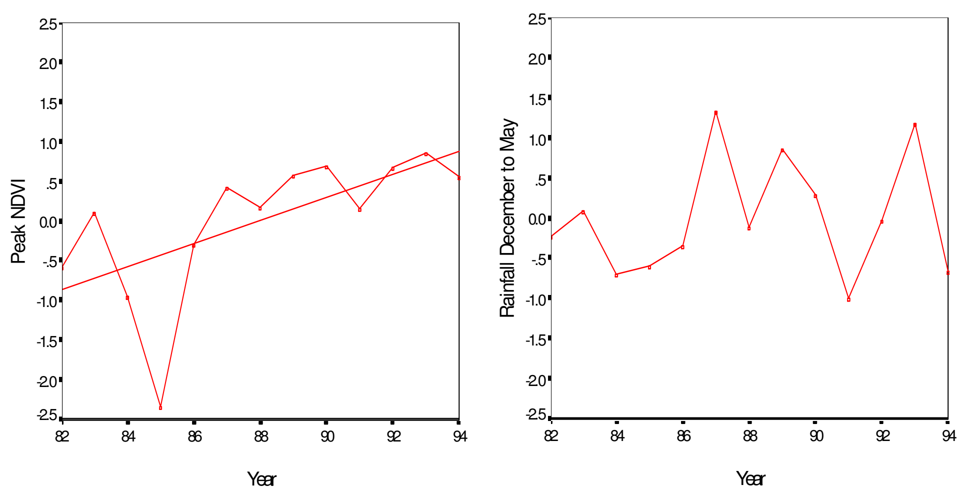


Figure 4.9a shows that there is a strong increase in peak NDVI in the desert zone over the 13 years of data. There is also a weak increase in rainfall over this period, although this does not extend into 1994, the year of highest NDVI. The spring rainfall of the early 1980s was low, whilst that of the 1990s was high. When this average value for winter-spring rainfall in the desert zone was regressed directly against the average value for peak NDVI, there was still no significant relationship (R^2 = 0.072 NS).

Figure 4.10a shows that peak NDVI also increases in the semi-desert zone, however, the relationship is probably largely due to the extremely low NDVI of 1985, which is proportionally much lower than the corresponding low value for rainfall which also occurred in that year and in the year before. Indeed, four NDVI decreases can be observed in 1984, 85, 91, and 94, corresponding also to years of low rainfall (Figure 4.10b). However there no significant relationship between winter-spring rainfall and peak NDVI in the semi-desert zone (R^2= 0.265 (NS)), although the P value was low (P = 0.07).

4.4.2 Possible reasons for the observed trends

To summarise, it appears that there has been a general (though not constant) increase in NDVI through the period of the study, particularly in the desert zone. This trend is most strongly influenced by a group of low NDVI years (1983, 1985, and 1986) at the beginning of the time period, and a group of high NDVI years (1993 and 1994) at the end. These trends are not significant for annual rainfall in the two zones, whether this is taken from January to December or from June to May. However, there is a trend for the desert zone in winter-spring rainfall which shows a weak increase over the time period of study.

The reasons for the NDVI trend, and for the poor relationships with rainfall could be among the following:

1. There is a real increase in vegetation which can be detected by NDVI, but which is due to some climatic variable which is not rainfall.

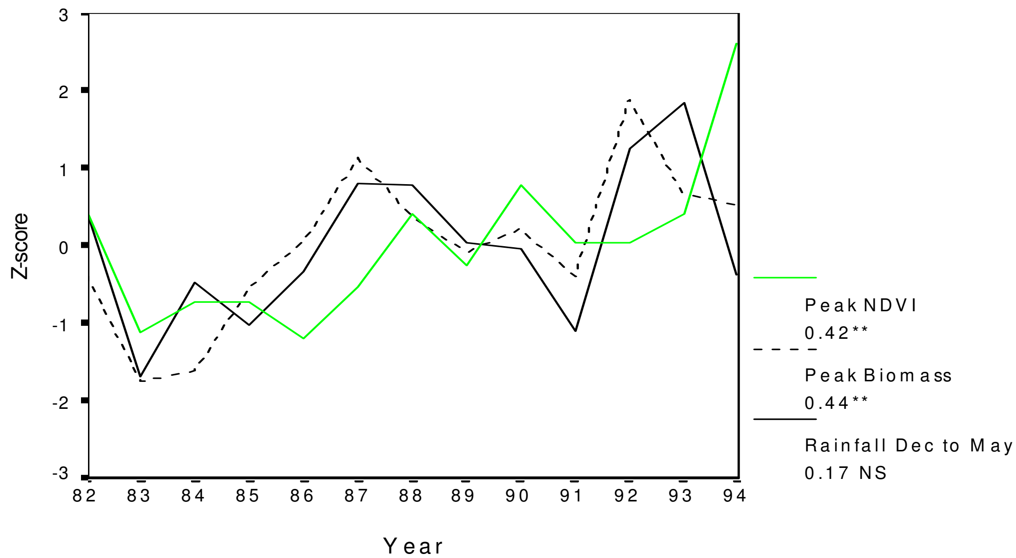
2. There is some real increase in vegetation which can be detected by NDVI and which is due to some factor related to human activity or land use.
3. Rainfall is the main factor affecting the NDVI, but its dynamics are complex and cannot be described by using simple single period rainfall indices.
4. The trend is due to low signal to noise ratios in the satellite images, or due to other factors arising from characteristics and processing of the pathfinder dataset.

Hypotheses 1 to 3, which assume that the NDVI trend really reflects vegetation change, are discussed here, and hypothesis 4 is discussed in section 4.5.

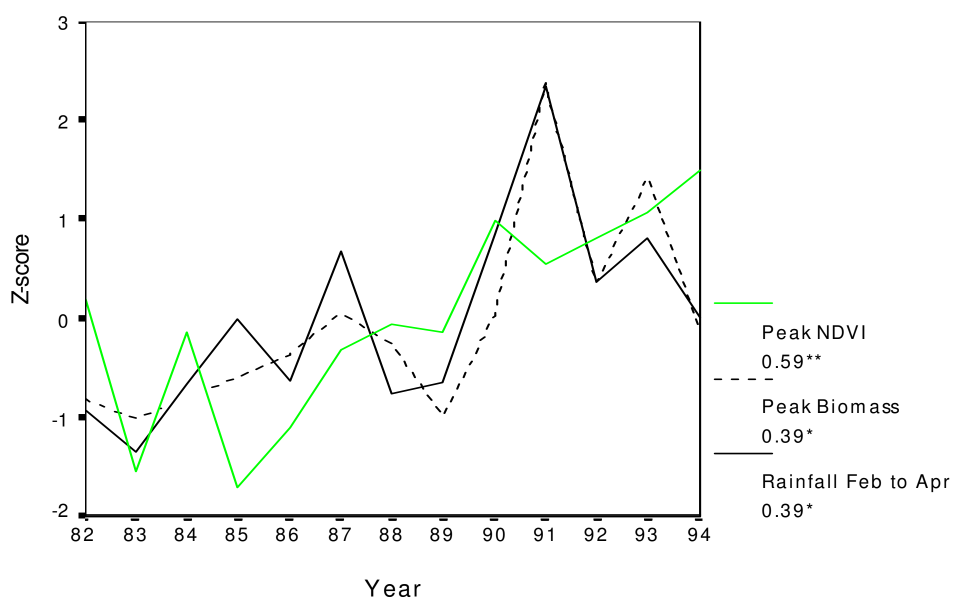
If the increase in NDVI is due to some climatic factor such as temperature, or some complex rainfall relationship, then it ought to be reflected in the biomass as well as the NDVI data. This would not be true if number 2 (above) is true, as the biomass was collected in exclosures and the methodology of collection should (theoretically) have remained the same. The biomass data are poor, however in Chapter 3 reasonable biomass-rainfall relationships were constructed for two stations for which biomass data coincided with the availability of NDVI data, using rainfall over key periods in spring and winter. Figure 4.11 shows trends in biomass, NDVI, and rainfall for these two stations (Tasty and Betpak-dala).

Figure 4.11: Graphs showing changes in peak biomass, peak NDVI, and rainfall at meteorological stations Betpak-dala and Tasty from 1982 to 1994. *The R^2 values for the relationships of each of these variables with year are shown in the legends.*
(a) Tasty, (b) Betpak-dala.

(a)



(b)



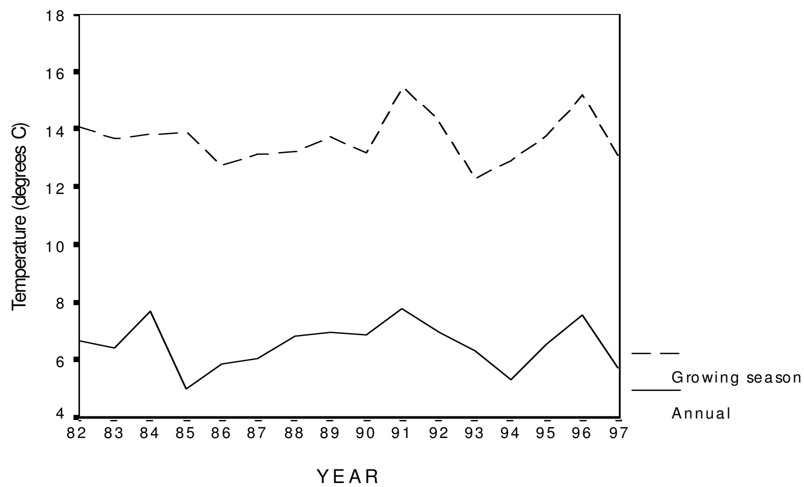
According to Figure 4.11, although biomass and NDVI do not show the same pattern (there is no significant correlation between them), both tend to increase at the two sites. Therefore, from this we cannot eliminate the hypotheses 1 and 3 above, i.e. that the reasons for the general increase are indeed climatic, and are affecting both biomass and NDVI. The lack of correlation of the peak biomass and NDVI data is more difficult to explain, but this may be due to noise in the NDVI signal, as will be investigated in section 4.5. The relationships between rainfall and biomass which were found in Chapter 3 suggest that at a given site, biomass can be predicted from rainfall over a constant period, and implying that hypothesis 3 (above) is probably not correct.

Hypothesis 1 suggests that some climatic factor other than rainfall might be responsible for the trend. As temperature data were available for the sites, these were analysed briefly to see if perhaps this could be a contributing factor.

Myneni *et al.* (1997) conducted a study into the effects of CO_2 increases on vegetation in northern latitudes (45-70 degrees north) using two global data sets, the pathfinder data set, used here (1981-1991), and the Global Inventory Monitoring and Modelling Studies (GIMMS) data set 1982-1990. The authors concluded that there was a general increase in NDVI over the study period, and believe that these increases observed are robust, despite varying satellite overpass time, lack of explicit atmospheric correction, and changes in sensor from NOAA 7 to 9. In Kazakhstan the factor limiting vegetation growth is rainfall and not temperature. Therefore it would be expected that increased temperatures would, if anything, produce decreases in vegetation quantity rather than increases.

Ten daily temperature data were available for six stations: Tasty, Ulan bel', Tiuken, Betpak-dala, Koktas, and Berlik. From these data, average temperatures for each year were found, from 1982 to 1997, both over the growing season and over the year as a whole. These were plotted against year, and the result shown in Figure 4.12. The temperature averages from 1982 to 1994 were regressed against year, but no significant trends were found (R^2 = 0.025 (NS) and 0.000 (NS) for the growing season and yearly averages respectively). Elevated temperatures can, however, be observed for the drought years of 1984, 1991, and 1995-96. Therefore hypothesis one above can be rejected.

Figure 4.12: Average temperatures in the study area from 1982 to 1997. *Values are averages of temperatures at Tasty, Ulan bel', Betpak-dala, Tiuken, Berlik, and Koktas.*



To summarise, there is no evidence that temperatures have changed markedly over the study period, suggesting that hypothesis 1 is not correct, and biomass cut in exclosures also shows an increase over the period, suggesting that hypothesis 2 is not correct. NDVI roughly reflects general rainfall trends if the correct rainfall period is taken, but the relationships are better using cut biomass data. It is probable therefore that hypothesis 4 is correct, and that the sensitivity of the NDVI data as an indicator of inter-annual biomass change is poor. This is discussed in section 4.5.

4.5 Sensitivity of NDVI to inter-annual vegetation change in Kazakhstan.

In this section we discuss the possibility that the lack of relationships between NDVI and rainfall are due to the fact that NDVI is simply not sensitive to the biomass fluctuations in question. As previously stated in section 4.2, various authors have found that NDVI-rainfall relationships broke down at annual rainfalls of less than 150-200 mm.

The reasons for this include the following, which are then investigated in sections 4.5.1 and 4.5.2.

- *Environmental factors: high signals from soils, or low signals from plants due to morphology or low chlorophyll content.* In this section, ground radiometric measurements of individual species and common communities are compared to those of bare soil in the region to see if perhaps high soils signals or particularly low signals from certain plant species could lead to a lack of sensitivity to biomass change.

- *Data related factors: low signal to noise ratios, sensor drift over time, artefacts from the processing of the data*. Typical signal to noise ratios for NDVI composites have been published in the literature, and are investigated here for the pathfinder dataset. The impacts of noise on this study are discussed together with an examination of the consequences of some of the pre-processing procedures on the data set. The impacts of the change-over from NOAA-7 to NOAA-9 and then to NOAA-11 are also examined.

4.5.1: An investigation into the effects of environmental factors on the NDVI signal

It has been shown that NDVI *is* sensitive to rainfall differences between sites and this is explored further in Chapter 5. This suggests that NDVI is sensitive enough to pick up the differences in biomass found between the locations of these sites. The biomass variability within and between years was discussed in Chapter 3. In Table 4.6 is a summary of the minimum, maximum, and average biomass yields for the six stations at which this was available from 1982-1994, the time over which the NDVI data was available. The average peak NDVI is also shown and ranked, for comparison with the biomass data.

Table 4.6: Comparison of biomass and NDVI data at 6 meteorological stations in the study area. *The data are for biomass from 1982 to 1994 except for the station Ulan bel' at which the data over this period were inconsistent (see Chapter 3). The biomass and NDVI data are also used to rank the stations in order of vegetation production (lowest first).*

Station	Average peak biomass DM kg/ha	Min. peak biomass DM kg/ha	Max. peak biomass DM kg/ha	Range of peak biomass DM	Rank (biomass data)	Average Peak NDVI	Rank (NDVI data)

				kg/ha			
Tasty 82 - 94	266	150	390	240	1	0.128	1
Ulan 67-84	425	230	870	640	2	0.160	2/3
Tiuken 82-94	435	100	900	800	3	0.159	2/3
Betpak 82-94	754	390	1600	1210	4	0.195	4
Koktas 82-94	838	500	1210	710	5	0.260	5
Berlik 82-94	1105	970	1470	500	6	0.291	6

It can be seen from Table 4.6, that the difference between the lowest and highest average peak biomass (between Tasty and Berlik) is 839 kg/ha. In fact, despite the problems with the biomass data discussed in Chapter 3, it can see that the NDVI reflects the ranking of biomass estimates exactly. Therefore, NDVI is sensitive to differences between these stations, whose average peak biomass yields over the 13 year period differ by an average of about 200kg/ha (excluding the difference between Ulan bel' and Tiuken which have the same NDVI and similar biomass levels). This suggests then, that differences in soils or vegetation morphology between stations are not suppressing the biomass signal.

Some of the inter-annual peak biomass differences at single stations have ranges of 200kg/ha or higher, suggesting that these should be picked up by the NDVI. The average difference between consecutive years at Betpak-dala (1982-1994) was 375kg/ha, at Ulan bel' it was 144kg/ha, at Koktas 197kg/ha, and at Berlik 396kg/ha. Therefore rainfall-biomass relationships should be expected at least at Betpak-dala and Berlik. One reason for the absence of such relationships could be that some plant species or associations have particularly low amounts of chlorophyll for their biomass, and these would produce very low NDVI signals compared with cut biomass yields. For example leaves of *Artemesia terrae-albae* are tiny, and are bluish rather than green, so it is possible that it reflects and absorbs light in wavelengths which would produce low NDVI signals. Another possibility is that some of the soils in the study area may have high NDVIs, overwhelming the NDVI signal from vegetation. These hypotheses were tested by measuring NDVIs of plants and soils directly in the field with a radiometer.

(i) Methodology

In June 1998 an expedition was run for a month in Betpak-dala, and in particular in the region of Zhetykonur sands. This expedition was run with members of the Institute of Botany, with the aim of collecting radiometric, cover and biomass measurements of various plant communities.

Radiometric measurements were taken by the author using a hand held ASD radiometer with automatic recording and saving of spectra. The radiometer collects spectra over 512 wavelengths, which were then subsampled by taking the mean of each groups of three bands, giving a total band number of 166 and a range of 0.2 to 1.2µm. From these wavelengths NDVIs corresponding to those from the AVHRR satellite were calculated by Wolfgang Mehl (Joint Research Centre, Ispra). The radiometric measurements were collected as follows:

Individual plants and soils: at each site, the radiometer was held at a height of about 50cm above a target plant or area of bare soil. One measurement was recorded, and then the instrument was held over a Barium Sulphate panel for a second measurement. Target and panel measurements were alternated in this way (using a different plant specimen or soil area each time) until between 30 and 100 specimens had been recorded for a given plant species or soil type.

Plant communities: radiometric measurements were collected every 2-3 metres over transects of 30-100 meters across the relevant plant community. Again ground and panel measurements were alternated.

At most of the sites members of the Institute of Botany collected biomass and cover measurements for each community present at the site according to their standard methodology. Accordingly, at each site, the vegetation was classified into associations, and the percent of ground covered by each of these was established roughly by eye. Within each association, the cover and biomass were measured, and the overall average cover and biomass for the site calculated from these measurements.

The methodology for biomass measurements was different for herbaceous plants and shrubs. For herbaceous plants five quadrats of 1.5m were placed at random, and total green biomass (growth in 1998 only) was cut inside each. In the case of shrubs, a 10x10m quadrat was marked out. Inside this quadrat representative small, medium and large shrubs were chosen, and the green mass taken from each. The number of shrubs in each size class was then counted and multiplied by the biomass of the representative shrub.

The sites were chosen by members of the Institute of Botany to represent a range of communities common in the study area, and were mostly to be found between 67.9-69.3 degrees of longitude, and 46.3-47.6 degrees of latitude, in the region of Zhetykonur sands and near the river Sarysu. Some of them, however, were taken just north of Ulan bel' or in an area of low hills in north eastern Betpak-dala which has more steppe-like vegetation. The co-ordinates of sites at which radiometric measurements were taken of transects and soils are shown in Appendix 4. The measurements taken during this fieldwork are used to provide examples of the NDVI signals which can be expected from common vegetation types and soils. They are not intended to be a statistically representative sample of the area. The biomass and cover data were collected for more sites than were sampled with the radiometer. These data are to be analysed in the future together with high resolution satellite imagery, but this is outside the scope of this thesis.

(ii) Results

Table 4.7 shows the NDVIs calculated from radiometric measurements for individual plants and soils. From these data, it can be seen that *Artemesia terrae-albae* does indeed have a low NDVI, and that shrubs such as *Salsola arbusciliformis* and *Haloxylon aphyllum* give the highest NDVI values. The bare soil measurements shown in the table represent the minimum and maximum of 16 soil samples including examples of the major desert soils classified by Soviet scientists: northern and southern desert brown soils, *solonets* soils (see Chapter 1), and sand.

Table 4.7: NDVIs of individual plant species and soils taken from radiometric measurements in the study area.

Species	NDVI
Anabasis salsa	0.414
Artemesia terrae-albae	0.326
Ceratocarpus utriculosis	0.337
Halocnemum strobilaceum	0.319
Haloxylon	0.575
Nanophyton erinaceum	0.280
Salsola arbusciliformis	0.519
Stipa kirghizorum	0.361
Bare soil	0.085-0.134

The average NDVI value over the 16 soil samples was 0.1. This was much lower than values for individual plant species, however if we look at the NDVIs of vegetation communities sampled across transects, we can see that in some cases signals from soils alone comprise a large proportion of the total signal. The transect data are shown in full in Appendix 4, and the NDVI data are summarised in Table 4.8.

Table 4.8: Average NDVIs of vegetation communities sampled over transects with a radiometer at various sites in the study area.

Dominant species	Minimum NDVI	Maximum NDVI	Average NDVI	Soil NDVI as % of transect NDVI	Observations (number of sites)
Agropyron fragile	0.213	0.249	0.230	57	3
Anabasis salsa			0.162	64	1
Artemesia terrae-albae *Artemesia semiarida*	0.16	0.235	0.207	49	5
Ceratocarpus utriculosis			0.203	55	1
Nanophyton erinaceum			0.189	55	1
Salsola arbusciliformis	0.162	0.407	0.274	47	9
Spirea hypericifolia			0.298	32	1
Stipa kirghizorum			0.297	43	1

The main observations to be made from the data in Appendix 4 and Table 4.8 are as follows: signals from soil alone comprises from 32-73% (average 48%) of the NDVI signal of transects. This is very high indeed, in particular for red soils of hills and sandy areas. Small saltworts such as *Nanophyton erinaceum* and *Anabasis salsa* are probably indistinguishable from soils by the AVHRR instrument, and *Artemesia terrae-albae* also has a very weak signal, and in some cases may not be distinguishable from soil. These low signals are not because 1998 was a dry year. In fact 1998 was a wetter than average year. Looking at stations Ulan Bel, Tasty, and Koktas, rainfall from December to May was between 18% and 21% higher than average (Betpak-dala meteorological station closed in 1997).

The biomass data shown in Appendix 4 seem unexpectedly low for a year with high rainfall, especially in the case of the *Salsola arbusciliformis* dominated communities which have a biomass 2-3 times lower than that recorded by Kirichenko for years of similar or lower rainfall. This could be due to differences in methodology between the Institute of Botany and workers who collected the data used in Chapter 3, it could be due to differences in soils, or it could be due to the fact that most of the sites were situated in areas which had been grazed to some extent in the past. Despite this, vegetation at most sites was described as being in good condition by the workers from the Institute.

How do NDVI measurements for transects compare with NDVI data from the satellite itself? Table 4.9 shows the minima, maxima and average peak NDVI values calculated for the 13 years of data.

Table 4.9: Minimum, maximum, and average peak NDVI values from the AVHRR instrument at 8 meteorological stations in the study area.

Station	Min. NDVI	Max. NDVI	Average NDVI
Tasty	0.09	0.22	0.128462
Ulan bel'	0.12	0.22	0.16
Tiuken	0.11	0.25	0.159231
Betpak-dala	0.13	0.25	0.195385
Balkhash	0.1	0.18	0.131538
Koktas	0.16	0.3	0.26
Berlik	0.21	0.32	0.291538
Karaganda	0.32	0.48	0.402308

From Table 4.9 it can be seen that the average peak NDVI signals from areas with low vegetation such as Tasty and Balkhash are close to those of common soil types. At other stations however, it should be theoretically possible to detect vegetation change, although in drought years vegetation may be indistinguishable from soil at many sites, reducing the strength of rainfall-NDVI relationships.

4.5.2 Investigations into the effects of signal to noise ratios in the NDVI data on rainfall-NDVI relationships.

Another of the possibilities discussed above for explaining the NDVI increase and the lack of a relationship with rainfall, could be problems with the NDVI data itself. For example, it is possible that the data are noisy, creating spurious results, or that the correction for sensor drift is not entirely effective. As described in section 4.1, the dates of changeover for the pathfinder satellite were November 1988 and January 1985. At these points, if vegetation change could be eliminated, discontinuities might be observable in the data. Other sources of noise include atmospheric water vapour, which was not corrected for in the pathfinder data set. Eklundh (1995) has shown that such atmospheric effects can create high noise levels in NDVI MVCs. However he also shows that this problem is less serious in dry regions of the world such as Kazakhstan. Poor geometric accuracy of the data can also be a problem - i.e. the area extracted around each meteorological station does not exactly correspond to the same real area on the ground on each date. However, this is unlikely to be a large problem given the homogeneity of the regions studied.

Cihlar *et al.* (1998) studied the extent to which inter-annual variations in NDVI could be explained by vegetation change and by noise. They used average NDVIs from June to August for various sites in Canada, including barren sites (which were assumed to be vegetation free). The inter-annual variation from such sites was assumed to be due to noise. The magnitude of inter-annual NDVI variation at barren sites had a maximum of 0.038. A similar exercise was conducted here.

(i) Methodology

The area most likely to be vegetation free in the pathfinder Asia scenes is the empty quarter of Arabia, famous for its lack of vegetation. Two areas were chosen in this region due to their particularly low NDVI values on the images, and a third area was chosen for which further information was available: in Walker (1986) Landsat images, aerial photos, and ground photographs of part of the empty quarter are shown, indicating that this region consists only of dunes, and is vegetation free. A map is shown indicating different types of dune, however none of the maps, photos or images indicate any wadis, oases, or other non-dune features which could be associated with vegetation. The co-ordinates in, decimal degrees, of the three areas chosen are as follows:

1.	2.	3. (from Walker 1986)
50.3,21.5	48.0,18.5	54.0,21.0
52.0,21.5	48.0,20.0	55.3,21.0
52.0,20.3	50.0,20.0	55.3,22.1
50.3,20.3	50.0,18.5	54.0,22.1
50.3,21.5	48.0,18.5	54.0,21.0

The peak NDVIs were extracted as yearly maxima of monthly averages of 10 daily MVCs exactly as the Kazakhstan data had been. Firstly, inter-annual variation between the Arabia and Kazakhstan data was compared, and then the actual values of peak NDVIs were plotted against year, with the Kazakhstan data, to see if there was a similar NDVI pattern.

(ii) Results

The inter-annual variations in peak maximum NDVI between one year and the next were calculated for the stations in Kazakhstan, and for the three sites in the empty quarter. The results are shown in Table 4.10, and are unsigned so that averages could be compared.

Table 4.10: Differences in peak NDVI between consecutive years for meteorological stations in Kazakhstan and three sites in the Arabian empty quarter. *Some statistics describing this inter-annual variation are also given in rows marked A, B, and C.*
A = The average difference in NDVI between consecutive years.
B = The difference between the lowest and highest NDVI values recorded for each site.
C = The number of times between 1982 and 1994 that the NDVI change between consecutive years was 0.03 or greater..

Year	Tasty	Ulan bel'	Tiuken	Betpak-dala	Balkhash	Koktas	Berlik	Karaganda	Arabia 1	Arabia 2	Arabia 3
82-83	0.053	0.003	0.010	0.067	0.003	0.013	0.003	0.113	0.000	0.013	0.007
83-84	0.013	0.017	0.003	0.053	0.040	0.010	0.037	0.083	0.010	0.000	0.003
84-85	0.000	0.007	0.003	0.060	0.043	0.070	0.053	0.027	0.007	0.003	0.007
85-86	0.017	0.030	0.030	0.023	0.027	0.087	0.067	0.080	0.020	0.020	0.010
86-87	0.023	0.020	0.023	0.030	0.027	0.000	0.040	0.040	0.010	0.010	0.000
87-88	0.033	0.057	0.040	0.010	0.047	0.020	0.010	0.047	0.003	0.003	0.007
88-89	0.023	0.040	0.007	0.003	0.007	0.020	0.007	0.043	0.003	0.020	0.007
89-90	0.037	0.023	0.007	0.043	0.007	0.013	0.000	0.000	0.000	0.003	0.010
90-91	0.027	0.003	0.010	0.017	0.007	0.012	0.003	0.053	0.017	0.003	0.010
91-92	0.000	0.020	0.013	0.010	0.003	0.000	0.017	0.050	0.010	0.003	0.003
92-93	0.013	0.040	0.020	0.010	0.030	0.000	0.010	0.043	0.000	0.003	0.000
93-94	0.077	0.030	0.067	0.017	0.007	0.027	0.013	0.103	0.017	0.023	0.010
A	*0.026*	*0.024*	*0.019*	*0.029*	*0.021*	*0.023*	*0.022*	*0.057*	*0.008*	*0.009*	*0.006*
B	*0.133*	*0.107*	*0.147*	*0.123*	*0.080*	*0.143*	*0.113*	*0.160*	*0.033*	*0.033*	*0.020*
C	*4*	*6*	*3*	*5*	*4*	*2*	*4*	*9*	*0*	*1*	*0*

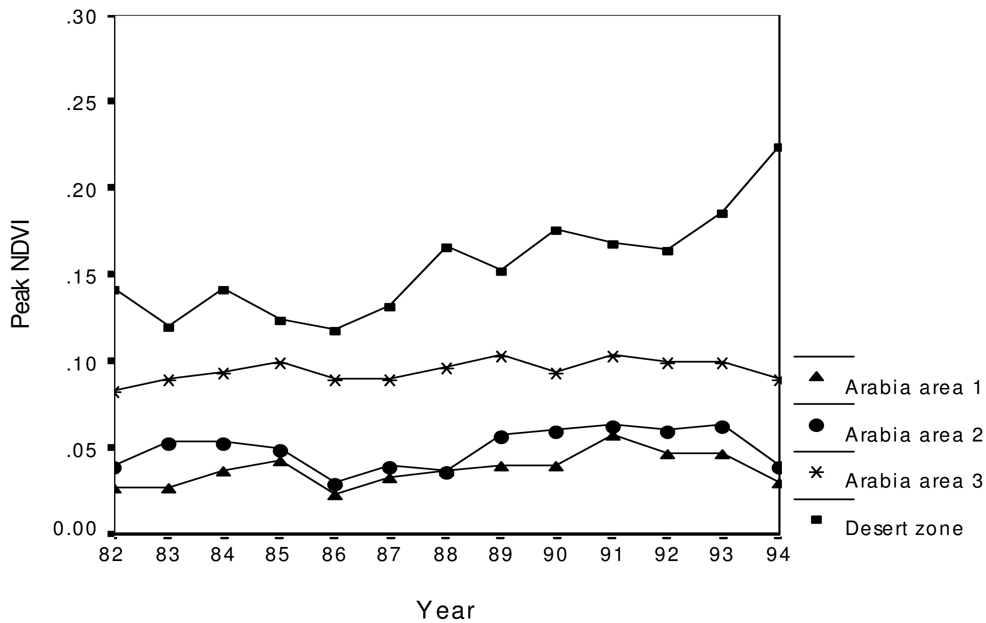
Arabian site three, which was the most likely to be totally vegetation free, had lower variability in NDVI than the others, but had higher absolute values of NDVI, probably due to soil differences.

From Table 4.10 it can be seen that inter-annual variations of peak NDVI in the empty quarter could be as high as 0.02 between adjacent years. The difference between the lowest and highest peak NDVIs recorded over the 13 years was 0.033 at Arabian sites 1 and 2, and 0.02 at Arabian site 3. These are close to the figures for inter-annual NDVI uncertainty given by Cihlar *et al.* (1998) of between 0.015 and 0.038. At the Kazakhstan sites the peak NDVIs had inter-annual ranges of between 0.08 to 0.16 depending on the site. These were higher than the figures for the Arabian sites, but still extremely low.

If inter-annual NDVI variation of less than 0.03 is taken as being noise, it is possible to see why few NDVI-rainfall relationships could be obtained at stations in the study area. At most of the stations half or more of the inter-annual differences were at or below this figure. Interestingly those stations which had the highest number of differences above this level (Ulan bel' and Karaganda), were also the only stations at which highly significant rainfall-NDVI relationships were found (see Table 4.5). This does not mean that all the inter-annual variation below 0.03 is certainly due to noise. The average inter-annual variation at the Arabian site 3 was 0.006, which is 4.5 times lower than the average inter-annual variation at the Kazakh sites (0.028).

Although we can conclude that the noise must interfere substantially with the signal, it seems unlikely that it is the cause of the strong time trend in NDVI. It is possible that the trend is due to sensor drift, which perhaps was not fully corrected for in the data set. In order to test this, the average peak NDVI for five stations in the desert zone was plotted against year, and the Arabian data was plotted on the same graph for comparison. The data from Arabia showed a different pattern from those of Kazakhstan, as can be seen in Figure 4.13 below.

Figure 4.13: Peak NDVI from 1982 to 1994 for three sites in the empty quarter of Arabia, and for the average of five meteorological stations in the desert zone of Kazakhstan.



The Kazakhstan data show an increase in NDVI from 1986 onwards. The Arabia data show no clear trend over time.

The change-over dates between sensors were January 1985 and November 1988. Therefore if sensor drift was a problem for this data we would expect to see particularly large differences in peak NDVI in the Arabian areas from 1984-85 and 1988-89. However, this is not the case. Therefore we can suggest that this is not a likely source of the observed trend.

Another point about the processing of the data, which has already been mentioned, is that the peak NDVI used was the peak of monthly averages of 10 day maxima. Using these rather than true annual maxima may have reduced the biomass variability. Such true maxima were extracted for each station and regressed against rainfall from June to May as in Table 4.5. The regression results between rainfall and NDVI were generally poorer than those in shown in Table 4.5 (column 2). Also using such maxima, average inter-annual variation between consecutive years at Arabia site 3 was 0.012, and the total NDVI range was 0.03. These are larger figures than those using the peak of 10 daily averages (0.006 and 0.02), and show that such an approach entails increased noise as well as increased NDVI. Thus it is not an improvement.

4.5.3 Discussion

It has been shown that a major reason for the lack of rainfall-biomass relationships for single regions is probably that the signal to noise ratios are too low for the biomass fluctuations involved to be picked up. We have also seen that much of the vegetation has very low signals, with NDVIs only slightly higher than those of soils. This is probably another factor contributing to the lack of relationships. However, if this is the case, then why can NDVI detect differences between station averages but not between different years at single sites, when we have seen (Table 4.6) that both may involve biomass changes of similar magnitude? Eklundh (1995) has suggested that in fact long term averaging may eliminate noise. He looked at signal to noise ratios for images of African countries, and found that scenes representing the average of several years data (an image of the average of nine annual integrated NDVI images) had almost zero noise, whilst 10 daily MVCs had signal to noise ratios of between 9 and 14. Therefore by looking at temporal averages of NDVI data we can reduce or even eliminate this problem.

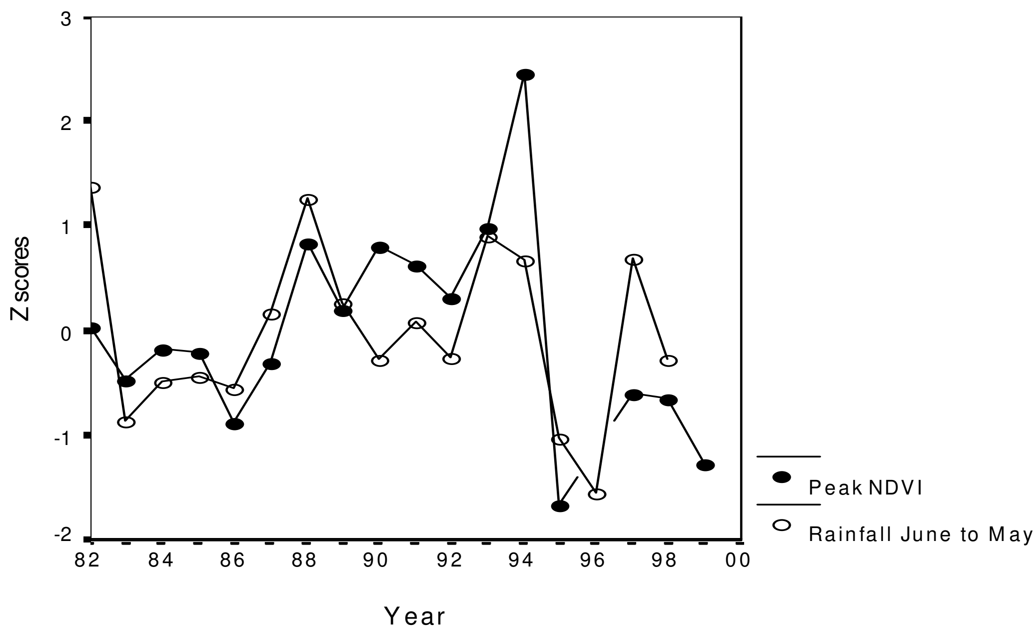
4.6 NDVI and the 1995 drought

Although the NDVI-rainfall inter-annual relationships are poor, in the desert zone at least, NDVI does seem to reflect the general rainfall pattern i.e. both NDVI and rainfall are low in the early 1980s, and undergo a rise in the late 1980s and 1990s.

Whether this NDVI trend is really related to rainfall can be tested. As can be seen from Figure 4.1, in the desert zone only about 50mm of rain fell in 1995. If the annual figure is taken from June to May (12 months up to the peak), it can be seen that the 12 months leading up to the May of 1995 and 1996 were both low (100 and 80mm). These are the lowest values of the thirty year data set available. If the NDVI is responsive to large changes in biomass then it should be very low in these two years.

Just before the submission of this thesis, the pathfinder data from 1995 to 1999 came on line (although data for 1996 were missing, so only one of the two drought years could be analysed), and therefore it was possible to look at the NDVI after 1994 in order to test the reaction of the NDVI to this extreme event. The NDVIs were extracted for the three desert zone stations as for other years, and the 16 years of NDVI and rainfall data plotted on the same graphs. The data for the three southernmost stations showed the same pattern, and thus averages over the three locations were found and the data from these plotted as Z-scores against the Z-scores of rainfall (Figure 4.14).

Figure 4.14: Z-scores of rainfall from December to May and peak annual NDVI plotted from 1982 to 1999 for three stations in the desert zone.



The following observations can be made from Figure 4.14:

NDVI shows an extremely sharp drop in 1995, and indeed this is the most striking feature of the whole time series. The drop constitutes a change in NDVI from the previous year of about 0.15, too large to be noise. Maximum NDVI in 1995 was below 0.1 at all three of these stations. Therefore, although the NDVI is noisy, it does appear that extreme events can be detected using the pathfinder dataset. In this case, if the average Z-scores of peak NDVI for the three stations are regressed against the average Z-scores of rainfall, there is a positive relationship ($R^2 = 0.318*$) although it is still weak compared to relationships in other studies in the literature. It does not suffer from non-independence of residuals, although it comes close to failing the test for correct functional form (P=0.096).

Figure 4.15 shows the peak NDVI image for 1995 and that for the average peak NDVI from 1982 to 1994. The effects of drought can be seen clearly in the 1995 image, and indeed appear to affect the whole country.

Figure 4.15

4.7 Summary and conclusions

In this chapter it has been shown that the predictions of NDVI from rainfall at single sites in the study area are generally poor. At some of these sites it had been shown using biomass data (Chapter 3) that, in the desert zone at least, much of the biomass variation could be explained by rainfall, and thus it can be concluded that the weak relationships are due mostly to the lack of sensitivity of the NDVI to inter-annual vegetation variation rather than to a lack of vegetation response to rainfall. This low sensitivity is due both to noise in the data and to the low NDVI signals of some of the most common plants, notably *Artemesia* species.

However, NDVI does seem to be sensitive to general trends and extreme events. For example, in the desert zone, rainfall was low in the early 1980s, and showed an increase until 1993. There was extremely low rainfall in 1995 and 1996, followed by recovery. These general trends can be seen in the NDVI, but much of the detailed inter-annual variation of NDVI does not show the same pattern as rainfall.

A particularly noticeable rise occurred in 1994 at all stations in the desert zone (Figure 4.9a). At the stations Tiuken and Tasty the magnitude of this rise was more than three times higher than the average inter-annual variation. However, it is was not mirrored in the biomass or rainfall data, (Figure 4.11), nor is it visible in the Arabia NDVI data. It is of course not the only point of the time series in which biomass and NDVI data show different patterns, however, in no other year is there such a large difference (Figure 4.14).

Stock data (for the first of January of each year) shows that in Kazakhstan from 1993 to 1994 sheep numbers decreased by 25%. In the desert zone of the study area most of the stock were from Dzhambyl *oblast* which suffered a 35% drop in sheep numbers from 1993 to 1994. It is tempting to suggest therefore that this increase in NDVI is due to the drop in stock numbers, and that it is visible mainly in the desert zone because it is this area which suffered from higher stock densities in the preceding years. However, an analysis of following years (1995 to 1999) cannot confirm or reject this hypothesis, as the extremely low rainfall in 1995 followed by increasing rainfall in subsequent years confounds any possible effects of stock removal on the NDVI signal.

As more years of pathfinder data become available, the behaviour and limits of the NDVI signal will be better discerned. Unhappily for much of this potential work, most meteorological stations in Kazakhstan are now closed, or likely to close in the coming years.

One result emerging from the work in this chapter is that NDVI seems to have a good relationship with rainfall when these are examined in space rather than in time. Therefore there seems to be some potential for looking at differences between long term vegetation averages between different sites, and this is investigated in Chapter 5.

Chapter 5: Rainfall Use Efficiency

5.1 The concept of Rainfall Use Efficiency and its applications

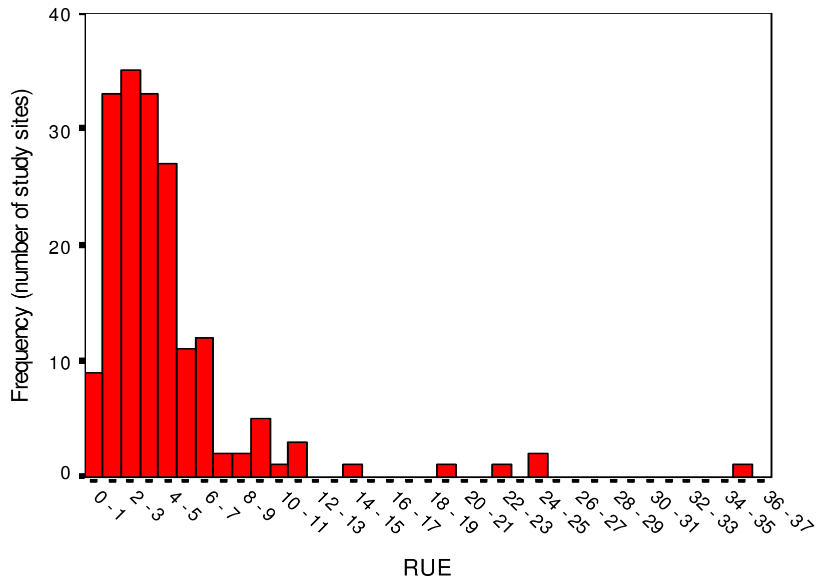
5.1.1 Definitions of rainfall use efficiency (RUE)

Rainfall Use Efficiency or RUE is the annual aerial biomass production from rainfall in (kg DM) produced per mm of annual rainfall. In other words it can be described as the ability of an ecosystem to produce above ground biomass from rainfall. In theory this concept can be used to highlight differences between ecosystems which may be due to geophysical factors or human management. For example two ecosystems having the same rainfall may have very different RUEs due to soil type, land use, or vegetation composition. RUE and its usefulness in understanding factors affecting NPP are reviewed and discussed in Le Houérou (1984). In this chapter we look at rainfall use efficiency in the study area and reasons for its variation.

RUE is very crude in that factors such as transpiration, soil evaporation, canopy interception of water, drainage, run-off, and changes in the water content of vegetation, are all confounded in one single measure (Prince *et al.* 1998). However, it is useful because in most areas NPP and rainfall data are more readily available than evapo-transpiration data.

Le Houérou (1984) reviewed RUE values calculated from 179 studies. RUE ranged from 0.47 (overgrazed area in Rajahastan), to 35 (Repetek, Tadjikistan). The frequency distribution of RUE for the studies reviewed by Le Houérou are shown in Figure 5.1. Particularly high values usually occur when vegetation has access to some water source other than that in the top layer of soil. For example Rodin, (1979), found an RUE of 24 for an area of Kazakhstan covered by dunes. This is many times higher than the rainfall use efficiencies recorded for higher rainfall areas, and has mainly to do with the fact that it is dominated by tall shrubs with very long root systems which can reach deep water reserves. Le Houérou concludes that normally RUE is between 3 and 6, values much lower than this probably meaning that vegetation growth is limited by high grazing levels or exceptionally poor soils.

Figure 5.1: A histogram of RUEs for the 179 studies reviewed by Le Houérou (1984).



There have been several studies which have used NDVI to obtain an estimate of RUE, sometimes called the rainfall to greeness ratio (Davenport and Nicholson 1993). Therefore NDVI per mm of rainfall becomes the parameter of interest rather than biomass per mm of rainfall. The advantage of this is that we can look at the RUEs of vegetation over large areas, which is not possible using biomass data as this is always only available from a few specific sites. The disadvantage is that NDVI is sometimes only poorly related to NPP, and so it is important to remember that RUE derived from NDVI may be considered as *analogous* to the true RUE, but may not give exactly the same results when different areas are compared.

Some studies show that RUE has a high variability between different zones. Nicholson *et al.* (1990) report that the ratios of NDVI to rainfall in East Africa are higher than in the Sahel by a factor or two. Nicholson and Farrar (1994) report that the ratio of NDVI to rainfall in Botswana is several times higher than in savannas in East Africa or the Sahel. Davenport and Nicholson (1993) calculated ratios of integrated NDVI and annual rainfall to produce an RUE map of East Africa and found that this map was very similar to maps of vegetation type, suggesting that those factors (such as rainfall and soil type) which determine vegetation type, also determine RUE. Factors affecting RUE variability are explored in more detail below.

5.1.2: Factors affecting RUE variability

(i) Aridity

Le Houérou (1984) suggests that, when compared between different sites, RUE should be inversely related to aridity since, within any given climate, the proportion of inefficient rain increases with aridity (i.e. evaporation and runoff are relatively more important). This is supported by Prince *et al.* (1998) working in the Sahel region of Africa, where sites with higher long term average rainfall had higher RUEs than those with lower rainfall. The same has been noted for the steppes of Central Asia (Gilmanov 1995). Noy-Meir (1985) has suggested the inverse, that in fact rainfall use efficiency should be *higher* in arid areas. This is because plants in these areas have developed physiological and structural properties to handle the low and irregular rainfall. This was also found by Malo and Nicholson (1989), who found that between sites in Niger and Mali, average RUE increased consistently as rainfall decreased.

Patterns may be different when RUEs for single sites are compared over several years. Prince *et al.* (1998) found that when rainfall was plotted against rain use efficiency for single sites over time that at lower rainfalls RUE was higher. Ellis and Lee (2000) found that for an area of Kazakhstan south of Lake Balkhash, RUE also tended to be higher in dry years and lower in wet years.

(ii) Climatic zone

From the data in Le Houérou (1984), it is suggested that the seasonality of rainfall and the winter temperatures do not affect RUE values very much. For example, areas of the mid-west such as Oregon, which has the same rainfall as areas of Africa, but which experience cold winters, have the same range of RUEs, the variation in which is due to soil type and management strategy. The existence of a cold season does not have much effect on total annual production, which has similar values for temperate and tropical arid zones. Kellog and Schware (1982) note that throughout the USA and Canada there is a linear relationship between annual precipitation and carrying capacity of grasslands, regardless of temperature or evaporation. Therefore in temperate grasslands it appears that temperature is not a key factor in the determination of NPP, although it might determine the timing of the peak biomass.

(iii) Land use and vegetation condition

Several authors have shown that RUE decreases with heavy grazing: Le Houérou and Claudin, (1974) showed that RUE dropped from 4.75 to 1.19 as the number of sheep per hectare went from 0 to 0.33 in Algeria. The perennial ground cover also dropped from 25% to 3%. Several authors reviewed in Le Houérou (1984) also showed reductions of RUE with grazing. In general, over the 179 studies reviewed, RUE rarely fell below 2 in areas which were ungrazed, and values below one were generally in heavily degraded rangelands.

Rainfall use efficiencies from NDVI have also been used to detect both drought and land degradation. Hielkema *et al.* (1986) in their study of NDVI at 12 rainfall stations over three years in the Sudan, noticed that rainfall use efficiency was lower in drought years. In these years, the actual amount of rainfall was the same as in non drought years, but the pattern meant that it was not efficiently used by the vegetation. Prince *et al.* (1998) used NDVI derived RUE as a method to detect degradation, examining a nine year data set of satellite and rainfall data for the Sahel. They found no decrease in RUE (or even a slight increase) over their study period, concluding that vegetation condition over this large area was, in general, not deteriorating over the nine years.

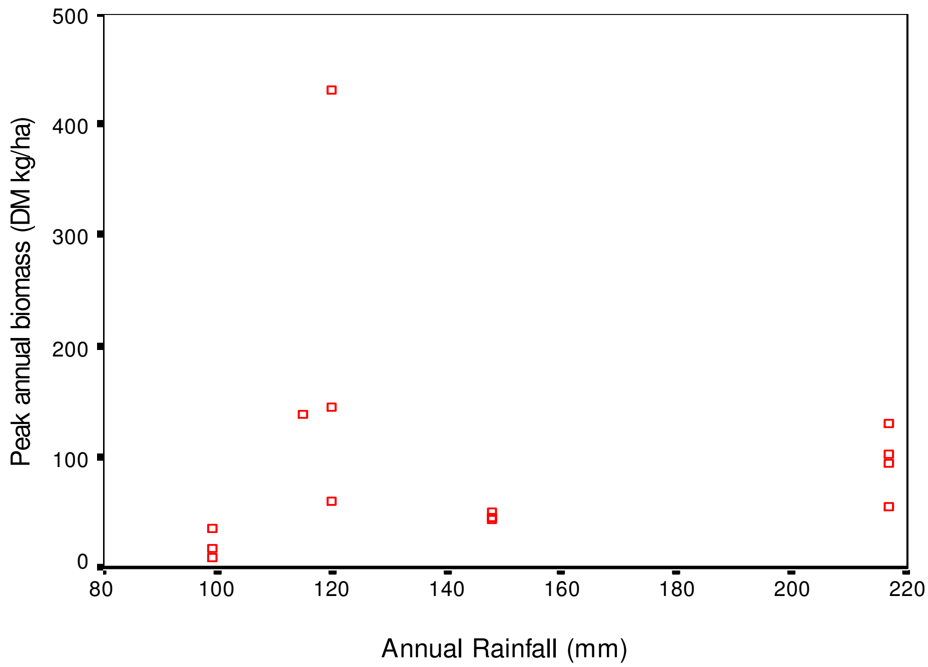
On a spatial, rather than temporal level, the same authors discuss the use of RUE as an index of degradation between different sites. Whilst not showing conclusively that low RUEs indicate degradation (as we have seen there are many other reasons why an area might have a low RUE), their study did show a weak link between RUE and degree of degradation as taken from the GLASOD (Global Assessment of Soil

Degradation) map (Oldeman *et al.* 1990). This relationship could have been obtained because in the Sahel lower RUE is also associated with low rainfall, and low rainfall sites are often those most susceptible to degradation. However, the authors have recommended that this approach be investigated further.

RUE, being a measure of productivity from rainfall, should really include all above ground plant material produced during the season, taking into account that some of it will have been eaten. For example, if the biomass is measured at the end of the growing season, and the offtake by animals is unknown, then real production will be underestimated. This is a problem when comparing RUE of grazed and ungrazed ecosystems. Another problem is that in the case of perennials, the production in a single year will perhaps only be a small percentage of the biomass existing. This would be the case for some shrubs which retain green leaves over winter. Therefore it is important that only green matter produced in that year is collected.

The main reason why it is difficult to use RUE to compare vegetation condition between different sites is that although there may be a general trend of increasing RUE with rainfall, different vegetation types may produce very different amounts of biomass simply because of the soil type on which they are found, differing morphology, and life history. This is clear from the RUE map of Davenport and Nicholson (1990) mentioned above, which mirrors maps of vegetation type. In Chapter 3 it was seen that different communities in the same rainfall zone have very different productivities. Some species such as *Haloxylon* may have very long roots, giving them access to deep water reserves, leading to an artificially high RUE.
This last problem is illustrated by the following: standing biomass information is available for 15 communities near meteorological stations in six different Central Asian deserts (in Rodin 1979). The RUEs for these communities (green aerial production) were plotted against rainfall and the results shown in Figure 5.2.

Figure 5.2: The relationship between rainfall and biomass production for vegetation associations from five Central Asian deserts. *Source: Rodin (1979). Each point represents a different vegetation type.*



In this case, at the station having 120mm rainfall per year there is a huge variation in biomass production depending on vegetation type, and the average RUE is much higher here than at other stations. This may be because the authors sampling at this station were using different methods from the others, or that the water table is much higher, or because some of the plants in those communities have a more shrubby morphology, or invest more in above ground production as opposed to below ground production. Such differences will be noted also in the analysis of the study area that follows.

Overall Le Houérou concludes that RUE is a useful tool for assessing the health and productivity of arid zone ecosystems, particularly when actual evapo-transpiration data are missing, as is the case for the Kazakhstan data. Prince *et al.* (1998) have shown that NDVI derived RUEs can be used to study degradation over time and space, although as discussed above there are many confounding factors.

In this chapter some of the methods used by Prince *et al.* (1998) (i.e. to examine RUE for sites over time, and between sites) are employed. RUE is investigated using both the biomass data and NDVI data. In part 5.5 methods for comparing ecosystems using variability in biomass and rainfall data are presented, which to some extent remove some of the confounding factors associated with the use of RUE for studying vegetation condition.

5.2 Rainfall Use Efficiency at meteorological stations

5.2.1 Rainfall Use Efficiency from biomass data

Table 5.1 shows the locations, average rainfall, NPP, and RUE for each of the stations in Betpak-dala for which biomass data are available. At some of the stations figures for two periods are given for reasons discussed in Chapter 3: at Ulan bel' during the period from 1967 to 1984 a constant biomass type was measured, whilst in other years the data could not be used as a mixture of vegetation types were collected. At Berlik and Tasty biomass data in the period from 1982-1997 were probably collected differently, or in a different area, from preceding data and are also shown separately.

From Table 5.1 it can be seen that rainfall use efficiency generally falls within the expected bounds observed by Houérou (1984). However it is particularly low at Tasty and Ulan bel'. One point observed from the data is that RUE tends to increase with latitude, a trend which is strongest if we take the data from Berlik (1982-1997) and from Ulan bel' (1967-1984) as being those which truly represent biomass in these areas. However, it is quite possible that this trend is not real as the RUE depends very much on which vegetation type was cut at a particular station. RUE is probably better investigated further using NDVI data, as the errors can at least be expected to be similar between sites, and being extracted for a large area around each station, the NDVI values represent green biomass for a range of vegetation types.

Table 5.1 : Location of meteorological stations and their annual rainfall, peak biomass, and RUE (averages over 30 years). *The rainfall averages for the time periods are taken using only rainfall from those years from which biomass data are also available.*

Station	Longitude of station	Latitude of station	Period	Average rainfall over	NPP (Average peak	RUE NPP/mm

				period (mm)	biomass kg/ha)	
Tasty	69.17	44.79	67-97	149.3	310	2.07
Tasty	69.17	44.79	82-97	124.7	260	2.08
Ulan bel’	71.14	44.82	67-97	156	535	3.4
Ulan bel’	71.14	44.82	67-84	165.6	425	2.5
Tiuken	72.36	45.35	67-97	143.9	455	3.1
Betpak -dala	70.20	46.33	82-96	141.1	670	4.7
Koktas	70.70	47.31	67-97	203.7	765	3.7
Berlik	69.49	48.88	67-97	243	895	3.55
Berlik	69.49	48.88	82-97	232.5	1218	5.2

5.2.2: Rainfall Use Efficiency from NDVI

In Chapter 4 it was proposed that averaging NDVI (or in this case peak NDVI), over the 13 years of data availability reduces noise considerably and that good spatial Rainfall-NDVI relationships can be achieved between different sites. Here we show that this is the case both for the study area and for Kazakhstan as a whole.

(i) Meteorological stations in the study area

When annual rainfall is averaged for each station over the 13 years, and regressed against peak NDVI, also averaged over the 13 years, for the 8 stations, the R^2 value is 0.916*** (see Figure 5.3). This regression does not suffer from non-random residuals. Therefore we can conclude that the relationship between rainfall and NDVI at each station is roughly constant, even though the vegetation type is different at each station.

Figure 5.3: The relationship between peak NDVI and annual rainfall, averaged over 13 years. *$100N_p = -3.7 + 0.14R_{Jan\text{-}Dec}$ where N_p=peak NDVI and $R_{Jan\text{-}Dec}$=annual rainfall. $R^2 = 0.916$***.*

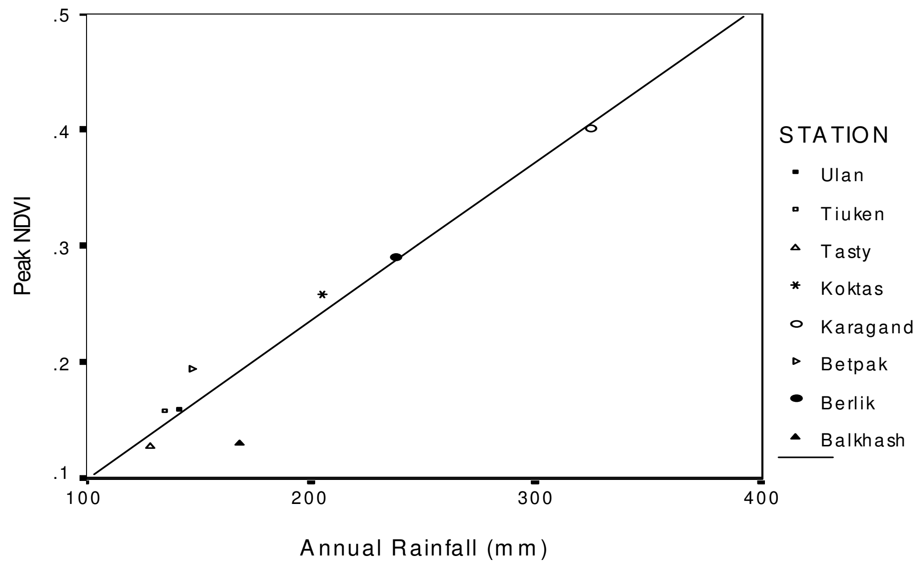


Figure 5.3 confirms that when long term averages are used, NDVI has a strong relationship with rainfall. The residuals in this regression correspond to differences in RUE. The rainfall and RUE at each station are shown in Table 5.2. The coefficient of variation of rainfall is also shown.

Table 5.2: Rainfall, its coefficient of variation, and rainfall use efficiency at 8 stations using the average of 13 years of annual rainfall and peak NDVI data. *The stations are listed in order of latitude, southernmost first. RUE =(100NDVI) / rainfall*

Station	**Average Rainfall 82-94 (mm)**	**CV of rainfall %**		**RUE**	**Rank RUE**
		long term	1982-1994		
Tasty	129.1	34	225	0.100	2
Ulan	142.1	30	28	0.110	3
Tiuken	135.5	34	23	0.125	5
Betpak	147.8	30	24	0.138	8
Balkhash	168.7	28	22	0.080	1
Koktas	205.8	25	26	0.135	6
Berlik	237.4	26	25	0.133	7
Karaganda	323.8	26	23	0.122	4

From Table 5.2 it can be seen that differences in RUE exist between different stations. In order to see if these differences were significantly linked to site or region a nested ANOVA was carried out with site number nested in region (southern or northern as defined in Chapter 4). The results were as follows:

Station nested in region: df =6, F=4.32, P=0.001

Region: df =1, F=10.46, P=0.002

This suggests both site and region are important in determining RUE.

The lowest RUEs are to be found at Tasty and Ulan bel' despite the fact that their position on the river Chu would be expected to give then higher than expected RUEs. The high NDVI along the river Chu can be seen in Figure 4.2. One reason for the lower RUEs observed at Tasty and Ulan bel' could be due to differences in rainfall, as it has been proposed that sites with lower rainfall tend to have lower RUE (Prince *et al.* 1998). However, in fact, if the mean rainfalls at Betpak-dala and Tasty over the thirty years of data are compared using a two sample t-test, they are not statistically different (t = 0.346 NS). The rainfall means at these two stations during the short period from 1982 to 1994 are also not significantly different (t = -1.381 NS). Therefore differences in annual rainfall may not be the reason why the RUEs are lower.

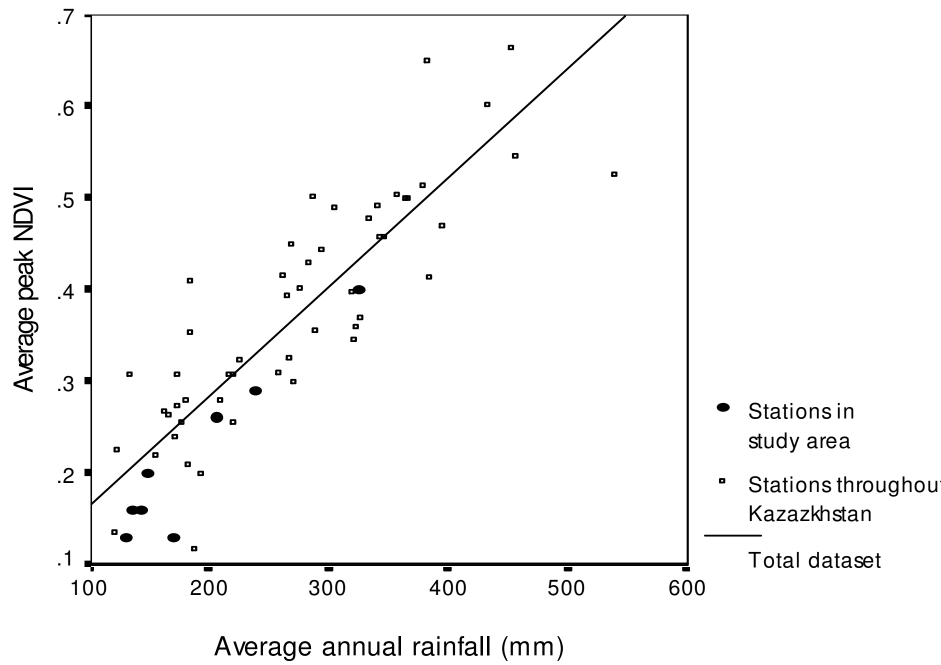
It could be hypothesised that the particularly low RUEs observed at Tasty and Ulan bel' exist due to high rainfall variability rather than to an actual lack of rainfall. However, whilst the coefficients of variation of rainfall (using the 30 year data set) *are* slightly higher in the more southerly sites than at the northern sites (see Table 5.2) there is, again, little difference between stations within each zone. For example, the variances of thirty years rainfall data for stations Tasty and Betpak-dala were not found to be statistically different using the F test (F =0.2 NS). The coefficients of variation of rainfall were seen to be even more similar between stations if data was taken only from 1982-1994. It is however, possible that the low biomass and NDVI at Tasty and Ulan bel' result from smaller proportions of 'useful' rainfall at these stations. For example, with decreasing latitude rainfall has an increasing tendency to fall in the winter which might explain the differences. Another possibility is that at the low values are due to the fact that Tasty, Ulan bel', and to some extent Tiuken, are situated in areas where grazing pressure was extremely high. However, the very low RUEs at these stations are also found in the biomass data, particularly at Tasty which has an RUE of only 2 (Table 5.1). As these data were collected in exclosures, and therefore not subject to grazing, it seems likely that the low RUE is not due to this factor, although as explained in Chapter 3, there are numerous problems with the biomass data, and the NDVI data represents a much larger area around each station and therefore a more representative vegetation sample. Figure 4.3 shows that the seasonal biomass curves at Tasty and Ulan bel' are much lower and flatter than those at Tiuken and Betpak dala which have similar vegetation, but which were not located in highly grazed areas.

(ii) Meteorological stations in Kazakhstan as a whole

In this section, RUEs were calculated for the extra 54 stations in Kazakhstan in the same way as was done for stations in the study area. The problem with this data set is that rainfall is often missing. Therefore for each station, the average NDVI and rainfall were calculated only from those years for which both were present. For some stations therefore this was an average of thirteen years whilst for others it may have been as few as five years. These 54 stations, plus the 10 for which NDVI was originally extracted (see Table 4.2) bring the dataset to a total of 64 stations.

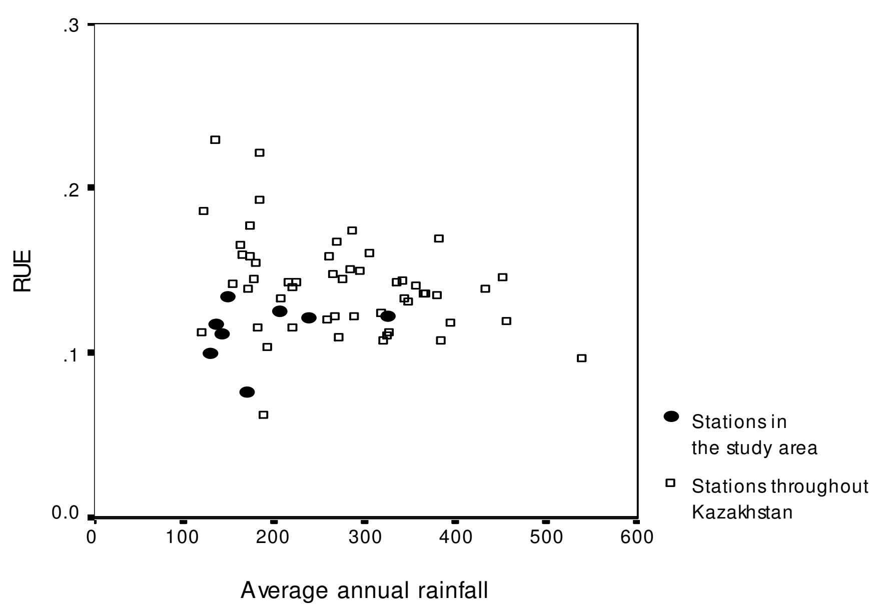
Figure 5.4 shows that, as for Betpak-dala, for Kazakhstan as a whole there is also a strong relationship between rainfall and peak NDVI when long term averages are taken. The rainfall range here is 120mm - 539mm per year (long term averages). The R^2 is lower, as there is more variation, but it is significant to the 99.9% level. The results using summed NDVI were almost identical. Some of the variation will come from sites with access to water sources other than rainfall.

Figure 5.4: The relationship between average annual rainfall and average peak NDVI for 64 sites in Kazakhstan. *R^2 = 0.76****



There is no relationship between RUE and average annual rainfall, as can be seen in Figure 5.5.

Figure 5.5: A scatter graph showing average annual rainfall plotted against RUE for 64 sites in Kazakhstan. *R^2 = 0.03 (NS).*



It has been seen from Figure 5.3 that NDVI is sensitive enough to detect climatically induced differences in biomass within the study area, even though the overall rainfall variation is quite small when compared that of other studies in the literature. RUE calculated from NDVI however, does not show a trend with rainfall.

One of the aims of this chapter is to compare RUE between areas with specific vegetation or land use types. The problem here with using rainfall data from meteorological stations is that they are not ideally situated for comparing areas representative of particular vegetation types or grazing regimes. NDVI extracted from a 72 km radius around the stations Tasty and Ulan bel' for example would include pixels covering two very different ecosystems, whilst Karaganda and Balkhash stations are located near towns. Many of the 54 stations represented in Figure 5.5 are near rivers or cultivated areas (see Figure 4.2). The next section deals with the determination of rainfall over large areas, representative of particular pasture types, and its relationship with NDVI extracted for those areas.

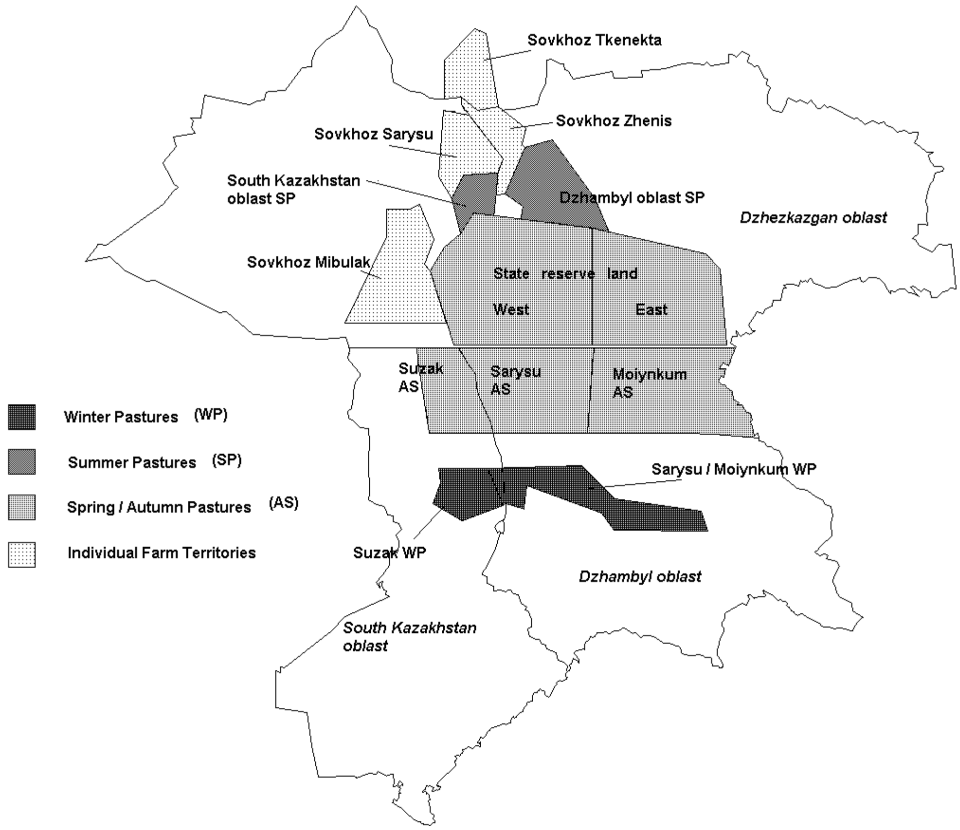
5.3 RUE, vegetation type, and land use: spatial comparisons

5.3.1 Determination of RUE for different land use types in the study area

(i) Extraction of NDVI

The study area was split into polygons, each representing a land use type (see Figure 5.6) For each of the polygons average NDVI values for each 10 day period over the 13 years of data were extracted. From these, the average summed and peak NDVIs for the 13 years were calculated for each land use type.

Figure 5.6: Polygons representing various farms or types of grazing area for which NDVI was extracted.



These areas and their vegetation and use (or over-use) have been discussed in Chapter 2, however Table 5.4 below summarises the relevant information, the names for each area corresponding to those in the map above. The words Moiynkum, Sarysu, and Suzak refer to areas in the *raions* of the same names, located in Dzhambyl and South Kazakhstan *oblasts*.

Table 5.3: Characteristics of polygons for which RUEs were calculated.

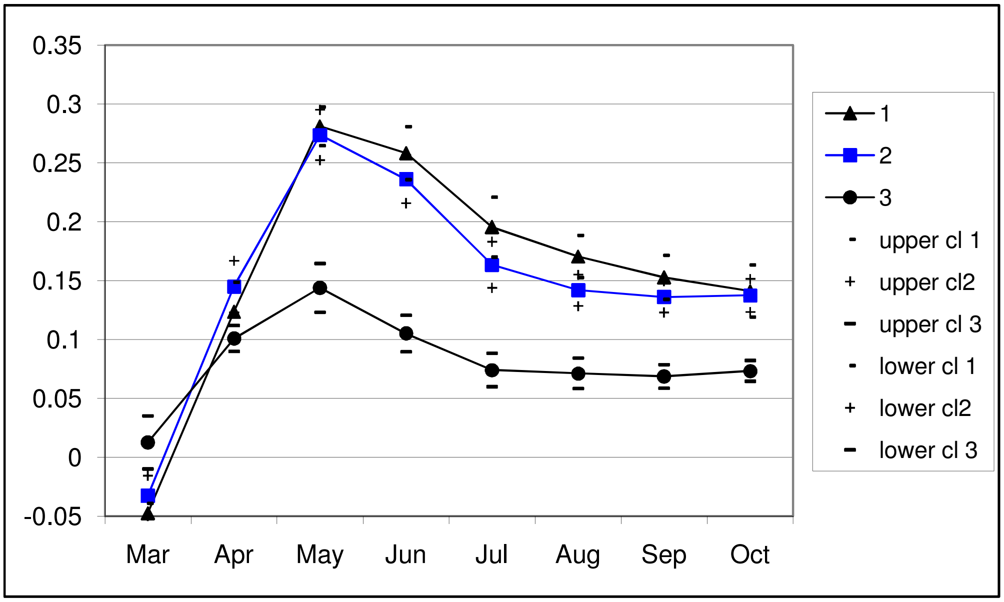
Land use type	Polygon extracted	Use	Vegetation	State
Moiynkum desert Winter pasture (WP)	1. WP Sarysu and Moiynkum 2. WP Suzak	Used in Winter only - November to March	*Haloxylon persicum* (east),*Calligonum* spp., *Salsola* spp., *Astragalus, atraphaxis* (west)	Seriously overstocked since the late 1960s.
Autumn - Spring	3. AS Moiynkum	These areas include *Sovkhoz* territories and	*Anabasis, Salsola,*	Since 1960s has been used for 3

Pasture (AS)	4. AS Sarysu 5. AS Suzak	some state reserve land. They are found in a band north of Moiynkum desert, but south of Dzhezkazgan *oblast*.	*Atriplex*	seasons, and became degraded in the 70s-80s.
State reserve land in Dzhezkazgan *oblast*	6. Western 7. Eastern	Located in Dzhezkazgan *oblast*. Used as migratory passage and autumn pasture for stock from Dzhambyl and South Kazakhstan *oblasts*	*Artemesia terrae- albae, Salsola arbusciliformis, Anabasis salsa*	In good condition. Never used for more than 1 season.
Summer Pasture in Sary Arka (SP)	8. SP Dzhambyl *oblast* 9. SP South Kazakhstan *oblast*	Located in Dzhezkazgan *oblast*, and used Jun-Sep as summer pasture for farms 300km to the South in Dzhambyl and South Kazakhstan *oblasts*	*Stipa Sareptana, Artemesia sublessingina, A. gracilescens, Festuca Sulcata,*	Good condition, never used more than 1 season
Individual *sovkhozes* in Dzhezkazgan and Karaganda *oblasts*	10. *Sovkhoz* Mibulak 11. *Sovkhoz* Sarysu 12. *Sovkhoz* Zhenis 13. *Sovkhoz* Tkenekta	On *Sovkhoz*es Zhenis and Tkenekta stock remain on the same pasture for autumn, winter, and spring. Mibulak and Sarysu have access to winter pasture on Zhetykonur sands.	*As above*	Zhenis and Tkenekta in poor condition. Sarysu and Mibulak in good condition.

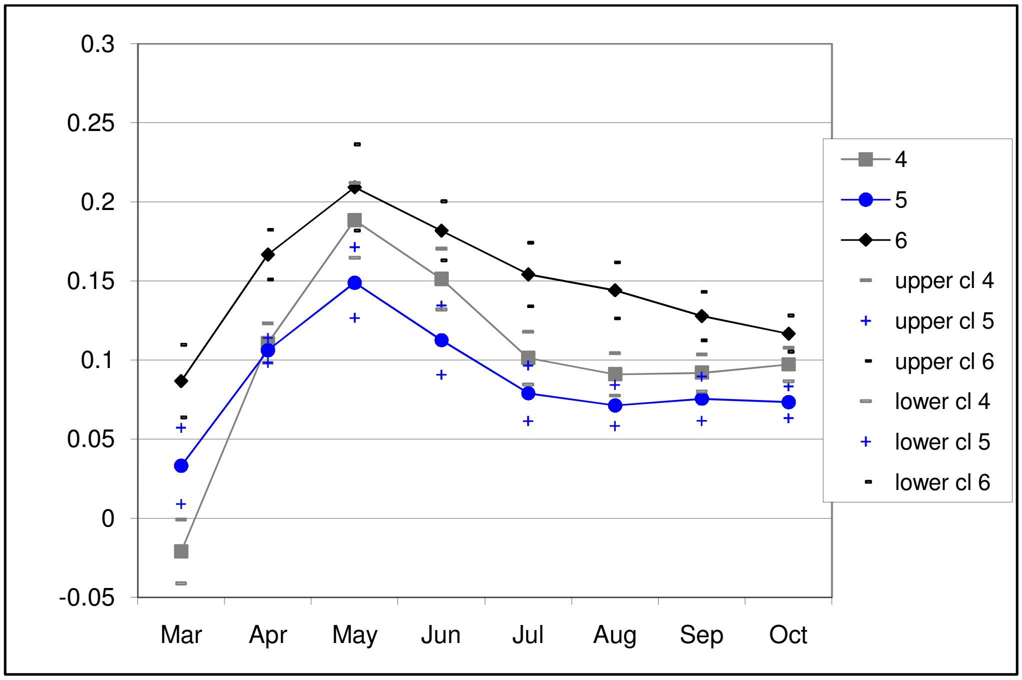
Therefore there are five major land use types - winter pasture, autumn-spring pasture, state reserve land (used during migration), summer pasture, and individual farms which have animals on their territory all year round. The NDVI change over the season for some of these land use types is shown in Figure 5.7.

Figure 5.7 NDVI change by dekad over the growing season for different pasture types with confidence intervals (cl). *Some curves represent several pasture areas having similar seasonal patterns.*

(a)
1: Sovkhoz Tkenekta, 2: Summer pasture (sovkhozes Sarysu and Zhenis show the same form), 3:Farms in Dzhambyl oblast (spring-autumn pasture)



(b)
4: State reserve land in Dzhezkazgan oblast (spring-autumn or migratory pasture, 5: Farms in Dzhambyl oblast (spring-autumn pasture),6: Moiynkum desert (winter pasture



The pattern is mainly as expected: that is that summer pastures in northern areas (for example Dzhambyl *oblast* summer pasture, line 2) have a higher peak than the autumn/spring areas further south (lines 3 and 5). The exception is the Moiynkum desert (line 6). The NDVI for this area is much higher than any of the others given its latitude. This could be because the curve shown is for the whole of the Moiynkum desert, southern areas of which are only 20km away from the foothills of the Tien Shan mountains, whose rainfall regime is probably influential. It could also be because the tall shrubs of this desert give a 'greener' signal than the grasses and semi-shrubs of other regions. In Chapter 4 it was seen that individual *Haloxylon aphyllum* plants have a very high NDVI when this is measured in the field with a hand held radiometer, and of all the soils measured, sand had the highest NDVI (0.134), although this was measured on Zhetykonur sands and not Moiynkum sands.

The winter pastures in Moiynkum desert are not covered with snow in March, whilst all the other areas are. This can be seen because the others all have negative values whilst in Moiynkum the NDVI at this time is above 0.05 indicating zero green vegetation, but no snow. The regions in the semi-steppe zone, summer pastures and *sovkhoz*es Sarysu and Zhenis have average annual rainfalls of 188-192mm. *Sovkhoz* Tkenekta has an average annual rainfall of 237mm, and has a higher NDVI than those of Sarysu and Zhenis. However this difference is not significant for the early part of the year as the confidence limits of the means overlap.

(ii) Interpolation of rainfall

In order to obtain rainfall values representative of polygons for which NDVI had been extracted, rather than of single stations, the rainfall was spatially interpolated. This was carried out with the software 'Arcinfo' by M. Parachinni of the Joint Research Centre, Ispra, Italy. A simple inverse distance weighted interpolation was used (discussed in Watson and Philip 1985) according to which rainfall in each pixel is determined according to a linear combination of the measured rainfall at the stations, each measurement weighted according to the distance from the pixel in question. The surface over which the rainfall was interpolated was assumed to be flat and without barriers. Nine of the ten stations available were used (see Figure 3.2). Turkestan was not included because its data only went up to 1993, and it was south of the Karatau mountains which constitute a barrier in the otherwise relatively flat region of the study area. Rainfall was not interpolated more than 50km south of Tasty (the southernmost station) or north of Karaganda (the northernmost station). This meant that only the northernmost areas of Moiynkum were analysed, as for the rest the rainfall data was considered to be too inaccurate, and as mentioned above, the south of the desert comes close to the mountains. One problem which may lead to errors in the rainfall interpolation is that there are some areas in the region studied which are not totally flat. For example, in Dzhezkazgan *oblast* there are several regions of small hills, the highest of which is 500 meters higher than the surrounding plain, most of which lies at between 300 and 500m above sea level.

The average rainfall values were extracted for each of the areas in question for each dekad. The rainfall use efficiencies were calculated from the average peak NDVI for each area as well as the average annual rainfall for each area. Both NDVI and rainfall were scaled so that the resulting values would fall between 1 and 255, as the software used to process the data could only read 8 bit data in this format. The rainfall grid produced has a course resolution of 0.5 degrees, as does the derived RUE image.

(iii) Results and discussion

The RUE image is shown in Figure 5.8. RUE was calculated as follows:

$$RUE = 500\ (100N/0.5R) \qquad \textbf{(5.1)}$$

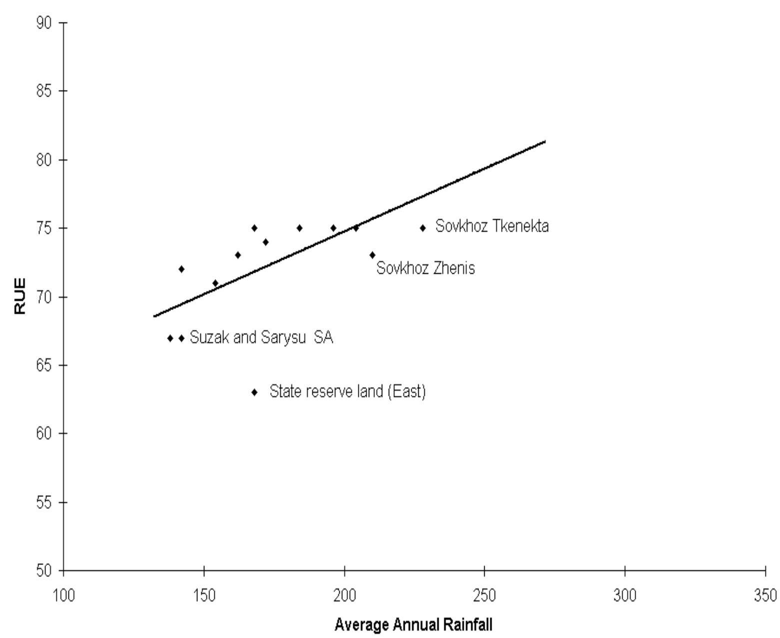
Where N= average peak NDVI and NDVI and R=average annual rainfall.
This way, the NDVI, rainfall, and RUE images all had values falling between 1 and 255. As might be expected, when NDVI was plotted against rainfall (using each 0.5 degree pixel as a data point), the regression showed a strong relationship (R^2 = 0.86***).

Figure 5.8 reveals Rain Use Efficiency to be low in the semi desert regions dominated by saltworts (*Salsola*, *Anabasis*, *Atriplex* and *Artemesia* spp.) lying between approximately 45 and 46 degrees of latitude. The areas to the north of these are increasingly dominated by *Artemesia* species (roughly 46 to 47 degrees) and then by *Artemesia* and grass species (Rachovskaya 1995) and have increasing RUEs, although towards lake Balkhash (the black area) this falls off considerably, and areas up to 2-3 pixels from the lake have the lowest RUE.

Figure 5.8

From the RUE image, it would appear that in general RUE increases with rainfall. This can be shown by plotting them against each other for the whole grid. The trendline shows the regression for the grid, and the values for the polygons are shown as scatter around this trend line.

Figure 5.9: The relationship between RUE and average annual rainfall for pixels of the RUE image. *The values for the different pasture types are shown as points. RUE was calculated from the image in Figure 5.8, and so is equivalent to:*
RUE = 500 (100N/0.5R). $R^2 = 0.16$***



Although the relationship is weak, Figure 5.9 confirms that between sites RUE increases with rainfall. Those areas falling below the line are have lower RUEs than expected. These areas are: autumn-spring pasture in Suzak and Sarysu *raions*, *sovkhoz* Zhenis, *sovkhoz* Tkenekta, and the Eastern state reserve land, towards lake Balkhash.

The area corresponding to autumn-spring pasture in Suzak and Sarysu *raions* has been described as being used for 3 seasons since the 1960s, leading to vegetation damage (I. Alimaev, pers. comm.), and *sovkhozes* such as Zhenis and Tkenekta which used the same pasture in autumn-winter-spring also were described as damaged (Zhambakin 1995). However the area around lake Balkhash, which is the most striking, is only described as slightly degraded (Babaev 1985). Kirichenko (1980) describes vegetation in this area as being sparse due to the small hills in the region, forming stony slopes and salty depressions unfavourable to vegetation growth.

None of the areas above the line include pasture which is used for more than one or two seasons, and it is tempting to suggest that this is why they have high RUEs. However it should be remembered that there are many other factors affecting RUE. The plants in the regions with low RUE in Dzhambyl and South Kazakhstan *oblasts* tend to be saltworts, in contrast to regions further north which become progressively dominated by *Artemesia* spp., and then by grasses. As already mentioned it is difficult to compare RUE across different plant associations and to be able to say anything about the reasons for the differences. For example of the areas under study discussed above, the one which suffered from the most degradation (if one believes the literature (see Chapter 2)), was that in Moiynkum desert. This area has a higher RUE than expected (it is above the trend line in Figure 5.9). This is because the plant communities there are dominated by large shrubs (for example *Haloxylon* spp.), whereas elsewhere the plant communities are made of semi-shrubs and grasses. *Haloxylon* spp. have extremely long roots which can take up deeper water than other plants. As previously mentioned, their shrubby morphology may also give a ‘greener’ signal than other type of vegetation.

Other factors affecting the RUE-rainfall relationships between sites are that, as already mentioned, the landscape is not completely flat, and that some pixels will contain high ground, or low ground with temporary spring streams or pools, leading to artificially high RUEs. Soils are not uniform throughout the region, leading to differences in available moisture which are not due simply to rainfall. For all these reasons we cannot imply that grazing regimes are responsible for any of the difference observed. This is confirmed by looking at RUE in conjunction with data from the map of land degradation in Central Asia described in Chapter 2 (Babaev 1985).

5.3.2 A comparison of RUE and vegetation condition in Kazakhstan using qualitative data on degradation

In this section RUE at sites in Kazakhstan for which some qualitative scale of degradation was available are calculated and analysed.

(i) Methodology

Of all the meteorological stations available for the whole country, 17 were located within the region covered by the desertification map described in Chapter 2 (Babaev 1985). The nine pixel (72km) regions extracted round each station were classified from the information in the map according to the amount and type of degraded land in the extracted area. Each station was given an index according to a weighted average of the degradation types. This was carried out according to the following example:

Table 5.4: Calculation of degradation classes.

Degradation class	**None**	**Slight**	**Moderate**	**Severe**	**Very Severe**
Weighting	0	1	2	3	4
Area extracted for example station (proportion)	0.8	0.1	0.1	0	0

The areas are multiplied by the degradation weighting to give an index ranging from 0-4. For the example station above, the degradation weighting would be:

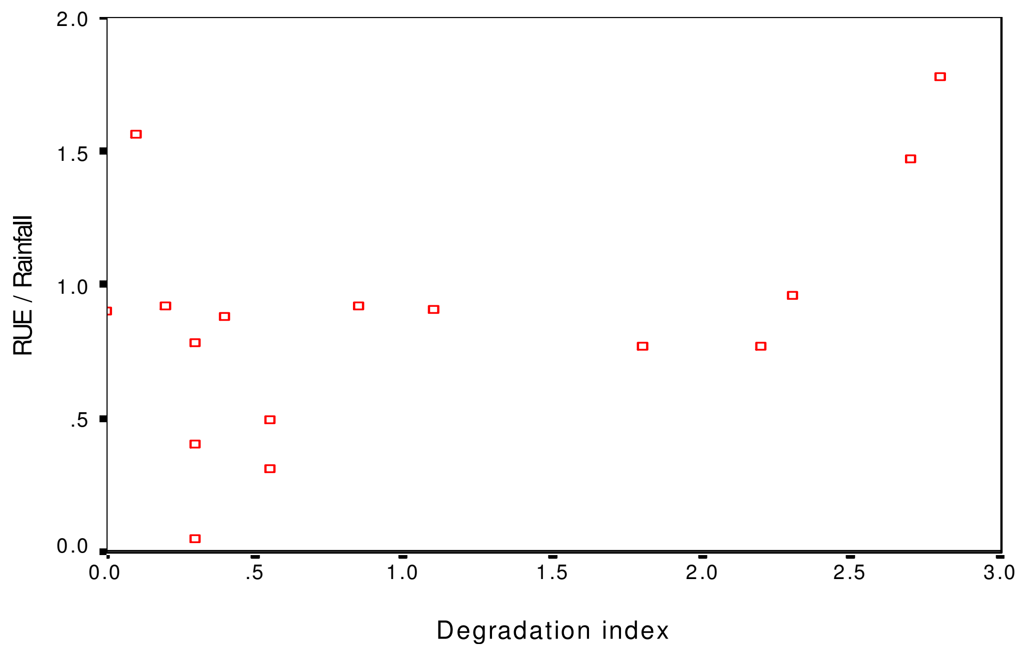
$$0.8 + 0.1 + 0.2 = 1.1 \qquad \textbf{(5.2)}$$

In this way, unlike for the Betpak-dala data, a *quantitative* (although still subjective) measure of degradation was available which could be compared to RUE or to the RUE/rainfall relationship.

(ii) Results

As seen in Figure 5.9, one of the main factors affecting RUE is rainfall itself, which has a positive relationship with the RUE. This effect of rainfall on RUE was removed by dividing RUE by rainfall, and the resulting value was regressed against the degradation index. The result is shown in Figure 5.10.

Figure 5.10: A scatter graph of RUE/rainfall, against degradation index for stations distributed throughout southern Kazakhstan.



There is certainly no negative relationship between the degree of degradation, and rainfall use efficiency, and indeed there is a significant, (though poor) *positive* relationship (R^2 = 0.24*). Therefore the stations found in areas containing severely degraded land tended to have relatively *high* rainfall use efficiencies, and is probably due to the fact that such sites are found mostly in regions on sandy soil with shrubby vegetation, or areas near rivers. This confirms that both in the study area, and outside it, soil and vegetation type have a much stronger bearing on RUE than the overgrazing described in the literature.

5.3.3 Summary of spatial comparisons of RUE

Spatially, for Betpak-dala, good relationships were obtained between long term averages for rainfall and peak NDVI. These relationships are less strong for Kazakhstan as a whole, probably because of the greater range of soil types or vegetation morphology involved. The study area (excluding the Moiynkum desert) is a good area for studying RUE as it is flat, and the vegetation consists of a gradual change from semi-shrubs to grasses over a large area with similar soils. Over this area, both rainfall and RUE show a relatively constant increase with latitude, and therefore different areas were compared by looking at their RUE per unit of rainfall.

Whilst it is true that the autumn-spring pastures show the lowest RUEs when these are corrected for rainfall, in agreement with the literature and general opinion that these areas are degraded, we cannot discount the hypothesis that they have a low RUE compared to rainfall because of the high variability and poor distribution of that rainfall compared to that of more northern areas. The intensity of land degradation in the country as a whole (albeit from qualitative sources) was seen to have no correlation whatsoever with RUE or RUE/rainfall.

5.4 Variation in NDVI and rainfall as indicators of vegetation condition

We have seen so far that realistically it is difficult to draw any conclusions about vegetation state in different areas by comparing their long term RUEs as these are affected by so many factors. One of these is rainfall, which can be corrected for by looking at RUE/rainfall. However the other factors are vegetation type and soils which causes large RUE variability from site to site regardless of rainfall, grazing regimes etc. In this section methods by which the state of vegetation in different areas can be compared whilst reducing the effects of these confounding factors are investigated. The methods involve studying the *variability* of NDVI, rainfall and RUE.

5.4.1 Indices of ecosystem stability

A measure of vegetation condition has been applied to the identification of pasture degradation with NDVI data in the Balkhash basin, Kazakhstan, by Ellis and Lee (2000). The authors looked at variability of RUE as a function of rainfall. As already discussed, although RUE increases with rainfall *across* sites, it decreases with rainfall at single sites so that when rainfall is low plants are more efficient at using it than when rainfall is more plentiful. Ellis and Lee proposed that this compensatory response to rainfall can be measured by looking at the R^2 value of the relationship between the RUE and rainfall (referred to in the rest of this chapter as the RR index). This is taken by the authors to be a measure of the sensitivity of vegetation to rainfall, and the stability of the vegetation response. In other words, an ecosystem exhibiting large fluctuations in NPP compared to those of rainfall is likely to be in poor condition. This can be criticised as areas with lower precipitation also have a proportionally greater amount of inefficient rainfall, and a greater rainfall variability. Therefore the rainfall efficiency is likely to vary much more in such areas regardless of grazing regime. Despite this, it was decided to analyse the data for the study area in order to compare with the results of Ellis and Lee (2000).

Le Houérou *et al.* (1988) conducted a survey of the variability of rainfall and NPP on pastures world-wide, and found that the ratio of the coefficient of variation of NPP and that of rainfall is an indicator of ecosystem stability, and negatively related to RUE. Here we call this ratio the *CV index*, and the higher the value, the more variable the vegetation compared to rainfall variability.

According to Illius and O'Connor (1999) an increase in inter-annual variability in primary production may result from the effects of herbivores on vegetation. They suggest that the stocking changes inter-annual variability in two ways. Firstly under conditions of overstocking, vegetation cover is reduced, and soil compacted, increasing runoff and decreasing infiltration. The other probable reason for this is that highly stocked areas tend to have a greater proportion of annuals in the vegetation, which in turn have a higher coefficient of variation (CV) of NPP because of threshold effects of rainfall on germination (Illius and O'Connor 1999). Kelly and Walker (1976) found that variability was four times higher on overstocked pastures

dominated by annuals than on those dominated by perennials. It is possible that such behaviour could exist on Kazakh pastures because (as described in Chapter 2) degradation processes typically involve an increase of annuals (Kirichenko 1980).
The RR index and the CV index were calculated for the different regions of the study area using the interpolated rainfall from June to May, and peak NDVI for each of the 13 years. RUE here is calculated as follows:

$$RUE = 500(100N/R_{jun\ to\ May}) \quad \textbf{(5.3)}$$

Where N=average peak NDVI and $R_{jun\ to\ May}$= total rainfall from June to May.
This is because here we are not looking at long term averages, but yearly data so it makes more sense to choose the annual rainfall variable which is most likely to affect peak NDVI from year to year. In the following sections the results are presented and discussed.

5.4.2. Results and discussion.

The data for each polygon (Peak NDVI, Rainfall, RUE, and RR index, and CV index) are shown in Table 5.6. Figure 5.10 shows plots of the relationship for selected areas.

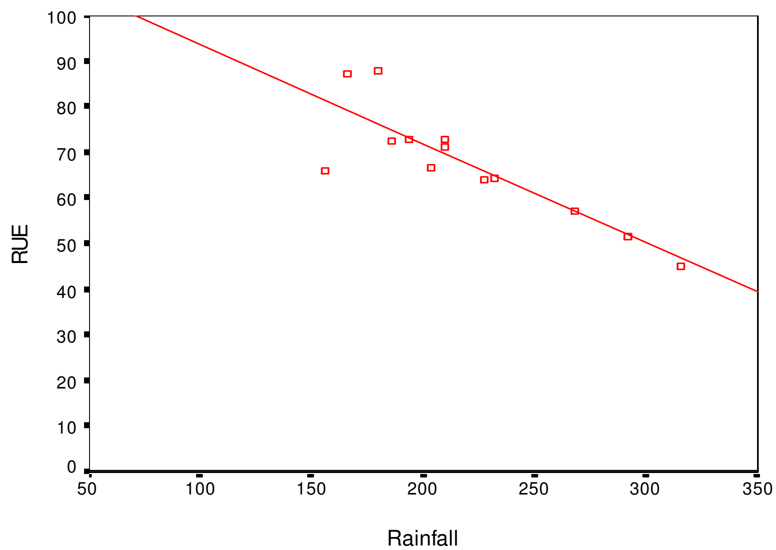
Table 5.5: Average Rainfall and RUE data for each polygon. *The polygons are listed in order according to annual rainfall, highest first.*
$RUE = 500(100N/R_{jun\ to\ May})$
RR index = the R^2 of the relationship between rainfall and RUE
CV index = ratio of the coefficient of variation of NDVI to the coefficient of variation of rainfall

Polygon	**Peak rainfall**	**Peak NDVI**	**RUE**	**RR index**	**CV index**
Sovkhoz Tkenekta	218.61	0.287	65.74	0.73	0.44
SP Dhzambyl *oblast*	208.30	0.274	65.91	0.51	0.73
Sovkhoz Zhenis	205.07	0.268	65.57	0.46	0.7
Sovkhoz Sarysu	196.46	0.277	70.67	0.65	0.54
SP S. Kazakhstan *oblast*	189.23	0.240	63.61	0.52	0.71
State land reserve (east)	170.61	0.188	55.30	0.42	0.126
State land reserve (west)	167.07	0.214	64.22	0.16	0.126
Sovkhoz Mibulak	164.00	0.225	68.87	0.47	0.85
AS Moiynkum *raion*	149.23	0.143	48.19	0.63	1.27

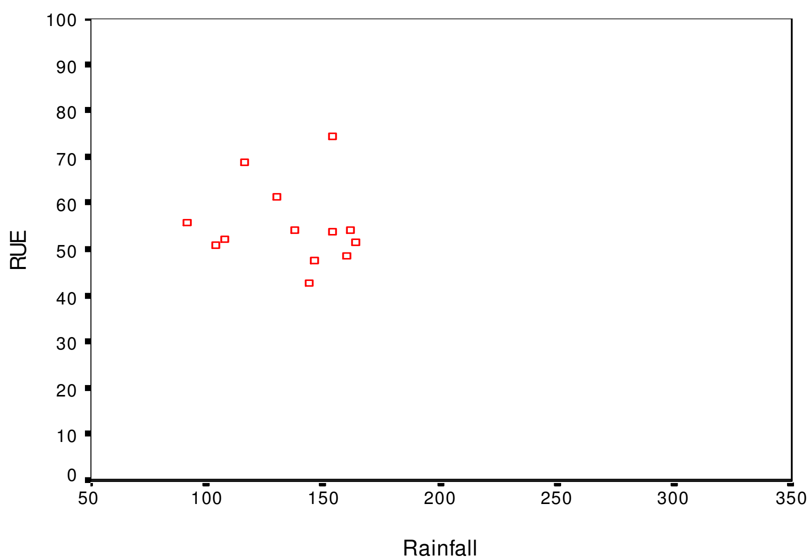
WP Dzhambyl *oblast*	146.61	0.183	62.52	0.57	0.77
AS Sarysu *raion*	138.00	0.140	51.00	0.29	1.98
AS Suzak *raion*	136.30	0.150	55.21	0.01	1.29
WP South Kazakhstan *oblast*	133.07	0.141	52.98	0.50	0.58

Figure 5.11: Plots of RUE against rainfall for selected polygons.

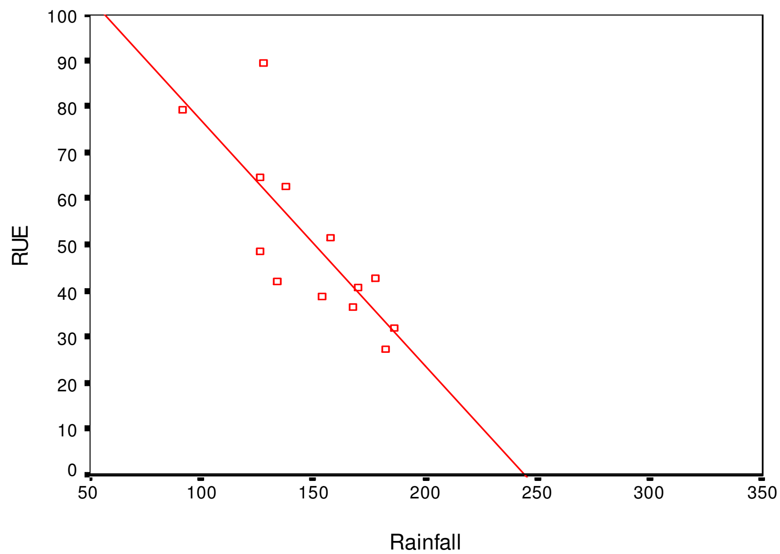
*(a) Sovkhoz Tkenekta (R^2 = 0.73***)*



(b) Autumn-Spring pasture, Suzak raion (no relationship)



*(c) Autumn-Spring pasture, Moiynkum raion (R = 0.63***)*



There appear to be relationships between rainfall and RUE at nearly every site. The strongest relationships between RUE and rainfall are in the north (Tkenekta, Figure 5.10a), whilst the worst tend to be found in the autumn-spring pastures (Suzak, Figure 5.10b), with the exception of that in Moiynkum *raion* (Figure 5.10c). In most cases the RR index is about 0.5. However, in some cases it is strikingly low. There are various reasons why this might be so: if the NDVI is stable (i.e. has a low variability), the RR index will in fact resemble the estimate for a regression of rainfall against a constant factor of itself, and the correlation coefficient will be high. This stability is either coming from the fact that the vegetation has a good compensatory response to rainfall, or because NDVI is too insensitive to pick up fluctuations. If NDVI increases strongly with rainfall (which could be would be a sign that the vegetation is unstable) the RUE will remain relatively constant, and the RR index will be low. However, any NDVI signal which is highly variable, whether this is due to rainfall or not, could also produce a low RR index. This is demonstrated in Appendix 5. Here, the behaviour of the RR index is tested using a computer generated dataset. Relationships are shown to be very unpredictable and highly dependant on the relative variability of NDVI and rainfall.

From the results it can be seen that those areas having low RR indices do indeed have a very high ratio between inter-annual NDVI variation and variation in rainfall (CV index). For example, the autumn-spring pasture in Sarysu *raion* has both the highest CV index, and the lowest RR index, whilst at Tkenekta the pattern is reversed. Are these patterns due to a real instability in the ecosystem due to overgrazing and invasion by annuals in some areas, or is the NDVI more variable in these areas for other reasons?

For example, one extra cause of NDVI inter-annual variability is noise. In the southern areas which have low biomass and cover, some of the NDVI signal is probably lost due to low greenness of the vegetation, leaving residual fluctuations from noise. If this is the case then we would expect the RR index to be artificially high, as the inter-annual NDVI fluctuation from noise is about three times smaller than that due to vegetation (see Chapter 4). However, this is not the case, and we can see from Table 5.8 that whilst the RR index is high in the areas in the semi-desert zone, it tends to be low, and in some cases extremely low, in the desert zone, suggesting that in this area NDVI is particularly variable with respect to rainfall fluctuations. The CV of NDVI itself doubles between northern sites (*sovkhozes* Zhenis, Sarysu, and Tkenekta) where it is about 10, and autumn-spring pasture areas where it is about 25.

Those areas with particularly low stability are the state land reserve, and autumn-spring pasture in Suzak and Sarysu *raions*. These areas include both those which were apparently most degraded (spring autumn pasture) and that which was the least degraded (state land reserve). Therefore these results do not seem to be saying anything about land use. In fact, if we look at both the CV and RR indices, it would appear that, apart from a couple of exceptions, the ‘stability’ of the ecosystem is simply improving with rainfall. This is not surprising as at low rainfalls it is much harder for vegetation to cope with variation, and there is a higher occurrence of drought years (Houérou *et al.* 1988).

However, the values for autumn-spring pasture in Suzak and Sarysu *raion*s are so different from the others (using both the RR and the CV index) that it seems very probable that the vegetation in these areas is highly disturbed. In the case of Suzak *raion*, the RR index is ten times lower than the next largest, and at Sarysu the CV index is larger than the next smallest by 50%. The winter pastures in Moiynkum desert do not show any extreme values for either index. This is in contradiction to suggestions in the literature that this area is severely degraded.

These observations are particularly interesting if compared with those of Ellis and Lee (2000) for the Balkhash basin. The sites in Betpak-dala which had the lowest RR index were of the same vegetation type as that of the site which in the Balkhash basin had the lowest RR index (0.06 when data is taken from 1982 to 1989). This latter area was also an area of spring-autumn pasture dominated by saltworts and *Artemesia*, and which had suffered from overgrazing. Ellis and Lee also found that sandy desert ecosystems (the Taukum desert) used as winter pasture in the Balkhash basin had higher RR indices than the spring-autumn pastures, even though they have lower rainfall. This is a very similar result to that found for the sandy Moiynkum desert which also has a lower and CV index than adjacent areas on clay soils. Houérou (1984) and Le Houérou *et al.* (1988) have observed that RUE is higher and NPP less variable on sandy soil than on silty soils, and therefore the results for the two sandy deserts confirm this pattern, and the fact that they were both apparently extremely overgrazed (especially the Taukum, Zhambakin 1995) does not come out in the analysis. The indices therefore pick up differences between vegetation types rather than the more subtle changes due to overgrazing, and thus are of limited usefulness.

5.5 Summary and conclusions

From the analysis of patterns of rainfall use efficiency in the study area, we can draw the following conclusions:

- Spatial differences in NDVI can be accurately predicted from rainfall in the study area and in Kazakhstan as a whole. From these NDVIs it is possible to calculate rainfall use efficiency for different areas of the country.

- RUE is particularly low in the south of Betpak-dala, in northern Dzhambyl and South Kazakhstan *oblasts,* and in the vicinity of lake Balkhash. Although the former of these regions apparently suffered from overgrazing we cannot conclude that this is the reason for the low RUE, which could be related to the saltwort vegetation typical of this region, soil colour, or rainfall itself.

- RUE increases with rainfall between sites. This is probably due to the lower proportion of inefficient rainfall (lost to runoff and evaporation) which exists at the higher rainfall sites.

- The relationship between rainfall and RUE is generally negative at single sites, implying that in most areas the vegetation has some compensatory response to rainfall, or that the biomass does not fluctuate enough for it to show up in the NDVI signal. In some parts of the study area relationships between RUE and rainfall were absent. The NDVI of these areas tended also to have a very high coefficient of variation compared to that of rainfall. These areas were all in the southern clay desert zone.

- Areas with low NDVI stability are also those of low rainfall, and therefore we cannot say that rainfall patterns, rather than overgrazing, are the cause of the instability. However, the particularly extreme values of variability indices in the autumn-spring pasture in Sarysu and Suzak *raion*s compared to surrounding zones (which have similar rainfall) seem to indicate that these areas are indeed degraded. The results of the analysis are qualitative and only interpretable in the light of other independent information. It would not be possible to use the indices to predict with any certainty which areas of the study are have suffered from overgrazing and which have not.

To summarise, as can be seen from the work in this chapter, there is no simple way of using NDVI to detect differences in vegetation condition which is not confounded by factors such as soils, rainfall and vegetation type. Even the indices which look at NDVI variability rather than its magnitude seem to be affected by rainfall itself. Probably the best direction for future work would be to analyse RUE-rainfall relationships before and after the massive destocking of 1994, although this would have to wait until enough years of pathfinder data were available to produce robust and significant results for the difference. Work of Ellis and Lee (2000) suggests that this strategy has promise, as, for a number of sites in Almaty *oblast* RR indices were higher in the period from 1990 to 1996 than in that from 1982 to 1989.