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DRAFT REPORT OF THE ADVERSE EFFECTS OF AGROCHEMICALS ON MIGRATORY WATERBIRDS IN AFRICA

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in the form of his MSc Thesis at the International MSc Programme:
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Foreword

This Report was compiled by Peter Wolanski in the form of his Master of Science Thesis at the International Master of Science Programme: Agricultural Science and Resource Management in the Tropics and Subtropics at the Department of Cultural Landscape Ecology and Animal Ecology, the Rheinische Friedrich-Wilhelms-Univrsität Bonn, Germany. It was supervised in cooperation with the UNEP/AEWA Secretariat.

Numbers of migratory waterbirds are declining, and to date the exact reasons are unknown. The objective of this thesis is to gather proof that the application of agrochemicals, amongst other factors, has an impact on migratory waterbirds. As empirical data is missing, this thesis is based entirely on relevant literature.

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List of abbreviations

ACSF-GC/CMEF	African Civil Society Statement to the Governing Council/ Global Ministerial Environment Forum
AEWA	Agreement on the Conservation of African-Eurasian Migratory Waterbirds
AEZ	Agro-Ecological Zone
AU	African Union
CAAPD	The Comprehensive Africa Agriculture Development Programme
ChE	Acetylcholinesterase
CMDT	Compagnie Malienne de Developpement des Textils
DDE	A metabolite of DDT
DDT	Dichlorodiphenyltrichloroethane
EMA	European Medicines Agency of the European Union
EPA	Environmental Protection Agency of the United States of America
FAO	Food and Agricultural Organisation of the United Nations
FAOSTAT	Statistical database of the FAO
GTZ	German Technical Cooperation
HBC	Hexachlorate
IPCC	Intergovernmental Panel on Climate Change
LGP	Length of growing period
NEPAD	New Partnership for Africa's Development
OC	Organochlorine pesticide
OP	Organophoshate pesticide
PAN	Pesticide Action Network
RAEZ	Regional agro-ecological zone
SPSS	Statistical Package for Social Sciences
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department for Agriculture
WDR	World Development Report
WHO	World Health Organisation
WHO-MCL	Maximum contamination limit for pesticides by the WHO

Executive Summary

Large numbers of migratory waterbirds are in decline. This study attempts to analyse the adverse effects of agrochemicals on migratory waterbirds in Africa, in order to investigate the possible causes for declines in populations within Africa

Migratory birds require massive body reserves to fuel their journeys. As food is not distributed equally along the routes, many die each year because of fatigue or have to face increasingly worsening conditions.

The migrants arrive in Africa at the end of the great rainy season when vegetation is green and insects are abundant; however conditions worsen increasingly until it is time for them to leave. The main factors having caused the decline in numbers are however thought to be drought, deforestation but also the replacement of natural habitats by agriculture.

Birds wintering in savannahs have suffered the strongest declines, birds wintering in woodland were least affected. Particularly steep declines were most commonly found amongst Afro-Palaearctic migrants breeding in farmland and steppe, more than half of the long-distance migrants are classified as birds of farmland and steppe in Eurasia.

One aspect of the negative impact of agriculture is the adverse effect of agrochemicals, in particular, pesticides and fertilisers. Mainly in Sub-Saharan Africa, pesticide legislation in poor, not implemented, or not enforced. Assessing the impact of agrochemicals - especially pesticides - on migratory waterbirds, is quite difficult. Empiric data is missing and agricultural liberalisation has led to illicit pesticide trade and unregulated application.

The increasing application of pesticides causes insects serving as the food for migratory birds to be less available and pesticides may also directly intoxicate and kill birds

An attempt of a statistical analysis, which due to inconsistent data is rather highly assumptive, has shown the following results:

- Of the 255 species covered by AEWA a total of 217 species of migratory waterbirds are either resident or winter on the African continent.
- A total of 382 populations are recorded by the AEWA/MOP 4.8[1] document as residing in Africa.
- The most important feed for the majority of birds are insects, their larvae and arachnids, crustaceans, gastropods and fish.
- Despite efforts to protect these populations of migratory waterbirds, large numbers are declining.
- The majority of the birds are Palaearctic.
- Palaearctic migrants seem to decline to a greater extent than Intra-African migrants.
- Populations in Northern Africa seem to be declining to a greater extent (40.3 per cent) than in other parts of Africa.

All results are most likely biased by unequal distribution of the sample sizes within the variables. All hypotheses need to be further investigated with empirical data.

Natural habitats compete with cultivated land. Population growth and the expansion of commodity markets lead to the transformation of natural vegetation into farmland. Farmland expansion and intensification are the main reason and accelerant for the degradation of habitats and loss of biodiversity.

[1] http://www.unep-aewa.org/meetings/en/mop/mop4_docs/mop4_docs.htm

Food demand is predicted to double in the next 50 years, mainly in developing countries, and agricultural intensification is likely to increase in Sub-Saharan Africa. Intensification in agriculture automatically results in the application of growing amounts of agrochemicals.

Agrochemical is a conceptual collective term for a wide range of chemical products used in agriculture. However the focus in this paper will be put on fertilizers and pesticides as they directly or indirectly affect migrating waterbirds and their habitats. The impact of agrochemicals on birds is manifold; a distinction must be made between direct and indirect impacts.

Fertilisers, for instance, can cause eutrophication and hence deterioration of habitats, which can lead to a decrease of available food sources and in the worst case starvation of birds; thus it is an indirect effect.

Direct impacts from pesticides for example are death, hormonal deregulations and breeding failures if, for example, a pesticide is absorbed by a bird with its food. An indirect impact for example is the deterioration of habitats, because of herbicides or fertilizers, as well as the loss of food, due to the impact of insecticides on invertebrates. It is worth mentioning that although a number of birds can recover quickly from direct pesticide impact, some populations may remain permanently low or even die out. However, it is difficult to assess the number of birds dying from pesticides.

Land use in Africa is complex and related to economic development, national policy and local customs of a country or a region. African agriculture is vulnerable, as it is threatened by drought, nutrient mining and hence decreasing soil fertility, growing livestock and pests. What distinguishes the majority of African farmers from European farmers is lack of control over their environment. The use of farm machine technologies is least developed in Africa, especially in the parts south of the Sahara. The use of inorganic fertilisers in Sub-Saharan Africa is the lowest in the world. Most of Africa is dry; irrigation is limited and most cultivation is rainfed. For this reason, agriculture often falls victim to periodic droughts. Crop loss and failure, for example, because of pests, represents a significant threat to well-being and physical survival.

Furthermore, the population in most African countries is increasing and is growing twice as fast in cities as in the countryside. This process is called urbanisation, which has a direct impact on agriculture. The demand for agricultural commodities is changing. Rice and wheat for bread replace traditional crops such as millet and sorghum. The majority of African farmers are too poor to intensify their production by means such as irrigation and agrochemicals, thus larger areas of land are required. Shifting cultivation, a traditional land use technique leaving land fallow to avoid depletion of soil nutrients has been gradually replaced with permanent cultivation. The consequence is nutrient mining resulting in a decrease of organic soil matter, a loss of soil nutrients and ultimately, in lower yields.

According to current world fertiliser trends, Africa only accounts marginally for the world fertiliser consumption. High transportation costs especially in land-locked countries and an array of other factors which further limit input and output markets, severely constrain fertiliser use.

Agricultural production in tropical agro-ecosystems is greatly impacted by pests i.e. arthropods, pathogens, nematodes and weeds. There are no annual breaks in the growth period of the tropical ecosystems. Hence, pests breed all year round without declines common to temperate climates. This makes tropical agro-ecosystems unpredictable and difficult to manage.

Over the centuries, African farmers have developed traditional methods to deal with pests and diseases and they have coped well with indigenous pests on indigenous crops. With the introduction of higher yields and more resistant varieties, African agriculture has changed and is increasingly dependent on pesticides. This is aggravated by the belief that pesticides are the way out of poverty, leading to an uncoordinated influx of pesticides from abroad resulting in large stocks of obsolete pesticides becoming an environmental hazard.

Structural adjustment programmes have put farmers under financial pressure. With rising prices for pesticides and fertilisers and the majority of farmers too poor to acquire them, productivity has declined. In order to cope with the decrease in productivity the cultivated area is expanding. Few nature reserves provide refuge for wildlife such as migratory birds. African authorities also lack funds and manpower to assure pesticide quality and control the application of agrochemicals.

Particularly smallholders, which the majority of African farmers are, lack funds to acquire pesticides from official sources and increasingly turn to illicit markets. These often involve trade in highly dangerous pesticides that have not been tested for quality. Limited information and knowledge for various reasons leads to application of wrong dosages, intervals that are too short or even improper pesticides.

The impact on the environment is noticeable. Biodiversity is declining, nutrient cycling depending on the turnover by the fauna is threatened and growing pesticide resistance is leading to a further increase in pesticide application.

The case studies confirm that pesticide pollution in Africa has taken and is still taking place. They also confirm that farmers have limited knowledge about pests and the pesticides they apply, and that the application of pesticides that are proven to have adverse impacts on birds, is rising.

All these findings support the hypothesis that the cause for declining numbers of migratory waterbirds is, among other factors, agricultural expansion and intensification and the resulting increase in the application of agrochemicals.

Introduction

For centuries the migration of vast numbers of birds has been one of nature's greatest spectacles and the effort it takes is still considered miraculous. The numbers of Afro-Palaearctic migratory and Intra-African migratory birds are declining; the reasons for this development have not yet been determined. Among other factors, agricultural chemicals such as pesticides (mostly herbicides and insecticides) and fertilisers applied in African agriculture (as in Europe) might have an impact on their populations. Agrochemicals can kill birds directly, affect their metabolism, their reproduction and their food sources and destroy their habitats.

However, it is difficult to assess the impact that agrochemicals, especially pesticides, have on migratory waterbirds in Africa, because empiric data is missing and agricultural liberalisation has led to illicit pesticide trade and unregulated pesticide application. Pesticide legislation, particularly in Sub-Saharan Africa, is poor, not implemented or not enforced. Large numbers of poor farmers acquire their pesticides via illicit trade and lack knowledge on how to regulate application amounts. The extension of agricultural areas is diminishing the natural habitats of migratory waterbird populations and, in all probability, they are also being affected by agrochemicals.

This thesis attempts - despite the limited availability of applicable literature - to gather proof concerning the adverse impacts of agrochemicals on migratory waterbirds.

- *Chapter 1* Gives an introduction to the ecology of bird migration and decline of migratory birds in Africa;
- *Chapter 2* assesses the information on 382 waterbird populations, which are covered by the AEWA agreement for Africa. It summarises the main findings of the statistical analysis, which was performed in order to assess the correlation between the declining waterbird populations and their migration behaviour and geographical distribution;
- *Chapter 3* defines the terms *agrochemical*, *fertiliser* and *pesticide* and describes the impact which fertilisers and pesticides have on the environment and birds;
- *Chapter 4* compiles available information about the application of agrochemicals in Africa and the impact they have on the environment. It comprises case studies of a number of countries, introduces the reader to the concept of agro-ecological zoning, describes different agricultural systems in Africa and tries to provide an outlook into the future of African agriculture; and
- *Chapter 5* sums up the information of all chapters in order to prove that migratory waterbirds are most likely to be affected by the application of agrochemicals in Africa.

1. An introduction to the occurrence of bird migration and the decline of migratory birds in Africa

For generations, the annual migration of birds has been considered a miracle by humans. The journey of migratory birds may extend over distances of more than 10,000km and involve the crossing of inhospitable areas such as seas and deserts (Newton 2008).

1.1 The occurrence of bird migration

The hardships of the annual migratory journey are balanced by the benefits. If it were not advantageous to migrate twice a year, this behaviour would not have evolved or typical natural selection would have eliminated it. Migration must therefore be seen as a marvellous strategy to survive.

The first benefit is the ability of migratory birds to inhabit two different areas during seasons when each region provides favourable conditions. The second benefit is that by departing in the spring from their wintering ranges to their breeding areas, migrant birds reduce the competition between themselves and other resident bird species for space and resources, such as food for themselves and their offspring.

However, migrations require, besides extraordinary navigation skills massive body reserves to fuel non-stop flights lasting ten hours at a time (Newton 2008 et al.) and even much longer. Fat stores are needed to fuel aerobic contraction of flight muscles that permit the bird to fly for long durations with minimal fatigue. Digestion is very rapid in birds. In order to replace the energy that is required for a long term flight, it is essential that either food is taken up at comparatively short intervals or be stored prior to migration. During non-migratory periods, fat comprises about 3-5per cent of a bird's body weight. However, their fat level increases to about 15per cent in the case of short and middle distance migrants and to 30-50per cent in the case of long distance migrants. Hence it can be said that migratory birds become “literally obese” (Zimmerman 1998). It is worth mentioning, that some species having mainly moved around by walking and swimming such as grebes and rails have hardly ever flown for months before they set off for migration. Some birds will even migrate by walking and swimming for at least part of their journey, even though they are able to fly. Nevertheless, the main advantage of flight remains the speed.

The capability of migratory birds for the non-stop flight is limited by the need for fuel, which is food, and water, rather than the need for a rest. However, increasing amounts of fuel taken along as fat, also decrease the maximum possible non-stop flight range (Newton 2008).

Most birds are diurnal and it is remarkable that many choose not the day but the night to travel (Zimmerman 1998). If different bird families are compared, no obvious and consistent connection can be found between migration times, difficulty of the journey, habitats, diet or other further ecological aspects (Newton 2008). Soaring land birds like storks depend on daytime thermals and therefore have to fly during the day.

Smaller insectivorous birds may migrate by night to avoid enemies, but also because of the advantage of being able to hunt during the day. They are entirely daylight feeders and if they arrived at their destination at nightfall, they would be unable to obtain food until the following morning. This inability to feed would delay further flights and might result in great exhaustion or even death should their evening arrival coincide with cold or stormy weather. The schedule of nocturnal migration permits complete recovery and continuation of the journey on the following evening after sufficient fat deposits have been restored. In short, nocturnal migrants have a full stomach during their night time journeys.

The effort of flying generates considerable heat. In order to maintain an optimum body temperature, flying birds lose heat actively through evaporation of water from their air sacs which are part of the breathing system. Night time migration also has the advantage of cooler environmental temperatures. Wading and swimming birds are able to feed at all hours and are able to migrate either by day or night, or even both. Some diving birds, including ducks that submerge when in danger, often travel over water by day and over land at night (Zimmerman 1998 et. al). Even though it might be of advantage for all migratory birds to migrate as fast as possible, minimising the time spent on the journey, and maximising the breeding, wintering or moulting time, just a few are able to accomplish the entire journey in one single flight. Long, non-stop flights require large fuel stores and therefore the migration is typically divided into periods of flight, depleting reserves and stopovers to replenish the reserves. Some birds may find available food throughout their migration route and are able to stop almost everywhere. Others have to bridge long distances between successive feeding sites. Starting at their breeding areas a number of birds migrate in one single flight to specific areas in the southern part of Europe; there they refuel and move without other long interruptions of their journey on to sub-Saharan Africa. Smaller birds cannot survive much more than a day without food. Their method of travel consists of short flights lasting just a few hours, followed by feeding. Larger birds, like swans and geese, are able to survive many days without food and are able to travel longer periods without refuelling. Especially soaring birds expend little more energy during migration than in normal daily life (Newton 2008).

During the process of migration, flocks of bird species keep to themselves and a mix of different species as can be observed within flocks of ducks containing several species of ducks is an exception. Generally, closely-related species or species feeding on the same food do not migrate at the same time through the same area.

Peak migration times have been staggered and bird species have been equally distributed throughout the entire season by the process of evolution to avoid an exhaustion of food supplies.

Many migrating bird species maintain a close flock formation; others maintain loose flock formation and some even travel alone. Flocking provides advantages, such as protection against predators, and facilitates the finding of food. V-shaped flocks have an energy conserving function and allow members of the flock to gain an aerodynamic advantage by the wing-tip vortices of the bird ahead (Zimmerman 1998).

1.2. Intra-African migration, migration within the African continent

Africa's area comprises less than half the size of the Eurasian breeding grounds, but even south of the Sahara, Africa is a vast landmass extending over 21 million km^2. On both sides of the equator, the rainfall and vegetation zones mirror each other. Hence, many birds can find equivalent habitats on both sides ranging from deciduous woodland to increasingly dry savannahs and grasslands. Wet seasons are reversed between the northern and the southern side. A total of 500 African bird species are resident to the African continent and perform migrations, these are called Intra-African migrants. Most migrate entirely within the northern tropics or stay entirely within southern tropics and temperate zones. The general trend is to avoid the dry season by moving from the dryer areas into wetter areas. Few species cross the equator to live in equivalent habitats. These breed in the northern tropics and spend their non-breeding season in the southern tropics. Additionally, within mountainous areas of east and southern Africa many bird species move between different altitudes (Newton 2008 et al.).

1.3 Palaearctic migration, migration from Europe to Africa

Each autumn, many millions of birds, after breeding in Eurasia, travel to wintering areas in tropical Africa, and back again the following spring. For the migrating birds this involves a difficult and long journey. Birds from western Eurasia have to cross the Mediterranean Sea and the Sahara Desert, and those from further east have to cross the deserts of Southwest Asia and Arabia. The bird species performing these migrations are called Palaearctic migrants (Newton 2008). Unfortunately, little is known about the "life histories" of the majority of bird populations crossing the Sahara. Most of the

Palaearctic migrants are waterbirds and insectivores. They disperse across the African continent. Some stay north of the Sahara but substantial numbers cross the Sahara to winter in the northern and southern tropics. The ones crossing the Sahara stay in Sub-Saharan Africa for about six months and disperse over the African continent (Zwarts 2009). The migration to Africa is not without hazard. The mortality of juvenile migrating birds crossing the Sahara is 31per cent, compared to a mortality of 2per cent for adult birds (Strandberg 2009).

Seven categories can be distinguished:

1. Birds occupying winter quarters in equatorial and southern Africa (e.g. European Honey Buzzard, Eurasian Hobby, Barn Swallow);
2. Birds wintering largely north of the Sahara, but substantial numbers of which cross the desert to winter in the northern and southern tropics (e.g. Grey Heron, Common Chiffchaff);
3. Birds wintering largely south of the Sahara, often widely dispersed across the continent and including the Sahel and coastal zone (e.g. Osprey, Common Greenshank);
4. Birds wintering largely south of the Sahara and moving gradually south of the Sahel to destinations in the Sudan and Guinea zone (e.g. Pied Flycatcher, Barred Warbler);
5. Birds staying in the Sahel and Sudan zone until November often moulting and fattening, before embarking on the second southward stage of migration into wintering areas in the Guinea vegetation zone (e.g. Thrush Nightingale, Great Reed Warbler and Garden Warbler);
6. Birds wintering in the Sahel in West Africa, but extending south in East Africa (e.g. birds from Eastern Europe and Asia such as Montagu's Harrier, Ruff and Common Sandmartin). This category includes species whose northern European populations leapfrog those from southern Europe (e.g. Eurasian Marsh Harrier, Yellow Wagtail); and
7. Birds staying in northern tropical savannahs throughout the northern winter, with an emphasis on the Sahel and adjacent Sudan and northern Guinea zone. This category includes waterbirds largely restricted to floodplains (e.g. Glossy Ibis and duck) and typical savannah dwellers (e.g. European Turtle Dove, Eurasian Wryneck, Greater Short-toed Lark) (Zwarts 2009 et. al).

For Palaearctic migrants less food is available north of the equator than south of it. Plant growth takes place during the wet season and these are the times of the highest productivity (Newton 2008).

The migrants arrive at the end of the great rainy season when vegetation is green and insects are abundant (Zwarts 2009). When the migrants from the north arrive, the wet season is over, and they encounter increasingly worsening conditions until the time they leave (Newton 2008). The vegetation changes, temporary pools dry out and insect numbers dwindle (Zwarts 2009). Especially wetland birds rely on the rainwater that accumulates in holes and floods extensive areas. With the end of the rain these reservoirs evaporate. Even though smaller areas dry up by late December, larger areas provide productive year-round feeding opportunities even at the height of the dry season, and supply the rich grassland imperative for the survival of whole wildlife communities. However, most of these areas are under threat as they are rapidly being reduced by drainage and human exploitation (Newton 2008). Tropical rainforests are almost completely avoided, while the Sahel receives disproportionally high numbers of Eurasian birds (Zwarts 2009).

The Sahel savannah zone stretching across the northern tropics of the African continent from west to east is of key importance for migratory Palaearctic birds. It is the first area where they are able to find food after they have crossed the Sahara and where many must fatten, at the driest time when food is most scarce, before they can cross the Sahara again on their way back. Despite the dryness, many migratory birds spend the whole or at least part of the winter in the Sahel.

Depending on the species, the migrants arrive at the Sahel between August and November. Most arrive in September when many African bird species, having bred in the Sahel, retreat south. This is the time when the rains finish and the landscape is still lush and green providing plenty of food. However, with the end of the rains the environment dries out steadily. Therefore many migrant birds stay for only a few months and then continue their migration to the south. In West Africa, most species migrate over several hundred kilometres to reach the less arid savannahs in the south. Others move even further south to cross the equatorial forest to reside in wet season conditions of the woodlands and savannahs of southern Africa.

In East Africa, forest areas are more unevenly distributed and the migrants come across suitable woodland and savannah habitats stretching from the Sahel southward into South Africa. In contrast to the equatorial forest, which marks a barrier in the west, the migrants in the east are free to move south without the necessity of a second migration. However, before each migration, birds have to feed in order to deposit enough fat enabling them to fly long distances. The majority of Palaearctic land bird migrants depend on arthropods for their feed. These are generally abundant during the wet season, but the Sahel also provides insects in abundance during the dry season. Generally, numbers of migratory birds vary between different parts of Africa dependent on the availability of rainfall determining the supply of food (Newton 2008 et al.).

1.4 The phenomenon of declining bird populations

Numbers of migrant birds residing in Africa have evidently been in decline since the 1970s (Zwarts 2009). One of the reasons might be the drainage of 56-65per cent of all European Wetlands for intensive agriculture by 1985 (Finlayson 2005). Between 1970-1990, 39 per cent of migratory waterbirds were in decline, in 1990-2000 these numbers increased to 55 per cent. This trend is significantly higher amongst Palaearctic migrants compared to residents and short distance migrants.

“For the period 1970 to 2005, 75 out of 127 species were in decline”, that is 59per cent of all trans-Saharan migrants. This equals a decline by 1.3per cent per year, a figure which could have even been higher, if monitoring had started earlier. Declines amongst Palaearctic birds spending most of the breeding season in Africa are especially high if they rely on the wetlands of the northern tropics. They depend heavily on a few floodplains in the Sahel, making them highly vulnerable to droughts and of human activity.

Birds wintering in savannahs have suffered the strongest declines, birds wintering in woodland were least affected. Particularly steep declines were most commonly found amongst Afro-Palaearctic migrants breeding in farmland and steppe, more than half of the long-distance migrants are classified as birds of farmland and steppe in Eurasia. This might be an indication that farmland birds are hit twice, once by agriculture in Eurasia and secondly by wintering in African woodlands and wooded savannahs. Unlike wetlands, which recover quickly from droughts, woodland and wooded savannahs have suffered damage that exceeds the capability of natural restoration (Zwarts 2009 et al.). Evidence proves that droughts in African wintering areas are a major cause for population declines of Eurasian bird species (Newton 2008), as well as drainage of European wetlands (Finlayson 2005).

Rainfall and hence the flooding of floodplains and abundance of vegetation plays a major role in securing the survival of migratory bird populations and is, for that reason, closely connected to the rise and fall in their populations (Zwarts 2009).

A growing human population is now said to be well above levels that allow, in particular, dry ecosystems to remain sustainable, let alone recover. Overgrazing, burning and woodcutting, as well as increasing drainage and water substitution accelerated a process that is called desertification. It is believed that with the destruction of vegetation by humans the climate of the Sahel has switched to a more desertlike alternate state. The cultivation of rice and the irrigation of crops have shrunk the wetlands, on which many migratory birds rely. Even though, that rice cultivation can also be beneficial for migratory birds, as many feed on the grain of rice.
The increasing application of pesticides causes insects serving as the food for migratory birds to be less available and pesticides may also directly intoxicate and kill birds (Newton 2008 et al.).

2. The state of the populations of migratory waterbirds covered by AEWA in Africa

This Chapter compiles the information of an attempt to perform a statistical analysis of the available data. The analysis can be found in Annex I.

The Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) covers a geographical area from northern Canada and the Russian Federation to the southernmost tip of Africa. AEWA is an international agreement of 118 countries (62 have become Contracting Parties) to protect 255 species of waterbirds depending on wetlands for at least part of the annual cycle. Empirical data was missing and all information was derived from the 4th Edition of the *Report on the Conservation Status of Migratory Waterbirds in the Agreement Area* (Delany 2008) and the *Handbook of the Birds of the World* (Hoyo J. D. 1992).

Of the 255 species covered by AEWA, a total of 217 species of migratory waterbirds are either resident or winter on the African continent. A total of 382 populations are registered by the AEWA/MOP 4.8 document to reside in Africa (Delany 2008).
Despite efforts to protect these populations of migratory waterbirds, large numbers are declining.

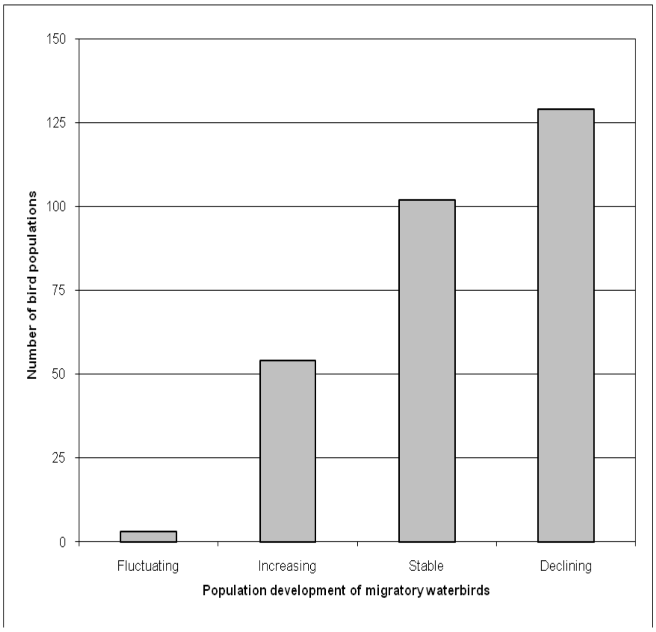

Figure 1: Status of population developments of waterbirds covered by AEWA in Africa. More than twice as many populations are declining than increasing.

A total of 211 populations are Palaearctic, meaning that they breed in the Northern hemisphere but migrate to the South in the winter months, and 169 are Intra-African migrants, meaning that they stay on the African continent all year long and migrate just between different African countries. Palaearctic migrants seem to decline to a greater extent than Intra-African migrants.

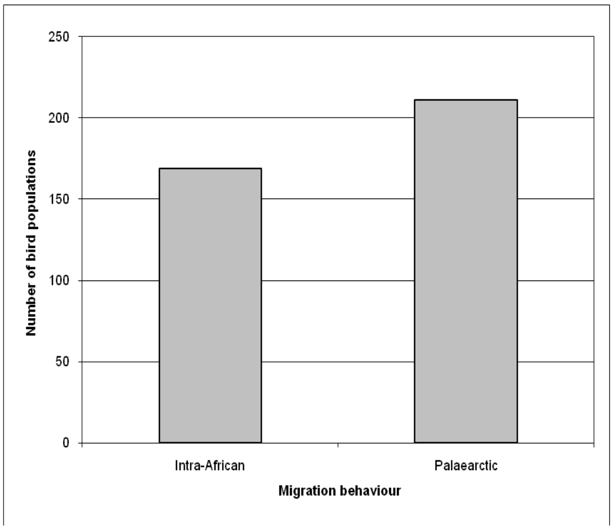

Figure 2: Numbers of Palaearctic and Intra-African migrants within the 382 populations of migratory waterbirds covered by AEWA in Africa. The majority of the birds are Palaearctic.

2.1 Distribution on the African continent

Occurrence of migratory waterbirds covered by AEWA in Central Africa is significantly lower than in all other sub-regions. Occurrence in Southern Africa is nearly twice as high as in Central Africa.
Within the statistical analysis, the test of significance has not proven to be valid for data from the variable West Africa. However, this may derive from the fact that numbers of birds within this particular variable are much higher than in the other variables of this dataset. The hierarchical cluster analysis has shown that populations in Northern Africa seem to be declining to a greater extent (40.3per cent) than in other parts of Africa, even though declining numbers also amount to quarter or more of the total population in other parts of Africa. This might be connected to the drainage of European Wetlands (Finlayson 2005). The high numbers of declining birds in Central Africa are most likely to be related to the much smaller sample size in this particular geographical sub-region. This requires further investigation.

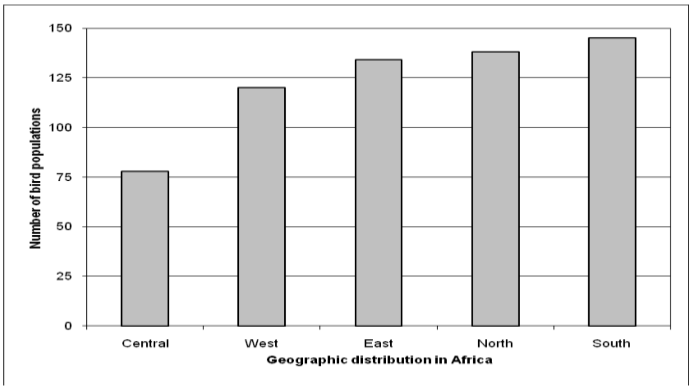

Figure 3: Occurrence of birds covered by AEWA in Africa in the five geographical African sub-regions. Occurrence of birds in Central Africa is significantly lower than in all other sub-regions. Occurrence in Southern Africa is nearly twice as high as in Central Africa.

2.2 Habitats

Inland water bodies are of high importance for migratory waterbirds. Occurrence around inland water bodies is more than three times as high as in grasslands and nearly twice as high as in agricultural areas. Within the statistical analysis, the test of significance has not proven to be valid for data from the variable inland water bodies. This may derive from the fact that numbers of birds within this particular variable are much higher than in the other variables of this dataset. The test of significance has not proven to be valid for data from the variable agricultural areas either.

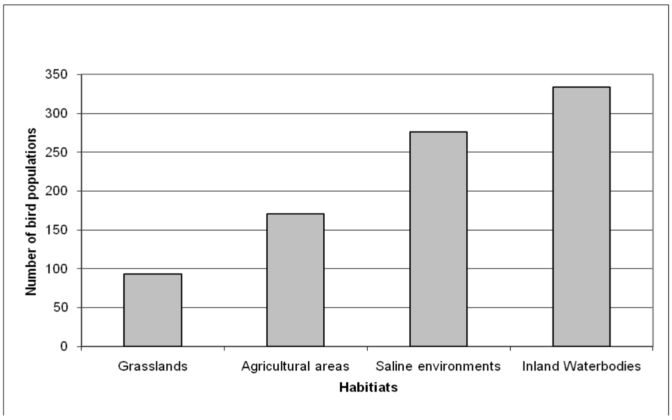

Figure 4: Occurrence of birds covered by AEWA in Africa in different habitats. Inland water bodies are of high importance for migratory waterbirds. Occurrence around inland water bodies is more than three times as high as in grasslands and nearly twice as high as in agricultural areas.

2.3 Food

The most important food for the majority of migratory waterbirds covered by AEWA is insects, their larvae and arachnids, crustaceans, gastropods and fish. Within the statistical analysis, the test of significance has not proven to be valid for data concerning insects, their larvae and arachnids. The same applies to crustaceans, gastropods, fish, amphibians and their larvae, worms, seeds and grain, aquatic plants, reptiles, smaller birds and eggs and mammals.

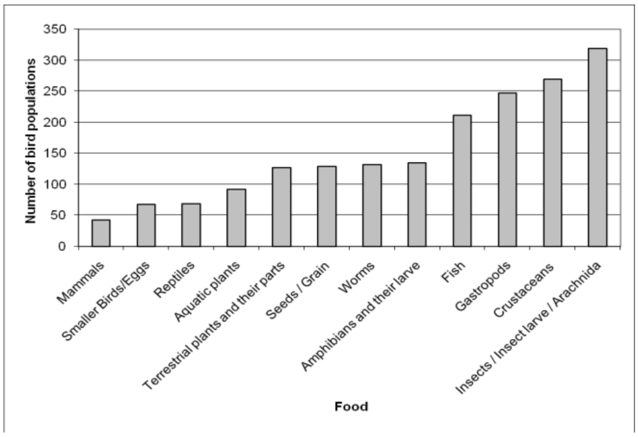

Figure 5: Ranking of the importance of feed for birds covered by AEWA in Africa. The most important feed for the majority of birds are insects, their larvae and arachnids, crustaceans, gastropods and fish.

This might be an indication for a relationship between declining numbers of bird population and these food items, but may also derive from the fact that numbers of birds feeding on them are very unequally distributed.

2.4 Conclusion

The African continent is of high importance for the AEWA because 217 of a total of 255 species of migratory waterbirds covered by the Agreement are either resident or winter on the African continent. The different populations winter and reside all over Africa. A few can just be found in one geographical sub-region, some can be found in several geographical sub-regions. The different species colonise diverse habitats. Most of the populations can be found in several habitats (Delany 2008 et al.), most of them along inland water bodies. Waterbirds feed on various animals and plant parts. Insects, crustaceans, gastropods and fish but also to a smaller extent on seed and grain are the food of most of the waterbirds.

The outcome of the hierarchical cluster analysis shows high population declines in Northern Africa and Central Africa. According to the findings about Central Africa two hypotheses can be made: Large areas of Central Africa are covered with tropical rainforest. These are almost completely avoided by Palaearctic migrants (Zwarts 2009). On the other hand, numbers could have been higher before and have been decimated over time.

The migratory behaviour also seems to play a role concerning numbers of declining populations. The declining numbers of Palaearctic migrants are 10per cent higher than the numbers of Intra-African migrants.

It is important to mention that all used data was derived from literature sources, most of them containing data being more than 10 years old.

Different sources of literature generally come with different levels of accuracy. It is therefore questionable, whether these sources of literature can be compared because of their differences. The results of this chapter can, for that reason, not be seen to be proof but as indicators for further scientific research.

Overall, the attempt of a statistical analysis has shown that the available data is insufficient to allow valid conclusions. The statistical analysis has been most likely biased by unequal distribution of the sample sizes within the variables. All hypotheses need to be further investigated with empirical data.

3. Agrochemicals and their impact on environment and wildlife

This chapter defines the terms *agrochemical*, *fertiliser* and *pesticide* and describes impacts of fertiliser and pesticide pollution on the environment and wildlife, in particular birds, to determine how they are affected and which pesticides are of particular danger for their wellbeing.

3.1 Agrochemicals a definition:

Agrochemical is a conceptual collective term for a wide range of chemical products used in agriculture, such as fertilizers, liming and acidifying substances, soil conditioners, pesticides and chemical substances used in animal husbandry.

- **Fertilizers** are used to enhance plant growth and crop yield by applying nutrients to the soil and plants. Fertilizers are either organic, such as compost, animal manure and recycled wastes, or they are synthetically manufactured (Encyclopædia Britannica 2009).
- Several plant nutrients need certain conditions in the soil so that plants can absorb them. If the soil is either too acidic or too alkaline, **liming and acidifying substances** help to achieve soil conditions that are beneficial for nutrient uptake (USDA 1999, Hart 2003).
- Certain soils do not have the ability to hold water and oxygen to an extent needed to successfully produce crops. Therefore **soil conditioners** such as manure, sewage sludge, peat etc. are applied to the soil in order to improve the conditions for plant growth (Vavrina 2000).
- According to the definition of the Environmental Protection Agency of the United States of America (EPA), the term pesticide is used for any substance or mixture of substances intended to prevent, destroy, repel, or mitigate any living organisms that occur where they are not wanted or cause damage to crops, humans or other animals, and are therefore considered a pest. Examples are insects, mice and other animals, unwanted plants (weeds), fungi, microorganisms such as bacteria and viruses, and prions (EPA 2008). The FAO extends the term to materials like repellents and insect growth regulators, which control the behaviour or physiology of pests and of crops during production or storage (FAO 2002)
- Various **chemical substances are applied in animal husbandry** in order to cope with diseases or improve the performance. Antibiotics, either injected or combined with feed are applied to cope with infectious diseases (EMA 2007). Hormones are injected to enhance growth and productivity. Livestock waste, containing antibiotics and hormones, is often used as fertiliser for farm fields or pastures and may result in pollution of ground or surface waters (Henderson 2009).

  Various pesticides are applied either by spraying or animal dip (a basin filled with a pesticide solution) to treat animals afflicted with ectoparasites like e.g. ticks (Holdsworth 2005).

This paper deals with wild migratory waterbirds and the impact of agrochemicals on them in Africa. It is unlikely that they are affected by liming and acidifying substances or soil conditioners as these primarily have an impact on the soils. Therefore the focus will be put on fertilizers and pesticides as they directly or indirectly affect the migrating waterbirds and their habitat. Especially avicides used to control large populations of seed eating birds, such as Red-billed Quelea (*Quelea quelea*) (Newton 1998), as well as insecticides to stop orthopter (locust) plagues (Mullié 2009), may also kill all other bird species.

3.2 Fertilisers and their impacts on environment and wildlife

Fertilisers

If plants or parts of them are harvested and picked from the ground the soils become impoverished of nutrients. These have to be returned to soils by fertilization (Kremser 2002). Fertilization is imperative for agriculture and the use of manure and composts as the first fertilizers is as old as agriculture itself (Encyclopædia Britannica 2009). Fertilizers provide nutrients like nitrogen, phosphorus, potassium, sulphur, magnesium, calcium and others, to the soil, in order to provide crops with the resources needed to generate beneficial yields.

Before mineral fertilizers were introduced in the nineteenth century, soil fertility was maintained by crop rotation with leguminous crops and the recycling of organic materials such as organic manure. However the nutrient content of manure may vary significantly, and if inadequately stored, most of the nitrogen is lost through volatilisation (the loss of a gaseous substance to the atmosphere), polluting the environment (FAO 2006a). Furthermore, available quantities of nutrients in manure are insufficient to meet today's requirements. Animal manures provide only about 11 per cent of the total nitrogen that is required for global food production (FAO 2006a).

Before the industrialisation of agriculture, hunger and diseases were common throughout and famines caused suffering and starvation. Ever since then, the fight against hunger and diseases due to malnutrition has become a permanent challenge. Until 1800 the average grain yield was about 800 kg/ha. Depletion of nutrients had caused soils to lose their fertility, and additionally the crops were heavily infected with plant diseases and pests. Therefore the food supply rarely met the demand of the population.

In the mid-nineteenth century, the nutritional needs of crops were discovered. The value of manures was stressed and the first mineral fertilizers were developed. In 1880, mineral fertilization started and became common practice by 1920. In 1950, the time of the Green Revolution, it was adopted on a larger scale.

The Green Revolution was the introduction of a combination of several instruments such as irrigation, introduction of high yielding varieties and fertilisation. The Green Revolution achieved the greatest progress ever made in food production. In 1900 the average grain yield was 2 tons/ha, but increased annually by 1.5 - 2.5 per cent and reached 7.5 tons/ha in the year 2000. In 1900 the world population comprised 1.6 billion, and nobody could have foreseen that one hundred years later world agriculture would produce sufficient food, forage and other agricultural commodities for 6 billion people.
Therefore, agricultural intensification has been adopted as one of the basic strategies for food production and to fight hunger. However, in order to secure high yields agricultural intensification depends on providing increased amounts of nutrients for crops (FAO 2006b).
As the worldwide demand for fertilizers in 2008/2009 was 201,482 thousand tons, it is expected to rise to 216,019 thousand tons in 2011/2012 (FAO 2008). These numbers illustrate how vulnerable the world's agriculture has become if shortages of chemical fertilizers should arise (FAO 2006b).

Major plant nutrients are nitrogen, phosphorus and potassium (FAO 2006b). At the beginning of the twentieth century, nitrogen was derived from sodium nitrate, a natural salt that was mined primarily in Chile, hence the common name Chile saltpetre. Its availability was restricted, limiting the availability of nitrogen fertilizers. At the beginning of the nineteenth century, however, this problem was solved by the invention of the Haber process, which extracts nitrogen directly from the atmosphere.

Between 1962/1964 and 2000/2002 the world-wide area of arable land increased by 13 per cent while the world population increased by 89 per cent. Nevertheless, over the years food remained readily available, cereal prices even steadily declined. Average grain yields have almost doubled since the 1960s, because yields of cultivated area per hectare also increased. However, while world population is steadily growing, land for agricultural expansion is restricted. For the time being agriculture will rely on agricultural intensification to increase crop production to feed a growing world population (FAO 2006a).

World-wide fertilizer use has increased fivefold since 1960 (FAO 2006a) and is bound to increase even more. Nitrogen is abundant in the air, and deposits of potassium are plentiful, but phosphate rock, the origin of phosphate fertilizer, has become scarce (FAO 2006b). The demand for phosphate in the year 2008/2009 was 37,554 thousand tons and is estimated to increase to 40,426 thousand tons per hectare in 2011/2012 (FAO 2008). The shortage of this essential plant nutrient will limit crop production seriously in future. Humankind will have to deal with decreasing amounts of fertilizers while having to meet higher demands for food. Strict rules for recycling and efficient fertilizer use are imperative in order to postpone food shortages.

Fertilizer effectiveness is related to soil moisture and hence irrigation. Where irrigation is not in place, fertilizer efficiency is limited. It can be further increased by combining organic and biological sources with fertilizer application, as organic compounds are beneficial beyond their nutrient contents (FAO 2006b).

Yield increases have slowed down as soils are degrading. Within the last 40 years nearly a third of the world's arable land was lost to erosion. The ongoing loss of more than 10 million ha a year causes massive losses of carbon in soils leading to the loss of soil fertility. These losses can be directly linked to the practices of the Green Revolution, as application of fertilizers and pesticides seem to have a negative impact on the soil structure, such as aggregate and percolation stability (FAO 2007).

Africa will account for less than three per cent of the total fertilizer consumption by 2011/2012. This is quite fortunate for the rest of the world, as many countries rely on phosphate fertilizers from African phosphate rock.

Africa has to import all the potassium it needs and fertilizer consumption is largely restricted to ten countries. The main consumers are Egypt, South Africa, and Morocco. High costs of transportation in landlocked countries contribute to prohibitively high fertilizer prices and a number of factors such as limits to inputs and outputs of markets further constrain fertilizer use (FAO 2008). That means that the majority of African farmers have to continue to rely on the traditional means of crop rotation, leguminous crops, and manure. In many developing countries, however, a substantial amount of available manure is not used for agriculture but rather as fuel. Manure, produced far away from the areas where it is needed, needs to be transported over long distances (FAO 2006a).

For now, world agriculture has to rely on fertilizers to feed a growing world population. But it is worth mentioning that fertilizer application in future also has to face the problem of depleting resources (FAO 2006b).

Impacts

Pollution with nutrients from agriculture causes environmental problems. Fertilizers are one of the main sources of these problems as they are carried away from agricultural areas by leaching, surface runoff and other processes. Especially aquatic ecosystems have been and are adversely affected (Kremser 2002).

Nutrients added through fertilizers, manures and composts have, as long as all nutrients are absorbed by the crops, the positive effect of providing nutrients to plants. However, if inputs are not properly or poorly managed, nutrients may be immobilized or lost from the soil by volatilization, diffusion, soil- and water erosion and leaching.

High levels of nutrient input to the soil, even under the best conditions, cannot be completely absorbed by crops. Depending on their chemical characteristics, chemical pathways of leftover nutrients vary, but all nutrients can be lost by surface runoff, as well as water and wind erosion as long as they are soluble in water, or soil particles containing them are removed and transported. Most of the excessive nutrients are bound to soil particles. These do not move freely with the soil water. Some like nitrate and to a lesser extend sulphur and boron are not bound strongly by soil particles and are thus washed down by percolating waters, contributing to an undesired enrichment of nutrients in ground waters and water bodies. Phosphorus, in contrast, generally moves very little from the site of application and if so through soil erosion and surface runoff. A particular cause of nutrient loss is the emission of nitrogen gases, which occurs constantly on a large scale. Under conditions of a low oxygen supply, like e.g. waterlogged soils (as in flooded rice paddies), soil microbes break down nitrate to nitrite and then to volatile nitrogen oxide, which is lost in the atmosphere.

Nitrate, lost by leaching or transported in surface waters may result in increased nitrate concentrations in drinking-water and eutrophication of surface waters. Leaching and surface runoff of phosphate can also contribute to the enrichment of water bodies and hence eutrophication. The loss of potassium, calcium, manganese and sulphur through leaching and erosion is considered a waste of resources but not considered an environmental hazard (FAO 2006b et al.)

The term eutrophication describes the enrichment of surface waters with plant nutrients (FAO 1996). It causes the initial nutrient status of waters to change, turning nutrient-poor (oligotrophic) water bodies into rich (eutrophic) water bodies (Newton 1998).

Agriculture is considered to be the major factor in the eutrophication of surface waters. Although both nitrogen and phosphorus contribute to eutrophication, the classification of the trophic status is determined by the limiting nutrient (FAO 1996). In fresh water bodies e.g. rivers and lakes, the limiting nutrient is usually phosphorus, in salt water bodies e.g. coastal and marine ecosystems the limiting factor is usually nitrogen (Hinga 2005).

Lakes are more likely to suffer from eutrophication than rivers, because they have their own hydrological basin, meaning that in contrast to rivers the residence time - indicating the average period of time a water molecule and other substances remain in the water body - is much longer. If a lake has no outflow even small amounts of substances like excessive nutrients become trapped and may become highly concentrated if none or only small sinks for the substances exist (Kremser 2002).

Symptoms of eutrophication comprise increased production and biomass of phytoplankton, attached algae, and macrophytes and a shift in habitat characteristics, due to a change in the composition of aquatic plants and the replacement of desirable fish by less desirable species (FAO 1996). Additional phosphorus may stimulate large blooms of algae, which do not naturally occur in abundance. Dense filamentous algal mats may form, changing the environment, excluding species and diminishing biodiversity (Hinga 2005).

As the algae sink to the bottom and are broken down by bacteria and other organisms the decaying plant material takes up oxygen from the water. When a certain amount of decaying plant material has accumulated the bottom water becomes anoxic, resulting in the death of fish (Hinga 2005, FAO 1996). Intense agricultural and industrial activities and dense human population have led to conditions in many aquatic systems making them unable to absorb excessive nutrients without detrimental effects. (Hinga 2005). The loss of biodiversity is also called deterioration, meaning that as the habitat is changing, many species cannot adapt and die. The consequence is a disruption of the food chain causing waterbirds, which are usually at the top of it, to lose their food sources, leading to starvation and causing their numbers to diminish (Newton 1998).

3.3 Pesticides and their impacts on environment and wildlife

Pesticides

Pesticide is a conceptual collective term for a wide range of chemical products. Pesticides are frequently subdivided by different nomenclatures. One way is to distinguish between pesticides used in agriculture and horticulture or in other non-agricultural circumstances, but some pesticides can be found in both groups. A more detailed classification can be based on the following four aspects:

- Relating to the **target organism** (Insecticide, Fungicide, Herbicide, Molluscicide, Rodenticide, Acaricide, Nematicide, Miticide, Avicide)
- According to the **chemical structure** (Organochlorines, Organophosphates, Carbamates, Pyrethroids, Phenols, Morpholines, Chloroalkylthiols etc.)
- According to their **mode of action** (Anticholinesterase, Chitin synthesis inhibitor, Ecdysone agonist, Juvenile hormone analogues etc.) (Marrs 2004 et al.)
- According to their **risk** according to the World Health Organisation (WHO) (Ia –extremely dangerous, Ib – highly dangerous, II – moderately dangerous, III – slightly dangerous) (WHO 2005)

Pesticides are not a modern invention (Pretty 2005). Historical records show that they have been used since before Christ (Bohmont 2007). In 2500 BC the Sumerians used sulphur compounds to control insects. Chinese farmers treated their seeds with various organic substances to protect them against insects, mice and birds, and inorganic mercury was used to control body lice (Pretty 2005). In 1200 BC ancient Egyptian records mention hemlock and aconite. In 1000 BC Homer suggested sulphur to be used on certain plants (Bohmont 2007) and like him Aristotle and Cato describe a variety of fumigants, oil sprays and sulphur ointments to be used by farmers. Pliny recommends the use of arsenic as an insecticide (Pretty 2005). After ransacking Carthage the Romans used salt to prevent the crops from growing, as they knew that it could also be used to keep weeds from growing. In the 9th Century AD the Chinese used arsenic mixed with water to control insects and in the 12th Century AD Marco Polo used mineral oil to treat mangy camels (Bohmont 2007).

With the agricultural revolution of the 17th and 18th centuries in Europe natural pesticides came into common use (Pretty 2005). Tobacco or rather nicotine was used especially as a contact insecticide and in 1773 nicotine fumigation from heated tobacco was effectively used on insect infested plants. From 1800 onwards copper-sulphate was used as a fungicide (Pretty 2005). Pyrethrin from *Chrysanthemum cineraria folium* (Pyrethrum) and rotenone which occurs naturally in the roots and stems of several plants were discovered as effective insecticides (Bohmont 2007). “Paris Green”, a mixture of arsenic and copper, was perfected in 1865 and first used in 1867 and came into use as the world’s first legislated pesticide in the US to control the Colorado potato beetle. In 1882 the Bordeaux mixture consisting of lime and copper sulphate, first used to prevent theft of roadside vines in France, was discovered to be useful as a fungicide to control downy mildew in grapes (Pretty 2005, Bohmont 2007).
Mercury was discovered in 1890 to be used as a seed treatment and in 1915 liquid mercury protected seeds against fungus diseases (Bohmont 2007). In 1920 Calcium arsenite replaced “Paris Green” and the use of arsenic pesticides became widespread.

In the beginning of the 20th century many dangerous products derived from arsenic, cyanide and mercury were used and provoked considerable public anxiety about the residues of these products on fruit and vegetables. Therefore the 1930s were the beginning of a new era of hundreds of synthetically produced organic pesticides, the Organochlorines (OCs) (Pretty 2005, Bohmont 2007). Paul Müller discovered the insecticidal properties of dichlorodiphenyltrichloroethane (DDT) in 1939. First manufactured in 1943, it was initially used to delouse people to prevent the spread of typhus and to control malarial mosquitoes, it was soon followed by the manufacture of several chlorinated hydrocarbon compounds such as aldrin, endrin, heptachlor, and phenoxyacetic acids, such as MCPA and 2,4-D, which were appraised for their herbicidal activity. All those synthesised products had in common that they were very persistent in the environment.

In the 1950s the Organophosphates (OPs) resulted from wartime research on nerve gas. They block cholinesterase, an enzyme that transfers nerve impulses across synapses and affects the nervous system. The first OP in use was Parathion, an effective insecticide that was soon found to be highly toxic to mammals. It was followed my Malathion, which had very low mammalian toxicity. The advantage of OPs is that they rapidly degrade in the environment to non-toxic secondary compounds, as opposed to OCs which are persistent.
OPs and OCs became widely used all over the world on almost every crop, with the disadvantage that they affected wildlife and people in ways that had not been anticipated before (Pretty 2005 et al.).

Within the late 1950s Carbamates were developed and opened the way to a new generation of insecticides, herbicides, and fungicides, which in contrast to OCs and OPs were less toxic to humans (Pretty 2005, Bohmont 2007).

From the 1960s onwards, the trend has been towards substances less broad in their effects and more specific and specialised to certain pests. Pesticides like pyrethroids, sulfonylureas and imidazolinones, are so biologically active that they are applied in very small amounts, offer greater safety to users and the environment (Bohmont 2007). However, these specific qualities make them expensive. Broadly effective pesticides are cheaper to manufacture and can be sold to a wider range of farmers. This is the reason why specific products have smaller markets (Pretty 2005).

Today pesticides manage pests in homes, schools, restaurants, museums, hospitals, orchards and landscapes, industrial sites and above all in agriculture. There they play a significant role in managing pest infestation of fruits, vegetables, grains, fibres and livestock (Whitford 2002). Measures to prevent or even stop the effects of weeds, pests, and diseases, extensive use of inorganic fertilisers and breeding of superior crop cultivars have achieved a plentiful supply of good quality food that is available throughout the year for people in the European Union, North America and parts of the Pacific Rim. Food shortages no longer occur in these areas and the effects of malnutrition and starvation generally belong to the past. Food production usually exceeds the national requirements. The United States are a major exporter of maize, soya and wheat and in the United Kingdom the production of wheat rose from less than 80per cent of the national requirements in the 1970s to over 120per cent in the 1990s. Indeed current food production may be sufficient to feed the entire world population but at a high cost.

However, this cannot be achieved without paying a high price. In the past 50 years, the use of pesticides in agriculture significantly increased to 2.56 billion kg per year (Carlile 2006 et al.). Humans coexist with more than one million kinds of insects and other arthropods and many of them are pests. Despite its pest control programmes US agriculture loses possibly 20per cent to 25per cent of its potential crop production to various pests, and without modern pest control these losses would probably double. This is because all over the world pests compete for our food supplies and they can either be disease carriers (vectors) or they cause damage. Modern agriculture has created artificial environments like vast monocultures, which are beneficial to pests. Hence it is the advance in food production technology that has increased and still increases the need for pesticides. They are used to produce not only a larger amount of food but also keep it virtually free of insect damage (Bohmont 2007 et al.).

Pesticides, like common drugs are beneficial to people, if they are properly used. However, handled incorrectly or misused they can be extremely dangerous. This is because most pesticides are designed to kill something and hence some are highly toxic to animals and people (Bohmont 2007). Every year an estimated three million cases of pesticide poisoning occur (Pretty 2005), resulting in over 355,000 deaths annually (WDR 2008). Therefore all pesticides should be handled as poisons (Bohmont 2007). As a consequence pest management requires more than knowing how to manage the pest itself. People engaged in the application need to be highly skilled individuals in order to perform a multitude of tasks ranging from preparation, handling, and application to storage and disposal. Pesticides need to be stored safely, in order to avoid an involuntary diffusion into the environment or theft and need to be disposed properly after their date of expiry (Whitford 2002). As many pesticides are absorbed through the skin, protective clothing is vital in order to avoid contact with skin, hair, eyes and neck. An overall or at least long trousers and a long-sleeved shirt, a water-proof parka, water-proof boots, protective goggles, a protective hard hat and polyethylene gloves, which need to be regularly replaced, are necessary to protect the health of those applying these substances. In order to avoid adverse health effects on wildlife and people it is vital that the correct pesticide is chosen, to effectively treat specific pests. The preparation such as the mixing of pesticides with a carrier substance e.g. water, should never be performed inside buildings. Application equipment must be clean, properly operational, and in good condition to avoid unnecessary hazards to the user and the environment. The application itself should be performed at the appropriate time, using recommended dosages. Drift-off, due to wind, onto neighbouring fields, pastures, livestock, and persons must be avoided. Extreme care needs to be taken in order to avoid contamination of water like wells, streams, ponds etc. (Bohmont 2007 et al.).

Pesticides should not be overused or misused. Their formulas are licensed by governments to use them according to their instructions under strict conditions and avoiding harm to the environment and human health. But overuse can occur, if farmers are advised to spray on a routine calendar basis, rather than when pest problems occur. Pesticides then become a simple insurance premium against crop failure and especially direct subsidies reducing the retail costs of pesticides tend to encourage overuse. Additionally problems occur, if safety instructions are either missing or are written in a language that a farmer who may speak only Ewe or Quechua cannot read (Pretty 2005).

As described above, the general progress in pesticide development has moved from highly toxic, persistent and bio-accumulating pesticides such as DDT, to pesticides that degrade rapidly in the environment and are less toxic to non-target organisms (FAO 1996). Therefore, industrialised countries have banned or severely restricted the use of many pesticides, in order to favour more modern pesticide formulas. But for some purposes like e.g. malaria control, old formulas like DDT remain highly effective. For developing countries, older pesticides remain the cheapest to produce and hence are marketed and used. Many developing countries, for example, in African, maintain that they cannot afford modern pesticides (Harris 2000, FAO 1996).

A total of 50per cent of all pesticide-related illnesses and 72.5per cent of recorded fatal pesticide poisonings occur in developing countries, as they lack effective monitoring systems. It is worth mentioning, that these countries account for only 25per cent of the pesticides used worldwide (Harris 2000). The practice of storage, handling, application and disposal by e.g. African smallholding farmers can be described as quite hazardous. The pesticide products used by many farmers were classified by the WHO as either extremely dangerous (WHO Class Ia) or highly hazardous (WHO Class Ib). It must be kept in mind that even WHO Class II products, which are considered less hazardous, should only be applied by trained and supervised operators.

Protective clothing is rarely used and, if at all, it is not exchanged, even if it is soaked with pesticides. This is mainly due to cost and availability factors. In Ethiopia women and children often stand in front of the farmers to guide the line of spray and some farmers, lacking money to buy or rent a sprayer, use bundles of twigs to splash pesticides onto their crops (Williamson a 2003). The levels of acetylcholinesterase (ChE) activity are significantly lower with Ethiopian farmers, an indication of the exposure to OPs (see above) (Harris 2000).

Most of the farmers have a very limited awareness of the hazards posed by pesticides, particularly of long-term effects on health, due to long-term exposure. Pesticide cocktails are mixed, non-approved products are used, empty pesticide containers are used to store beverages and food and pre-harvest intervals are not respected (Williamson a 2003). Furthermore many farmers do not check the date of expiry when buying pesticides or continue to apply pesticide leftovers. Therefore, many farmers use so-called obsolete pesticides. These are pesticides past their expiry date, which is usually two years after the manufacturing date. Expired pesticides may be ineffective and might lead to overuse or degrade into unknown by-products that affect users and final consumers via residues. Additionally, all over Africa, several thousand tons of unused and unsafely stored obsolete pesticides exist, causing danger to food, water, soil and air and the poorest of the poor (Mwandia 2006). Often they were donated by developed countries to increase yields and improve food security. However, poor storage conditions, deteriorating containers and labels, and excessive amounts of products resulted in a vast disposal dilemma (Kearney 1998). In Mozambique pesticides were burned and subsequently covered with soil. The surrounding soil, contaminated by residues from the incineration was found to be poisonous to fish. Local people used it to catch fish in the local river, as they died instantly floating up to the surface. In Morocco and Republic of Tanzania obsolete pesticides were stolen from the storages. In Mali, a dry country in the Sahel, corrosion of old containers resulted in leakage of pesticides

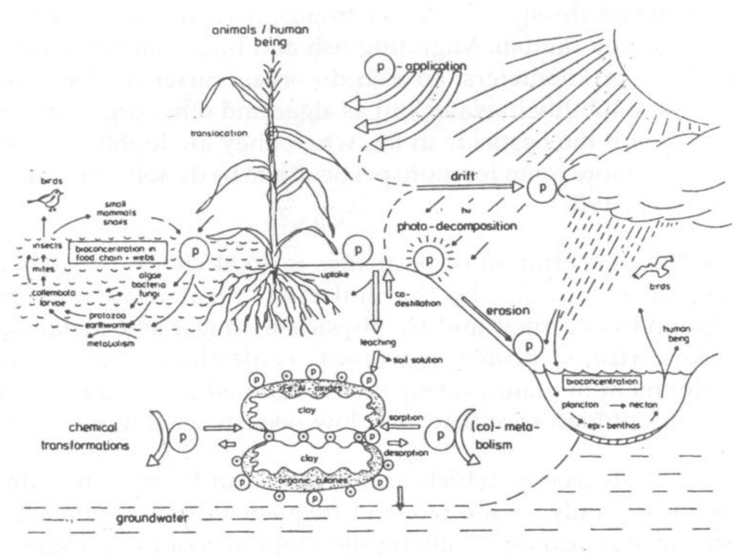

Figure 6: Behaviour and fate of pesticides in soil, water and air (Agarwal 2002)

into the groundwater, contaminating wells used by local villagers (Mwandia 2006 et al.).

Impacts

Pesticides cause environmental concerns. They can contaminate water and soils, pollute air, destroy natural vegetation, and affect the food supply of non-target organisms, such as fish, livestock, and wildlife including birds (Watson 2004).

Pesticides are generally applied as liquids, powders or granules to soils, plants, water bodies and human settlements by means such as hand sprayers, tractors with spraying trailers or even aircraft (Agarwal 2002). Most of the product is either taken up by plants and animals or, in the end, is degraded by microbial and other chemical processes, but some is dispersed to the environment; vaporised to be deposited by rainfall later, some remains in the soil and some reaches surface and groundwater by runoff and leaching (Pretty 2005). If applied by a spraying device, some liquid is taken up by the air, circulates through the lower troposphere and is deposited by rainfall (Agarwal 2002). This process is called volatilization or drift. If applied by air, often as little as 25 to 50 per cent of pesticide formulas reach the target area. Most of the drift is confined to within a few kilometres from the application site. However, some may remain as drift in the atmosphere contaminating remote areas (Agarwal 2002). Once in the air, pesticides cannot be controlled and may settle into waterways, woods and heavily populated areas (Bohmont 2007). This explains why persistent pesticides like DDT, toxaphene etc. having long been banned in the developed countries, can be found in the high arctic, as chemicals that are applied in tropical and subtropical countries are transported over long distances via global circulation (FAO 1996). Oceanic currents and migrating species like e.g. birds or fish can also carry pesticides over great distances around the world (Agarwal 2002).

When applied, pesticides penetrate the environment not just through volatilization and drift, but also through spillages, or waste derived from humans, animals, plants and industrial processes (Agarwal 2002). Pesticide spillages are created at every stage of pesticide production and use. Research, development, manufacture, transportation, distribution, as well as commercial and private application offer abundant opportunities for the occurrence of pesticide spillages. However, the most important source for pesticide spillage is agriculture. Developing countries, like most African countries, import pesticides from developed countries. But it is not uncommon that factories producing pesticides in the capitals of the developing countries create new pesticide formulas and integrate active ingredients that are useful to cater to/for the needs of the dominant crops. These factories already play a significant part in the pollution by pesticides. Pesticides are mainly applied by smallholders using back-pack sprayers. Small holdings are the predominant form of agriculture in Africa, and all economies of African countries depend on them. The small amounts of unused pesticide solution, left over after spraying, and the contaminated water from cleaning the sprayer are called rinsate. Rinsates are usually not managed and soil and water contamination occurs frequently.

The contamination of soil, water and air by pesticides is an environmental concern (Kearney 1998 et. al). We have evidence today that pesticides are spread by wind and water all over the globe, contaminating soil and water bodies and damaging the environment.

Soils are vital for food production. Fertile and healthy soil is an imperative requirement in order to feed humans. Pesticides often become attached to fine soil particles. When it rains, the topsoil erodes and they are carried along with the water running off the fields (Bohmont 2007). Depending on their mobility, overdosed pesticides remain in the soil for a long time, limiting planting of sensitive crops or, if moderately or

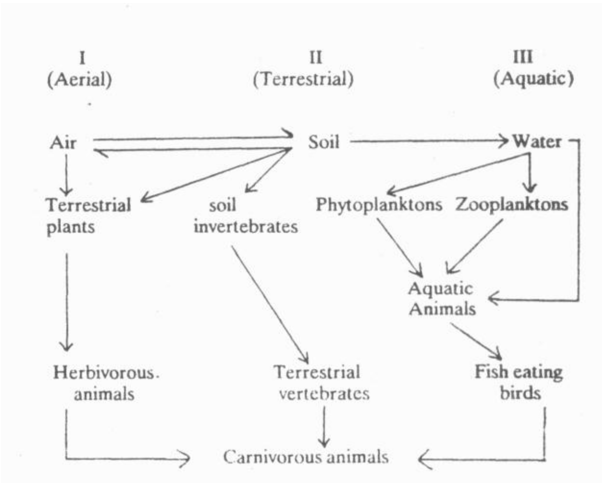

Figure 7: Biological transfer of insecticides (Agarwal 2002)

highly mobile, they are washed down into the groundwater (Bohmont 2007). It is worth mentioning that groundwater accounts for 96per cent of the world's total drinking water resources. The pollution of the water with pesticides can occur in several ways. Either they are applied on purpose to control aquatic plants or animals e.g. malarial mosquitoes; they may accidentally run into the water or be washed down into the groundwater if attached to soil particles. Once contaminated, the water is nearly impossible to clean (Bohmont 2007). Pesticides in ground water, surface waters and drinking water have become a serious and increasingly expensive environmental side effect. Especially early generation pesticides, such as DDT, arsenical and paraquat are strongly adsorbed by soil particles and tend to be lost, if the soil erodes (Pretty 2005).

The damage to the environment by pesticides results in an interaction with biotic components, responsible for the imbalances in the environment and respectively various types of hazards to plants and animals. Especially broad spectrum pesticides may destroy prey, predators and parasites, causing repeated outbreaks of pest epidemics and enable minor pests to become major ones. If pesticides just impacted target species there would be no pesticide pollution (Agarwal 2002), but insecticides kill other invertebrates beside the target insects, reducing the availability of food for bird fledglings (Carlile 2006). Pesticide pollution occurs in the form of two principal mechanisms of bioaccumulation, namely bioconcentration and biomagnification (FAO 1996).

- Bioconcentration is the movement of a pesticide from the surrounding medium into an organism. The primary medium called "sink" for some pesticides is the fatty tissue called "lipids". Some pesticides, such as DDT, are lipophilic, meaning that they are soluble and accumulate in the fatty tissue of living organisms (FAO 1996). Bioconcentration takes place because of pesticide persistence, meaning that pesticides withstand degradation processes. Therefore pesticide development focuses on high specificity and low persistence (Agarwal 2002).
- Biomagnification is the accumulation in various biological systems (Agarwal 2002). It describes the increasing concentration of a pesticide, as food energy is transformed within the food chain. Smaller organisms are eaten by larger organisms, and the concentration of pesticides magnifies increasingly in tissues and organs. Highest concentrations can be measured in top predators (FAO 1996).

The rate of accumulation, however, is not the same in different environments. Bioaccumulation in terrestrial environments can usually be observed in agro ecosystems. Pesticides are taken up from the soil by invertebrates such as earthworms or soil insects and enter the food chain (Agarwal 2002).

Aquatic environments are especially predestined for high rates of biomagnification. As described above, pesticides dissolve better in lipids than in water. Therefore, when pesticides enter an aquatic environment, their movement is facilitated by the water as they remain intact. They are then taken up by organic lipid-containing organisms, such as algae, which remain suspended in water. Within the organisms, the pesticides enter the food chain and become accumulated in the biomass. These particles are taken up by different organisms, resulting in a higher accumulation than in the less efficient accumulation process found in terrestrial environments. Pesticides can also be accumulated by plants and terrestrial animals from the air in the case of drift, but this way is considered to be the least effective (Agarwal 2002).
Bioaccumulation is determined by three factors:

1. Physiochemical properties of pesticides, namely their chemical stability, solubility in water and lipids, and their partition coefficient.
2. Competition, which in this context means the competition between different matters taking up pesticides from their surroundings. As a result of competition, dilution takes place. This phenomenon is called "biological dilution".
3. Rate of consumption and speed of elimination, meaning the amount taken up by food digestion. Smaller animals have a higher ratio of food consumption per unit of their weight. Hence, they are more likely to consume higher amounts of pesticides. Nevertheless, it has been observed, that amounts of pesticides found in larger animals were higher than in smaller animals. This can be explained by the higher metabolic rate of smaller animals, positively

affecting the rate of elimination, preventing pesticides from accumulating in their bodies (Agarwal 2002).

Pesticides, taken up by higher plants and animals, do not remain in their original form, as they are transformed by metabolic reactions. These processes are called biotransformation, a term describing the transformation of pesticide molecules, usually processes comprising long chains of detoxification reactions (Agarwal 2002). However, some pesticide decomposition products are in fact the reason for metabolic disturbances. DDE, for example, a metabolite of DDT, affects the reproduction of birds, as it reduces the availability of calcium carbonate, which is needed for the formation of eggshells (Newton 1998).

One characteristic impact of pesticide pollution, namely the impact of endocrine disruption, has not yet been fully understood. The endocrine system releases hormones that act as chemical messengers, interacting with specific receptors in cells to influence growth, development and reproduction. Some pesticides such as some pyrethroid insecticides, notably permethrin, are potential endocrine disruptors. Today pesticides are stringently tested for endocrine disrupting abilities. However older pesticide compounds may not have been tested to modern standards (Carlile 2006).

The toxicity of a pesticide is determined by quantifying the response of laboratory animals to a series of increasing doses of pesticides. A common measure to define acute toxicity is LD_{50}, the lethal dose for 50per cent of the tested animals. The higher the LD_{50}, the lower is the toxicity of the pesticide (Whitford 2002). The toxicity of different pesticides varies quantitatively and qualitatively, as they consist of diverse chemical groups. However, in many cases the mode of action of pesticides in the target species can be compared to their impact on the metabolism of e.g. a mammal. Insecticides, for example, kill insects by affecting their nervous system. This is relatively easy accessible for pesticides compared to a mammal's nervous system. However, in a sufficient dosis, such insecticides may have similar effects on similar macromolecules in the nervous systems of mammals. Examples are OCs, some OPs, carbamates and synthetic pyrethroids. Fungicides, or more precisely their azole group, may affect the steroid synthesis in both fungi and animals. It is also possible to design pesticides that specifically interfere with the metabolic pathways of target organisms, which do not exist in mammals. Examples are chitin synthesis inhibitors in insecticides and glyphosphates in herbicides (Marrs 2004 et al.). The environmental contamination by pesticides has serious consequences to wildlife. Adverse effects may arise ranging from death and injury and contaminated food to internal hormonal regulation, causing changes in physiology and behaviour. (Pretty 2005).

The decease of non-target invertebrates living in water is commonly associated with direct spraying of natural waters in order to kill disease-transmitting insects like e.g. malarial mosquitoes. But also point-source pollutions from pesticide spillages, careless disposal and rinsing of sprayer tanks may contaminate waters. Animals that were treated against pests, in an animal dip and subsequently entering waters, may also be contaminants. The results might be direct reductions in population of non-target aquatic invertebrates (Carlile 2006).

Fenitrothion (an OP insecticide) and deltamethrin (a pyrethroid insecticide) for instance reduces populations of invertebrates such as insects, crustaceans and microscopic fauna significantly. Some invertebrates may recover within a few weeks, others like shrimps can disappear completely. Fenithrotion may cause population declines of more than 75per cent in several non-target insect groups (Williamson 2003 a). Herbicides, especially those inhibiting photosynthesis can be directly toxic to phyto- and zooplankton, the basis of the aquatic food chain. OCs, such as DDT, have been shown to reduce shell growth of filter-feeding mussels, and water fleas are especially sensitive to pesticides, insecticides in particular. The following invertebrate population crashes are temporary for most species but reduce the amount of food available to predators. Pesticides, if not lethal to invertebrates, may also be accumulated by them in sublethal concentrations. Hence, predators like fish and waterbirds might further accumulate pesticides and their residues to levels that are damaging or even lethal.

The toxicity of most herbicides to fish is low, and they do not seem to accumulate in fish. Fungicides are seldom detected in natural waters and most are not toxic to fish. Experiments showed that fish metabolised and excreted fungicides with no evidence of accumulation. Insecticides cause most problems to fish; highly toxic are OCs, pyrethroids and rotenone. The latter is commercially used to clear lakes and ponds of fish prior to restocking. Fish can be affected by point-source spillages causing their deaths in streams and brooks a few hundred metres away or even hundreds of kilometres away in cases of massive pollution. Even at low doses, DDT is considered to be acutely toxic to fish. Like other OCs it is absorbed by the passage of contaminated water to their gills, entering the bloodstream directly and concentrating in the liver. If so, it potentially leads to endocrine disruptions causing imposex, meaning developing sex organs that are the opposite of the actual sex, and intersex, meaning having biological characteristics of both the male and female sexes. In contrast to OCs, OPs do not accumulate in fish. Pyrethroids, however are considered highly toxic to fish, as their brain tissue is more sensitive to them as that of birds and mammals. Frogs and toads seem to be more tolerant than fish to pesticides such as DDT and other OCs. However, sublethal effects including morphological abnormalities from DDT have been observed in polliwogs, as concentration of DDT and other OCs in frogs and other amphibians. The impact of atrazine, a herbicide, to amphibians is considered to be responsible for hermaphroditism and is suspected to cause deformed limbs.
Some reptiles, such as turtles, snakes and crocodiles may accumulate OC-insecticides to a higher level than amphibians, as they consume other smaller animals as prey. Dead snakes have been found with 500 µg/g bodyweight of DDT. Following a pesticide spillage in Florida in 1980, alligators were demasculised and super-feminised, due to endocrine disruptions (Carlile 2006 et. al).

3.4 Impact of agrochemicals on birds

Natural habitats compete with cultivated land. Population growth and the expansion of commodity markets lead to the transformation of natural vegetation into farmland. Particularly, in developing countries, farming is the major source of food and income for poor rural households and their numbers are growing despite urbanisation and overall economic growth. The changing use of land is the main reason and accelerant in the loss of biodiversity, as farm land expansion and intensification inevitably leads to a degradation of habitats (Bolwig 2006 et al.).

Food demand is predicted to double in the next fifty years mainly in the developing countries, and agricultural intensification is likely to increase in Sub-Saharan Africa. Between 1970 and 2000 Sub-Saharan Africa’s agriculturally used area increased by 4per cent, fertilizer consumption almost trebled and pesticide imports increased more than fivefold. The istribution of agricultural land is a strong indicator of wildlife threat status and intensification of agriculture has been linked to declines in bird populations in Europe and Africa (Sanderson 2006).

Agricultural intensification is understood either as increased cropping frequency in small-scale agricultural systems, with a corresponding reduction in areas with fallow and natural vegetation, or land use conversion to large-scale monocultures characteristic for plantation agriculture. The reduction in space and food resources, loss of roosting and nesting places, and fragmentation of habitats restricting movement and seed dispersion cause most specialist species to disappear, or at best survive in much reduced numbers (Bolwig 2006 et al.).

Birds are thought to be good indicators of overall farmland biodiversity (Donald 2000) and provide services like the pollination of crops and feeding on insect pests, having a positive influence on agricultural production and thus the economy. Agricultural intensification clearly leads to a large loss in bird species and it is evident that small-holding farms support a much richer biodiversity than large scale plantations (Bolwig 2006 et al.).

The impact of agrochemicals on birds is manifold. A distinction must be made between direct and indirect impacts. Direct impacts for instance are death, hormonal deregulations and breeding failures if e.g. a pesticide is absorbed by a bird with its food. An indirect impact for example is the deterioration of habitats, because of e.g. herbicides or fertilizers, as well as the loss of food, due to the impact of insecticides on invertebrates (Newton 1998).

The frequent use of lethal but non-persistent pesticides can have consequences as severe as the less frequent use of persistent pesticides. Although a number of birds can recover quickly from direct pesticide impact, some populations may remain permanently low or even die out (Newton 1998). However, it is difficult to assess the number of birds dying from pesticides. Defining an average agricultural field and quantifying its bird presence at the time of pesticide application is rather complicated and the mortality of birds in the fields is unlikely to be detected, unless the birds in question are large and highly visible, or if they die in large groups and areas of high public visibility. As dead birds are likely to be scavenged, the absence of bird carcasses is not a reliable indicator that pesticide poisoning has not taken place or recommended pesticide application does not impact birds. Even if direct kills could be estimated, it would be even harder to asses less obvious chronic or sub-acute behavioural or physiological effects that some pesticides have on birds such as compromised escape behaviours and breeding success, as well as indirect food-mediated effects that might also negatively affect bird populations. Bearing all this in mind one can imagine the enormous impact that a few farmers applying pesticides could have on the bird population assembled at wintering staging grounds. These facts indicate that the publicised kills are not isolated events, but rather the ‘tip of the iceberg’ (Mineau 2005 et al.).

Eutrophication and hence deterioration of habitats may lead to a decrease of available food sources and in the worst case starvation of birds, and is therefore an indirect effect. The impact of excessive nutrients, mostly nitrogen and phosphorus from fertilizers, sewage, animal waste and domestic effluent, causes widespread eutropication, especially in aquatic ecosystems. This causes the plant, invertebrate and fish populations to change. Macrophytic plants (water weeds) expand because nitrates and phosphates enable them to grow. Their growth provides new substrates for invertebrates, meaning more food and cover for fish. Therefore the food supply for herbivorous and carnivorous birds increases greatly. Fish stocks change as bigger coregonid fish give way to coarse fish, which have higher reproduction rates and mature earlier, supporting even larger numbers of fish eating birds.

However, as nutrients continue to increase, algae multiply and cloud the water. This reduces light penetration and causes water weeds to decay, and in its wake invertebrates and fish die. It is worth mentioning that certain algae and other micro-organisms produce toxins, poisoning fish and birds feeding on them. Dense algal populations sink to the bottom and decomposing processes may de-oxygenate the water. Under these circumstances fish and other aquatic life dies and the water may become almost lifeless. The bacteria causing the decay might be replaced by anaerobic bacteria, triggering other processes harmful to most organisms.

In contrast to lakes, rivers naturally re-aerate themselves, but under heavy organic input even their water can become totally devoid of oxygen. The problem increases, if water is taken out of the river for e.g. irrigation and other purposes. Eutrophication has also become a problem in shallow coastal areas (Newton 1998 et al.).

The **contamination of environments by pesticides** has become a widespread occurrence (Pretty 2005). The majority of pesticides including herbicides and fungicides are a minor threat to birds; a few however may be acutely toxic to birds (Carlile 2006). Contamination or even elimination of food sources, as well as disruption of the internal hormonal regulation and intoxicating are some of the negative impacts by pesticides on birds (Pretty 2005). Birds are killed regularly and frequently in fields treated with pesticides, as due to their mobility it is difficult to keep them away from pesticide-treated areas. Furthermore birds are opportunistic foragers, meaning that they respond to agricultural pests by purposefully entering fields treated, in order to feed on the pest species (Mineau 2005).

Birds are often exposed to a combination of different pesticides, as two or even more are applied together, or birds move from one crop to another. Combined effects from several toxicities can be much greater than effects from single intoxications. Also water bodies may contain a mixture of several chemical pollutants, as run-off from farmlands and industrial sights occurs.

It is impossible to determine the definite source of intoxication, if birds are exposed to several pollutants (Newton 1998).

Insecticides, foremost **carbamite insecticides** (like carbofuran, carbosulphan, aldicarb etc.) and **organophoshate insecticides (OPs)** (like diazinon, malathion, parathion, famfur etc.) (Newton 1998), may be acutely toxic to birds (Carlile 2006). Carbamites and OPs are neurotoxicants disrupting the nervous system. They inhibit the enzyme acetylcholinesterase, which is responsible for the breakdown of acetylcholine, a neurotransmitter responsible for the transmission of nerve impulses at cholinergic nerve endings (all nerve endings using acetylcholine, comprising the entire parasympathetic and partly the sympathetic nervous system) and myoneural junctions (nerve endings in muscle tissue). As ChE-inhibiting pesticides are taken up, the inhibition of ChE allows the build-up of acetylcholine resulting in continued stimulation and fatigue of cholinergic end organs and muscles. Nerve impulses can no longer be transmitted anymore, leading to tremors, convulsions and eventually death from respiratory failure (Friend 2001, Newton 1998). It is evident that ducks, for instance, can acquire a lethal dose of anti-ChE pesticides, even if the chemicals where applied in recommended rates (Wilson 1998). It is worth mentioning that **carbofuran** is especially toxic to birds, as its formula based on silica particles, ensures ample exposure to birds feeding on the granules by scavenging on fields (Mineau 2005). Another compound most frequently identified to cause poisoning of wild birds is **phosphamidon**, as it accounted for 23 mortalities in 41 cases in a Korean inquiry (Kwon 2004).

Carbamate- and OP compounds are used worldwide in agricultural lands, forests, rangelands, wetlands, as well as in residential areas and commercial sites as insecticides, herbicides, nematocides, miticides, fungicides, rodenticides, avicides, and bird repellents (Friend 2001). They are taken up either directly, as in the case of carbofuran, which is available in granular form and remains on the soil surface to be eaten directly by birds, or contaminate other food organisms, such as earthworms and insects (Newton 1998). In case of fatality, in more than half of the incidents, the pesticide source remains unknown, as it rapidly degrades under the influence of light and microbes (Cox 1991).

Birds rapidly dying with neurological symptoms may leave evidence of their struggle, like vegetation clenched in their talons or vegetation that they disturbed during thrashing about or convulsions. Sublethal doses impair the nervous system and alter the bird's behaviour. Often decreased ChE in the bird's brain is the reason for crashing into vehicles, strike buildings and predation. Furthermore, studies evaluating the exposure to sublethal amounts to OPs and carbamates have proven impaired reproduction, a reduced ability to regulate body temperature, and hence reduced tolerance to cold stress, which causes reduced activity leading to decreased feeding and weight loss (Friend 2001). Additionally OPs are known to cause anorexia (loss of appetite), which may be especially disastrous for migrating bird species, as their fat reserves are essential. **Dictrotophos**, also an OP, has been shown to disrupt parental care. A single oral dose results in the female making fewer trips to feed their young and increases the amount of time the mother spends away from their young (Cox 1991). **Profenofos** (an OP insecticide) is on an acute basis highly toxic to birds (EPA 2000). **Chlorpyrifos** (an OP insecticide and ChE inhibitor) and **fenitrothion** (an OP insecticide) have shown to result in population declines of birds. They decrease the amount of food available, disrupt ChE-levels and affect fledglings negatively by either reducing the numbers of fledged birds or killing them soon after they leave the nest (Mullié 1993). Brain ChE activity will increase again within birds when recovering from OP or carbamate intoxication. However, ChE activity may remain below normal levels for up to three weeks, depending on the compound and on the dose received thus impairing the chances of the bird to survive (Friend 2001).

One of the prominent problems in research related to OP or carbamate intoxication of birds is finding their carcasses, as these are frequently scavenged especially in farmlands (Mineau 2005). Instead, carcasses of predators, other carnivorous wildlife and insectivorous wildlife can often be found following OP or carbamate exposure (Friend 2001), proving that the negative impact of ChE-inhibiting pesticides does not stop after the death of birds.

Still the OPs and carbamates are considered an advantage in contrast to the OCs. **Organochlorines (OCs)** are known for their extreme persistence and high fat-solubility, enabling them to move up the food chain, becoming more and more concentrated (Newton 1998). After their application, OCs remain in the environment for long periods of time and accumulate in body fat reserves, allowing OCs to bioaccumulate and biomagnify. The combination of bioaccumulation and biomagnification may harm or even kill wildlife, especially some species of birds (Friend 2001). OCs move up the food chain, because of their fat-solubility and persistence and concentrate at successive trophic levels. At the first trophic level (plants) the concentration is lowest, but already rises significantly at the second trophic level (herbivorous animals). The third trophic level (carnivores) comprises the highest concentrations of OC-chemicals, rising further with the size of prey animal and predator. Hereby the trophic level is not decisive; instead it is the rate of exposure or intake, which matters. Rates of accumulation for instance are often higher in aquatic systems, as aquatic animals absorb OCs through their gills additionally to the intake through their food. The persistence in the body may cause effects of OCs on individual birds to show weeks or months after acquisition. Mortality is most likely to take place at times of fasting, such as migration or hard weather or other occasions when body fat reserves are metabolised and OCs are released into the circulation (Newton 1998 et al.). The residues are carried to the brain, where they can reach toxic levels resulting in acute poisoning, even reaching lethal levels in the nervous system (Friend 2001). Furthermore, birds have a less effective detoxification system for OCs than mammals, explaining why they are generally more contaminated than mammals from the same area where application took place (Newton 1998).

OCs are broad spectrum applications used in agricultural crops, forestry lands and to a lesser extent for human health protection by destroying mosquitoes and other potential disease carriers. OC compounds include **polychlorinated biphenyls (PCB), dioxins, dibenzofurans, cyclodiene pesticides** (like aldrin, endrin, dieldrin etc.), **lindane, hexachlorobiphenyl (HCB), toxaphene, chlordane and DDT**. Most of the persistent OCs were banned from European and North American markets, however many are still used in Africa, Asia and South America (Fry 1995). Migratory birds therefore remain exposed to persistent OC- compounds, and effects are usually not observed until they reach other areas on their migratory route (Friend 2001). It is worth mentioning that OCs may be turned over much faster in a tropical climate, than in a temperate climate, as higher temperatures favour faster degradation and volatilisation (Newton 1998). Furthermore, their movement differs between terrestrial and aquatic environments. In aquatic systems the movement is much quicker and effects are seen almost immediately. This holds especially true for DDT (Middleton 2005)

DDT is the best known OC (Friend 2001). DDT is not especially toxic to birds and very high exposures are needed to kill a bird outright (Newton 1998) by poisoning its nervous system (Cox 1991). The nervous system of birds can also be altered by DDT and other OCs to cause pathological behaviour, such as lethargy, slowness, depression, locomotive and muscle incoordination (ataxia), tremors and convulsions, reduced nest attentiveness and nest abandonment, violent wing beating, abnormal wing and body posture, as well as body spasms causing the body to bend backwards and become rigid (opisthotonos) (Friend 2001).

The main effects, however, are on breeding (Newton 1998). DDE and DDD (Friend 2001) (metabolites of DDT) reduce the availability of calcium carbonate, needed during the formation of eggshells. Hence, the eggshells become too thin, and either break under the weight of the breeding parents or the embryo dies of dehydration, caused by excessive water loss through a thinned shell (Newton 1998). DDT and other OCs are also able to mimic the action of oestrogen. Even though the oestrogen receptor potential is low with original pesticides, even tiny amounts of their hydroxylised metabolites may have very similarly binding affinities, such as oestrogen (precisely oestradiol, a steroid and most important oestrogen).

The hormone control of the reproductive system of birds differs from the reproductive system of mammals. In mammals the heterogametic sex is the male (XY) and the homogametic sex is female (XX). But in birds the heterogametic sex is the female (ZW) and the homogametic sex is male (ZZ). The homogametic sex is the default sex, the phenotype into which the embryo will develop in absence of sex specific hormones and other compounds. Therefore in birds the default sex is male, and specific female gene products must be translated to synthesise oestradiol, differentiating gonads into ovaries. Lipophilic OCs, which bioaccumulate and are deposited into the yolk of eggs have been identified to have effects on the differentiation of the sexes of birds. Males are feminised and the right oviduct of females may be abnormally large, hence functional changes in left oviduct and shell gland may occur when the female fledglings reach adulthood, laying eggs with defective, thin, or soft shells. Embryos of birds are particularly at risk from OC metabolite products, as they are not excreted from the egg, but remain in the blood circulation throughout incubation (Fry 1995 et al.).

Three groups of birds have been particularly affected by DDT; firstly raptors, especially if they feed on fish and other contaminated fauna; secondly fish-eating birds; and thirdly various seed-eating birds, like geese and cranes, as they feed on newly-sown seeds of cereals and other plants, treated with pesticide as protection against insect pests (Friend 2001, Newton 1998).

Hydroxylated PCB has also been identified as oestrogenic, including a large variation in potency between its hydroxylated metabolites. Small doses cause induction of liver microsomal enzymes and subsequent larger doses are being rapidly hydroxylated to active oestrogens (Fry 1995). There is proof that the reduction in the main breeding rate of individuals causes a decline of the population, as breeding becomes insufficient to match mortality (Newton 1998).

Endosulfan is another OC pesticide and, although less persistent, it comes from the same chemical family as DDT (Glin 2006). Birds in general are sensitive to endosulfan poisoning. The defined acute toxicity (LD_{50}) for young ducks is 33 mg/kg, for mature mallards 205-243 mg/kg, for bobwhite quail 805 mg/kg and for ring-necked pheasants 1,275 mg/kg. Male mallards from three to four-months-old exhibit wings crossed high over their back, tremors, falling, and other symptoms as soon as ten minutes after an acute, oral dose. The symptoms may persist for up to a month (Extoxnet 1993).

Other OCs namely **cyclodienes**, such as **aldrin** and **dieldrin** are several hundred times more toxic to birds than DDT. They are capable of killing birds outright, increasing their mortality to an extent which causes rapid population declines. Primarily used as seed treatments, cyclodienes mainly kill seed-eating birds as well as predatory birds feeding on them (Newton 1998). Birds and their progeny are threatened by pesticides as they impair the food sources such as weed seeds and insects (Carlile 2006).

Rhodenticides are especially dangerous to birds of prey, if their prey has been contaminated (Carlile 2006) and in addition they also cut down on the availability of small mammal prey for raptors (Campbell 1997). But they are also used to treat grain to protect it against mice and rats. When sown out, geese and other seed-eating birds may also become victims of rhodenticides (Hunter 1996).

Avicides are pesticides that are deliberately applied against birds. These are mostly OP- compounds, like **fenthion** or **parathion** used to control large populations of seed eating birds, such as Red-billed Quelea (*Quelea quelea*) in Africa. Avicides are usually applied by plane spraying roosts or feeding flocks, killing target and non-target birds alike, as they are inhaled or orally digested (Newton 1998).

Herbicides are generally less toxic to birds, as they are supposed to treat plants. Some, however, are lethal even in small doses, such as **Dinoseb**, a dinitrophenol herbicide interfering with the basic energy metabolism of cells within plants and animals. A dose of seven mg/Kg is sufficient to kill a bird outright making it as acutely toxic as most of the toxic insecticides. Quaternary nitrogen herbicides such as **paraquat** and **diquat** are also toxic to birds. Several hundred milligrams per kilogram can kill adult birds, and bird fledglings die at doses almost as low as dinoseb's lethal dose (Cox 1991). Nevertheless, herbicides can also impact birds indirectly causing starvation or forcing them to leave treated areas, when herbicides destroyed the habitat of their prey (Cox 1991).

Indirect effects of pesticides comprise the deprivation of birds from their crucial food supply. There is evidence that the application of agrochemicals has greatly reduced the availability of bird feed. These reductions may persist for weeks or even months, long enough to cover most of a breeding season of some species (Campbell 1997). In fact, besides direct impacts of agrochemicals, the second central mechanism of the population decline in birds results from indirect effects of pesticide and herbicide application (Newton 1998).

Long-term herbicide applications reduce the populations of various farmland weeds, on which many seed-eating birds depend. Most herbicides themselves are not cumulative; however their effects lead to a depletion of soil seed-banks. Hence some once common arable weeds have even become rare (Newton 1998), leading to an increased mortality of adult seed-eating bird species through starvation. Furthermore some herbicides have a direct insecticidal impact. As the abundance of food plants for phytophagous (plant eating) insects diminishes, so do their numbers. Moreover, a number of invertebrates depend on weeds as host plants for immature stages of their offspring. Herbicides, therefore, indirectly reduce the amount of suitable insect food for fledglings.

In addition, herbicides lead to the loss of nesting sites or at least a deterioration in their quality. The destruction of vegetation may even prevent ground-nesting birds from the attempt to breed or their nests might me more prone to failure as a result of predation and the impact of weather conditions.

Pyrethroid insecticides, which are of minor toxicity for birds, kill wide ranges of different pest and non-pest organisms. Especially waterbirds feeding on aquatic insects, small insectivorous birds and fledglings fed on insects during the breeding season are affected by them (Cox 1991). This leads to poor conditions of adults and nestlings, resulting in reduced breeding success, poor chances for fledglings to survive and also increased adult bird mortality (Campbell 1997).

Fungicides reduce the food supply and hence the population of insects feeding on fungi (Campbell 1997 et al.).

Molluscicides decrease the abundance of snails, slugs, earthworms and other invertebrates, leading to an increased mortality of nestlings or newly fledged young.
Veterinary products with insecticidal properties can also reduce invertebrate populations, which feed on or even colonise cattle droppings, again reducing the availability of feed for specialised birds (Campbell 1997).

3.5 Impact of pesticides on migratory birds in Africa

Since the 1960s, pesticides were introduced to fight locust plagues and grasshoppers. Grasshoppers, in contrast to locust swarms, occur annually over vast areas. Like locust plagues they are treated with chemical insecticides. Consequently their dispersion over vast areas makes their control more damaging for the environment.

In the beginning, barrier treatment with the OC dieldrin proved to be effective against growing numbers of locusts and grasshoppers. However, it was also dieldrin causing population declines of various European and North American bird species and hence it was soon suspected to have contributed to population declines of bird species living and wintering in Africa. During the 1980s, dieldrin was replaced by OPs and other chemical compounds that were less persistent and therefore rather short-lived. Repeated full-cover spraying was needed for dieldrin to be effective, and treatment became costly.

Chemical controls with broadband insecticides kill large numbers of insects, target and non-target alike. The eradication takes place in a short space of time, within a few hours to less then one day. Hence insectivorous birds are deprived of their food source almost instantly and massive numbers will leave areas treated with pesticides.

Economic barrier treatment became possible again with the introduction of fipronil, a persistent insecticide. Unfortunately it became clear that fipronil had major environmental drawbacks (Mullié 2009).

At present fipronil is no longer recommended as full-cover treatment against locusts. Nevertheless, it is worth mentioning that massive amounts of mainly OP insecticides have been applied since 1965.

Dead insects are usually not attractive to birds. Bio-insecticides such as fipronil weaken insects instead of killing them right away. In this way they become easier prey and birds are drawn to treated areas. Field records and experimental studies have provided overwhelming evidence that birds may suppress low, medium and sometimes even high populations of locusts and grasshoppers, making costly chemical control questionable (Mullié 2009).

4. Agriculture and application of agrochemicals in Africa

This chapter compiles available information about the application of agrochemicals in Africa and the impact they have on the environment. It comprises case studies of a number of countries, introduces the reader to the concept of agro-ecological zoning, describes different agricultural systems in North and Sub-Saharan Africa and tries to provide an outlook into the future of African agriculture. Data about pesticide consumption in Africa in the statistical database of the FAO (FAOSTAT) was not used, because it was considered too old or too inconsistent at that time.

4.1 An introduction to land use in Africa:

Land use in Africa is complex and related to economic development, national policy and local customs of a country or a region. African agriculture employs more people than agriculture in more developed parts of the world. In 2003, 54per cent of all Africans (62per cent of all Sub-Saharan Africans) were involved in agriculture, though with large variations between different countries (e.g. 6per cent in Libya and 90per cent in Burkina Faso). Living off the land, however, is a risky business. A total of 24per cent of all people in Sub-Saharan Africa are undernourished, most of them are children.

Even though 37per cent of the land for the continent of Africa as a whole was classified as agricultural by the FAO in 2001, not all of it can be considered as suitable for the cultivation of soil, as agricultural land also includes pastures and animal husbandry. Agriculture in Africa has changed dramatically in most places but has also remained virtually unchanged in more marginal locations. However, the family remains the unit of production and consumption, as most of the labour is provided by family members and most of the food is produced by the family (Cole 2007). These family farming units are called smallholders.

What distinguishes the majority of African farmers from European farmers is lack of control over their environment. The use of farm machine technologies is least developed in Africa, especially in the parts south of the Sahara. The use of inorganic fertilisers in Sub-Saharan Africa is the lowest in the world. Most farmers use organic fertilisers from animal manure, composted household wastes, agricultural wastes, night soil and ashes. Most of Africa is dry; irrigation is limited and most cultivation is rainfed. For this reason, agriculture often falls victim to periodic droughts. Crop insurance, common to most Western countries, is rare, and crop loss and failure e.g. because of pests represent real threats to well-being and physical survival (Cole 2007 et al.). This is particularly true if we consider the growing demand for food by a growing world population. Since the beginning of the second millennium, the population in most African countries increased by about 3per cent per year, and is growing twice as fast in cities than in the countryside. This process is called urbanisation, and it has a direct impact on agriculture.

Demand for agricultural commodities is changing. Rice and wheat for bread replace traditional crops such as millet and sorghum. As the majority of African farmers are too poor to intensify their production by means such as irrigation and agrochemicals, larger areas of land are required. Shifting cultivation, a traditional land use technique leaving land fallow to avoid depletion of soil nutrients has been gradually replaced by with permanent cultivation. The consequence is nutrient mining resulting in a decrease of organic soil matter, a loss of soil nutrients and accordingly in lower yields.

In 2004,

African farmers kept 254 million sheep, 239 million cattle and 232 million goats. Especially in the Sahel zone stocking densities increased since the 1960s and the growing numbers of livestock caused pastures to increase. The combination of expanding cropland, increasing livestock and great numbers of African people relying on firewood for cooking causes deforestation.

The African continent comprises 974 protected areas covering 175 million hectares (ha) which amounts to 6.8 per cent of total area of the continent of Africa. Most of the protected areas can be found in eastern and southern Africa. More than 60 per cent of them are situated in only seven countries. Two countries incorporate more than 10 per cent of the African total, namely Zambia with 13 per cent and Ethiopia with 10 per cent. Hence there are not many refuges for wildlife and destruction of natural environments continues in one form or another. Wildlife of all kinds faces habitat loss. For birds depending on natural woodlands or grazing land these circumstances mean a loss of their habitat on a large scale. Birds feeding on fallow land are facing depleting food sources, as shifting cultivation is replaced by permanent cropping (Zwarts 2009 et al.).

4.2 Application of agrochemicals in Africa

According to current world fertiliser trends and an outlook to 2011/12, Africa will account for marginally less than 3 per cent of the world fertiliser consumption. High transportation costs especially in land locked countries and an array of other factors which further limit input and output markets severely constrain fertiliser use. Africa will continue to import all potash fertiliser it needs and remain a major exporter of phosphate fertiliser and to a lesser extent but with increasing tendency, of nitrogen. Production capacities for nitrogen exist only in 11 countries and for phosphate only in six countries. Fertiliser consumption is largely restricted to 10 countries. The main consumers of fertilisers are Egypt, South Africa and Morocco (FAO 2008 et al.).

Agricultural production in tropical agro-ecosystems is greatly impacted by pests i.e. arthropods, pathogens, nematodes and weeds. The tropical climate has no natural seasons; therefore, there are no annual breaks in the growth period. Hence, pests may breed all year round without declines common to temperate climates. This makes tropical agro-ecosystems unpredictable and difficult to manage.

Over the centuries African farmers have developed traditional methods to deal with pests and diseases and they have coped well with indigenous pests on indigenous crops. After the introduction of new crops from abroad, local pests adapted rather slowly and farmers had plenty of time to choose cultivars with sufficient resistance. But the introduction of pests from abroad overwhelmed the African farmers. Suddenly they had to cope with their indigenous site-specific pests, migratory species e.g. locusts and the many introduced pests. Due to these changes, the average African farmer needs sufficient education, training and pesticides or he faces a life in dire poverty deriving from low yields drawn from high losses due to pests (Williamson 2003 a). Many African governments supported the cultivation of high value export crops by smallholding farmers. The objective was to provide them with income and promote economic growth. Agricultural productivity was meant to increase with technical means and agricultural inputs (Williamson 2003 a). Pesticides were subsidised or even provided for free via governmental commodity boards and extension services (Williamson 2003 b).

With the implementation of the structural adjustment programmes in the 1990s, governments were obliged to reduce state interventions within food production. Responsibilities, such as providing agricultural inputs and services, were intended to be taken over by the private sector. However, the liberalisation policies did not always have the intended effects. Drastic cutbacks in government-funded research and extension followed the liberalisation. State controlled crop commodity boards and food grain market boards were dismantled and privatised, leaving a major gap for smallholding farmers, as the private sector was not willing to invest in them and many were living in remote areas. By the way, it is questionable if advice about pesticide applications should be provided by retailers, as their central motivation is most likely to be sales and not the protection of the environment. As a result, application of agrochemicals was reduced leading to a decline in the quality of the export crops, and the use of fertilisers collapsed among many smallholders. After liberalisation the productivity declined and smallholders compensated by increasing the acreage under cultivation. Furthermore, smallholding farmers, depending on cash income to cover expenses for health and education, shifted from growing a mix of food and cash crops to exclusively growing food crops, i.e. maize and beans and sell them for cash. (Williamson 2003 a et. al.).

Declining revenues from certain crops and rising costs of agrochemical inputs leave farmers no choice but to acquire chemicals from dubious sources, even if they are of doubtful quality.

Pesticides, no longer free nor subsidised by the government are acquired via informal, unlicensed dealers. Petty traders visit village markets or sell their products in larger towns. Many of these products are of dubious quality and frequently repackaged and relabelled, while their contents may have been diluted, mixed or changed so that they no longer correspond to the declaration on the label. Informally sold herbicides are often sold without any label.

Another source for smallholding farmers to acquire pesticides is via the diversion from cash crops that are still substituted by the government, such as cotton. Farmers then deliberately grow cotton to gain access to cotton pesticides, such as the persistent and toxic endosulfan, which happens to be highly toxic to birds (Extoxnet 1993). Cotton pesticides are applied on cowpea and vegetables or even sold to other non-cotton growing farmers. Despite the difficulties smallholding farmers face acquiring pesticides, they have become more reliant on pesticides and application has increased again in the last 10 years (Williamson 2003 b et al.).

Particularly among cash and horticultural crops such as cotton, cocoa, oil palm, coffee and vegetables, the use of pesticides is on the rise (Pretty 2005). However, pesticide consumption in Africa is the lowest of all continents, as it accounts only for 2 per cent of the world pesticide sales and this may lead to the assumption that continuous low level application of pesticides causes minimal health and environmental hazards (Pretty 2005). But, particularly in Sub-Saharan Africa, quality control of pesticides is weak. About 30 per cent of the pesticides marketed do not meet internationally accepted quality standards, and cause a threat to human health and the environment.

Furthermore, small-scale subsistence farming systems are generally considered to be low-input systems with only marginal use of pesticides and give the misleading impression that pesticide application relates mainly to large-scale and commercial agriculture.

However, pesticide application is not related to the size of the farm but to the crops that are grown. The largest consumers of pesticides are cash crops and many of these are predominantly grown by smallholders. Hence pesticides are applied by millions of African farmers, even though volumes applied per hectare are often far smaller than in more intensive cropping systems of developing countries. However, even applied in low amounts, pesticides may be a threat to human health and the environment (Williamson 2003 a). Widespread deregulation of input supply has caused rapid growth of informal pesticide trade, particularly with poor quality products. Old and potent pesticides, that have been banned, re-emerge in local markets and are used by farmers without restrictions (Pretty 2005). High proportions of the products are classified by WHO to be extremely, highly, or at least moderately hazardous.

The choice of a particular pesticide and ways of application depend on available information. Lack of information may lead to unnecessary measures, including over- and misuse of pesticides. But generally, imited information is available for farmers, extension workers and pesticide dealers on the proper and efficient use of the different pesticides. General lack of information about possible losses, expected severity of pest outbreaks and about alternative measures to control and protect crops encourages pesticide use as an insurance against unpredictable losses.

Retailers supply pesticide information to farmers, especially to illiterate smallholders. Pressure might be put on farmers by dealers, who want to sell their products, and produce buying agencies and traders demanding good quality products. Some distribute their own extension material with recommendations on use and application rates, and some even train domestic extension workers in the use of their pesticides.

It can therefore be assumed that most contacts with pesticide dealers or exposure to field demonstrations by wholesalers result in higher pesticide use compared to a situation where objective information is available (Gerken 2001 et al.).

Farmers and farm workers do not have adequate clothing and equipment. Poor application techniques may cause leaching of pesticides into drinking and ground water, killing wildlife and livestock and promote the development of resistances e.g. by insects to the applied pesticides. Pest and pest-predator circles might be disrupted and agricultural biodiversity reduced.

Many farmers classify the potency of a particular pesticide by its ability to kill insects and other animals. Hence, devastation of animal population in treated fields is seen as proof of pesticide potency. Very little specific knowledge of how pesticide treatment affects non-target organisms exists. Field research, providing information about implications for biodiversity and environmental health, is lacking. Published data is very limited and most research has focused on those pesticides applied over large areas for locust control.
Pesticide treatments may cause decimations of flies, moths, grasshoppers, earthworms and complete disruptions of ant and termite colonies. It is worth mentioning that earthworms, termites and other soil organisms play a significant role in soil nutrient cycling. Their decimation will result in a decline in soil fertility.

In contrast to arthropods and worms that are directly affected after application, larger animals such as birds flee from treated fields. Keeping insect pest populations in balance, they are also needed as natural arthropod predators. If birds are poisoned by insecticides it is more likely to be by the consumption of pesticide treated seeds. Particularly, the expansion of cotton causes birds to stay further away from fields.

So far, there has been very little assessment about the impact of agrochemicals on African agro ecosystems and the environment. One of the shortcomings of the few existing studies is that they focus on OC-compounds. These however, are less commonly used than OP-compounds pyrethroids, for example. Endolsulfan, widespread in cotton and other crops was even exempt. It was introduced to African cotton systems to fight the cotton bollworm after it became resistant to pyrethroids. Farmers in Ethiopia, Ghana and Benin have observed poisonings of their livestock and other animals after application of insecticides. Endosulfan was hereby described as the most toxic. Its projecting persistence may even poison several weeks after application (Williamson 2003 a et al.).

All African states with exception of Somalia, West-Sahara and Zimbabwe have signed the Stockholm convention on persistent organic pollutants (POPs). This is a global treaty to protect human health and environment, banning the use of aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene, chlordecone, alpha hexachlorocyclohexane, beta hexachlorocyclohexane, lindane, pentachlorobenzene (UNEP 2009).

However, there are many challenges African governments face if they attempt to control the use of pesticides. There is a lack of data about pesticide imports, sales and use in each country. Authorities i.e. the Ministry of Agriculture, Health and Environment are chronically under-resourced in terms of funds and human capacities, making developing and implementing of regulations and monitoring difficult (Williamson 2003 a).

In 2006 the “African Civil Society Statement to the Governing Council/ Global Ministerial Environment Forum” of the United Nations Environmental Programme (ACSF-GC/CMEF 2006) stated that according to the FAO, poor nations were led to believe that the only alternative to pests in agriculture or elsewhere would be to use pesticides. Assistance from developed countries, results either in direct supply of pesticides or in form of contributions of financial support to purchase them. This leads to an uncoordinated influx of pesticide donations and trading and consequently to an excessive supply. Though some donations are genuine others take the opportunity to dump unwanted and illegal pesticides on poor and unsuspecting countries.

ACSF-GC/GMEF also stated that currently limited access to data and information on chemicals in Africa is available, comprising different levels including limited information from industries on the chemicals they produce and use, as well as from governments about the kinds of chemicals being imported. Additionally poor management practices, such as weak policy, legal and institutional frameworks of chemicals in African countries result in harm to people and the environment (ACSF-GC/GMEF 2006).

The assumption that a low level application of pesticides causes only leads to minimal health and environmental hazards is therefore proven wrong. Many African countries bear a legacy of pesticide provision by development assistance agencies often supplying free pesticides directly into the hands of untrained and non-literate farmers growing staple food. Only if regulations on export crops are introduced, does the application of these products become an issue, while in most domestic markets maximum residue levels are usually not enforced. Following the recent introduction of maximum residue levels in industrialised countries, the use of pesticides for crops destined for export has been restricted (Pretty 2005 et. al.) alongside with a withdrawal of approvals for hundreds of pesticides, affecting foremost the participation of smallholders in the export markets (Williamson 2003 a).

4.3 Introduction to agro-ecological zoning and the diversity of African agriculture

All agricultural crops need certain climatic conditions to grow. These climatic conditions are defined in a framework called agro-ecological zoning. Zoning can be used to appraise land resources. It leads to an assessment of land suitability and potential productivity. The concept of agro-ecological zoning is applied by the FAO by defining zones on the basis of combining soils, landforms and climatic characteristics (FAO 1996b). The classification of agro-ecological zones (AEZs) is based on the availability of rain-fed soil moisture in the terms of the reference length of growing period (LGP).The information about soils is derived from the FAO-UNESCO Soil Map of the World.

Nine AEZs can be distinguished on the basis of the FAO-AEZ land inventory:
1. Warm arid and semi-arid tropics;
2. Warm subhumid tropics;
3. Warm humid tropics;
4. Cool tropics;
5. Warm arid and semi-arid subtropics with summer rainfall;
6. Warm subhumid subtropics with summer rainfall;
7. Warm/cool humid subtropics with summer rainfall;
8. Cool subtropics with summer rainfall; and
9. Cool subtropics with winter rainfall.

The application of AEZ on Africa leads to one regional agro-ecological zone (RAEZ) for North Africa and four RAEZs for Sub-Saharan Africa (FAO 1994 et al).

Table 1: RAEZs of North and Sub-Saharan Africa (FAO 1994)

Region	**North Africa**	**Sub-Saharan Africa**			
Name	Cool subtropics with winter rainfall	Warm arid and semi-arid tropics	Warm subhumid tropics	Warm humid tropics	Cool tropics
Daily mean temperature	5-20°C	< 20°C	< 20°C	< 20°C	5-20°C (cool tropics) 15-20°C (moderately cool tropics)
Climate (with length of the growing period)	depending on latitude and altitude arid (LGP 0-75 days) semi-arid (LGP 75-180 days) sub-humid (LGP 180-270 days) humid (LGP 270-365 days)	arid (LGP 0-75 days) semi-arid (LGP 75-180 days)	sub-humid (LGP 180-270 days)	humid (LGP 270-365 days)	Arid (LGP 0-75 days) semi-arid (LGP 75-180 days) subhumid (LGP 180-270 days) humid (LGP 270-365 days)
Countries	Algeria Egypt Libya Morocco Tunisia Western Sahara	Angola Benin Botswana Burkina Faso Cape Verde Chad Djibouti Ethiopia Gambia Kenya Madagascar Malawi Mali Mauritania Mozambique Namibia Niger Nigeria Senegal Somalia Sudan Swaziland Republic of Tanzania Uganda Zambia Zimbabwe	Angola Benin Burkina Faso Comoros Ethiopia Guinea Guinea Bissau Madagascar Malawi Mozambique Nigeria Republic of Tanzania Togo, Uganda Zambia Zimbabwe	Cameroon Central African Republic Congo Côte d'Ivoire Equatorial Gabon Ghana Guinea Liberia Madagascar Mauritius Nigeria Sao Tome Sierra Leone Zaire	Angola Burundi Ethiopia Kenya Lesotho Madagascar Rwanda Republic of Tanzania

Figure 8: Political map of the African continent (CAAPD 2003)

RAEZs just indicate different lengths of growing periods. Natural resources like water, land, grazing areas, forests, the climate considering altitude as an important determinant and the shape of the landscape, including slopes, also impact agriculture.

Furthermore, sociological factors such as farm size, tenure organization, farm activities, household livelihoods such as field crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities, and main technologies, determine the intensity of production and integration of crops, livestock and other activities (FAO 2001). Furthermore, the classification of all African countries into the RAEZ-frame shows that all are situated in the tropics. Tropics can be characterised by high sunshine radiation throughout the year, high amounts of micro-organisms, tropical rains, varied soil types, varied soil ecology and various soil climatologic conditions. The basic needs for survival prevail in all aspects of life. The unpredictability of the weather may cause crop harvests to be totally destroyed either by drought or the outbreak of pests. Hence the priority for all farmers lies in acquiring a good harvest, rather than conserving the environment (Wandiga 2001).

Under tropical conditions pesticides degrade faster than in temperate climates. Volatilisation and microbial degradation rates are higher and cause the lives of pesticides in most cases to shorten by a factor of six to ten (Rosendahl 2008).

Therefore, bioaccumulation occurs at very low levels compared to temperate climates (Wandiga 2001). The different factors indicate that agriculture cannot look the same all over Africa (FAO 2001).

Table 2: Farming systems of North and Sub-Saharan Africa. A full description of each farming system can be found in Annex III.

North African farming systems	Sub-Saharan African farming systems
Irrigated farming system	Irrigated farming system
Highland mixed farming system	Tree crop farming system
Rainfed farming system	Forest based farming system
Dryland farming system	Rice-tree crop farming system
Pastoral farming system	Highland perennial farming system
Sparse (arid) farming system	Highland temperate mixed farming system
Costal artisanal farming system	Root crop farming system
Urban based farming system.	Cereal root crop farming system
	Maize mixed farming system
	Large commercial and smallholder farming
	Agro-pastoral millet/sorghum farming system
	Pastoral farming system
	Sparse (arid) farming system
	Coastal artisanal fishing system
	Urban based farming system

Different farming systems exist that need different amounts of agricultural inputs, i.e. pesticides and fertilisers. In North Africa it is the irrigated farming system that utilizes large amounts of pesticides, even leading to pesticide pollution of water. The rainfed mixed farming system in Northern Africa also employs excessive amounts of pesticides. In Sub-Saharan Africa, the forest based farming system is said to cause the destruction of wildlife habitats and the maize mixed farming system is said to suffer from soil acidity as a result of prolonged fertiliser application (FAO 2001 et al.).

4.4 Case Studies

Benin

In 1990 Benin's rural development policy was reoriented towards market entry, economic liberalisation and improved competitiveness of peasant agriculture. The key strategy to increase rural revenues and improve food security was the promotion and diversification of export crops. Instead of just growing Benin's main export crop, cotton farmers were encouraged to grow pineapple, cassava, cashew, oil palm, and groundnuts as well. Nevertheless, cotton remained the main livelihood strategy especially in Benin's northern savannah zone.

But the agricultural system had changed since liberalisation. Before, the government had supplied the farmers with seeds and inputs such as agrochemicals. This system was now replaced by a market oriented approach, selling inputs to farmers, and formally contracted to train farmers in application of agrochemicals. This however creates a conflict of interest, whereby the trainers are companies with the aim to persuade farmers to buy large amounts of agrochemicals.

Increases in Benin's cotton and food crop production since liberalisation were achieved exclusively by expanding acreage and reducing fallowing. This led to a severe decrease of soil fertility, as well as yields of cotton and other crops and further degradation of natural resources. Pesticide use has increased with the expansion with a tendency to apply higher doses at an increased frequency. Some farmers also use the cotton agrochemicals on maize and other food crops. But even with rising application of external inputs, yields are declining in cotton and other food crops.Population growth, cotton expansion and failing yields have declined food availability at household, village and local level (Williamson 2003 a et al.). There is no current data available about total quantities of pesticides imported to and consumed in Benin (Williamson 2003 a). However, there is data available for quantities of pesticides imported to be used in cotton, the crop consuming most of the pesticides. Between 1990 and 1996, 8,084 tonnes of pesticides were imported for cotton. Since 1993 over 2000 tonnes of insecticides have been used each year. Additionally, Japan's development aid programme provided 50 tonnes of insecticides and 7.5 tonnes of herbicides in 1998. Furthermore, although outlawed in 1993, DDT is still sold in local markets. Beninoise cotton farmers reported using 13 different products on their cotton crop. Active ingredients comprised endosulfan, malathion, chlorpyrifos, and fenitrothion, all having proven adverse impacts on birds.

Under- or overdosing pesticides, just 20per cent of the interviewed farmers were aware about the existence of recommended application rates. Moreover, instead of the recommended six pesticide treatments per season, some farmers treated their crops 8-12 times a season.

Vegetable production is most developed in the peri-urban zone of Benin's capital Cotonou. Farmers grow a range of local crops including okra, chilli pepper, onions, tomatoes and leafy vegetables, but also vegetables of European origin such as lettuce, cabbage, parsley, cucumber, courgettes, aubergines, onion, sweet pepper, carrots and other tubers. Demand has encouraged the adoption of high germination and high yielding varieties and cultivation is characterised by the increasing reliance on pesticides. Especially the vegetables of European origin are more susceptible to pests, but there is also a general trend to apply more pesticides across all kinds of vegetables. It is worth mentioning that Beninoise vegetable farmers use their income from vegetables to purchase food and household needs and do not cultivate any food for home consumption (Williamson 2003a et. al). Beninoise farmers reported to use 28 different products on their vegetables. Active ingredients comprised endosulfan, malathion, carbofuran, parathion, chlorpyrifos, and endrin, all having proven adverse impacts on birds (Williamson 2003 a, Rosendahl 2008).

Pesticide application significantly increased from three applications per season in 1990, to 6-12 applications per season in 1995 and 12-30 applications per season in 2003. This development is sustained with cheaper Nigerian pesticides coming through illicit channels and vegetable farmers have no choice as they have to compete in the market with cheap vegetable imports from Togo and Nigeria. Furthermore it is this competition exposing consumers to increasing amounts of residues of highly toxic compounds, as Beninoise are left no other choice than to follow the same trend of illicit products just as well as practiced by neighbouring countries. After the first pesticide application Beninois farmers observed mass kills of large earthworms, suggesting the cumulative decimation of earthworm populations in cotton fields (Williamson 2003 a).

Burkina Faso

All farmers interviewed in a study of Pesticide Action Network (PAN) used endosulfan and a formulation of cypermethrin and profenofos (Glin 2006), all proven to have adverse impacts on birds.

Cameroon

Farmers in Cameroon interviewed in a study of PAN indicated that they suffer health problems like itching, vertigo and nausea after treating their fields. As most farmers are illiterate, they were unable to provide precise information on products involved (Glin 2006).

Ghana

The situation in Ghana concerning pests in agriculture is typical for tropical countries. Arthropod pests prevail in the dry season and diseases prevail in the wet season (Gerken 2001) and many OC insecticides such as DDT, aldrin, dieldrin and endosulfan have been used in Ghana for more than three decades. Since the 1990s, Ghana has seen growing interest and increasing investment in agriculture in order to increase its production of food. This has led to an increased use of pesticides to control and eradicate agricultural pests. Most of these pesticides are non-specific and can therefore affect both target and non-target organisms (Taylor 2003). A study performed in 1994 on 30 organised farms and 110 kraals distributed throughout 10 regions of Ghana discovered that 20 different pesticides were used. A total of 45 per cent of these pesticides were OPs, 30 per cent pyrethroids, 15 per cent carbamates and 10 per cent were OCs. The OC lindane was the pesticide most widely distributed and used by 35 per cent of all farmers and 85 per cent of all herdsmen. The favourite method of application was by hand dressing and post application intervals for consumption of meat or milk were not observed.

The results of a study in 1997 showed that the knowledge of farm workers of personal protective measures was poor and the use of personal protective equipment was minimal.
Another study in 1997 measured lindane and endosulfan in river water and fish tissues collected from rivers flowing through intense cocoa producing areas. It revealed that water and fish samples from 1995 contained both lindane and endosulfan, but also to a lesser extent DDT and other OCs. Pesticide concentration in all the fish varied by species and month of sampling but was generally higher for lindane and much higher for endosufane (Williamson 2003 a).

In 1996 price subsidies for pesticides were removed. With the process of intensification improved varieties of food crops such as maize, cowpea, groundnut, and sorghum were promoted. The improved cowpea varieties in particular tend to mature faster and have higher yields than local varieties. But the improved varieties are far more susceptible to pests in the field and later in storage and require high investments to manage the pests. Intensification and cotton programmes expanded the use of pesticides. Almost all smallholders use pesticides and herbicides instead of manual weeding (Williamson 2003 a).

Generally it can be said that the more a crop is cultivated for sale on the local market or for export, the more it is treated with pesticides. Vegetables, cocoa, coffee and cotton are usually intensively treated with pesticides and almost all the farmers cultivating them use chemical pesticides. The same applies to about two-thirds of pineapple and other fruits.

Cocoa is treated with lindane and unden against capsid and other insect pests. In a survey performed by the University of Hanover in collaboration with the German Technical Cooperation (GTZ), high proportions of cocoa farmers could neither name the particular pest they wanted to treat nor the pesticide they applied. Between 1995 and 2000, on average 814 tons of pesticides were officially imported, 70 per cent of which were insecticides, 14 per cent,fungicides, 13 per cent herbicides, and 2.6 per cent nematicides (Gerken 2001).

The most important insecticides are unden (21 per cent) and lindane (20 per cent) usually used with cocoa. More than 12 per cent of the imported pesticides were are classified as extremely and highly hazardous (Classes IA and IB of WHO scheme), while 62 per cent are in Class II (moderately hazardous). It is worth mentioning that pesticides classified as most hazardous tend to be cheaper on international markets.

The actual extent of pesticide application can only be estimated, as the official import figures for pesticides do not cover all the pesticides that can be found on the market (Gerken 2001 et. al). 20per cent of Ghana's pesticide imports derive from illicit cross border trading (Williamson 2003 a).Ghanaian farmers have limited information on pesticides and rely to a large extent on recommendations from pesticide dealers. Pesticide labels are often not specific enough for farmers to apply the product properly and effectively. It is common practice among pesticide dealers that they repack large proportions of pesticides and sell them without proper labelling. This happens in response to farmers' demand for small quantities of pesticides due to cash problems and small areas to be treated (Gerken 2001).

Agricultural pesticides are used in the cocoa growing industry, cotton farming, vegetable production, and other mixed-crop farming systems involving maize, cassava, cowpeas, sugarcane and rice. Most of the pesticides used in agriculture are applied in forest regions located in Ashanti, Brong Ahafo, western and eastern regions of Ghana. OCs are widely used by farmers, as they are cost effective and applicable to a broad spectrum of diseases. In 1997 the import and use of lindane was banned, but it continues to be the backbone of pest control in the cocoa sector (Williamson 2003 a). It is widely used on coca plantations, vegetable farms and coffee plantations. Endosulfan is widely used in cotton growing areas, vegetable farms and coffee plantations.

Vegetables in particular are treated with inappropriate and highly hazardous pesticides, which are specifically designed for cotton and cocoa.

Active ingredients applied in Ghanaian cowpea cultivation comprised endosulfan, chlorpyrifos, and profenofos, all proven to have adverse impacts on birds. Active ingredients applied by Ghanaian vegetable farmers comprised carbofuran, DDT, diazinon, and chlorpyrifos, also proven to have adverse impacts on birds (Rosendahl 2008).

It is worth mentioning that most Ghanaian vegetable growing areas are situated along rivers that also serve as the water supply for irrigation and drinking water (Taylor 2003). The level of concern for water pollution and soil contamination is considered to be quite high. At the same time however, the ability to control these problems is found to be low or insufficient.

Intensive tomato production, 90 per cent of the cultivated vegetables (Taylor 2003), is mainly done at riverbanks for reasons of easy irrigation. This creates the possibility of run-off of fertilizers and pesticides into the river. Many farmers use water from the river to clean the equipment after applying fertilizer and pesticides. Some even clean the equipment right in the river. OC insecticides were the focus of two studies carried out to examine possible residues in water, crops, fish and human body fluids. An analysis with gas chromatography for both studies showed significant residues in the materials examined (Gerken 2001).

From January 1993 to October 1995 water and fish samples were taken from three rivers in the Ashanti Region. The rivers were selected because they were flowing through areas of intensive agricultural production, mainly cocoa, vegetable and tomatoes. In 1993 the analysis showed low levels of lindane and no residues of endosulfan. In 1995 a similar analysis showed significant residue levels for both pesticides. Residues found in fish were higher than those in water, most likely to be caused by the accumulation of pesticides in fish (Gerken 2001 et. al).

In 2001 a study measured OC pesticide residues in water, sediment and tomatoes, and in human fluids such as blood samples and mothers' milk. It was found out that the water samples contained endosulfan sulphate, α-endosulfan, β-endosulfan and lindane. Sediment samples contained aldrin, dieldrin, endrin, 2,3,5-TCB, benzene hexachlorate (HBC), DDD and DDT, heptachlor epoxide, lindane and endosulfane. Lindane was dected at the highest level, followed by HBC, heptachlor epoxide, and DDT. HBC and DDE were also found in blood and milk samples but considered to be lower than in tests undertaken in industrialised countries (Taylor 2003).

Ethiopia

Since the late 1960s agricultural policy in Ethiopia focused on the expansion of food production by increasing the yields through new improved cereal varieties and inorganic fertilisers (Scoones 2002). In 1995 government subsidies and the monopoly over pesticide distribution were removed. But control measures of major pests i.e. locusts; armyworm and quelea birds continue to be managed by the government.

In 1996 the Ethiopian government launched a programme of agriculturally led industrialisation, focusing on farmers. Intensification of the agricultural sector aims to transform Ethiopia's subsistence farmers, growing traditional crops, into commercially-oriented farmers growing higher value crops. This is to be achieved by promoting high input production and the use of new technologies. Pesticide imports during 1992-2000 averaged at 1,452 tonnes. Furthermore, since 1992, 125 tonnes per year of OP and carbamite insecticides were donated predominantly from Japan (Williamson 2003 a).

Ethiopian farmers moved away from traditional livestock, cereal and legume crops systems. The use of pesticides by the farmers has increased considerably since 1990. Pesticides are applied to more lucrative crops e.g. maize, grasspea, vegetables, khat and sometimes teff. Vegetable farmers in Ethiopia reported to use 10 different products. Active ingredients comprised endosulfan, DDT, malathion, diazinon and bromadiolone, all having proven adverse impacts on birds.

Pesticides are applied at least three times a season, in contrast to only one application per season a few years earlier. Farmers claimed that the rise in application frequency was necessary, because pest manifestation had increased and regular pesticide treatments had shown to be completely ineffective. Many farmers therefore mix pesticide cocktails in order to reduce application frequencies. One of the most effective, so farmers said, was a mixture of malathion and DDT, both hazardous to birds. Better off farmers buy their pesticides from the government and licensed distribution companies, but poor Ethiopian farmers purchase their pesticides from informal traders (Williamson 2003 a).

Kenya
Agriculture has been the core of the Kenyan economy and hence Kenya depends on agricultural production. Pesticides have been applied in Kenya since 1921 and application has increased during the last forty years. Between 1987 and 1990, 31,234 tonnes of pesticides were imported. The bulk was consumed locally and less than 3 per cent was exported to neighbouring countries. By 1997 the Pest Control Products Board (PCPB) registered 370 formulations and 217 active ingredients to be used in Kenya. A total of 22 per cent were highly hazardous, 20 per cent moderately hazardous, 45 per cent slightly hazardous and the rest remained unclassified. In 1985 the import of DDT and in 1992 the import of aldrin and dieldrin stopped. Other OCs such as endolfulfan and lindane are still used.

Approximately 33 per cent of the Kenyan farmers use pesticides, foremost large-scale operators. In contrast, small-scale farmers, with mostly subsistence-level farms use minimal amounts of pesticides (Taylor 2003 et. al). About 50 per cent of all important pesticides are applied to cash crops such as coffee and another 25 per cent to horticultural crops. Furthermore cotton, sugarcane, maize and tea also require significant quantities of pesticides, and herbicides are used as an alternative to hand weeding in coffee, maize, barley, wheat, sugarcane and tea.

Broad spectrum pesticides are also used to control storage pests, but long term treatment of agricultural products in storage has resulted in an imbalance in the relationship between pest-organisms and their natural predators. The most important vectors of disease agents in domestic animals are ticks, causing great loss of livestock. After they developed resistance to arsenics, BHC, HCH, and toxaphene and since DDT was banned, they are now treated with carbaryl, quitiofos, chlorfenvinphos, coumaphos and formamidines (Taylor 2003 et. al).

In Kenya rice is grown under irrigation in the Nyanza province and the Eastern province, a haven for *Anopheles gambie,* a mosquito and common vector for malaria. Fields were sprayed regularly against agricultural pests with DDT until it was banned and later with fenitrothion and carbofuran. The direct exposure of mosquitoes to agricultural pesticides created a selection pressure that led to resistance to applied chemicals and others with similar modes of action. Hence in 1988 *Anopheles gambie* showed high resistance to fenithrotion and DDT, but just little or no resistance to pesticides such as dieldrin and malathion, which were not used to control pests in these areas. The development of resistance to insecticides by malaria vectors is one reason for the resurgence of malaria in these regions (Taylor 2003 et. al).

In 1985, fish in freshwater and estuarine ecosystems showed residues of DDT and endosulfane, insecticides that had been previously used in agriculture and areal control of mosquitoes. Livers had the highest concentration, as fat content is highest in liver, followed by eggs and muscle tissue. DDT and its metabolites formed the largest proportion of OC residues in fish samples, a result consistent to previous studies (Taylor 2003 et. al).

Pesticides have been found in the milk and tissue of domestic and wild animals. In 1970 DDE (a DDT metabolite) residue levels in two bird species, African cormorants (*Phalacrocorac Africanus*) and individual White necked cormorants (*Phalacrocorac carbo lucidus*). The results showed that African cormorants had 15 times as much DDE as individual White necked cormorants. This can be explained by the feeding habits of both birds. The African cormorant feeds mainly on fish, frogs, aquatic insects, crustaceans and small birds while single white necked cormorant feeds on fish, frogs, crustaceans and molluscs. Small birds consuming pesticide-contaminated grain caused the higher level of pesticides in African cormorants. Furthermore, levels of DDE in white pelicans (*Pelecanus onocrotalus*) doubled between 1970 and 1981, indicating an increase in contamination of the lake system by DDT and its metabolites. Bioaccumulation of DDE was also in biota, fish and birds in different lake ecosystems. Wild animals such as game were also affected (Taylor 2003 et. al).

In 1998 Kenyan farmers in the Kiambu district were found to use OCs, OPs, and carbamate pesticides all year round. In Kiara, 72 households conceded that they had been using eight types of pesticides between 1994 and 1995. Around 25 per cent of these households had detectable levels of DDT, carbofuran, or carbaryl in their water. At most sites the concentration of pesticides in the water did not exceed the maximum contamination limit for pesticides by the WHO (WHO-MCL), but at some individual sites, levels of carbofuran exceeded the WHO MCL by 20-fold (Taylor 2003 et al.).

Some problems of pesticide use in Kenya include resistant pests, lack of protective clothing, lack of personnel and funds to test pesticides in the Kenyan environment and to ensure that private companies adhere to the regulations stated in the Kenyan pest control products act. Furthermore, lack of proper knowledge about pesticides among farmers leads to the indiscriminate use of pesticides and an inability to identify restricted and banned pesticides. Therefore some banned chemicals find their way back onto shelves of the stores despite government efforts (Wandiga 2001).

Pesticides like Carbufuran are also used to poison birds for dietary purposes. Bait, like small fish or termites are laced with pesticide granules and powder made from grinding them up. Even though, it is well known to poachers that the pesticide is highly toxic, they believe that roasting or overhanging the carcasses will detoxify them. The birds are consumed by the local population (Odino 2010).

Mali

The *Compagnie malienne de developpement des textiles* (CMDT), a parastatal cotton marketing body, supplied farmers with cotton, improved cereal seeds, inorganic fertilisers and pesticides, as well as agricultural extension advice. When fertiliser prises rose with devaluation of the CFA franc in 1994, the soil fertility strategy needed to be modified by integrated methods such as the application of manure, the demand of which rose as a consequence. With the implementation of structural adjustment programmes, subsidised credit programmes ended and made inorganic fertiliser inputs more expensive and harder to provide.

Organic and chemical fertilisers are therefore mainly applied to cotton with cereals receiving the residual benefits in the following year.

The availability of credit and inputs are linked to cotton cultivation. Credit and inputs are available on the open market, but not many farmers have left the CMDT system, preferring the security of input supplies, transportation and guaranteed price deriving from credit and inputs for cotton. In this respect intensifying the production of other crops such as maize is directly linked to cotton (Scoones 2002). In a survey performed by PAN, farmers could name pesticides they used, but found it difficult to follow instructions about how to use the products (Glin 2006). Vegetables are treated with fipronil, endrin, carbofuran, DDT, deltamitrin, lindane (Rosendahl 2008), highly persistent and hazardous chemicals, all proven to have adverse impacts on birds.

Senegal

In 1995 the Senegalese government adopted an adjustment programme for the agricultural sector. The strategy to increase agricultural productivity was to promote the exports for groundnut, cotton, fruit and vegetables. The state withdrew from the provision of agricultural services, now provided by the private sector. It is worth mentioning that by 1999 there was still no official list of authorised and prohibited pesticides in Senegal.

High-yielding hybrid vegetable varieties were introduced after liberalisation. But the higher yields come at a cost, as they are more expensive and more susceptible to pests and diseases. Despite rising pesticide prices, pesticide consumption increased, particularly in vegetable production, and increasing numbers of smallholders seek access to pesticides.

Senegalese cotton farmers reported using four products on cotton and five products on food crops. The majority of farmers stated that they had increased the volume of applied pesticides. Active ingredients comprised endosulfan, fentitrothion and carbofuran, all having proven adverse impacts on birds. It is also worth mentioning that many cotton insecticides end up on food staples, as they are sold illicitly by cotton farmers to vegetable growers.

Senegalese vegetable farmers reported using 25 different products. Active ingredients comprised endosulfan, malathion, parathion, diazinon, chlorpyrifos, carbofuran, and lindan, all having proven adverse impacts on birds. With increasing and more severe pest attacks, farmers were obliged to increase the amounts of pesticides applied on their crops (Williamson 2003 a et. al).

Zimbabwe

Private local and transnational companies undertake research in crop plant breeding and testing, seed production and distribution, horticulture, fertilisers and pesticides, machinery and equipment. The application of inorganic fertilisers started in the 1960s after the introduction of cotton. During the 1970s the use of inorganic fertilisers intensified with an increase in cotton production and a decrease in soil fertility. Pesticides and plough and drought-resistant cotton were the reason for high crop yields from 1987.

After independence, the use of hybrid maize steadily increased and credit packages stimulated the use of inorganic fertilisers. In intensive explicitly cash crop-oriented systems, inorganic fertilisers became even more important than manure in order to sustain soil fertility. However, the removal of agricultural subsidies in the 1990s caused the use of fertilisers to fall back to a low level. Research on fertilisers and pesticides is undertaken in Zimbabwe by private local and transnational companies (Scoones 2002 et. al).

The use of pesticides played, and still plays a major role in maintaining high levels of Zimbabwe's agricultural productivity. In addition to their use in agriculture, pesticides are also used to control diseases like malaria, nonhemorrhagic fever, African tryptopanosis (sleeping sickness), Glossina and typhoid. Especially OC pesticides have been used since the early 1960s to control tsetse fly and malaria vectors.

DDT was used in Zimbabwe from 1946 to 1983 to control tsetse fly and malaria vectors, as well as to control agricultural pests like maize stalkborer, cotton cutworm and cotton bollworm. In 1983 the use of DDT was restricted to control tsetse flies and mosquitoes only, as it was registered by the Ministry of Health as a chemical that can endanger humans and domestic and wild animals. Other OC pesticides registered to be used in agriculture comprise dieldrin, endosulfan, BHC, aldrin, chlordane, dicofol and chlorthaldimethyl.

Zimbabwe's primary agricultural commodity has been tobacco. Other important agricultural commodities are cotton, tea, citrus, livestock, wheat, sugar and maize. A major factor for the dispersal of pesticides from agricultural sites into the environment, are climatic conditions. Rain usually occurs in form of short, heavy tropical storms, resulting in highly erosive runoff during the rain periods as most pesticides are applied in agriculture e.g. between November and January. The erosive runoff leads to silting behind dams and much of the applied pesticides find their way directly into sediments of rivers and lakes. The accumulation of OC residues in sediments of lakes has been proven (Taylor 2003 et. al).

The vegetable production sector operated by small farmers also relies mainly on synthetic pesticides to protect primarily non-indigenous vegetables from a range of serious pests and diseases. Primary concerns about the application of pesticides in this field derive from shortcomings in protective clothing for applicators, large deviations from recommended doses and excessive runoff into the soil.

In 1972 a major problem concerning the application of persistent OC pesticides used to control tsetse flies in Zimbabwe was the impact pesticides had on wildlife, but evidence of a heavy build-up of DDT, DDE, DDD, BHC, dieldrin, aldrin and endosulfan from this activity could not be proven.

Nevertheless, evidence was found that agricultural spraying caused build-up of pesticides in terrestrial and aquatic environments. The highest levels of OC pesticide residues were found on agricultural land, though traces of DDD, DDE, and DDT were also found in eggs of crocodiles and the liver of elephants from game reserves, even though no agricultural activities take place in these areas (Taylor 2003 et. al).

In 1976, contamination of non-target species such as birds, reptiles, amphibians, fish and some mammals was noticed in the Zambezi River valley, following the aerial spraying of endosulfan against tsetse flies (Glin 2006).

The link between agriculture and the incidence of pesticide residues in wildlife was further supported by the fact that residues were found in the eggs of birds near the border with Botswana with very little agricultural activity. Bird eggs of black-headed heron, feeding on aquatic animals, from districts outside the tsetse control area, in contrast, contained pesticide residues. Furthermore pesticide residues were found in fish-eating birds in another region, living in basins receiving drainage from agricultural areas. These findings were supported by similar findings in 1980 with crocodile eggs. Chlorinated hydrocarbon residues were widespread in Zimbabwe. Crocodile eggs collected from several locations showed residues of DDT and its metabolites, with levels found to be related to land use practices. Toxaphene was also identified in crocodile eggs from cattle ranching areas and polychlorinated biphenyls were documented near industrial areas (Taylor 2003 et. al).

4.5 Future of African agriculture

Africa’s fertiliser application - with around 10 kg per ha - is very low compared to other continents. Calls have been made to create an *African Green Revolution*, similar to the one that led to the yield increases in Asia and Latin America. This time the effort is to be put on less favourable areas and crops that were missed out in the first Green Revolution. In order to increase the productivity of staple food, irrigation is also seen as critical. Farmers are encouraged to apply more synthetic fertilisers and high-yielding, disease-, pest- and drought resistant improved varieties have been introduced.

However intensive production techniques entail adverse environmental effects. Degradation of the environment by agriculture after the green revolution has been widely acknowledged. Now there are calls for a ‘doubly green revolution’ conserving natural resources and the environment while improving productivity (Williamson 2003 a et al.).

The *G8 Africa Action Plan* released at the G-8 summit 2002 in Kananaskis (Canada) stated that in order to protect the environment, the use of agricultural chemicals should be decreased. The Comprehensive Africa Agriculture Development Programme (CAAPD) initiated by the African Union (AU) and the New Partnership for Africa’s Development (NEPAD) states that productivity should be “increased on a sustainable basis by improved plant varieties adapted to local conditions, integrated plant nutrients and pest management systems with a minimum dependence on purchased inputs” (CAAPD 2003).

However, modern agricultural systems make pest management indispensable. In contrast to the highly diverse traditional systems, new simple cropping systems, usually maize and cassava-based monocultures without groundcover, promote the use of pesticides. Newly introduced genetically modified crops resistant to pests or tolerant to herbicides will further support this trend. (Pretty 2005). The reality is, however, that technologies are promoted, the long-term environmental impact of which remains unknown (Williamson 2003 a).

Concerning the process of global climate change, Africa was identified as one of the most vulnerable locations on the planet. Its climate is already warm and dry and its economy depends to a large extent entirely on agriculture. Therefore livelihoods and welfare of hundreds of millions of Africans depend on how climate change will affect African agriculture (World Bank 2008).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (AR4) predicts Africa to be especially affected by climate change owing to the range of projected impacts, multiple stresses and low adaptive capacity. Between 75 and 250 million people are projected to be exposed to increased water stress by 2020. Furthermore, in some countries, yields from rain-fed agriculture could be reduced by up to 50 per cent. Agricultural production, including the access to food, in many African countries is projected to be severely threatened. This would further adversely affect food security and aggravate malnutrition. In the densely populated African mega deltas, adaptation to the projected sea level rise towards the end of the 21st century as well as river flooding and storm surges could amount to at least five to ten per cent of GDP. Five to eight per cent of arid and semi-arid land in Africa is projected to increase by 2080. Southern Africa will suffer a decrease in water resources (IPCC 2007).

The fate of the African continent relies and will most likely continue to rely on its Agricultural productivity. It is needed to sustain the economies and to feed the growing population. However, African Agriculture is vulnerable, as it is threatened by drought, nutrient mining and hence decreasing soil fertility, growing livestock and pests. With the introduction of improved high yielding and more resistant varieties, African agriculture has changed and is increasingly dependent on pesticides. This is aggravated by the belief that pesticides are the way out of poverty, leading to an uncoordinated influx of pesticides from abroad resulting in large stocks of obsolete pesticides becoming an environmental hazard.

Structural adjustment programmes have put farmers under financial pressure. With rising prices for pesticides and fertilisers and the majority of farmers too poor to acquire them, productivity has declined. In order to cope with the decrease in productivity, the cultivated area is expanding. Few nature reserves provide refuge for wildlife like migratory birds. African authorities lack funds and manpower to assure pesticide quality and control the application of agrochemicals.

Particularly smallholders - representing the majority of African farmers - lack funds to acquire pesticides from official sources and increasingly turn to illicit markets. These are often selling highly dangerous pesticides that have not been tested for quality. Limited information and knowledge for various reasons leads to the application of wrong dosages, intervals that are too short or even improper pesticides.
The impact on the environment is noticeable. Biodiversity is declining, nutrient cycling depending on the turnover by the fauna is threatened and pesticide resistance is leading to a further increase in pesticide application.

The case studies confirm that pesticide pollution in Africa has taken and still takes place. They also confirm that farmers have limited knowledge about pests and the pesticides they apply, and that the application of pesticides that are proven to have adverse impacts on birds, is rising.

The description of the farming systems shows that African agriculture is not homogenous. It confirms the decline in productivity arising from market liberalisation, but information about the application of agrochemicals is limited. However, in North Africa it is the irrigated farming system that utilizes large amounts of pesticides, even leading to pesticide pollution of water. The rainfed mixed farming system in Northern Africa also employs excessive amounts of pesticides.

In Sub-Saharan Africa, the forest-based farming system is said to cause the destruction of wildlife habitats and the maize mixed farming system is said to suffer from soil acidity as a result of prolonged fertiliser application.

The future of African agriculture holds a great many challenges. On the one hand, a new *African green revolution* is planned, which, eager to avoid the mistakes of the green revolution in India and South America, will most likely transform the environment and hence have an impact on wildlife. On the other hand, the impact of global climate change is threatening the productivity of Africa’s agriculture and with it the livelihoods of millions of Africans.

5. Synopsis

This Chapter deals with the question of whether agrochemical application in Africa will have an impact on the environment and migratory waterbirds.

The information gathered for this entire study was derived entirely from publications and grey literature. Hence, conclusions made in this chapter cannot be interpreted as proof. They can rather be used as indictors for further empirical research. Overall, the data available at the time this thesis was written, must be considered insufficient to deliver scientific evidence. Hence, all conclusions remain highly assumptive.

Migratory bird numbers are declining by a rate of 1.3 per cent per year. A large proportion of AEWA species are declining. This can have various reasons which could be connected with the application of agrochemicals in Africa. The majority of the populations covered by AEWA in Africa reside at inland water bodies, such as wetlands. However, these are in decline, especially in the dry Sahel, where water is generally scarce and most of the Palaearctic migratory waterbirds winter. Furthermore, the majority of the AEWA species in Africa feed on insects. Agriculture is said to have shifted in most parts of Africa from traditional shifting cultivation to more intensive permanent cultivation. With the tropical climate promoting pests and new high yielding varieties being more susceptible than the traditional varieties, the application of pesticides, especially insecticides is on the rise. With the increased application of insecticides insect numbers are dwindling and insectivorous birds are most likely to be affected.

Nevertheless, with the ever-increasing human population, and aggravated by the extension of cultivated areas following the liberalisation of the African agricultural commodity markets and the resulting yield declines, natural habitats are being transformed into agricultural areas. The few existing nature reserves cannot offer sufficient refuge for wildlife and migratory waterbirds are likely to be increasingly expelled.

The impact of agrochemicals is most likely to be worsened by the fact that governmental agencies are under-resourced and understaffed. Policies to protect wildlife and environment are not implemented. Literature confirmed that banned pesticides were still being sold. Nearly all African states signed the Stockholm Convention against POPs. The data for the case studies was collected in 2003 and many countries described joined the Stockholm Convention in 2004. It is therefore necessary to verify, if the banned substances have really disappeared.

Smallholding farmers, often lacking education and knowledge, apply increasing amounts of pesticides classified by the WHO to be extremely and highly hazardous. They often apply the wrong pesticides on the wrong crops, like e.g. endosulfan, a cotton pesticide, on vegetables. This is acerbated by the fact that they lack funds to purchase their pesticides from official dealers and have to rely on petty dealers selling them low quality pesticides of unknown composition. Furthermore, the system of dealers who want to sell their products and farmers lacking knowledge, promotes increasing and sometimes unnecessary pesticide application. The fact that pesticide effectiveness is determined by the visibility of its impact e.g. the killing of earthworms and termites, which are imperative for the cycle of nutrients in tropical agro-ecosystems, further aggravates the situation.

The active substances, which the farmers featured in the case studies apply, correspond to the descriptions of pesticides with adverse impacts on birds. The farmers themselves state that the amounts of pesticides are increasing and the intervals between applications shortening. Still, because of the illicit trade applied, amounts cannot be determined and the amounts applied remain unknown.

If the farmers in the case studies are taken as examples for many other African farmers, it is most likely that migratory waterbirds are affected. Furthermore the case studies show that pesticide pollution is not a new problem, as it has also be taken place in the past.

The statistical analysis shows that most AEWA species are declining in northern Africa. This would correspond to the fact that high amounts of fertiliser application may cause eutrophication and hence deterioration of natural habitats. The greatest use of fertilisers appears to be in Egypt and Morocco, both lying in northern Africa. Furthermore, the irrigated and the rainfed mixed farming systems in northern Africa are described to employ excessive amounts of pesticides that even in the case of the irrigated farming systems, lead to water pollution.

The statistical analysis also shows that Palaearctic migrants are in stronger decline than Intra-African migrants. This could be explained by the fact that many Palaearctic migrants must refuel in the Sahel for their way back to Eurasia. As the environment of the Sahel is deteriorating, fewer birds are able to refuel sufficiently and do not survive the journey. Furthermore, if birds were intoxicated with pesticides, by e.g. feeding on pesticide- contaminated crops, these could accumulate in the fat tissue to be released during migration, intoxicating the birds while migrating.

All these findings support the hypothesis that the declining numbers of migratory waterbirds are caused, among other factors by agricultural expansion, intensification and hence an increasing application of agrochemicals.

It has been proven that incidents of drought in Africa decrease the numbers of migratory birds. The fact that the human activities are changing the environment either by direct action on-site like e.g. deforestation and overgrazing or indirectly by changing the climate in a long-term process, is going to make droughts a more widespread phenomenon in Africa. Despite the adverse impact of agrochemicals, man-made drought will be the greater killer of migratory waterbirds.

Last but not least, not just chemical residues and toxins from agriculture and industries cause poisoning of migratory waterbirds. Domestic garbage and also lead, deriving from rifle bullets causes migratory bird populations to decline (Olivier 2006). The usage of non-toxic ammunition provides the solution to mitigate this adverse effect of hunting (AEWA 2008).

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Annex I - Attempt of an analysis of the AEWA populations in Africa

This Chapter compiles the information available for 382 waterbird populations covered by AEWA for Africa. The Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) covers a geographical area from northern Canada and the Russian Federation to the southerrnmost tip of Africa. AEWA is an international Agreement covering 119 countries (64 have become contracting parties) to protect 255 species of birds depending on wetlands for at least part of the annual cycle.
As empiric data is missing, all findings are based on information from literature.

Information is derived from the 4th-Edition of the *Report on the Conservation Status of Migratory Waterbirds in the Agreement Area* (Delany 2008). In a second step, an attempt is made to perform a statistical analysis and to assess the correlation between the decline of bird populations in conjunction with their migration behaviour and their geographical distribution.

Material and Methods

Programs used for analysis were Microsoft Excel 98 and SPSS V.14.0 German. Information about population size, population trends, distribution, and migratory behaviour was derived from the 4th-Edition of the *Report on the Conservation Status of Migratory Waterbirds in the Agreement Area* (Delany 2008).

The alignment of populations into the five African geographical sub-regions takes place according to Annex 3 of the *AEWA - Agreement Text and Action Plan* (AEWA 2008).

Information about breeding time, feeding habits, habitats and time of residence in Africa was derived from the *Handbook of the Birds of the World* (Hoyo J. D. 1992).

Unfortunately, data about breeding time and time of residence in Africa was inconsistent as the Handbook of the Birds of the World could not provide the information for all AEWA species and were therefore disregarded.
The records were entered in Excel and summed up and visualised in block diagrams.
The Excel table was then transformed into an SPSS data sheet to be tested for significance with a Chi-square test.

The Chi-Square Test (written χ^2) is an inferential statistics technique designed to test significant relationships between two variables organised in a contingency table. The Chi-Square Test is a test of the Null Hypothesis. The Null Hypothesis (written H_0) states that no association exists between two cross- tabulated variables in a population, and therefore variables are statistically independent.
Contingency tabulation is a technique to analyse the relationship between two variables that have been organised in a table that displays the distribution of one table across the categories of another table.
To receive authentic results from the χ^2-Test, certain preconditions must be fulfilled (Frankfort-Nachmias 1997). One is that the expected frequencies in the particular tabulator field may not be too small, for SPSS this means not smaller than 5. Another one is that tables should not contain more than 5 fields. For each field of the table the squared variation (expected from actual frequency) is divided by the expected frequency. χ^2 results from the sum of quotients of all fields of the contingency table.

With n lines and m columns the calculation of χ^2 takes place with the following formula:

$$\chi^2 = \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{\left(n_{ij} - \hat{n}_{ij}\right)^2}{\hat{n}_{ij}}$$

Figure 9: Formula for the test of significance (Brosius 2004)

In this formula n_{ij} designates the observed frequency in a cell from line i and column j; the correlative anticipated frequency is n;^ $_{ij}$

The larger the deviation in a field of the table the larger is χ^2. The line and column numbers settle in the degrees of freedom. Degrees of freedom indicate in how many cells of the table frequency can be freely assigned within a marginal distribution. With χ^2 and the number of degrees of freedom, the χ^2 – test determines the probability, if the resulting divergence between observed and expected frequency can exist, even if there is no connection between the variables in the main unit. The common χ^2 – test is the Pearson Test. Its outcome is a number indicating the statistical significance. The bigger the number the more likely is the probability of error. The critical value lies usually at 5per cent; meaning it should not be higher than $\chi^2 = 0.05$ (Brosius 2004 et al.).

The significance test was applied in order to test the relationship between the variable indicating bird populations to decline in relation to geographic distribution, migratory behaviour, habitats and feeding habits to investigate probable characteristic patterns. Distributions within the three of the four entities turned out to be rather disproportionate, hence just two entities, namely migration behaviour and geographical distribution were further processed with SPSS.

A hierarchical cluster analysis (Ward method, binary data - pattern difference) was performed amongst the two data sets. The variables were the different sub regions (North, East, South, Central and West) or the two migratory patterns (Palaearctic and Intra-African) labelled by the different populations. The result was then summarised, being the “Group variable” with the “Declining variable”.

The numbers of birds declining within the cluster were counted and divided by the total amount of birds within the cluster. To avoid mistakes this procedure was performed with Excel. For the rest of the data sets the distribution within the variables was considered too unequal to receive valid results form a hierarchical cluster analysis.

Results

AEWA covers a total of 255 species. 217 species of migratory water birds are either resident or winter on the African continent. A total of 382 populations are reported to be resident in Africa by document AEWA/MOP 4.8 (Delany 2008).

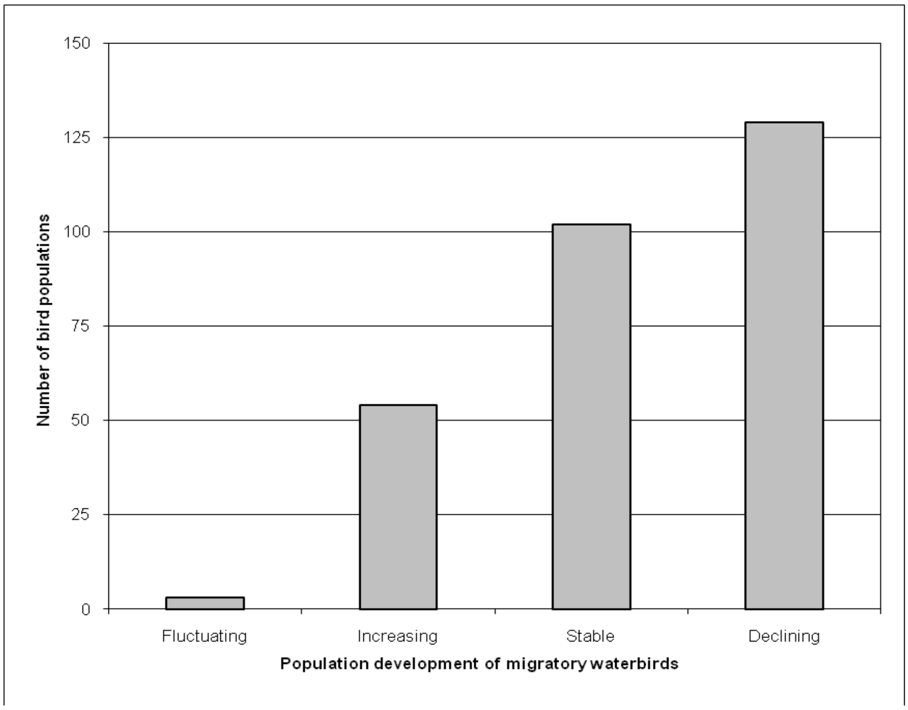

Figure 10: Status of population developments of birds covered by AEWA in Africa. More than twice as many populations are declining than increasing.

A total of 129 populations are declining, 102 are stable, 54 are increasing and 3 are fluctuating.

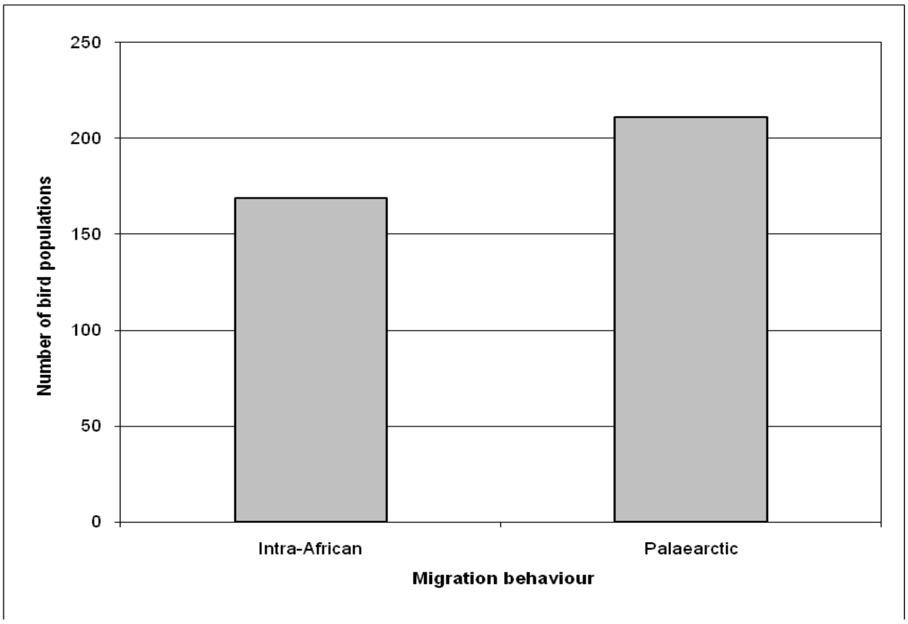

Figure 11: Numbers of Palaearctic and intra-African migrants within the 382 populations of migratory waterbirds covered by AEWA in Africa. The majority of the birds are Palaearctic.

A total of 211 populations are Palaearctic, meaning that they breed in the Northern hemisphere but migrate to the South in the winter months, and 169 are intra-African migrants, meaning that they remain on the African continent all year long and migrate just between different African countries.

Table 3: Overview of results concerning the test of significance of the migratory behaviour of birds covered by AEWA in Africa. The test holds true for both variables. Original contingency tables can be found in Annex II.

Migratory behaviour	**Variable 1**	**Variable 2**	χ^2
	Intra-African	Declining	0,004
	Palaearctic	Declining	0,034

The contingency tables concerning the feeding habits of the birds included in the AEWA species list do not indicate relations between the migratory behaviour and the numbers of birds declining.

Table 4: Relative frequency of the value declining = 1 from the hierarchical cluster analysis of the migration behaviour if 1. Frequency of declining numbers is higher among Palaearctic migrants.

Cluster	**Migratory behaviour**	**ratio**	**result**	**per cent**
1	Intra-African	47/172	0,273	27.3
2	Palaearctic	82/210	0,390	39

Palaearctic migrants seem to decline to a greater extent than intra-African migrants.

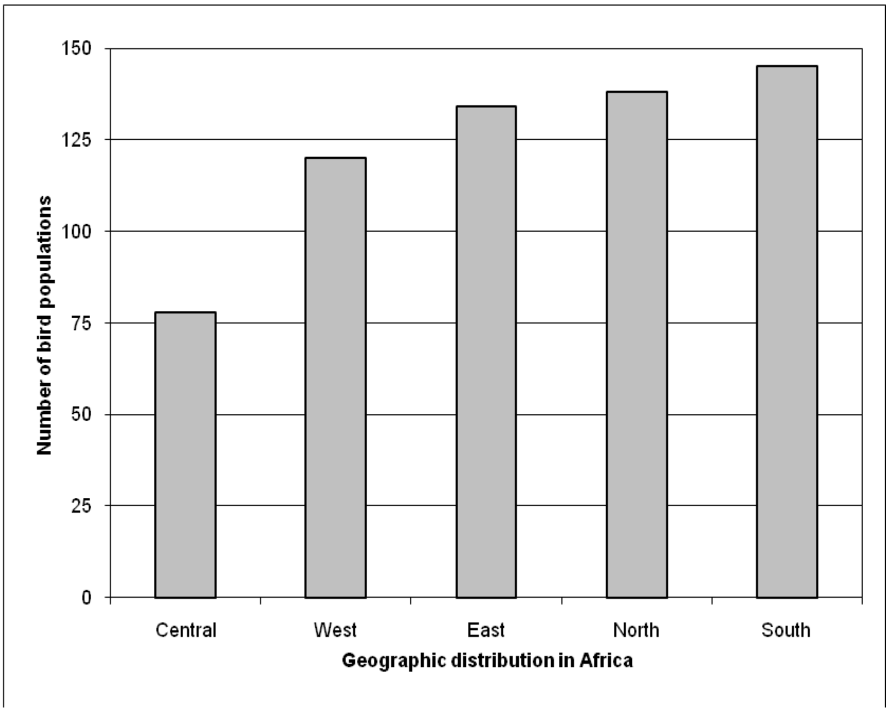

Figure 12: Occurrence of birds covered by AEWA in Africa in the five geographical African sub-regions. Occurrence of birds in Central Africa is significantly lower than in all other sub-regions. Occurrence in Southern Africa is nearly twice as high as in Central Africa.

A total of 145 populations can be found in Southern Africa, 138 in North Africa, 134 in East Africa, 120 in West Africa and 78 in Central Africa.

Table 5: Overview of results concerning the test of significance of the geographic distribution of birds covered by AEWA in Africa. The test does not hold true for data deriving from the variables of Central and West Africa.Original contingency tables can be found in Annex II.

Geographic Distribution	**Variable 1**	**Variable 2**	χ^2
	Central	Declining	0,475
	West	Declining	0,723
	East	Declining	0,036
	North	Declining	0,034
	South	Declining	0,046

Apart from the data from the variables for West and Central Africa, the contingency tables concerning the geographic distribution of the birds included in the AEWA species list do not indicate relations between the distribution among different geographic sub-regions and the numbers of birds declining. The test of significance has not been proven to be valid for data from the variable Central Africa. This may derive from the fact that numbers of bird populations within this variable are much lower. The test of significance has not been proven to be valid for data from the variable West Africa, either. This means that numbers of birds declining within this variable do not occur by coincidence. This might be an indication for a relationship between declining numbers of bird population and their residence in Western Africa.

Table 6: Relative frequency of the value declining = 1 from the hierarchical cluster analysis of the geographical cluster if 1. Frequency of declining numbers is highest in North Africa. High frequency of declining numbers in Central Africa is most likely to be related to low population numbers in this particular variable.

Cluster	Geographic sub-region	ratio	result	per cent
1	North Africa	52/129	0,403	40.3
2	East Africa	23/75	0,306	30.6
3	South Africa	21/87	0,241	24.1
4	West Africa	20/63	0,317	31.7
5	Central Africa	10/18	0,555	55.5

Populations in Northern Africa seem to be declining to a greater extent (40.3 per cent) than in other parts of Africa, even though declining numbers also amount to roughly a quarter of the total population, and more, in other parts of Africa. The high numbers of declining birds in Central Africa are most likely to be related to the much smaller sample size in this particular geographical sub-region.

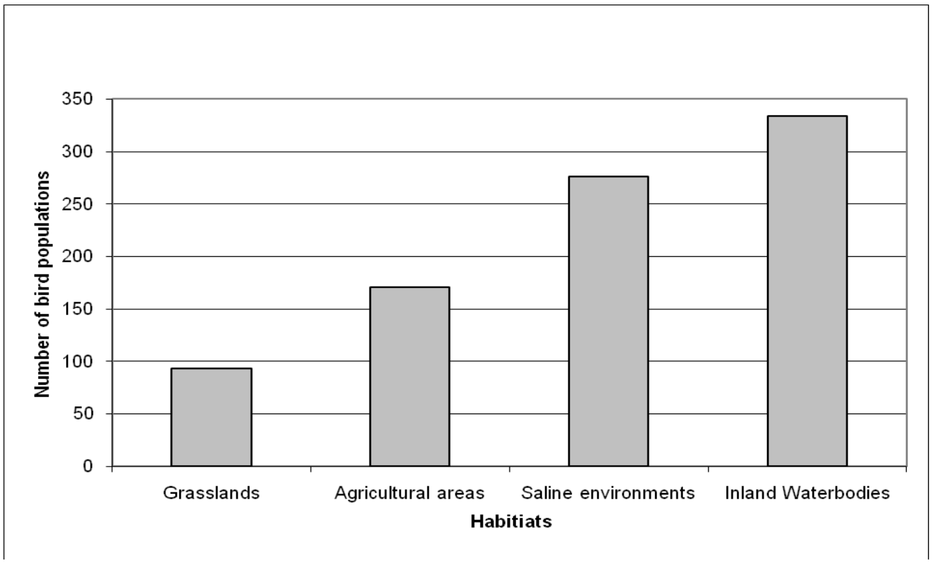

Figure 13: Occurrence of birds covered by AEWA in Africa in different habitats. Inland water bodies are of high importance for migratory waterbirds. Occurrence around inland water bodies is more than three times as high as in grasslands and nearly twice as high as in agricultural areas.

A total of 334 populations may inhabit inland water bodies, 93 populations settle in grasslands, 171 species occupy agricultural areas, 276 dwell in saline environments.

Table 7: Overview of results concerning the test of significance of the habitats of birds covered by AEWA in Africa. The test does not hold true for data deriving from the variables of inland water bodies, grasslands and agricultural areas. Original contingency tables can be found in Annex II.

Habitats	Variable 1	Variable 2	χ^2
	Grasslands	Declining	0,247
	Agricultural areas	Declining	0,115
	Saline environments	Declining	0,047
	Inland water bodies	Declining	0,946

The test of significance has not proven to be valid for data from the variable grasslands. This may derive from the fact that numbers of bird populations in this habitat are much lower than in other habitats. The test of significance has not been proven to be valid for data from the variable inland water bodies. This might be an indication for a relationship between declining numbers of bird population and this habitat, but may also derive from the fact that numbers of birds within this particular variable are much higher than in the other variables of this dataset.

The test of significance has not been proven to be valid for data from the variable agricultural areas. This might be an indication for a relationship between declining numbers of bird population and this habitat. For the variable saline environments, the contingency table does not indicate a relation to declining numbers of birds.

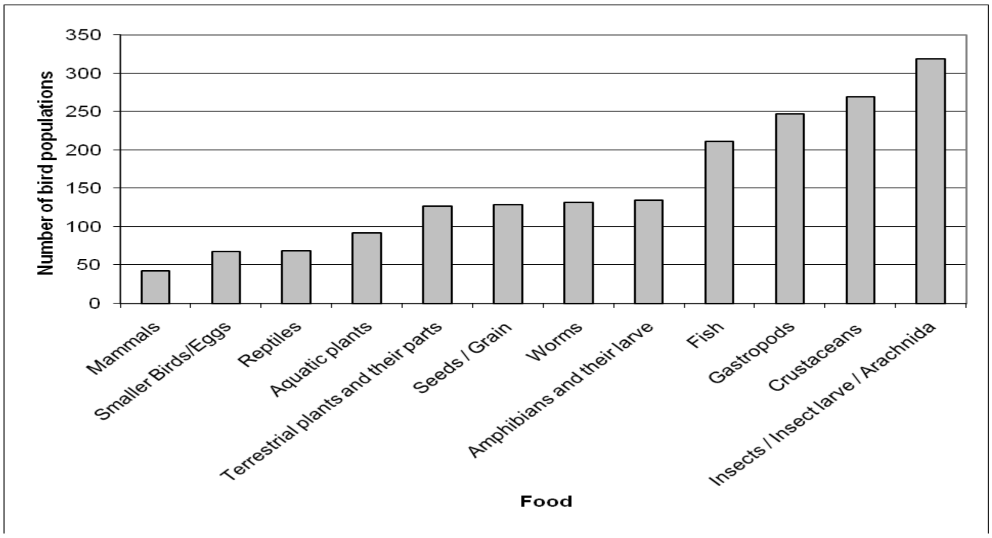

Figure 14: Ranking about the importance of feed for birds covered by AEWA in Africa. The most important feed for the majority of birds are insects, their larvae and arachnids, crustaceans, gastropods and fish.

A total of 319 populations feed on insects, arachnids and their larvae, 269 on crustaceans, 247 on gastropods 211 on fish, 134 on amphibians and their larvae, 131 on worms, 129 on plant seed and grain, 127 on terrestrial plants, 92 on aquatic plants, 68 on reptiles, 67 on smaller birds and their eggs, and 42 on mammals.

Table 8: Overview of results concerning the test of significance of feed of birds covered by AEWA in Africa. The test does not hold true for the majority of the variables. Original contingency tables can be found in Annex II.

Feeding habits	**Variable 1**	**Variable 2**	χ^2
	Mammals	Declining	0,450
	Smaller Birds/Eggs	Declining	0,859
	Reptiles	Declining	0,769
	Aquatic plants	Declining	0,212
	Terrestrial plants and their parts	Declining	0,011
	Seeds / Grain	Declining	0,054
	Worms	Declining	0,778
	Amphibians and their larvae	Declining	0,692
	Fish	Declining	0,355
	Gastropods	Declining	0,052
	Crustaceans	Declining	0,501
	Insects / Insect larvae / Arachnida	Declining	0,936

The majority of variables have failed the test for significance. This could derive from the fact that numbers of birds feeding on some food items are much larger than numbers feeding on others.

However, the test of significance has not been proven to be valid for data from the variable insects, their larvae and arachnids. The same applies to crustaceans, gastropods, fish, amphibians and their larvae, worms, seeds and grain, aquatic plants, reptiles, smaller birds and eggs and mammals.
This might be an indication for a relationship between declining numbers of bird population and these food items, but may also derive from the fact that numbers of birds feeding on them are very unequally distributed.

Discussion

The African continent is of high importance for the agreement because 217 of a total of 255 species covered by the agreement of migratory water birds are either resident or winter on the African continent. The different populations winter and reside all over Africa. A few can just be found in one geographical sub-region, some can be found in several geographical sub-regions. The different species colonise diverse habitats. Most of the populations can be found in several habitats (Delany 2008 et al.) along inland water bodies. Waterbirds feed on various animals and plants and their parts, mainly insects, crustaceans, gastropods and fish. The reason why this paper has been written is related to the fact that despite efforts to protect the 383 African populations, large numbers, specifically 129 populations, are declining.

Waterbirds living along inland water bodies seem to be declining to a greater extent than others residing in other habitats. Feeding on insects, arachnids and their larvae also seems to have a negative impact on the survival of waterbirds. But those findings may also, and most likely so, be connected to the fact that the majority of birds within these samples live along inland water bodies and feed on insects, their larvae and arachnids.

The outcome of the hierarchical cluster analysis shows high population declines in Northern Africa and Central Africa. According to the findings about Central Africa, two hypotheses can be made. Large areas of Central Africa are covered by tropical rainforest. These are almost completely avoided by Palaearctic migrants (Zwarts 2009). On the other hand numbers could have been higher before and have been decimated over time.

The migratory behaviour also seems to play a role concerning numbers of declining populations. The declining numbers of Palaearctic migrants are 10 per cent higher than the numbers of intra-African migrants. It is important to mention that all used data was derived from literature sources, most of them containing data going back ten years or more.

Different sources of literature generally offer different levels of accuracy. It is therefore questionable, whether these sources of literature can be compared because of these differences. The results of this chapter can, for that reason, not be taken as proof but as indicators for further scientific research.

Overall, the attempt of a statistical analysis has shown that the available data is insufficient to deliver scientific evidence. The statistical analysis has been most likely biased by unequal distribution of the sample sizes within the variables. All hypotheses need to be further investigated using empirical data.

Annex II - Original contingency tables

Original contingency tables analysing geographic distribution

Table 9: Original contingency table analyzing the variable for declining numbers of birds with the variable for North Africa; χ^2 indicate that there is no contingency between the two variables.

		Declining		Total
		0	1	
North	0	171	73	244
	1	82	56	138
Total		253	129	382

$\chi^2 = 0{,}034$

Table 10: Original contingency table analyzing the variable for declining numbers of birds with the variable for East Africa; χ^2 indicate that there is no contingency between the two variables.

		Declining		Total
		0	1	
East	0	155	93	248
	1	98	36	134
Total		253	129	382

$\chi^2 = 0{,}036$

Table 11: Original contingency table analyzing the variable for declining numbers of birds with the variable for Central Africa, χ^2 indicates contingency between the two variables.

		Declining		Total
		0	1	
Central	0	204	100	304
	1	49	29	78
Total		253	129	382

$\chi^2 = 0{,}475$

Table 12: Original contingency table analyzing the variable for declining numbers of birds with the variable for South Africa; χ^2 indicate that there is no contingency between the two variables.

		Declining		Total
		0	1	
South	0	148	89	237
	1	105	40	145
Total		253	129	382

$\chi^2 = 0{,}046$

Table 13: Original contingency table analyzing the variable for declining numbers of birds with the variable for West Africa, χ^2 indicates contingency between the two variables.

		Declining		Total
		0	1	
West	0	172	90	262
	1	81	39	120
Total		253	129	382

$\chi^2 = 0{,}723$

Original contingency tables analysing migratory behaviour

Table 14: Original contingency table analyzing the variable for declining numbers of birds with the variable for palaearctic migration; χ^2 indicate that there is no contingency between the two variables.

		Declining		Total
		0	1	
Palaearctic	0	123	48	171
	1	130	81	211
Total		253	129	382

χ^2 = 0,034

Table 15: Original contingency table analyzing the variable for declining numbers of birds with the variable for intra-African migration; χ^2 indicate that there is no contingency between the two variables.

		Declining		Total
		0	1	
Intra-African	0	128	85	213
	1	125	44	169
Total		253	129	382

χ^2 = 0,004

Original contingency tables analysing habitats

Table 16: Original contingency table analyzing the variable for declining numbers of birds with the variable for inland water bodies, χ2 indicates contingency between the two variables.

		Declining		Total
		0	1	
Inland water bodies	0	32	16	48
	1	221	113	334
Total		253	129	382

χ^2 = 0,946

Table 17: Original contingency table analyzing the variable for declining numbers of birds with the variable for grasslands, χ^2 indicates contingency between the two variables.

		Declining		Total
		0	1	
Grasslands	0	196	93	289
	1	57	36	93
Total		253	129	382

χ^2 = 0,247

Table 18: Original contingency table analyzing the variable for declining numbers of birds with the variable for agricultural areas, χ^2 indicates contingency between the two variables.

		Declining		Total
		0	1	
Agricultural areas	0	147	64	211
	1	106	65	171
Total		253	129	382

χ^2 = 0,115

Table 19: Original contingency table analyzing the variable for declining numbers of birds with the variable for saline environments; χ^2 indicate that there is no contingency between the two variables.

		Declining		Total
		0	1	
Saline environments	0	62	44	106
	1	191	85	276
Total		253	129	382

$\chi^2 = 0{,}047$

Original contingency tables analyzing food

Table 20: Original contingency table analyzing the variable for declining numbers of birds with the variable for fish, χ^2 indicates contingency between the two variables.

		Declining		Total
		0	1	
Fish	0	109	62	171
	1	144	67	211
Total		253	129	382

$\chi^2 = 0{,}355$

Table 21: Original contingency table analyzing the variable for declining numbers of birds with the variable for insects, their larvae and arachnida, χ^2 indicates contingency between the two variables.

		Declining		Total
		0	1	
Insects / Insect larvae / Arachnida	0	42	21	63
	1	211	108	319
Total		253	129	382

$\chi^2 = 0{,}936$

Table 22: Original contingency table analyzing the variable for declining numbers of birds with the variable for worms, $\chi 2$ indicates contingency between the two variables.

		Declining		Total
		0	1	
Worms	0	165	86	251
	1	88	43	131
Total		253	129	382

$\chi^2 = 0{,}778$

Table 23: Original contingency table analyzing the variable for declining numbers of birds with the variable for gastropods, χ^2 indicates slight contingency between the two variables.

		Declining		Total
		0	1	
Gastropods	0	98	37	135
	1	155	92	247
Total		253	129	382

$\chi^2 = 0{,}052$

Table 24: Original contingency table analyzing the variable for declining numbers of birds with the variable for crustaceans, χ^2 indicates slight contingency between the two variables.

		Declining		Total
		0	1	
Crustaceans	0	72	41	113
	1	181	88	269
Total		253	129	382

$\chi^2 = 0{,}501$

Table 25: Original contingency table analyzing the variable for declining numbers of birds with the variable for amphibians and their larvae, $\chi 2$ indicates contingency between the two variables.

		Declining		Total
		0	1	
Amphibians and their larvae	0	166	82	248
	1	87	47	134
Total		253	129	382

$\chi^2 = 0{,}692$

Table 26: Original contingency table analyzing the variable for declining numbers of birds with the variable for smaller birds and eggs, $\chi 2$ indicates contingency between the two variables.

		Declining		Total
		0	1	
Smaller Birds/Eggs	0	208	107	315
	1	45	22	67
Total		253	129	382

$\chi^2 = 0{,}859$

Table 27: Original contingency table analyzing the variable for declining numbers of birds with the variable for mammals, $\chi 2$ indicates contingency between the two variables.

		Declining		Total
		0	1	
Mammals	0	223	117	340
	1	30	12	42
Total		253	129	382

$\chi^2 = 0{,}450$

Table 28: Original contingency table analyzing the variable for declining numbers of birds with the variable for reptiles, $\chi 2$ indicates contingency between the two variables.

		Declining		Total
		0	1	
Reptiles	0	209	105	314
	1	44	24	68
Total		253	129	382

$\chi^2 = 0{,}769$

Table 29: Original contingency table analyzing the variable for declining numbers of birds with the variable for seed and grain, χ^2 indicates slight contingency between the two variables.

	Declining		Total
	0	1	
Seeds / Grain 0	176	77	253
1	77	52	129
Total	253	129	382

$\chi^2 = 0{,}054$

Table 30: Original contingency table analyzing the variable for declining numbers of birds with the variable for terrestrial plants and their parts; χ^2 indicate that there is no contingency between the two variables.

	Declining		Total
	0	1	
Terrestrial plants and their parts 0	180	75	255
1	73	54	127
Total	253	129	382

$\chi^2 = 0{,}011$

Table 31: Original contingency table analyzing the variable for declining numbers of birds with the variable for aquatic plants, χ^2 indicates contingency between the two variables.

	Declining		Total
	0	1	
Aquatic plants 0	197	93	290
1	56	36	92
Total	253	129	382

$\chi^2 = 0{,}212$

Annex III - Farming systems of Africa

Farming systems of North Africa

North Africa consists predominantly of arid and semi-arid areas with low and variable rainfall. A few more humid areas have a Mediterranean climate, which is characterised by long, dry summers and mild, wet winters. Even though these moderately humid zones account for less than 10 per cent of the land area, they are home of nearly half of the agricultural populations, unlike the drier areas that account for nearly 90 per cent of the land area but are inhabited by just 30 per cent of the populations. Centres of populations in the drier areas often lie dispersed in intensively irrigated areas (FAO 2001 et. al).

Rainfed crops are only grown during the wetter winter period, in contrast to irrigated areas that allow year-round cultivation. The main rainfed crops are wheat, barley, legumes, olives, grapes, fruit and vegetables. A wide range of subtropical crops, including fruit and vegetables, are grown in the summer months under irrigation. Livestock, such as sheep and goats play a crucial role in many farming systems as they provide key linkages between different systems (FAO 2001 et. al).

Since 1961 cultivated land has expanded by 14 per cent and within the same period cropping intensity has increased by over 15 per cent. The use of cultivated land is expected to expand further until 2030. Newly cultivated land, however, will often be seriously constraint by climate, slope or poor soils. Hence access to land will become increasingly difficult over the coming years and the expected cultivation of marginal land will lead to significant environmental degradation. The aridity of the region necessitates irrigation to be the principal means of agricultural intensification.
Until 2030 crop production growth is projected at 1.7 per cent per annum and current fertiliser consumption is projected to rise gradually (FAO 2001 et. al). Compared to other developing areas of the world North Africa can be considered as not a particularly impoverished zone. However, poverty is much more widespread in rural than in urban areas and crop failures, resulting from droughts, pests, or the failure of the annual flood in the Nile Valley may still threaten rural areas with malnutrition (FAO 2001).

The FAO distinguishes between seven farming systems in North Africa:

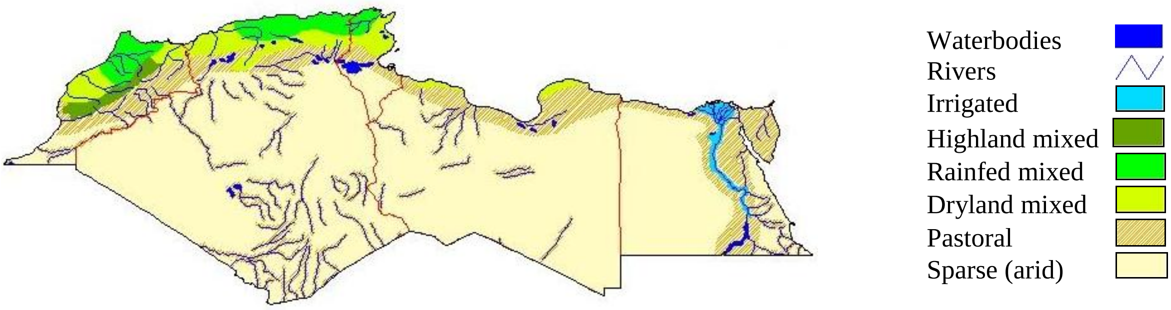

Figure 15: Map of the farming systems in Northern Africa (FAO 2001)
Smal-scale irrigation system, coastal artisanal fishing system and urban based farming system are not mapped, as they are highly dispersed or too small

The FAO distinguishes between seven farming systems in North Africa:

Irrigated farming system
Considering the arid and semi-arid environment of North Africa, the irrigated farming system has always been of crucial importance for this region. Large- and small-scale irrigation schemes produce a significant amount of Northern Africa’s food. The irrigated agricultural areas are densely populated but farms are generally very small. Poverty within the large- and small-scale irrigation schemes is moderate (FAO 2001 et. al).

Large-scale irrigated systems can be found along major river systems and downstream from dams. They allow intensive year round cropping. In recent years, privately financed and operated new large-scale irrigation schemes have emerged. They grow high-value crops for export, using water from tubewells and distributing it through sprinkler or trickle systems. Within the large-scale farming system, patterns of water use vary greatly throughout the region. However, perennial surface water resources are seldom used efficiently. The high volume of water extracted from deep aquifers is contributing to declining water tables as the rate of extraction exceeds the rate of recharge. Measures are now being promoted in order to reduce crop demand for water through rationing or switching to crops with a lower water requirement.

Inappropriate policies on water pricing and centralised management have resulted in significant economic and environmental externalities, such as excessive utilisation of non-recharged aquifers or excessive application of irrigation water resulting in rising groundwater tables, soil salinisation and sodisation problems. The costs of seed, fertiliser, pesticide and energy still exceed the costs of water. However, as an intensive farming system, the large-scale irrigated system's high use of fertilisers and pesticides is also affecting the water quality (FAO 2001 et. al).

Small-scale irrigated systems are not as important as the large-scale systems. They involve smaller numbers of people and produce smaller amounts of food and other crops. Although, small-scale irrigated systems are a significant element for the survival of many people living in arid and remote mountain areas. Very small units of land (0.02 – 1 ha) are farmed often within the boundaries of larger, rainfed farming systems and can therefore be seen usually as part of the rainfed farming system. The plots typically contain fruit trees and intensively grown vegetables. Small-scale irrigated systems are often found in isolated areas and provide food and other products primarily for local markets.

Amongst the crucial issues the small-scale irrigated systems face are water shortages and food deficits (FAO 2001 et. al).

Highland mixed farming system

The Highland mixed farming system is the most important system in terms of population. It is called a mixed farming system because of its two sub-systems that both comprise more than just one form of agriculture and depend on the exploitation of high altitude arable and grazing lands where cold winters lead to dormancy or very slow growth of crops and fodder species.

The first sub-system is dominated by rainfed cereal and legume cropping together with tree crops, fruits, olives on terraces together with vines. The cereals, mostly wheat and barley are adapted to survive under snow and withstand cold weather periods. Cereals are cultivated primarily in monocultures with occasional fallow periods. Fruit trees, olives and vegetables are planted on terraces along high-altitude slopes that were created several thousand years ago. The terraces are sometimes irrigated in the summer months to sustain high value fruits and crops such as melons.

The second sub-system is based primarily on animal husbandry, specifically the raising of livestock, predominantly sheep on communally managed lands. The highland mixed system is prone to poverty, as markets are often distant, infrastructure is poorly developed and degradation of natural resources is a serious problem. Furthermore continuous cropping and low nutrient returns result in declining soil fertility in some areas. Where livestock is present, overgrazing has also contributed to soil degradation. Scarcity of drinking water, for both humans and animals is one of the most serious problems of the system (FAO 2001 et. al).

Rainfed mixed farming system

The rainfed mixed farming system is by definition principally rainfed, but an increasing area is now benefitting from new drilling and pumping technologies, which make it possible to irrigate plots supplementarily in winter and even fully in summer. The agricultural system is dominated by tree crops, such as olives, fruit trees, nut trees and grapes. These are intercropped with cereals, vegetables and melons while the trees are immature. When the trees are mature they become a monoculture.

Crops are grown in summer followed by a winter fallow. Common crops are wheat, barley, lentils, chickpeas, sugarbeet, faba beans and fodder crops such as vetches and alfalfa for cattle. Some crops such as potatoes, vegetables and flowers are grown to access the specialised markets of Northern Europe and need special attention. They are often grown within polythene tunnels and with supplementary irrigation.

Yet, the rainfed mixed farming system faces several issues. The population density within the system is rising and global influence on the system is increasing. Quality land faces an increasing number of small farmers, resulting in over-cultivation of the light soil, which. as a result is prone to soil erosion on slopes during rainstorms and wind. The result of erosion is the loss of land for agriculture. Furthermore the system suffers from the imports of subsidised cereals obviating the access to markets. As a result, subsistence farming is declining and large-scale commercial interests are involved in high-input agriculture of export crops and livestock. This has resulted in major negative environmental impacts, such as frequent deep ploughing, excessive water extraction for irrigation and the excessive use of pesticides (FAO 2001 et. al).

Dryland mixed farming system
The dryland mixed farming system can be found in dry subhumid areas receiving just 150 to 300 mm of rainfall a year. Rainfed barley and wheat are grown in rotation with an annual or two-year fallow. The risk of drought is high and food insecurity is considerable. Cattle and small ruminants interact strongly with cropping and fodder cultivation. The local variety of barley is well adapted to the system. In good years, the rainfed barley can be grown for the grains, but with insufficient rainfall barley remains immature and is then fed as fodder to livestock. Access to water is constrained, linkages to markets are poor and poverty within the system is widespread (FAO 2001 et. al).

Pastoral farming system
The pastoral farming system consists of large sparsely populated semiarid steppe lands that are used for grazing of mainly sheep and goats but also cattle and camels, with small dispersed patches of irrigated cropland. Seasonal migration of the livestock herds is particularly important for the pastoral farming system in order to minimise risks and depends on the availability of grass, water and crop residues in neighbouring farming systems.

Pastoral systems are important. They are an important link between the major farming systems in the region and satisfy the continually growing demand for meat. However, the central long-term problem the pastoralists face is desertification. Total rainfall is the foremost limiting factor in the dry rangelands. Drought limits rangeland productivity and affects species diversity and hence feed quality in a negative way. Heavy grazing is also degrading land and vegetation. Nevertheless, for most of the year, livestock densities in arid and semiarid zones are above the potential carrying capacity of the land. These are also the areas where most of the desertification takes place. Poverty of the pastoralists and farmers within the system is extensive (FAO 2001 et. al).

Sparse (arid) farming system
The sparse or arid farming system covers a vast area of Northern Africa. The agricultural population lives in oases and a number of irrigation schemes growing irrigated crops, such as dates and other palm trees, vegetables and fodder for cattle, sheep, goats and camels. Boundaries between opportunistic grazing of livestock and sparse agricultural plots are indistinct and depend on climatic conditions. Population pressure is limited and for this reason poverty is generally low (FAO 2001 et. al).

Coastal artisanal fishing system
The coastal artisanal fishing system is one of the oldest in the region. For thousands of years small-scale artisanal fishermen have lived along the Mediterranean coast and the coast of the Atlantic Ocean. Their income derives from the selling of fish and is supplemented by small-scale crop and livestock production. However, modern technology and the offshore fishing industry have diminished the system (FAO 2001 et. al).

Urban based farming system
The urban-based farming system consists of urban residents that engage in small-scale horticultural production of fruit and vegetables and small-scale livestock production in feedlots e.g. poultry. As cities are growing and food demand is rising, the urban-based farming system may become increasingly important in coming decades (FAO 2001 et. al).

Farming systems in Sub-Saharan Africa

The African continent south of the Sahara comprises several AEZs. The arid and semi-arid AEZ encompasses 43 per cent of the land, the dry subhumid AEZ 13 per cent and the moist subhumid and humid AEZ 38 per cent (FAO 2001). Agriculture is imperative for Sub-Saharan Africa. About a quarter of the potential agricultural area - to be precise - 173 million ha of 2455 million ha total land area, are under annual cultivation or permanent crops. Agriculture is the main source of livelihood for poor people, employing 67 per cent of the total labour force and accounting for 20 per cent of the region's GDP. Agriculture is the dominant export sector for East Africa, accounting for 47 per cent of total exports and a significant source of exports in other regions, such as South Africa with 14 per cent and West Africa with 10 per cent. Main agricultural export commodities are cocoa, coffee and cotton.

The area under cultivation is slowly increasing by 0.73 per cent, mostly through conversion of forest and grasslands into agricultural areas and shortening of fallows (FAO 2001 et. al). The area affected by land degradation is also increasing. Soil erosion, soil compaction, reduced soil organic matter and declining soil fertility and soil biodiversity are evident in the majority of all farming systems. However, degradation is particularly notable within Highland perennial and Highland temperate farming systems, where high population densities are placing a strain on the land (FAO 2001 et. al).

Despite the declining soil fertility, consumption of inorganic fertiliser is very low. The total consumption of fertiliser is at 1.3 million tons of nutrient, which is an equivalent of only 8 kg/ha compared to 107 kg/ha in all developing countries. The use of compost and other soil amendments cannot compensate for the low levels of fertiliser use. Farmers are confronted with poor access to many agricultural inputs, such as fertilisers, pesticides and improved seeds, as well as uncertain prices for grain. This is because structural adjustment programmes, which have been implemented in many countries, have conferred macroeconomic stability on many economies but deteriorated terms of trade. Sub-Saharan Africa suffered massive losses from the decline of its share in world trade.

In the coming three decades, the population of Sub-Saharan Africa is projected to increase by 78 per cent. The region has the highest proportion of people living in dire poverty in the world. Rural poverty accounts for 90 per cent of the total poverty and approximately 80 per cent of the poor depend on agriculture or farm labour for their livelihood (FAO 2001 et. al).

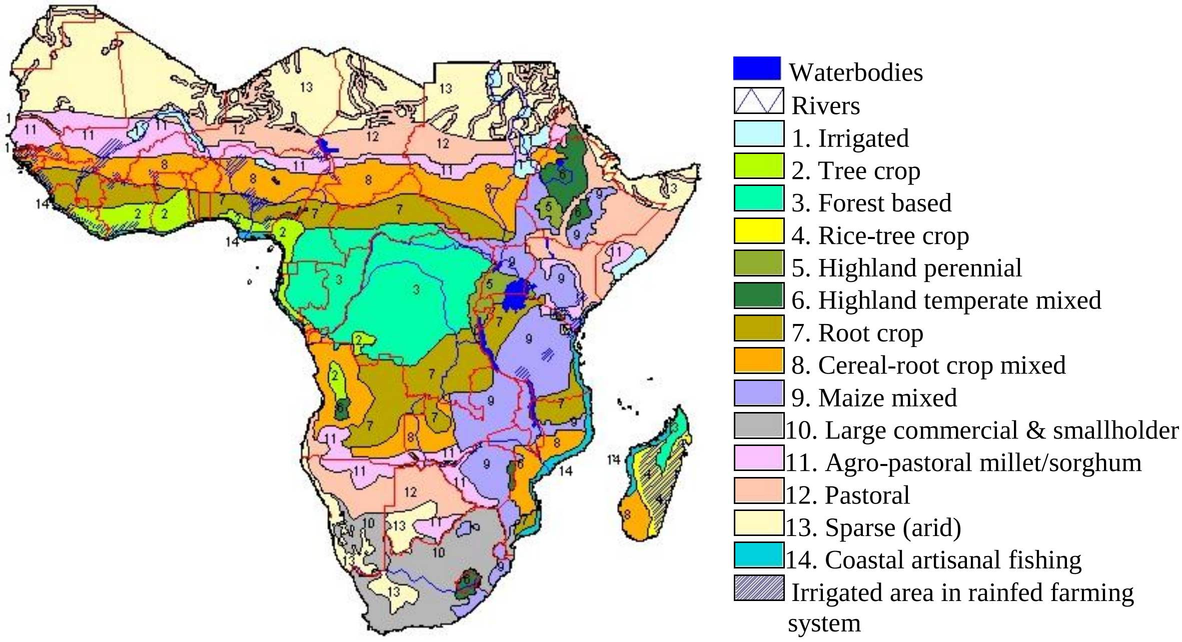

Figure 16: Map of the farming systems in Sub-Saharan Africa (FAO 2001). The urban based farming system is not mapped, because the areas are too small

The FAO distinguishes between fifteen farming systems in Sub-Saharan Africa:

Irrigated farming system

The irrigated farming system in Sub-Saharan Africa comprises large-scale irrigation schemes, extensive riverine and flood recession-based irrigation. Irrigated agriculture is still not widespread. Just 1.4 per cent of the land area of Sub-Saharan Africa is irrigated by (mostly) state-run schemes. The main crops are rice, cotton and vegetables. Irrigation agriculture is in most cases supplemented by rainfed agriculture or animal husbandry e.g. with cattle or poultry.

The size of the irrigated holdings may vary from 1 - 22 ha and crop failure is generally not a problem. However, the livelihoods of farmers are vulnerable to water shortages, breakdowns of irrigation schemes and deteriorating prices of commodities. Incidences of poverty are lower than in other farming systems (FAO 2001 et. al).

Tree crop farming system

The tree crop farming system is widespread in the warm humid AEZ. It stretches from Côte d'Ivoire to Ghana, from Nigeria and Cameroon to Gabon and can also be found in to a smaller extent in Congo and Angola. Industrial tree crops, such as cocoa, coffee, oil palm and rubber are grown and intercropped with food crops such as cassava, yams and cocoyam, which, in contrast, to the tree crops are cultivated for subsistence. Livestock keeping is limited due to tsetse infestation in many areas and fields have to be prepared by hand.

The system was originally developed by indigenous farmers. Each year, a household would have cleared a patch of forest the size it managed to cultivate (about 0.5 - 1 ha). After one or two years, however, the labour force of one family would not be sufficient to manage both the plots prepared the year before and the newly cleared land. Therefore farmers contracted immigrant farmers from the Savannah zone to take care of their second and third year coffee gardens in exchange for the right to intercrop food crops among the trees. Once the tree canopy closes light becomes too scarce for certain food crops but the fruit of the tree crops is then ready to be harvested and enough to pay for hired labour.

However, today's commercial tree crop farming system stands in sharp contrast to the indigenous system. A minimum plot size of around 5 ha is set and farmers are expected to establish an entire area in a single year. This may force farmers into debt and makes, as staggered planting was abandoned, the crops more susceptible to pests and diseases.

Nevertheless, tree crops and food crop failure is uncommon and the extent of poverty can be described as being limited to moderate, but concentrated among very small farmers and farm workers.

In recent years the use of mineral fertilisers and agrochemicals declined because of high prices, low profitability and lack of credit, as governmental input supply and marketing services have been dismantled and terms of trade have worsened. As a consequence some tree crops have been neglected and demand for hired labour has decreased. The result has been increasing poverty and growing social conflict between crop growers and migrant workers, especially in Côte d'Ivoire (FAO 2001 et. al).

Forest based farming system

The forest-based farming system can be found in humid forest areas of the Congo Democratic Republic, the Republic of Congo, Southeast Cameroon, Equatorial Guinea, Gabon, Southern Republic of Tanzania, as well as in the northern tips of Zambia, Mozambique and Angola.
Within the system, farmers are practising shifting cultivation. Trees are cut down every year in order to clear a new field from forest. The field is cultivated for two to five years with cereals or groundnuts in the beginning and later with cassava and then abandoned for seven to twenty years to bush fallow, allowing the natural vegetation to return.

However, with increasing population densities, fallow periods are progressively being reduced, causing soil depletion and destruction of wildlife habitats. The main staple of the farmers within the system is cassava, which is complemented by maize, sorghum, beans and cocoyam. Amounts of cattle and ruminants are low. Poverty within the system is widespread. The main sources of cash are forest products and wild game, which are both in short supply (FAO 2001 et. al).

Rice-tree crop farming system

The rice-tree crops farming system can be found in the moist subhumid and humid AEZs of Madagascar. Farm sizes are small and a significant amount of the plots is irrigated. Banana and coffee are grown and complemented with rice, maize, cassava and legumes. Numbers of cattle are relatively low. Despite small farm sizes, shortages of appropriate technologies and poor development of markets are incidences resulting in moderate poverty (FAO 2001 et. al).

Highland perennial farming system

The highland perennial farming system can be found in the humid and subhumid AEZs of Ethiopia, Uganda, Rwanda and Burundi. With more than one person per ha of land it supports the highest rural population density. Agricultural plots are very small and land use is very intense, as more than 50 per cent of the plots are smaller than 0.5 ha. Perennial crops, such as banana, plantain, enset (*Ensete ventricosum*) and coffee are grown and complemented by cassava, sweet potatoes, beans and cereals. Cattle are kept for milk, manure, bride wealth, savings and social security. The system is suffering from diminishing farm sizes, declining soil fertility, shortages of appropriate technologies, increasing poverty and hunger (FAO 2001 et. al).

Highland temperate farming system

The highland temperate farming system can be found in the subhumid and humid AEZs at altitudes between 1800 and 3000 metres in the highlands and mountains of Ethiopia and to a lesser extend in Eritrea, Lesotho, Angola, Cameroon and Nigeria. Average farm sizes are small and the average population densities are high. The main staples are small grains, such as wheat and barley complemented by peas, lentils, broad beans, rape, teff (in Ethiopia) and potatoes. Cattle are kept for ploughing, milk, manure, bride wealth, savings and emergency sale. The main sources of income are the sale of sheep and goats, wool, local barley beer, potatoes, pulses and oilseeds. The crops are typically grown during a single cropping season, although some parts of Ethiopia have a second, but shorter cropping season.

Nevertheless, the farming system is facing major problems. Soil fertility is declining because of erosion and shortage of biomass and cereal production is suffering from a lack of inputs. Crop failures are common in cold and wet years and early and late frosts at high altitudes may severely reduce yields. The farmers have to weather through a hungry season from planting time until the main harvest. Incidences of poverty are moderate to widespread (FAO 2001 et. al).

Root crop farming system
The root crop farming system is performed in moist subhumid and humid AEZs. It extends from Sierra Leone to Côte d'Ivoire, Ghana, Togo, Benin, Nigeria and Cameroon. On the southern wetter side, the system is confined by tree crop and forest based farming systems. On the northern dryer side the system is confined by cereal-root crop mixed farming systems. Similar conditions and systems can also be found in Central and Southern Africa and on the south side of the forest zone e.g. in Angola, Zambia, southern Republic of Tanzania, northern Mozambique and in a small area in southern Madagascar.

As rainfall occurs either twice a year or almost continuously, the risk of crop failures is low. Great numbers of cattle (17 million) are kept and incidences of poverty are limited to moderate (FAO 2001 et. al).

Cereal-root crop mixed farming system
Cereal-root crop mixed farming is applied in the dry subhumid AEZ. It extends from Guinea through Northern Côte d'Ivoire to Ghana, Togo, Benin and the mid-belt states of Nigeria to Northern Cameroon. Similar zones exist in Central and Southern Africa. The system is quite similar to the maize mixed farming system but differs in lower altitude, higher temperatures, and lower population densities, higher numbers of households, and poorer transport and communications infrastructure.

Cereals such as maize, sorghum and millet are grown, if animal traction is available. If not, as for example, the presence of tsetse flies limits livestock numbers and prevents the use of animal traction, root crops such as yams and cassava are more important than cereals. Furthermore, a wide variety of different other crops is intercropped and marketed. The system is vulnerable to drought but incidences of poverty are limited, and the extent of poverty is modest (FAO 2001 et. al).

In systems in the northern part of the area, long-lasting mechanisation of land preparation resulted in the loss of organic matter and soil structure. Soil fertility in all systems is declining and soil acidity is increasing, sometimes associated to prolonged use of inorganic fertilisers. Although, price liberalisation and falling input/output ratios have caused application of mineral fertilisers to decline, farmers face difficulties in maintaining soil fertility and weeds such as *Striga gesnerioides*, a parasitic plant, have become more difficult to control (FAO 2001 et. al).

Since the abandonment of governmental agricultural programmes which supplied farmers with seeds, fertilisers and agrochemicals, farmers have found it risky to purchase fertilizers and agrochemicals. As a consequence, productivity declined and pests and diseases flared up (FAO 2001 et. al).

Maize mixed farming system
The maize mixed farming system is the most important system for food production in East and Southern Africa. It expands at altitudes of 800 to 1500 metres across the highlands and plateaus of Kenya and the Republic of Tanzania to Zambia, Malawi, Zimbabwe, South Africa, Swaziland and Lesotho. The climate may vary from dry subhumid to moist subhumid and rainfalls typically occur once a year, in some areas twice a year.
Local varieties and hybrid maize and minor crops such as pulses and oilseed are grown both for subsistence and as cash crops. Additionally, coffee, tobacco, groundnuts and sunflowers are grown as cash crops.

Cattle are very important for the system as they are integrated into the routine of the farming system. The traction power of oxen is used to prepare the land and bovine dung is collected to be used as manure. Animals are increasingly fed in stables with crop residues supplemented by cut fodder from fodder trees, hedges and forage plots. It is worth mentioning that although the livestock density is quite high within the system, most farmers cannot afford to keep more than two oxen and one milking cow plus maybe one or two calves or heifers.

Smallholder maize production in East and Southern Africa was subsidised by governments with high quantities of inorganic fertilisers and hybrid maize varieties. With the liberalisation of markets and prices, the subsidies on inputs became uneconomic. Since smallholder input credit and market services collapsed, smallholders have been struggling to adjust to rising prices of inputs and declining prices of maize.

The differences in the wealth of farmers are significant. Wealthier families own better farmland, better varieties of cattle and larger areas with cash crops. Fields are sometimes irrigated on medium and larger farms and more hybrid seeds, fertilisers and agrochemicals are used.

Poorer families in contrast are landless or own small plots (less than 0.5 ha), they often have no cattle (40 per cent of all households) nor high value crops and off-farm income. These are farmers often suffering from food deficits. Soil fertility is declining and soil acidity is increasing where there has been prolonged application of mineral fertilisers. Land degradation is spreading and hence crop yields are declining. Chronic poverty is likely to increase, which, in turn, increases the risk of disastrous famines in the case of droughts (FAO 2001 et. al).

Large commercial and smallholder farming system
Large commercial and smallholding farms can be found across the northern part of the Republic of South Africa and the southern part of Namibia, in mostly semiarid and dry subhumid zones. Two particular kinds of farms can be distinguished; they are either scattered smallholdings or large-scale commercial farms. Both kinds of farms administrate a cereals-livestock system, with maize dominating the north and east, and sorghum and millet dominating the west. Additionally cattle and small ruminants are kept. However, the farming system suffers from poor soils and is prone to droughts. The overall prevalence of poverty is moderate, but chronic and intensive poverty exists among smallholding families (FAO 2001 et. al).

Agro-pastoral millet/sorghum farming system
The agro-pastoral millet/sorghum farming system can be found in semiarid AEZs of West Africa from Senegal to Niger and also in large areas of East and Southern Africa from Somalia and Ethiopia to South Africa. The soil is usually prepared with the help of oxen or camels, or with a hoe if the plots lie along river banks. The main sources of food are rainfed sorghum and pearl millet and hence they are rarely sold. Sesame and pulses which are also grown are, in contrast to Sorghum and Millet, sometimes sold.

Keeping of livestock is of equal importance to the farmers. Large amounts of cattle (25 million) and sheep and goats are kept. Livestock is kept for various reasons. For subsistence, as it provides farmers with milk and milk products, as means of land preparation e.g. oxen and camels, means of transportation e.g. camels and donkeys, breeding, means of sale and exchange, savings, bride wealth and insurance against crop failure.

The system is vulnerable to droughts. They lead to crop failure, weak animals and distress sales of assets e.g. livestock. Rainfall decreased during the past two decades leading to low crop yields and abandonment of groundnuts and late-maturing sorghum. Soil fertility is declining and weeds such as *Striga gesnerioides* infest cereals and cowpeas, other pests and diseases infest cowpeas and groundnuts.

Livestock suffers from short dry-season grazing and draught power by e.g. oxen (directly affecting agricultural productivity) is declining. Specific problems of the system are damage to crops caused by birds and locusts. Poverty is widespread and often severe (FAO 2001 et. al).

Pastoral farming system
The locations of the pastoral farming systems are the vast arid and semiarid zones stretching from Mauritania to the northern parts of Mail, Niger, Chad, Sudan, Ethiopia, Eritrea, Kenya and Uganda. Pastoral zones can also be found in the arid zones of Namibia and in parts of Botswana and Southern Angola. The system is based on livestock such as cattle (21 million), sheep, goats and camels. During the driest months, the Sahelian pastoralists move south to feed their herds within the cereal-root crop mixed system and return north during the rainy season. The climate is highly variable and droughts occur frequently. Poverty is wide-spread; herders often loose most of their animals due to drought or stock theft, which is a consequence of livestock-loss and poverty (FAO 2001 et. al).

Sparse (Arid) farming system
The sparse farming system can be found in Sudan, Niger, Chad, Mauritania, Botswana and Namibia. Nevertheless, within the vast area, just 0.7 million ha are cultivated. Mostly scattered and traditionally irrigated, the sparse farming system can be seen as part of the pastoral system, as it is used in most cases by pastoralists to supplement their livelihoods. Grazing within the sparse system is limited. Because of low population, density and limited production potential, the sparse farming system is considered to be of limited significance. Poverty is extensive and often severe after droughts (FAO 2001 et. al).

Coastal artisanal fishing system
The coastal artisanal farming system provides a livelihood to three per cent of the agricultural population, excluding households depending on fishing in fresh waters. In East Africa, the system stretches along the coast from Kenya to Mozambique including the coasts of Zanzibar, the Comoros and Madagascar. In West Africa it stretches from the Gambia southwards to the Casamance in Senegal further along the West African coast via Guinea Bissau, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Nigeria, and Cameroon to Gabon. The livelihood of the people living within the system is based on fishing with traditional means, supplemented by cultivation of crops. The crops are grown in home gardens, which are sometimes irrigated and prepared with several stories, for instance root crops under coconuts or fruit trees with cashews or swamp rice. Small amounts of animals e.g. poultry and goats are also kept. The prevalence of poverty is moderate (FAO 2001 et. al).

Urban-Based farming system
The urban population of Sub-Saharan Africa is estimated to be greater than 200 million. About 11 million city- or large town dwellers are farmers, which is a significant number. The urban farming system is very heterogeneous. It comprises small-scale but capital-intensive market-oriented vegetable growing, dairy farming and livestock fattening, and part-time farming by the urban poor. However, there are some concerns related to food quality and the environment of urban farming (FAO 2001 et. al).