CROP DEPREDATION BY WILD HERBIVORES AT THE WESTERN BOUNDARY OF TADOBA-ANDHARI TIGER RESERVE (TATR), CHANDRAPUR, MAHARASHTRA, INDIA

A THESIS

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BY

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CERTIFICATE

Certified that the work incorporated in the thesis entitled, "**Crop depredation by wild herbivores at the western boundary of Tadoba-Andhari Tiger Reserve (TATR), Chandrapur, Maharashtra, India**", submitted by **Abhijeet Bayani** was carried out by the candidate, under my supervision. The work presented here or any part of it has not been included in any thesis submitted previously for award of any degree or diploma from any other University or Institution.

Date: 17/08/2016.

Signature

Prof. Milind Watve
(Thesis supervisor)

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DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all the principles of academic honesty and integrity and have not misrepresented, fabricated or falsified any idea/data/fact/source in my submission. I understand that violation of the above will be cause for disciplinary action by the institute and also evoke penal action from the sources that have not been properly cited or from whom proper permission has not been taken when needed.

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1) **Bayani, A.**, Tiwade, D., Dongre, A., Dongre, A.P., Phatak, R., and Watve, M. (2016). Assessment of crop damage by protected wild mammalian herbivores on the western boundary of Tadoba-Andhari Tiger Reserve (TATR), Central India. *PLoS ONE*, 11: e0153854.

2) **Bayani, A.** and Watve, M. (2016). Differences in behaviour of the nilgai (*Boselaphus tragocamelus*) during foraging in forest versus in agricultural land. *Journal of Tropical Ecology*, 32 (6), 469-481.

3) Watve, M., **Bayani, A.**, and Ghosh, S. (2016). Crop damage by wild herbivores: insights obtained from optimization models. *Current Science*, 111 (5), 861-867.

4) Watve, M., Patel, K., **Bayani, A.**, and Patil, P. (2016). A theoretical model of community operated compensation scheme for crop damage by wild herbivores. *Global Ecology and Conservation*, 5, 58–70.

CHAPTER 1

INTRODUCTION

HUMAN-WILDLIFE INTERACTION IN TERMS OF 'CONFLICT'

Human-wildlife conflict is defined as "any interaction between humans and wildlife that results in negative impacts on human social, economic or cultural life, on conservation of wildlife populations, or on the environment" (WWF 2005; Woodroffe et al. 2005). The conflict occurs not only where people stay in proximity to wildlife but also when these two entities are spatially distant, though the intensity and frequency of occurrence of conflict situations is higher or more noticeable at the points of geographical closeness

The interaction between humans and wildlife is not a newly emergent phenomenon (Gordon 2009). Fossil records indicate that hunting occurs as significantly by carnivores on human populatins as of humans on ungulates. (e.g. Byers and Broughton 2004). In one celebrated case, the young of *Australopithecus africanus* probably killed by an eagle has been discovered in Taung South Africa (Dart 1925). Similarly, fossil record of well-preserved crocodilian tooth-marks on two individuals of *Homo habilis* from Olduvai Gorge (Brochu et al. 2010) suggests carnivore-human interaction in prehistoric time. Certain studies indicate that a wide diversity of prey species, including the ones domesticated today, were preyed upon by large carnivores that are now extinct (e.g. Prevosti & Vizcaino 2006). Also, investigation of dietary components of prehistoric herbivores has revealed opportunistic consumption of early domesticated maize (Emery 2000; White et al. 2001), and cereals like millet (Tafuri et al. 2009).

The foremost solution to reduce threats to livestock and crops was to have a lethal control on wild animals (Conover 2002; Treves & Naughton-Treves 2005). However, due to increased human population, and continuous decline in wildlife population, conservation efforts towards saving the wildlife have increased in the recent past (Treves & Karanth 2003). Since lethal control of wildlife is considered as a principal factor for species extinction (e.g. Greenaway 1967; Fuller 2000; IUCN 2002), people are discouraged from adopting such techniques. To ensure restriction over lethal control, wild species are now given legal protection and thus the earlier method of reducing the threat through destruction is now not possible (Treves & Naughton-Treves 2005). This has forced the people to adopt non-invasive and nonlethal techniques which often do not provide enough protection to their property. Legal restrictions on intuitive methods involving exterminating the problem individuals or species have increased the resentment amongst local people and negative attitude towards wildlife.

The human-wildlife conflict can be classified based on the type of species involved in it. Functionally, there are two types, viz. human-carnivore conflict and human-herbivore conflict (Conover 2002). Conflict with carnivores includes livestock-lifting and injuring or killing human beings. Across the globe, predominantly big cats (*Panthera* sp., *Uncia uncia*, *Puma conclor*, and *Acinonyx jubatus*) and different species of bears (*Melursus urcinus*, and *Ursus* sp.) have been repeatedly found to be conflicting with humans within their range of distribution (Ray et al. 2005). On the other hand, economic loss due to damage to agriculture either by active foraging on various stages of standing crops, post-harvest stages or stored grain and occasional injuries/casualties by wild herbivore species are the major components of human-herbivore conflict.

In this thesis, I have focussed on crop-raiding/crop depredation by small-to-medium sized herbivores. Also, my study focuses on damage to standing crops, nevertheless, damage to post harvest stages is considered at the appropriate places. I chose crop depredation for several reasons as explained below.

CROP DEPREDATION

Crop-raiding or crop-depredation involves damage to agricultural produce by foraging either on standing crops in agricultural fields, post-harvest stages or stored agricultural produce. It is evident that conflict with carnivores has received higher attention than crop depredation for a multitude of reasons (Ogra & Badola 2008; Peterson et al. 2010). Carnivores cause a direct threat to human life, and therefore victims tend to take retaliatory actions against problem individuals immediately (Woodroffe & Ginsberg 1998). Most of the carnivore species that are involved in conflict are a conservation priority either on a national or a global level, due to which maximum efforts are taken to reduce the negative attitude towards the carnivores in the conflict areas

(Treves & Karanth 2003). Further, the loss due to carnivores is compensated relatively immediately to undermine resentment and consequent retaliatory action (e.g. Ogra & Badola 2008). In contrast to this, herbivores (except elephants) do not threaten human life directly. Loss to agriculture is not directly responsible for immediate human casualty and hence to a certain extent this loss may be tolerated. Also, most of the herbivore species (except elephant and rhino) are not treated with same conservation priority as the carnivores. Thus, the magnitude of herbivore-human conflict has so far remained underestimated.

Maximum proportion of research on crop depredation across all the continents has so far focussed on identifying different animal species that are involved in raiding the crops, as listed below. A few studies focussed on various factors responsible for crop depredation as well. Interestingly, there are some popular thoughts regarding a fundamental question, 'why animals raid crops?' which I discuss below. The mitigation measures that are suggested based on different studies, their efficacy, and the shortfall in the overall research are discussed subsequently which leads to my research questions and approaches to answer them.

Animal species involved in crop depredation

Mega-herbivores like elephants (Asian and African) being charismatic and apparently most destructive, are the most widely studied animals from conflictual perspectives (Sukumar 1990, 1995; Parker and Osborn 2001, 2002; Osborn 2004; Fernando et al. 2005; Sitati et al. 2005; Rode et al. 2006; Youngstar 2006; Nath et al. 2009; Graham 2009; Monney et al. 2009; Chiyo et. al. 2011). In India, apart from Elephant (*Elephas maximus*), One-horned Rhinoceros (*Rhinoceros unicornis*), and large-to-medium-sized herbivores like Gaur (*Bos gaurus*), Nilgai (*Boselaphus tragocamelus*), Blackbuck (*Antilope cervicapra*), Sambar (*Rusa unicolor*), Chital or Spotted Deer (*Axis axis*), Wild Pigs (*Sus scrofa*) and Wild Ass (*Equus hemionus khur*) are reported to cause economic loss to farms (Bhattarai and Basnet, 2004; Bhattta, 2008; Dave, 2010). In Neotropical and Palearctic regions White-tailed Deer (*Odocoileus virginianus*) and red deer (*Cervus elaphus* ssp) are also observed to cause serious damage to agricultural lands (Irbi, 1992; Vecellio et. al., 1994; Craven et. al., 2001). Different species of primates across globe are known to cause damage to crops. Langurs (*Semnopithecus sps*.) and Macaques (*Macaca sps*.) in

India; Baboons (*Papio sps*) and other primates (*Chlorocebus sp., Colobus sp.,* and *Cercopithecus sp.*) in Africa are studied from conflict perspectives as well (Hill, 1994; Chhangani et. al. 2004; Priston, 2008; Marchal and Hill, 2009; Strum, 2010). Other small herbivores e.g. Indian Hare (*Lepus nigricollis*), Palm Squirrels (*Funambulus sps*.), Racoons (*Procyon lotor*), Badgers (*Meles meles*) (Moore, 1999; Chakravarty, 2008); various rodents, especially *Rattus* sp., *Mus* sp., *Mastomys* sp., *Microtus* sp., *Phyllotis* sp., *Peromyscus* sp., *Reithrodontomys* sp., and *Sigmodon* sp., are also serious pests to crops (Sanchez-Cordero & Martinez-Meyer 2000; Stenseth et al. 2003; Buckle & Smith 2015) predominantly damaging stored grains.

Not only mammals but also different bird species such as parakeet (*Psittacula* spp.), Sarus crane (*Grus antigone*) crows (*Corvus* sp.), house sparrows (*Passer domesticus*), and weavers (*Ploceus* sp.) in India are known to raid various crop species (Dhinsa & Saini 1994; Borad et al. 2001). The red-winged blackbird (*Angelius spp*.) in Quebec, Canada goose (*Branta canadensis*), lesser snow goose (*Chen caerulescens caerulescens*) in United States, and different species of goose (*Anser* spp.) in Europe, are reported to cause heavy damage to cultivation (Patrick et. al., 1982, Henrich & Craven 1990, Abraham et al. 2005, Hake et al. 2010).

Different crop-raiding species damage crops differently, based on which they are ranked in terms of their destructiveness. Elephants are the most destructive of all the species, causing heavy damage to crops even in one visit (Sukumar 1990; Sitati et al. 2005). It has been observed that wild pig all over its distribution range (including SE Asia, Europe and Africa) cause serious damage to crops and ranked highest as a crop raider everywhere (Mackin 1970; Chhangani & Mohnot 2004; Linkie et al. 2007; Cai et al. 2008; Schley et al. 2008; Mathur et al. 2015). In India particularly, nilgai along with wild pig is considered as ‘pest’ and in many states, both the species are declared as vermin (Mathur et al. 2015). Amongst primates, chimpanzees and olive baboons are ranked as most damaging species in Africa, whereas different *Macaca* species in SE Asia (including India) are claimed to cause serious damage to cultivated crops (Hill 2005; Srivastava 2006).

Why do animals raid crops?

Since a wide diversity of animal species show tendency to forage on cultivated crops, it becomes imperative to ask, what are the reasons that make these herbivores forage on crops? To answer this fundamental question, researchers have developed different hypotheses that can be categorized into two types, viz.

1) Crop depredation occurs due to loss of natural forage,

2) Crop depredation occurs as crops have higher nutritious value than natural forage,

At first glance the two hypotheses do not seem mutually exclusive. In both a higher nutritional quality of crops is assumed to be the responsible factor. The difference lies in the question what causes the difference. According to the first hypothesis a natural pristine forest is no inferior in nutritional quality to crops. However, only because of degradation of forest habitat, crop becomes superior to natural forage in terms of its availability. According to the second hypothesis, crops always have higher nutritional quality than wild forage. This is because humans selectively bred highly nutritious species as crop plants. By this hypothesis improving forest quality will not be sufficient to stop crop raiding by wild herbivores.

1) Loss of natural forage: It is regularly argued that as wild animals do not get enough food in their natural habitat, they are compelled to forage on cultivated crops. Quantity of natural forage (both grass and browse) is dramatically reduced due to widespread expansion of agricultural areas in and around the natural habitats (Zhang & Wang 2003; Graham 2010). One study examines effect of such monotonous land use or monoculture on crop raiding tendency of Japanese deer (*Cervus nippon*) and monkeys (*Macaca fuscata*) in Japan (Agetsuma 2007). Loss of natural forage is further attributed to habitat fragmentation (Koirala et al. 2015). Small-to-large scale agricultural areas interspersed in the natural habitats cause fragmentation, due to which wild animals frequently come across the agricultural lands and thus tend to raid crops more frequently. It is argued that fragmentation of natural habitat leads to loss of ‘traditional’ movement routes of elephants (Joshi & Singh 2007) which causes more damage to the agricultural lands. Nevertheless, this notion is rather impressionistic. There is no clear demonstration of effect of loss of natural forage in terms of quantity on crop depredation.

2) High palatability/nutrition of crops: It is argued that animals take to crops due to their high palatability. It is obvious that through artificial selection, most of the plant defences have been reduced drastically in domestic crops for easy consumption. Further, as crops are cultivated for food, they have higher nutrition quality as compared to grass and browse. This notion led to the hypothesis that animals raid crops to fulfil their nutritional requirement. Numerous studies compared nutritional values of natural forage and cultivated crops and showed that animals prefer crops over the natural forage owing to the difference in nutritional quality (Eley et al. 1989; Altmann et al. 1993; Warren 2003; Rode et al. 2006; Weyher et al. 2006). Crop depredation is also thought to be an inseparable part of animal ecology (Sukumar 1990; Rode et al 2006). For instance, crop species such as maize, millet, sorghum, cowpea, groundnuts etc. are said to be preferred by African elephants to fulfil phosphorus and calcium requirements (Koksey 2016).

Study of these two hypotheses further leads to identification of factors that may affect the crop raiding behaviour of animals. Numerous studies especially on elephant and primates have attempted to provide empirical evidences particularly for the second hypothesis in different ways, as described below. It is evident from the literature that although the hypotheses described above are put forth considering all herbivores species that raid crops. However, they have so far focussed only on elephants and a few species of primates. Thus, it is yet not established that whether the same hypotheses may hold true for different ungulate species as well.

Factors affecting crop depredation

Distance from the natural habitat

It is observed in the Asian elephant that individuals distributed at the periphery of the forest i.e. at the close interface of agriculture tend to show a higher tendency towards raiding crops (Sukumar 1990). Crop-raiding frequency decreases with distance from forest as observed in Asian and African elephant (Graham et al. 2010; Guerbois et al. 2012). A similar spatial trend is also observed in crop-raiding frequency in primates such as olive baboons, chimpanzee and redtail monkeys (Hill 1997; Naughton-Treves et al. 1998). The trend is likely to be a result of the fact that animals need forest cover to retreat. They come out of cover to raid crops but have to take refuge in the cover again. As a result there is a limit to which they can travel away from the cover.

Season and crop availability

It is observed that African elephants appear to damage the crops more in dry season (Parker & Osborn 2001; Osborn 2004; Chiyo et al. 2005). Similarly in southern India, Sri Lanka, and Cambodia, Asian elephant tend to show higher tendency to raid dry season crops (Sukumar 1990; Fernando et al. 2005, Webber et al. 2011). This might be taken to support the hypothesis that reduced forage in the wild induces crop raiding. However, seasonal crop raiding intensities appear to depend on the crop species as well. The crops such as banana that were available all the year did face equal amount of depredation by olive baboons showing almost no temporal trend (Treves et al. 1998).

Crop preference

Different animals show preference for different crop species. Both African and Asian elephants show a greater tendency to raid maize, millet, sugarcane, banana and rice in different parts of Africa and SE Asia (Sukumar 1990; Sitati et al. 2005, Joshi & Singh 2008; Eknayaka et al. 2011). Primates in Africa (chimpanzee, baboons, and monkeys) preferred banana over the other crops. Wild pigs, on the other hand raided any species of crop without any discernible preference, all over their range of distribution (Chhangani & Mohnot 2004; Linkie et al. 2007; Cai et al. 2008; Schley et al. 2008; Mathur et al. 2015).

Abiotic factors

Different abiotic factors such as photoperiod, ambient light intensity, temperature and rainfall do affect crop raiding behaviour of animals in various ways. It is observed that most ungulates raid crops in night hours. African elephants raided agricultural lands in night but more frequently on moonless nights compared to full moon nights (Barnes et al. 2006; Gunn et al. 2014). Effect of temperature on crop-raiding is not studied in wide diversity of species; however, Chacma baboons (*Papio ursinus*) are shown to raid crops less in summer than in winter owing to thermoregulatory costs in high ambient temperature in summer (Hill et al. 2006; van Doorn et al. 2010). Rhesus macaques (*Macaca mulatta*) also showed lesser tendency to raid crops in summer which is attributed to both high temperature and less availability of cover/shade (Jaman & Huffman 2013). Rainfall is a very important abiotic factor as it affects both the natural habitat and agriculture. Due to this reason crop-raiding is believed to be tightly linked with rainfall (Bell 1984; Litoroh et al. 1992; Osborn 1993). Maize raiding was found to be negatively correlated with rainfall, whereas banana was raided more or less equally frequently irrespective of rainfall as studied in olive baboons, chimpanzee and redtail macaque in western Uganda (Treves et al. 1998).

Sex of herbivores

It is interesting to note that male elephants (Asian and African) show a higher tendency towards crop-raiding (Sukumar and Gadgil 1988; Monney et al. 2010; Chiyo & Cochrane 2005; Chiyo et al. 2011). Study on African elephants also showed that males raid crops at the age when they leave the herds and while approaching reproductive competition (Chiyo and Cochrane 2005). Since cultivated crops are more nutritious than wild forage, elephants that habitually raid crops tend to grow larger in size, which may give them an advantage in terms of sexual selection (Chiyo et al. 2011).

Mitigation measures suggested

Different animal species show choice for different crop species and demonstrate different behavioural patterns, based on which human coping strategies change. The most widespread method adopted for reducing the damage is manual guarding of crops. Local people through experience know the time (in terms of photoperiod as well as crop stages) of arrival of the crop raiders to their cultivation sites and guard them accordingly. Farmers stay vigilant in their farms and deter crop raiders by shouting, throwing stones, using fire-crackers, and chasing them away. Nevertheless, the traditional methods due to various limitations are thought to be inefficient and hence researchers suggest different mitigation measures to reduce conflict.

Physical methods

Physical methods are mainly employed to keep the raiders away from the crops i.e. by creating physical barriers (VerCauteren et al. 2006; Woodroffe et al. 2014). The physical barriers include trenches, ditches, moats and various types of fences made out of thorny bushes, bamboo, barbed wire, mesh and electric fence (Palmer et al. 1985; Hygnstorm & Craven 1988; Geisser & Reyer 2004; Sitati & Walpole 2006; Kioko 2007).

Chemical methods

A wide range of chemical deterrents are suggested to keep the raiding animals away from crops. Chemical extracts and smoke of chillies, artificial chemical compounds mimicking predators' scent, pheromones etc. are amongst the most widely used and experimentally tested chemical repellents (Sullivan et al. 1985; Osborn & Rasmussen 1995; Avery et al. 2001; Hedges & Gunaryadi 2009). Synthetic chemicals such as Avitrol (to deter birds), HATE C4 (to deter deer), and Lithium Chloride (to deter primates) have been tested on experimental farm plots (Conover 1984; Fortham-Quick 1986; Dolbeer et al. 1994; Strum 1994).

Biological methods

King et al. (2011) recommended that simple fences can be supported using biological agents (so called 'eco-deterrents') e.g. beehives planted onto them which upon disturbance from any crop raider would deter the raiders especially elephants. Use of carnivore scat and urine, displaying dead animal parts, use of guard dogs, guard donkeys is also suggested to deter the crop raiders away (Sullivan 1985; Musyoki 2014).

Alternative crops

Growing alternative crops that are less palatable to herbivores are suggested as an efficient strategy (Dickman 2010). The alternative crops either bear thorns as a physical defence or have chemical defences, in the form of secondary metabolites, which make them unpalatable. A wide variety of cash crops e.g. safflower, tobacco, tea, coffee (Rao et al. 2002; Chiyo et al. 2005; Parker & Osborn 2006) and medicinal plants e.g. neem (*Azadirachta indica*) which are found to be non-palatable to wild animals are recommended in different parts of world (Santiapillai et al. 2010). These plants are sometimes cultivated along with the traditional crops whereas in some parts where the market is readily available, such alternative crops are taken instead of the traditional crops.

Efficacy of mitigation measures

The above listed mitigation measures are applied in different geographical locations but tested only on an experimental scale, their efficacy on larger spatial scale is largely unknown (Sitati et al. 2005). Electric fence is expensive in terms of its purchase cost and its daily usage cost, it needs meticulous maintenance as well. Therefore such methods are not adopted largely although they show high effectiveness in keeping the crop raiders away (VerCauteren et al. 2006). As human-herbivore interaction is an arms race, animals are likely to develop strategies to overcome the barriers (Seige & Baldus 1998; Geisser & Reyer 2004). Animals learn to avoid such measures and find solutions themselves. Herbivores may learn to forage on the non-palatable plants sometimes, in which case the crop depredation may remain persistent (e.g. Provenza et al. 1992; Clayton & Emery 2005).

Why problem of crop depredation is still not resolved?

It is very important to note that the problem of human-herbivore conflict has not been resolved despite numerous studies on human-herbivore conflict. There are multiple reasons including lack of studies in species other than elephants and primates, lack of long-term monitoring of the problem, failure of mitigation measures, and most importantly inadequate bridging between proximate and ultimate causes of crop depredation. In spite of very little success in solving the problem given the high cost of research and management, discussion over reasons for failure of minimizing the conflict is scarce.

Crop damage compensation

The problem of crop-raiding by-and-large remains unresolved in many areas despite the number of mitigation measures applied. Due to persistent economic loss, and less efficiency of many mitigation measures people often shift to invasive methods (Karanth et al. 2012). The invasive methods employed by local people undermine conservation efforts and thus to change the negative attitude of locals towards wildlife and reduce resentment, a certain amount of compensation is often paid to the victims as a partial relief (Ogra and Badola 2008; Karanth et al. 2012, 2013).

Almost all the countries having the problem of crop-raiding support the farmers through some way or the other using monetary compensation (De Klemm 1996). This may be either in the form of insurance, compensation or ex-gratia relief. Not only the governmental agencies but also many non-governmental agencies compensate the victims for the damage caused by wild animals. However, it is seen that in certain cases provision of compensation does not change the attitude of locals (Studsrod & Wegge 1995; Bulte & Rondeau 2005). There are many other reasons that are responsible for this e.g. inadequate amount of compensation (often less than assured amount), delay in payment etc. (e.g. Ogra & Badola 2008).

In Maharashtra, where my study area is located, there is a legal provision for compensating farmers' damage by wild herbivores. This is based upon the extent of damage estimated. However, there are no clear guidelines about how to estimate or measure the damage. Also, there appears to be a lack of quantitative understanding about the expanse and severity of the problem. Decisions appear to be taken based on unreliable data. For example in 2013 the state government constituted a committee to reshape the compensation policy. The data supplied to this committee has many obvious flaws. For example, 70% of the total reported damage came from Aurangabad, Beed and Yavatmal circles which have little wildlife. On the other hand districts of Vidarbha in eastern Maharashtra where states major wildlife areas reside interspersed with agriculture, only 7% of total compensation had been paid according to the report. The reason for the discrepancy is likely to be that the data are based on successful compensation claims, rather than on actual first hand estimates of damage. Farmers differ in their tendency to file claims and the rate of success of claims is highly variable depending upon the handling officers. The report also fails to differentiate between damages caused by wild versus feral animals.

Extent of damage and its measurement

This has been a major inadequacy in research on crop depredation. There are two ways by which researchers have so far estimated the loss 1) Damage estimation based on people's perception and 2) Actual measurement on farms. There are many studies that assessed the extent of damage to various crop species based on perception of local farmers, but only a handful of studies attempted first hand measurement of damage.

1) <u>Perception studies</u>

When farmers are asked about how much damage they really face, there are two types of responses, *viz.* (i) anticipated/perceived loss, and (ii) comparative deficit in the yield. Farmers' response regarding their loss is often based on their anticipation i.e. the amount of damage they face when the crops are not protected fully. This perceived loss is also sometimes based on experience of someone else. For instance, 20-50% loss to different crop species and seasonal vegetables in Uttarakhand (Ogra & Badobal 2008) by ungulates, up to 60% loss to maize and cassava in Uganda (Hill 2005) by primates and ungulates, nearly 70-100% damage to soybean, chickpea, wheat, millet, maize, rice by wild pigs, nilgai and blackbuck (Mathur et al. 2015) etc. but, this information does not reveal the actual loss of the farmer. Very few farmers convey the actual deficit in the yield in comparison with the maximum yield that they could obtain in the previous years, or in comparison with the yield obtained by some other farmer in the same area. Although this deficit is a measurable number, it still does not convey the actual loss due to crop-raiding. The deficit in the yield as responded by farmer could be because of several other reasons, e.g. abiotic factors like rainfall, temperature, humidity and biotic factors like pest, quality of seed etc. The deficit in yield can also be due to variable use of fertilizer and pesticide that vary greatly across years and the type of soil. There are many studies that give an estimate of crop loss due to crop-raiding in terms of yield (weight of the agricultural produce) and market price (O'Connell-Rodwell et al. 2000, Chhangani & Mohnot 2004; Mathur et al. 2015). However, it should be treated carefully as it is a loss that is inclusive of all factors that may affect the yield and not necessarily only crop depredation by wild herbivores.

2) <u>The actual measurements of damage</u>

Some studies attempted to make first hand measurements of crop damage by wild herbivores. On field measurement of number of damaged plants and the area of damage of a given farm is primarily done to estimate the loss (e.g. Sukumar 1990; Naughton-Treves 1998; Hill 2000, Nyhus et al. 2000; Borad et al. 2001, Buckle & Smith 2015). Nelms et al. (1990) compared the yield in protected and unprotected blueberry plantation. Wiens and Dyer (1975) applied population bioenergetics simulation model to assess impact of red-winged blackbirds on grain crops. These studies although provide quantitative estimates of crop damage, they still do not discuss whether these visually measured damage estimates correspond to the actual loss in yield. There are only two studies that discuss this issue. Kear (1970) found no significant correlation between visual estimates of damage and actual loss to winter-wheat, spring-barley damaged by wild geese. Additionally, Woronecki et al. (1980) showed that visual assessment of simulated bird damage to corn kernels underestimates net loss. Since grain yield is what actually matters to a farmer, other methods of damage assessment need to have a good correlation with loss in grain yield.

RESEARCH QUESTIONS AND APPROACH

It is clear from the literature that there is an urgent need to address certain fundamental questions carefully.

1) How to estimate the damage realistically and in an unbiased manner? How well do the currently used methods perform and is it necessary and possible to have new ways of estimating loss?

2) How do farmers optimize the costs-benefit of agriculture under a high risk of crop depredation?

3) How do herbivores alter their behaviour to optimize cost-benefit while foraging in human-dominated landscapes (in this case agriculture)? Can insights obtained from it be applied to wildlife management?

4) Is it possible to have a solution (mitigation or compensation) that can be operated largely by local communities with minimum dependence on the infrastructure of park management?

Following three approaches were used for answering the above questions

Observations on field

Systematic observations on field using appropriate sampling methods can provide substantial first-hand data. In this context, observations of raider animal species, farmers' responses, amount of damage, grain yield etc. can be recorded. A long-term monitoring of such various observational parameters will be helpful in understanding various patterns of crop-raiding. This approach was used predominantly for answering partly the question (1) and (3). I collected data on raiding probability, frequency, grain yield, extent of damage, spatial and temporal trends in crop-raiding. I also collected data on behaviour of nilgai, a main crop raider, to see whether there is any alteration in the behaviour while it forages on agriculture.

Experiments on field

To obtain empirical data on various parameters/factors that may affect crop-raiding, experimental approach is needed. This approach was used to obtain empirical values of parameters involved in question (1). By this I collected data on effect of fence on yield of farm plots, and effect of simulated mega-herbivory on grain yield.

Mathematical modelling

Sound theoretical basis of most of the crop-raiding research is substantially lacking. Since mathematical models can give many novel insights, I used this approach to address question (2), (3) and (4).

STUDY ORGANIZATION

Study on crop depredation at Tadoba-Andhari Tiger Reserve started in 2008. In 2008-09 Kiran Rahalkar, Amol Handore and Dr. Amol Khedgikar researchers from Pune, Maharashtra under guidance of Prof. Milind Watve (my PhD supervisor) initiated the work. This team selected the study area and set up a field research station. Three local residents Dilip, Ashok and Arawind worked for the study throughout the study period. Further, Rasika Phatak in 2009 joined the team on a short term and did surveys regarding damage estimation. She did preliminary transect surveys to estimate the probability of damage and spatial trends in it. I joined this work in 2010. After getting acquainted with the terrain, people and local situation, I designed problem-oriented questionnaires and along with Dilip, Ashok and Arawind carried out the survey. Most of my work included cultivation of crops and therefore involvement of local farmers was essential. Few local farmers adjoining my experimental farm have been practicing agriculture since many years, they helped me cultivating crops as per my requirement and then further monitored by Dilip, Ashok and I until the last stage of PhD work. I later designed various experiments on this experimental farm to obtain the required data.

Mathematical modelling covers a substantial part of my thesis. Discussions with Prof. Watve, Kajol Patel and Samriddha Ghosh encouraged me to play with equations, simulations and helped me in interpreting the predictions. My contribution to the models was less in writing equations and more to relate them to actual field data and empirical findings.

Having a genuine interest in natural history, I also initiated study of nilgai population structure and its foraging behaviour. Long term monitoring for nearly 5 years provided me with a lot of new insights, some of which are analysed and discussed in this thesis.

THESIS ORGANIZATION

In this thesis, I attempt to answer some of these critical questions using various field and computational methods. Chapter-2 gives detailed information about Tadoba-Andhari Tiger Reserve (TATR) which is my study area. Chapter-3 covers the perception and attitude of local farmer community towards crop depredation and wildlife conservation. This socio-economic survey generated many testable hypotheses. In chapter-4, I attempt to estimate crop damage using a multitude of methods and comparing them. An important implication of this analysis is to test the reliability of the currently practiced damage estimation method. As mentioned earlier, a large volume of crop depredation studies feature elephant, but medium-to-small sized herbivores have received little attention. I chose to study nilgai and various aspects of its foraging and vigilance behaviour, which are described in chapter-5. Since, cost-benefit of farmers' agricultural practices in response to crop-raiding, especially in 'high-risk' zones is not studied adequately; I describe the microeconomics of agriculture using mathematical models in chapter-6. The same cost-benefit optimization models are further applied to understand the theoretical basis for the behaviour of crop raiders. Similar to cost-benefit of agriculture, there are few attempts to study the theoretical basis for various compensation schemes. In chapter-7, an alternative method of compensation based upon behavioural economics is described.

CHAPTER 2

STUDY AREA

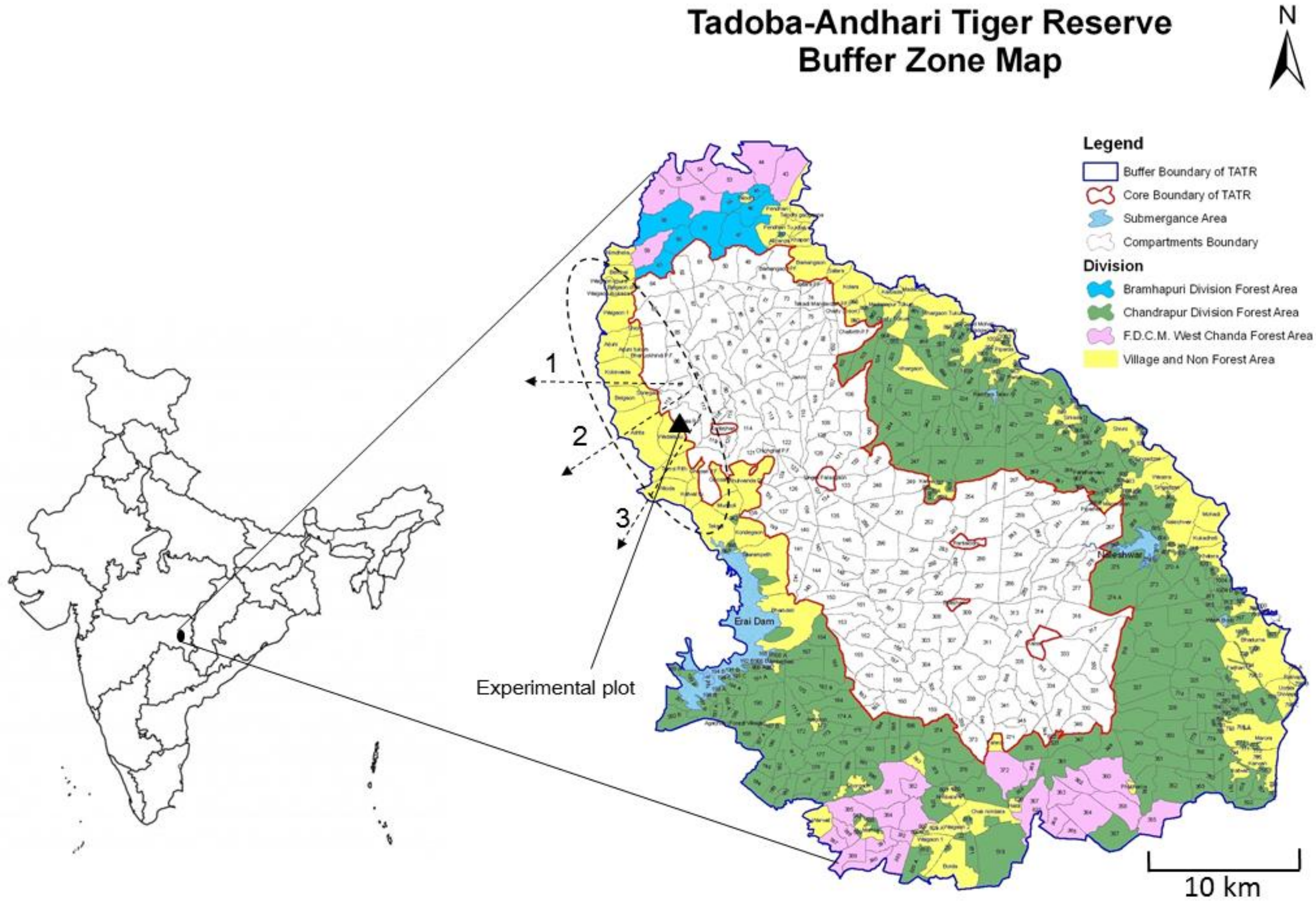
TADOBA-ANDHARI TIGER RESERVE

Tadoba-Andhari Tiger Reserve (TATR) is one of the most important tiger reserves in Central India. It is situated in Chandrapur district of Vidarbha region in eastern Maharashtra. It is a composite area of Tadoba National Park and Andhari Wildlife Sanctuary forming one of the 48 "**Project Tiger"** areas of India. The name *Tadoba* seeks its etymology in the name of a historic human figure, *Taru*, who died in a mythical encounter with a tiger. *Taru dev* (God Taru) still stands as a local deity in core area of TATR worshipped by local tribes. The existing TATR areas were the hunting grounds for local *Gond* kings until 1935. After a complete ban on hunting, Tadoba NP proceeded as the first national park of Maharashtra established under Madhya Pradesh National Parks Act, 1955, and along with Andhari (named after river *Andhari*) WLS created in 1986, the whole area ensued into the second Tiger Reserve of Maharashtra by 1994. TATR is important conservation area due to its recognition as source site for tiger population in Maharashtra (Joshi et al. 2013; Yumnam et al. 2014) and hence comparatively higher attention has been given to its development, maintenance and conservation.

AREA AND LOCATION

Geographically, TATR exists in 20° 4'- 20° 25' N and 79° 13'- 79° 33' E which extends over 1727 sq. km out of which 625.40 sq. km. remains as a core zone. Core zone has three ranges namely Tadoba, Moharli (part of earlier Tadoba NP) and Kolsa (part of earlier Andhari WLS). (see Figure 2.1).

Figure 2.1: Tadoba-Andhari Tiger Reserve. Dashed ellipse represent total sampling area, dotted lines (numbered 1, 2 and 3) represent the transects perpendicular to forest.



CLASSIFICATION OF THE AREA

Biogeographical Kingdom: Paleotropical.

Sub-kingdom: Indo-Malayan.

Biogeographic Zone: 6- Deccan Peninsula.

Biotic province: 6- B Central Plateau.

Forest type: 5A-CI-1B Southern tropical dry deciduous forest.

Agro-ecological Sub Region (ICAR): Eastern plateau (Chhota Nagpur) and Eastern Ghats, Hot sub-humid Eco-region (12.1).

Agro-Climatic Zone (Planning commission): Western plateau and Hills Region (IX).

Agro-Climatic Zone (NARP): Central Vidarbha Zone (MH-8).

GEOLOGY

Based on the deposition of rock types following geological divisions can be made:

Northern side consists of a small patch of detrital mantle consisting of alluvial deposits. Gondwana sediments exposing the Kamthi formations and Lametas at the surface in the southwestern side (Prasad & Khajuria 1995; Ghosh 1997; Ganji & Hasde 2014). They are underlain by coal bearing Barakar formations (Dikshit *in* Diddee et al. 2002; Ganji & Hasde 2014). Precambrian Vindhyan formations covering most of the central part and extending in north-west and south east direction (Diddee et al. 2002; Ganji & Hasde 2014). Archean metamorphic rocks as patches along the NE corner and in the western boundary (Sawarkar 1964; Prasad & Khajuria 1995; Ghosh 1997; Ganji & Hasde 2014). A major boundary *Fault* along Chandankheda–Panchagaon–Moharli villages divides the Gondwana sediments in the southern side with Archaean and Precambrian formations (Ganji & Hasde 2014).

There are several kinds of soils in the area. However, more robust soil classification of eastern Maharashtra includes alfisols, vertisols and alluvial soils (Challa et al. 1995) The alluvial soils are moderate-to-deep with fine silt, sand and clay (Challa et al. 1995). The soil in the Gondwana sediment area shallow with ferruginous concretionary material. The Archaean metamorphic areas are covered by moderate dark/greyish brown soil. The soils in Vindhyan areas are shallow, reddish brown and ferruginous too (Sahasrabudhe et al. 1969; CRIDA 2012). The stony soil suffers from excessive drainage and thus poor for cultivation but the alluvial soil is fertile enough for kharif and rabi crops (Sahasrabudhe et al. 1969).

Entire area of Tadoba-Andhari Tiger Reserve falls in Godavari system. There are two major rivers draining the reserve area, Erai, tributary of Wardha in the western half and Andhari, tributary of Wainganga in the eastern half. Both these rivers flow from north to south and their course seems to be controlled by the boundary *fault*. The presence of base flow in these rivers confirms the fact that are gaining rivers i.e. groundwater is being discharged in the rivers (Shende 2013). Apart from these two rivers the other important surface water bodies in the reserve are Tadoba lake and Telia lake.

The Gondwana formations comprising of Kamthi rocks at the surface and underlain by Barakars are the most potential area for groundwater exploitation (Shende 2013). Groundwater occurs in the primary as well as the secondary porosity of the rocks. Deep/Shallow tube wells constructed at Agarjhari, Aregoan, Moharli and Dewada villages tapping these rocks have yielded good discharges. The general water level in these formations varies from 6 to 8 m below ground level and the dug wells generally do not go dry in the summer season. The presence of Erai reservoir with its vast aerial spread acts as a good source of groundwater recharge to these formations.

The topologically high areas occupied by the Vidhyans and Archaeans can yield in moderate quantities of groundwater through the fractures present in the rocks (Shende 2013). So, the availability of groundwater in these formations is subject to presence of favourable fractures and weak zones. The depth of water in dugwells is generally deep ranging from 4 to 12 m bgl (below ground level) that yields up 30 m^3/day (Shende 2013).

TERRAIN

Terrain is undulating and hilly with a mosaic of forests and grasslands at northern and western boundary. Chimur hills start east of Chimur and with one break of 8 km run southwards as far as Moharli gradually diminishing in height from north to south. The range is 32 km in length and 10 km in breadth with an average elevation of 150 m above the surrounding plains. In the basin of the hills, lies Tadoba lake, which is 120 Ha spread. The elevation of the highest point is 350.7 m MSL and that of lowest point is 212.45 m MSL. The average elevation is 284 m MSL. Hilly areas give rise to various streams, some of which are perennial.

CLIMATE

There are three distinct seasons with distinct weather patterns. Summer is hot and dry between March to June; well distributed rainfall during south-west monsoon between July to October which is hot and humid, and cold dry winter between November to February. Average annual rainfall reported is 1175 mm. Temperature is summer is as high as 48°C and as low as 3°C in winter. Humidity reported is as high as 70% in monsoon and as low as 20% in summer.

HABITAT

TATR is predominantly a well wooded forest, although scrub forest and grasslands can be seen patchily distributed in the landscape. As described above, forest is deciduous and teak (*Tectona grandis*) is a dominant tree species. Forest in the core zone is a mixture of Tendu (*Diospyros melanoxylon*), Mahua (*Madhuka latifolia*), Ain or Saaj (*Terminalia elliptica*), and Dhawda (*Anogeissus latifolia*). Certain parts are interspersed with Karu (*Sterculia urens*) along the rocky areas e.g. *Pandarpauni* area, and with mango (*Mangifera indica*), jamun (*Syzygium cumini*) and Arjun (*Terminalia arjuna*) near the natural waterholes e.g. in *Katezari* area. Peripheral parts of the forest are dominated with Palash (*Butea monosperma*) along with teak especially at western boundary. Bamboo (*Dendrocalamus* sp.) system along with these tree species in core zone form another type of habitat.

Trees in the forest are not densely packed in many regions and in such regions the understorey diversity is rich in many herbs and grasses. Palatable grass species belonging to genera such as *Themeda, Ischemum, Chrysopogon, Heteropogon, Aristida* etc. Such areas form major foraging grounds for most of the herbivores. Many areas have continuous patches of grasslands, especially along the western boundary. Barren and abandoned grounds in the cores zone from where villages have been relocated outside the reserve have developed vast patches of grasslands e.g. Navegaon, Jamni etc. Kolsa range of TATR is majorly a grassland. Western boundary especially outside the PA also have grassland patches especially near Chandankheda, where abandoned agricultural lands and flat rocky areas together possess a larger spread of grassland meadows.

TATR harbours many natural and perennial streams e.g. *vasantbandhara, chichghat valley, Ramdegi* area forming riparian zones. Along these streams Mango and Arjun (*Terminalia arjuna*) are the most dominant tree species. There is also a high abundance of bamboo along these streams making canopy over them.

Buffer area of TATR is also interspersed with scrub tree species. *Acacia (Vechellia) leucophloea, Acacia (Vichellia) nilotica, Acacia (Senegalia) catechu* are major tree species. *Prosopis juliflora* is predominant near agricultural lands. Although scrub forest is not spread over a large expanse, intermediate areas between forest cover and agricultural lands are sparsely filled with this plant community.

FAUNA

TATR is known mainly for its significant population of tigers (66-74 adult unique individuals) in Tadoba-Chandrapur (Quereshi et al. 2014). TATR tiger population is also considered as a source population in central India due to consistent growing trend in population and high dispersion from TATR to other protected areas in central India. Other large carnivores like leopard (*Panthera pardus*), sloth bear (*Melursus ursinus*), dhole or Indian wild dog (*Cuon alpinus*) have a large sustaining population in TATR. Small carnivores such as jungle cat (*Felis chaus*), rusty spotted cat (*Prionailurus rubiginosus*), common palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), honey badger (*Mellivora capensis*) also can be sighted occasionally. Herbivore diversity includes gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), four-horned antelope (*Tetracerus quadricornis*), sambar deer (*Rusa unicolor*), chital or spotted deer (*Axis axis*), muntjac or barking deer (*Muntiacus muntjac*), Wild Pig (*Sus scrofa*), Indian hare (*Lepus nigricollis*), and hanuman or grey langur (*Semnopithecus dussumieri*). In eastern part of TATR bonnet macaque (*Macaca radiata*) lives along with hanuman langur. Western boundary areas outside the TATR, near village Chandankheda, a pair of Indian wolf (*Canis indica*) and a small population of chinkara (*Gazzella bennettii*) was also sighted a few times (pers. obs.). Nearly 27 species of bats can also be found in TATR (Pradhan 2006). Caves in Ramdegi in north of TATR are inhabited by large number of colonies of *Hipposideros* cf. *speoris* (pers. obs. and pers. comm. with Dr. S. Talmale, ZSI). Interestingly, the orange morph of this species is dominant over black-brown morph in all the colonies. A small group of false-vampire bat *Megaderma lyra* could be regularly observed foraging of frogs, shrews and rodents in field station situated at western boundary.

TATR is not only rich in it mammalian diversity but also in its avian, reptilian and amphibian diversity. Mahabal (2006) reported 192 bird species in TATR. Nevertheless, over 40 more bird species were reported during the study period, and the most notable of them are Lesser Adjutant, Greater Spotted Eagle (*Clanga clanga*), Indian Spotted Creeper (*Salpornis spilonotus*), Crested Serpent-eagle (*Spilornis cheela*), Besra (*Accipiter virgatus*), and Crested Hawk-eagle (*Nisaetus cirrhatus*) (Bayani & Dandekar, manuscript under preparation). 54 species of reptiles including snakes (28 species), lizards (20 species), crocodiles (1 species) and testudines/chelonians (5 species) (Pradhan *in* Conservation area series, TATR, ZSI 2006). Occurrence of rare Dumerill's black-headed snake (*Sibynophis subpunctatus*), red sand boa (*Eryx johnii*), and Indian egg-eater snake (*Elachistodon westermanni*) are the noteworthy observations (pers. obs.). Endangered and Schedule-I species, Indian monitor lizard (*Varanus benghalensis*) can be seen frequently near rice fields, termite/ant mounds and in tree holes in forest. Other lizards include Blandford's rock agama (*Psammophilus* cf. *blandfordanus*), *Sitana spinaecephalus*, *Geckoella* cf. *collegalensis*, and *Hemidactylus gracilis*, can also be seen. Diversity of amphibians in TATR is comparatively less (13 species), however, *Hydrophylax bahuvistara, Polypedates maculatus, Duttaphrynus scaber, Spaerotheca cf. rolandae* are some notable frogs found. Fish diversity is widely known from TATR and represented by 84 species out of which 14 species are considered to be good food species and regularly consumed by locals (Yadav *in* Conservation area series, TATR, ZSI 2006).

WESTERN BOUNDARY

Western boundary buffer of TATR is unique as the boundary between forest cover and agricultural lands represents a rather sharp ecotone. Forest cover in majority of the area ends abruptly and continues as a vast expanse of cultivated land up to 12 km while going away from forest. Certain agricultural areas are infiltrated into forest, i.e. there is forest that surrounds bunch of agricultural lands from at least 3 sides. Terrain is mostly undulating due to presence of small hillocks having shallow slope. These hillocks also have grasslands at the base that are used for cattle grazing.

There are 18 villages in western boundary buffer *viz.* Bembla, Nimdhela, Waygaon, Kinhala, Ashta, Arjuni, Wadhala, Ghosari, Mudholi, Tekadi, Khutwanda, Villoda, Katwal, Kokewada, Kondhegaon, Sitarampeth, Bhamdheli and Moharli. Out of these Ashta and Moharli are the largest in area and in population, whereas Wadhala and Ghosari are smallest. Ghosari, Khutwanda and Mudholi are surrounded by forest from at least three sides and so do the agricultural lands. Rest all have forest from only one side, Kokewada is the farthest village from which forest is ~5 km away. Moharli and Khutwanda have the tourist entry gates for wildlife safaris.

Western boundary has good number of inland water bodies, some of which are natural whereas many others are man-made. Each village has at least one common village lake that provides water for agricultural and domestic purposes. These lakes may dry in summer but get filled again in monsoon. At nearly 6 km from core boundary, river Irai flows southwards which is a tributary of Godavari. A dam on this river near village Moharli creates a large waterbody that remains filled with water all the year. Irai river and the dam back water is the most important water source at western boundary as it provides water to the majority of agricultural lands.

The villages especially the agricultural lands are frequented by wild animals. The herbivores like nilgai, wild pig, chital are the most frequent ones that raid the cultivated crops. In the farms that are very close to forest, especially in Khutwanda, Gaur and Sambar also raid the crops occasionally.

I selected western boundary for my study due to multiple reasons. The sharp ecotone between forest and farm provided ample opportunities to observe the crop-raiding phenomenon. A very large number of agricultural lands are exposed to wild animals which provided me with enough sample size for my surveys, observations and experimental studies. An established field station with an agricultural land for the observations and experiments at the close front of western boundary near Katezari gate was an additional incentive (see colour plate 2.1). This area is also free of tourism and hence no interference from other external factors. Monotonically decreasing probability of raids enables the use of distance as a surrogate of the gradient of risk of damage.

Colour Plate 2.1

Study Area

Field station

Machan

Experimental plot

The fenced and unfenced plots

Field assistants (left to right Arawind, Dilip and Ashok)

CHAPTER 3

FARMER COMMUNITY IN THE STUDY AREA

INTRODUCTION

Human-wildlife conflict is a complex issue. Not only the wildlife but also the human dimension of this problem needs to be addressed appropriately. Without understanding the perception and attitude of local people towards the wildlife, the actual magnitude of conflict may remain unnoticed. Most importantly, effective long-term wildlife conservation needs support of local people (Gillingham & Lee 2003) and to get their support, various problems faced by them should be addressed appropriately. The people living in conflicting situations often develop various assumptions based on their own observations and coping strategies to reduce the conflict. It is thus imperative to consider their observations and interpretations as hypotheses and test them scientifically.

METHODS

I selected 15 out of 18 villages (listed in chapter-2) on the western boundary of TATR for survey. Data on population of each village and total number of families of the village was obtained from each village head or *Gram Panchayat*. I sampled 20% families (in turn 20% farmers) from each selected village randomly using predesigned questionnaire written in Marathi. Before conducting the surveys, I obtained informal consent from village head of each village. Every interviewee was assured his/her anonymity. I interviewed 439 farmers for understanding the extent of human-wildlife conflict (both herbivore and carnivore) at the western boundary. Additionally, while sampling for crop damage estimation, I interviewed 137 farmers along the transects perpendicular to forest cover and 90 farmers having their farms surrounded by forest for the crop-raiding and perception about the same (see chapter-4).

Two different questionnaires were used for crop-raiding and for livestock depredation respectively. They included questions about the agricultural practices, cropping patterns, perception about interaction with wild herbivores, crop-raiding patterns, raider animals, crop protection measures and guarding. The farmers were also interviewed for their opinion about crop loss and their estimates of crop loss, risk perception and attitude towards raider herbivore species. The other questionnaire included information about livestock such as livestock species, their numbers, herding strategies, use and economic importance. It also involved the attitude towards the carnivores they may encounter with, their estimates of loss owing to livestock depredation, and their views on conservation of wild carnivores.

The number of compensation claims for crop damage was less compared to that for livestock loss. I witnessed and analysed three claims of crop damage compensation (out of total six claims made from the study area in five years) and 56 cases of livestock depredation in detail. Crop damage compensation claims were analysed to understand the procedure of damage estimation and negotiations over compensation amount. Due to a small sample size, I treated all three crop damage compensation cases separately without subjecting the data to any statistical tests. The data of livestock depredation cases were mainly used to understand and compare the compensation procedures with that of crop damage compensation claims and the intrinsic differences between the two.

I involved three local farmers for carrying out the questionnaire surveys. With appropriate training and demonstration of over 50 interviews, the trained individuals were able to carry out surveys as per required standards. All the data were filled in questionnaire forms in Marathi in the presence of the interviewees, later translated by me in English and analysed. Together we carried all the interviews in year 2011-2012.

Since oral histories and impressions are not quantitatively reliable the data obtained from questionnaires were mainly treated as qualitative and used for developing hypotheses and designing further study.

RESULTS

Agricultural practices and perception about crop depredation

Agriculture has been the main livelihood of local people in the study area, whereas animal husbandry and labour work was secondary. Agriculture was done in two seasons *Kharif* (Monsoon crops i.e. July to October) and *Rabi* (winter crops i.e. November to March). Kharif included rice and soybean as the predominant crops apart from which, turmeric is taken but to lesser extent. Cotton, which was another important cash crop in the study area, stands for longer period of time distributed evenly in kharif and rabi months (sowed in July and harvested in January/February). Rabi crops included wheat and chickpea predominantly whereas other secondary crops were linseed/ flaxseed and Indian blue pea. Crop fields that were used for rice and soybean in kharif were usually used for wheat and chickpea in rabi, whereas cotton fields were used exclusively for cotton.

Farming was done in traditional way, though modern techniques and equipment were sometimes adopted, e.g. use of tractor and rotary tillers to plough the farms. Local farmers preferred pair of bullocks for basic agricultural practices such as ploughing and sowing as it was thought to give better results compared to tractors. Kharif crop was by-and-large completely rain-fed. Traditionally, water was stored in what is locally called as *bodi* which is essentially a temporary and small-scale dam constructed upstream to rice farms. If necessary water is pumped in from wells, natural pits or canals, however, use of irrigation equipment was scarce.

Use of chemical fertilizers along with cattle dung and chemical pesticides was widespread (also see below). Nevertheless, traditional way of controlling pest was also practiced, which included use of leafy branches of *Cleistanthus* sp. in the rice fields. Further, the water of Tadoba lake was believed to be sacred and having medicinal properties. Thus, sprinkling some amount of that water on rice fields would not only kill pest but also enhance the yield! However, I did not find any farmer following it during the study period.

Rice being a major crop, farmers put more efforts in cultivating and protecting the rice crop than any other crop. Some farmers were observed to skip rabi crops when rice gave satisfactory yield. Rice grains were also used as exchange and used as ‘currency’ for paying the labour charges. Except for Wheat and Chickpea, the other crops were taken mostly for self-use/domestic purposes. As rice production is quite high having a good market value all over the state of Maharashtra, the major economy of this region is based on rice production.

Crop-raiding (for almost all crop species) was found to be a phenomenon experienced by farmers very frequently. As a result, farmers were well aware of the crop raider species, their crop species preferences and stage at which the crop was most vulnerable. Farmers perceived threat from two main species of herbivores namely nilgai and wild pig followed by chital. All of them raided crops at night (see colour plate 3.1 & 3.2). The 2.5 km distance from forest cover appeared to be a threshold distance for chital. Out of 88 farmers sampled within 2.5 km stretch, 87 farmers perceived nilgai, wild pig and chital as equally destructive species. In a zone between 2.5 to 3 km, only 3 out of 14 farmers listed chital along with nilgai and wild pig. Beyond 3 km, only nilgai and pig were reported to damage the farms. At the distance of 9 km and beyond, there was no report of damage.

The main protection measure employed by farmers was manual guarding by staying vigilant at night to scare off the raiders. Farmers constructed a 10 to 12 feet tall watchtower or guarding platform or *Machan,* (locally called as *"mara"*). It is an elaborate structure made using teak (*Tectona grandis*) / bija (*Pterocarpus marsupium*) / ain (*Terminalia elliptica*) / khair (*Acacia catechu* and *Acacia leucophloea*) wood logs, and thick and stiff bamboo platforms (also see colour plate 2.1). Farmers also constructed a roof over the platform as partial protection from rain and wind which is usually made out of flexible sheets of bamboo. The raider individuals were scared off using torches, LED searchlights, loud scream, rarely using firecrackers and throwing stones at animals. Many times raiders were chased for long distances. During the study period there was no case of any animal being injured because of the guarding operations. Active guarding was thought to be necessary every night since a single unguarded night was perceived to be sufficient for complete loss. October to March i.e. the last few weeks of kharif and throughout the rabi season, the crops were actively guarded.

Fencing the crop lands was thought to provide additional protection and about 42% of farmers, predominantly those closer to the park made fences. The type of fence varied as per the severity of raiding incidences. It can simply be a lose construction of medium thick twigs of *Butea,* teak and at times bamboo. This type of fence was also modified by using thorny plants like *Acacia* sp., *Prosopis* sp. and *Zizipus* sp. These fences were reconstructed almost every season using freshly cut wood; the older wood was then used for fuel. Barbed or unbarbed wire fences constructed by farmers were not durable and could be penetrated by animal relatively easily. Elaborate and expensive fences like electric fences were very rare in the study area (see colour plate 3.3 & 3.4). Battery operated electric fences were not preferred by farmers in spite of being aware since they came with lesser battery life and high costs. Farmers also responded that there was a high possibility of some other animal species such as tiger or leopard getting electrocuted, due to which the electric fence was not preferred.

Not all farmers fenced their farms from all sides. Generally, the boundaries facing roads and animals paths were fenced and the boundaries between farms left open. I observed that fences were constructed in the region only up to 5 km from the forest. Majority of the farmers believed that fencing might not provide sufficient protection. Only 3.8% farmers up to 1 km, 5.27% between 1-2 km, 16.2% between 2-3 km, 21.7% between 3-4 km, and 13% farmers between 4 and 5 km believed that fencing was a sufficient measure for protection from crop raiders. Animals were said to be able to locate weaker points along the fences and break open, dig a way underneath or jump over them (see colour plate 3.2).

Farmers generally did not keep watchdogs in their farms. Case studies of perceptions revealed that there were two major reasons for not keeping watchdogs to scare off the herbivore raiders. 1) The carnivores such as tiger and leopard are known to hunt dogs, which ultimately threaten farmers' lives; and 2) the dogs may kill a wild animal which in turn would cause trouble to farmers if noticed by forest officials.

The extent of damage to different crop species was different and so was the vulnerability. Also, different animal species showed choice for different crop species (see table 3.1). Out of two predominant kharif crops, rice is raided least by animals. Only wild pigs were reported to feed on rice and in very rare circumstances gaur were said to raid the fields which were close to forest cover. Early flowering and fruiting were the preferred stages for raiding. Pigs were seen to eat the lower stem of rice in early flowering and complete fruiting body in the later stages. It was also found that pigs would selectively feed on fruiting bodies (i.e. grains) from the stack of rice that remains in field after harvest until husking.

Soybean was perceived to be the most susceptible crop for herbivory. It was claimed that a soybean farm of one hectare area could be easily and completely damaged by a herd of 10-15 Nilgai or Pigs in one night when left unguarded. Thus, farmers close to forest boundary showed less preference for soybean. I also observed a sharp downward trend in the choice for soybean amongst farmers during the study period, although the market value remained unaltered.

In rabi, the damage was said to be more intense than in kharif. Chickpea was raided least amongst all the rabi crops although all stages and all plant parts were equally palatable. However, raiding chickpea at fruiting stage resulted into heavy loss to the crop. Higher incidences of crop-raiding were noted for wheat as all the stages are equally palatable except the fruiting stage. As per the farmers, wheat was first attacked by Hares damaging the fresh leaves, and then by Nilgai and Chital upon growth until the fruiting stage. Farmers also reported that wheat plants become fragile at the time of harvest and can be easily trampled by nilgai/chital/pig herds which make it difficult to harvest.

Table 3.1: Preference for different crop species and their phonological stages as shown by different crop raiding animal species as perceived by farmers. This table shows that not all crop species at all stages are equally vulnerable to mega-herbivory.

Crop species	Stage vulnerable	Animals
Rice	Early flowering and fruiting	Wild Pigs
Soybean	All stages	Wild pigs, Nilgai, Chital, Sambar, Gaur
Chickpea	Fruiting	Indian Hare, Wild Pigs, Chital, Nilgai
Wheat	All stages except fruiting	Indian Hare, Wild Pigs, Chital, Nilgai

Langurs were also reported to feed on chickpea in daytime. However, farmers did not report any heavy damage caused by them during the study period. This was also evident from the fact that farmers did not protect crops in the daytime.

Crop damage compensation

Farmers generally did not make compensation claims although they were aware of the government compensation schemes for crop damage. Out of the total 846 farmers, (including farmers interviewed for different methods used for damage estimation in chapter 4), we interacted with over five years there were only six cases of compensation claims. The main perceived reasons for the reluctance to claim compensation were the compensation amount being highly inadequate, the procedure being too tedious and corruption prone and the way of estimating damage being grossly inappropriate. Farmers often felt that the damage was not evident enough to be noticed and measured visibly during any inspection. The currently practiced procedure of estimating damage during a single inspection visit after claiming compensation therefore was not perceived to offer a justifiable compensation.

Livestock

Livestock including cattle, buffalo, sheep, goat, dog and domestic fowl was another essential component of local residents' life. Though livestock husbandry was not the main livelihood for majority of people, 98.4% families owned at least some livestock. It was found that most valuable livestock was bullocks (a pair) as it was regularly used in agricultural activities and 97.9% of farmers possessed at least one pair of bullocks which was either purchased, passed to them traditionally from the previous generation or bred locally. It was observed that about 97% farmers owned cows (cattle) that were primarily used for dung, milk (for domestic purpose) and for breeding. Some cattle bulls were castrated and used for agriculture and/or sold, however, there was neither a clear pattern in this business nor could I find farmers who practiced it regularly. Often, when bulls were not castrated, they were used to obtain next generation of cattle. This new stock was either kept with the owner or sold as per the requirement. Only 4.32% people possessed buffalos, which were important for getting dung and milk. Sheep and goat were reared almost exclusively for meat.

The monetary benefit from livestock was quite small compared to agriculture. Income from agriculture ranged between ₹ 20,000 and 60,000 (average ₹ 39,142/- per annum per family) as compared to ₹ 1000 to 7000 (average ₹ 5843/- per annum per family) from livestock inclusive of milk, dairy products, renting out for agricultural operations and meat. This included renting out bullock pair (₹ 600-800 per day), small scale business of milk and milk products, and dung (₹ 1000-1500 per tractor trolley). An additional income from livestock trading ranging from ₹ 150 to 450 per kg of meat was also obtained. The meat consumption was found to be ~300 gm per capita per week.

Herders took livestock for grazing usually along the forest periphery with marginal infiltration into the protected areas (PAs). All livestock herds were usually carried by a few assigned cattle herders and shepherds for a given village. The grazing herds were separated as per species i.e. herds of cattle, buffalo and goat-sheep were kept separate and taken to different grazing grounds. Bullocks and adult bulls were kept separated from the other herds, often retained and stall fed. Buffalos were very rarely mixed with cattle particularly if their number was below 5-6. All livestock grazed for 7 to 8 hours daily typically being taken to grazing grounds (patchy grasslands at the periphery, interestingly called as *savannah* locally) around 1000h and driven back by 1700h in winter and monsoon. In summer the cattle were kept free ranging, but buffalos and goat-sheep herds were attended by herders and shepherds. The herds were often accompanied by watchdogs. These watchdogs were not claimed to be owned by the shepherds/cattle herders, instead they were said to be feral. In village, the livestock was protected with cattleshades made up of simple and non-durable wooden structures. In some villages e.g. Mudholi, all the cattle from village were kept in one single cattleshade fenced loosely with bamboo and barbed wires.

Livestock depredation and perception about human-carnivore conflict

Attitude towards carnivore and herbivore raiders was different. Carnivores were not perceived as nuisance, whereas nilgai and pigs were believed to be the most troublesome animals. All the respondents claimed seeing tiger, leopard, and sloth bear at least once. 73.4% people claimed to see tiger once in a month but only while grazing, whereas 69% people claimed to have seen tiger coming near villages, however, quite infrequently i.e. nearly 2-3 times in 5 years before this survey (year 2006 to 2011). Tiger was found to be the sole species attacking livestock at the western boundary. No cases of human attacks by tiger were reported during the study period in the study area. The experiences with leopard and dhole were very rare, but those with sloth bear were quite frequent especially in the post monsoon months. Farmers claimed to see sloth bear 4-5 times a week while guarding the crops in night. Sloth bear seemed to be the most feared animal amongst all others. Nearly all respondents ranked sloth bear as most fearsome carnivore followed by tiger. I witnessed three cases of sloth bear attack on farmers which occurred while guarding the farms in night. Encounters with dhole were rare in general and hence no fear or negative attitude was expressed against it.

Only 11.6% of the interviewed farmers lost at least one of their livestock to tiger during 2006 to 2011. All the cases of livestock raiding occurred while grazing in the forest. Apart from these, I witnessed only two cases where tiger lifted young cow from village. Cattle seemed to be a preferred livestock species over goat and sheep, although farmers perceived all three species to be equally vulnerable to tiger predation. Out of 51 incidences of livestock depredation reported in questionnaires, 38 were that of cow, 5 cases of goat/sheep and 7 cases were that of young bullocks of age < 2 years; all of them were claimed to be killed by tiger. As per one respondent, 6 goats were killed in one day by a pair of tigers in the monsoon of year 2010. The livestock lifting by other species was rare. Only two respondents reported to lose their watchdog and two goats to leopard. There was another incidence where a lone male wolf killed three sheep in one day in December 2015. Since the carcasses were not retrieved, they were not claimed for the compensation in case of both leopard and wolf.

In the questionnaires it was evident that all the cases of cow and young bullocks killed by tiger were reported to forest officials immediately for compensation and all the claimants received the assured compensation amount. It was clear from the victims’ response that the forest department provided compensation relatively quickly in comparison with crop damage compensation. It is interesting to note that goat and sheep killed by tiger were not claimed for compensation. In fact, goat and sheep killed by tiger was considered ‘sacred’, locally termed as ‘*waghmodi’,* and thus taken away for consumption. The meat if not consumed by owners or herders was often sold in village, which provided more money than compensation (₹ 350 to 450 per kg of meat).

Therefore the common custom was to retrieve sheep and goat kills and eat or sell them. This was never practiced with cattle since eating beef is a taboo due to religious reasons. Therefore unlike goats, cattle kills were generally claimed for compensation.

When asked what preventive measures could be taken against carnivores, nearly 100% of the interviewees answered “scream loud” or “run away or “climb tree” as a way to be safe or scare off the carnivore. Only 2 out of 439 people expressed a feeling to retaliate by saying “beat the animal” by which they may not dare to come and attack again. The ways to injure also seemed less invasive which included throwing stones, beating with stick etc. Demand for culling any carnivore was not made during the surveys; in other words any serious feeling of retaliation was not found to be prevalent. It was perhaps because livestock raiding is a sporadic phenomenon and the compensation for livestock was obtained fairly smoothly and as per the expectation. Since livelihood was rather depended upon agriculture and livestock provided a surplus monetary benefit, the carnivores were not perceived to be a nuisance.

Case studies of livestock depredation

During study period (between year 2010 to 2015), I witnessed 56 cases of livestock lifting along the western boundary. All the cases involved tiger as the predator and all the kills occurred while livestock was grazing at the periphery outside core boundary. 45 out of 56 cases were of cattle (27 females and 18 males), 4 of female buffalo, 2 of goat and 5 of sheep. All the carcasses were retrieved by the team consisting of herders, owner and forest guard. It was found that average age of the prey species was 4.36 years for cattle and buffalo, 3 years for sheep and goat. All of the kills occurred during daytime i.e. between 1400h to 1600h in the presence of the herder. Livestock depredation achieved a peak during monsoon between July to September (total 26 cases). On field examination of carcasses revealed that all the individuals were killed either by suffocation (holding the throat from below) or cervical dislocation. In most of the cases sex and age of predator could not be ascertained except for two cases where photographic evidences could be obtained. It was seen that two sub-adult males had killed two cows on two consecutive days (see colour plate 3.5). In all the cases as per the information obtained from the herders who witnessed the kills the prey was dragged at least 200-300 m away from the killing spot to cover.

Only 16 out of 56 kills were eaten at the spot or immediately after killing, rest all were kept for more than 12 hours. In remaining 40 cases predator was deterred by people either out of panic or to retrieve the animal back. In these cases the predator did not come back to the kill.

The compensation amount of all the cases addressed here was delivered within 6 months to the claimant. Perhaps loss in losing livestock did not hamper economy of locals much and hence cattle herders, shepherds and the owners did not show any retaliatory action against tiger. There were no cases of poisoning the carcass during the study period.

DISCUSSION

Severity of crop depredation was perceived to be higher than the livestock depredation. Farmers responded that they face up to 100% loss in grain yield per season if the farms are not protected every day. Further, it was seen that loss in grain yield could be up to 50% in spite of labour intensive guarding of crops especially in a zone of 1-2 km from forest (see chapter-4 for more details).

Agriculture is clearly a main livelihood for the locals, where livestock provides only surplus and opportunistic monetary benefit. Thus more attention in resolving crop depredation problem is needed. It is evident from the farmers' response that they tend to invest substantial man-power in protection of crops. Farmers did not believe in constructing durable fencing structure in spite of availability of subsidised raw material since they perceived every type of fence equally penetrable to crop raiders. Since such investment would be useless in long-run, farmers showed preference to protect crop with manual guarding.

A clear difference in crop damage and livestock damage compensation is observed. Although the wildlife damage in agriculture is higher than in livestock, farmers seemed to be more consistent about claiming compensation for livestock loss. This is perhaps due to the fact that procedure to claim compensation for livestock damage is easier, more straightforward and higher attention given by forest officials to livestock depredation. Further, compensation amount obtained against livestock loss is an additional monetary benefit since there is no dependence on livestock. Importance is given more to carnivores as compared to herbivores and it can be evidently observed from the readiness in paying compensation for livestock loss and also a substantial media coverage given to conflict with tiger and leopard. Since the procedure of crop damage compensation claim is rather tedious and not as straightforward as for livestock damage, both farmers and forest officials tend to overlook the problem. The difference between perception about crop damage compensation and livestock depredation compensation by the same set of people demonstrates that there was some fundamental difference between the executions of the two compensation schemes. The reluctance and resentment of people about crop damage was not a non-specific response of dissatisfaction with bureaucratic procedures since the same set of people had a different perception about livestock compensation procedures. It is necessary therefore to make crop damage by herbivores the main focus of study.

COLOUR PLATE 3.1

CROP-RAIDING ANIMAL SPECIES

Indian hare raiding the wheat crop in early leaf stage on the unfenced experimental plot.

Wild pigs visiting the rice crop and the adjacent waterhole on unfenced experimental plot.

Crop-raiding Nilgai: females (left) and male (right) on the unfenced chickpea experimental plot.

COLOUR PLATE 3.2

CROP-RAIDING ANIMAL SPECIES

Penetrable fences: Nilgai (left) and chital (right) could raid fenced farms

Crop raiding Plum-headed Parakeets. Note the wheat fruiting body with each individual

COLOUR PLATE 3.3

TYPES OF FENCES

Electric fence (left) and barbed-wire fence with additional protection of thorny plants (right).

Simple wired fence with home-made up of ‘bells’ that would scare off the raider animals (left). Simple femnce made out of thorny bushes (right).

Simple wired fence with additional means to scare off the raiders.

COLOUR PLATE 3.4

TYPES OF FENCES

Fence made out of bamboo (left). Fence made out of bamboo broken by pigs (right).

More elaborate fence made out of metal wires, and trees (*Butea*, *Tectona*, *Zizipus*, and *Acacia*) lopped from forest (left). An additional protection given to the stack of rice in farm, note two watch towers and an additional fence to protect the produce (right). This demonstrates the high perceived risk of crop-raiding.

COLOUR PLATE 3.5

LIVESTOCK DEPREDATION

Sub-adult male tiger killed a cow in monsoon 2012

Camera trap picture of two tigers on a bullock carcass in winter 2012. Note that the tiger on right side is same one as seen in picture above.

CHAPTER 4

REALISTIC ESTIMATION OF DAMAGE

INTRODUCTION

Crop depredation is a wide spread phenomenon across globe. In spite of being a serious threat to conservation, reliable primary data on the extent of crop damage and its patterns are inadequate (Naughton-Treves and Treves, 2005). Although a good number of studies on crop raiding is published addressing the problem in different habitats and caused by different species of wild animals, very few utilize extensive methods for primary estimation of damage (Zadoks, 1985; Guerbois, 2012, Mathur et al., 2015). There is little discussion on the 'pros and cons' of different possible methods of estimating damages and attempts to validate or cross check the estimates (e.g. Schwerdtner and Gruber, 2007). Most of the studies are based on impressionistic judgments of damage by someone including the farmers, park officials or others without much attention to validate the claims or estimate errors or biases in the method of damage assessment (Ogra and Badola, 2008). It also needs to be appreciated that the patterns of damages caused by different herbivores can be substantially different and estimating them using one single method may not be possible. For example, raiding by elephants leads to visibly obvious damage over a measurable area whereas different species of deer and antelopes may nibble some specific parts of a plant such that the damage is inconspicuous at a glance (Chauhan and Singh, 1990). In the case of damage by elephant, the fraction of the total area trampled or uprooted might be able to give a reliable estimate of the fraction of damage (Sukumar, 1989). The lack of standardized methods and the subjectivity of recorded estimates often made by different individuals or groups of individuals having direct or indirect vested interests make it difficult to compare data across different areas with different damaging species.

Even though it is assumed that there is some way of accurately estimating the damage during an inspection following the raid, there are further more complications most of which go unnoticed. The crop species are living entities that respond to inflicted damages in an adaptable manner. When damage is not lethal to a plant, it regenerates and tries to make up for the loss at least partly. Therefore, the net damage at the end of the season may be substantially different from what appears immediately after a raid. One study that addresses this question has shown that the visible damage may not be correlated well with the grain yield at harvest (Kear, 1970).

I studied crop-raiding which was motivated by the perceived orders of magnitude difference between the government records on crop damage and people's perception about it. I felt a need to undertake a third party assessment of the magnitude of the problem to check which of the two perceptions were more realistic. Since the problem addressed was about unbiased and validated estimates, I employed five different approaches to estimate crop damage. Although it is difficult to find a single field method free of errors and biases, it is possible to reach a robust inference by triangulation (Bogdan and Biklen, 2006; Altrichter et al., 2008). If different methods having different sources of errors and biases converge on a similar inference, they serve to validate each other. If they do not converge, a comparison shows whether some of them give consistent under or overestimates as compared to others. At an experimental scale, it is also possible to inflict controlled artificial damage and study its effects. Using such a multi-tool approach I examine whether the currently employed method of damage assessment is realistic or whether people's perception is more realistic or both are biased in different ways.

METHODS

Following are the 5 independent methods to directly or indirectly estimate crop damage.

(1) Periodic visual examination of crop damage on transects and farms infiltrated into forest.

(2) The net grain yield per unit area along the transect lines.

(3) Comparison of yields on protected and exposed neighbouring farms.

(4) Comparison of grain yields after controlled artificial herbivory.

(5) Comparison of independent estimates of visual vegetative damage by different assessors.

Methods (1), (3) and (4) were primary quantitative based on observations. In contrast to it, method (2) and (5) mainly depended on information obtained from farmers or other people but it was quantitative. In method (2) nearly 20% of cases could be verified first hand. Across the five methods one or more of the three parameters were monitored *viz.* (i) Frequency of visits by wild herbivores (ii) Estimates of visual vegetative damage, and (iii) Grain yield at harvest, all the three were estimated taking an individual farmer's cultivated farm as a unit and then normalized by the area under cultivation in that farm. I conducted this study with the help of three field assistants in the period of 2010 to 2015. I could not utilize all the methods throughout the study period owing to manpower limitations but there are sufficient overlaps between the approaches to allow a comparison of methods (see details below).

1) Visual estimates of frequency of raids

Three transect lines each 10 km long were laid approximately perpendicular to the boundary of the core area of TATR. Since there was no forest cover available to animals outside the park boundary on the western side, I expected the raiding frequency to be a monotonic function of distance from forest. Therefore, transects going away from the forest were expected to reflect this pattern. Geographical location of the centre of each farm that was cut by the line was recorded using handheld GPS device (Garmin 60). Baseline information about the farm owners, the cropping season, crop species, total area of farm, area under cultivation of each crop, irrigation facility and other agriculture related information was noted (also see Appendix 1). A total of 188 farms lined along the transects were then visited once every week by my team (three field assistants and I) during daytime to observe whether there were visible areas of damage. Whenever damage was noted, the approximate area with visible vegetative damage was measured in meter squares. The weekly observations continued until the crop was harvested. This information was treated as binary to calculate per day probability of damage assuming that the raids were random and therefore followed Poisson distribution. Same method was employed on to the farms (n=90) which are surrounded by forest at least from three sides.

2) Grain yield at harvest

The farms along the transect lines up to 6 km and those surrounded by forest (mentioned above) were visited at the time of harvest to note the total grain yield for each crop per unit area. Usually the yield is estimated in terms of number of bags; we (three field assistant and I) asked each owner about amount (in kg) per bag for each crop at the time of sale and later calculated it in terms of actual weight in quintals. We studied the farms along transects for subsequent years and recorded yields at 180 farms in year 2010 and 2013 to 2015 for rice, soybean, chickpea and wheat each (see the text below). Grain yield was later normalized with individual farmer's land area under cultivation (in hectares), it was expressed as quintal(s) per hectare (Q/Ha)

3) Experimental plots

A plot of approximately one hectare at close proximity to forest was used as an experimental farm. This farm was one of the first from the forest along one of the transect lines (<500m away from forest cover). The experimental area (2 Ha) with homogeneous soil and irrigation conditions was divided into four sub-plots two of which were fenced with a combination of barbed wire and thorny bush and the other two left unprotected. Four crop species namely rice and soybean during kharif and wheat and chickpea during rabi season were grown in neighbouring protected and unprotected farms keeping the parameters of cultivation such as soil preparation, fertilizer use, seed density and irrigation identical. All the experimental farms were protected during daytime to avoid any damage by domestic animals and were observed silently at night from traditionally prepared 10-12 ft tall wooden watchtowers or guarding platforms i.e. *machan* locally termed as '*mara*'. The daily-recorded parameters included frequency of visits by wild herbivores, their group size, frequency of visible damage and area with visible damage. At the end of the season, the grain yield per unit area was recorded.

4) Artificial herbivory

To study the effect of different levels of damage on individual plants, particularly their regrowth after damage and the resultant grain yield, I cut the plants manually using scissors at different heights and different ages and compared with uncut control plants at the time of harvest. These experiments were performed in a fenced area independent of method 3. Three species namely soybean, chickpea and wheat were subject to these experiments during two consecutive seasons of 2013 and 2014. In one set of experiments, the main stems of all plants in a unit sampling area were cut at different heights (5, 10, 15 cm for wheat and chickpea; 5, 10, 15, 20 cm for soybean, see the details in result section) from ground in a pre-flowering stage (at 60 days for wheat, 55 days for soybean and chickpea). In another set of experiments the tips comprising leaves and buds in the upper 2-3 cm were cut at different ages of the crop (25, 45, and 55 days for wheat; 20, 45 days for soybean and chickpea, see details in the result section). The plants were allowed to regrow through rest of the season. All the treatment plots of all crop species were provided with the same amount and combination of fertilizers, pesticides, and water as the control plots. At the time of harvest, all the treatment and control plants were uprooted carefully to measure the different parameters such as the height of the regrown plant, canopy height and width (for chickpea only), number of branches (for soybean and chickpea), the number of pods/heads and number of grains/seeds (for all the three crop species).

5) Comparison of visual vegetative damage estimates

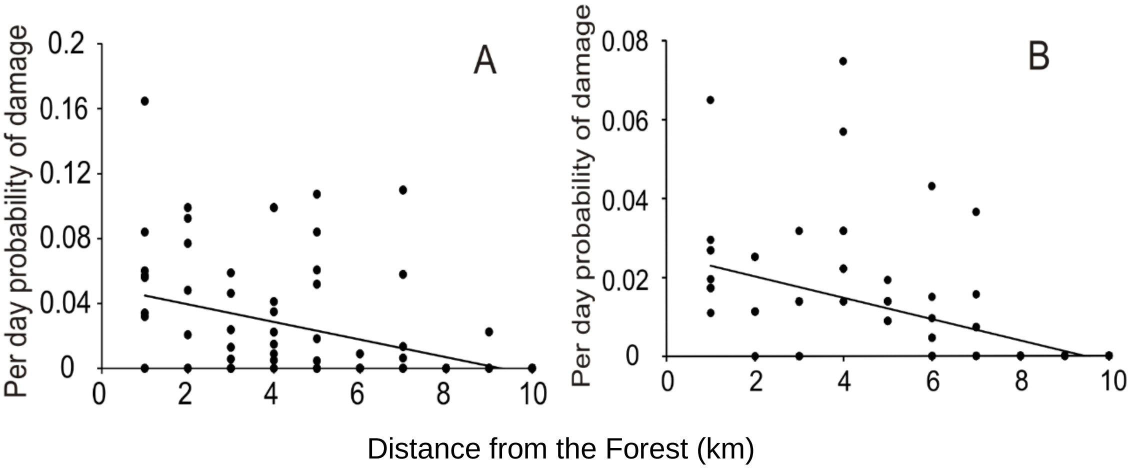
Currently in India, compensation is paid based on extent of visually estimated vegetative damage approximately converted in rupees. After filing a claim by the victim a panel consisting of the village head, representatives of park management and neighbouring farmers, visits the site and verifies the claim. To understand the inherent subjectivity in assessment of the within and between individual variation in such estimates, we approached four independent persons, and asked them to give their estimates (independent of each other) of damage on a raided farm. They were assured anonymity and clearly told that this experiment is about comparing the damage estimates done by them with the same done by other anonymous persons. They were asked to record their own personal estimate of the extent of total damage inflicted in terms of the market value of the crop. This was used to reflect inter-personal variation in visual inspection and assessment.

RESULTS

Periodic monitoring of farms along transects

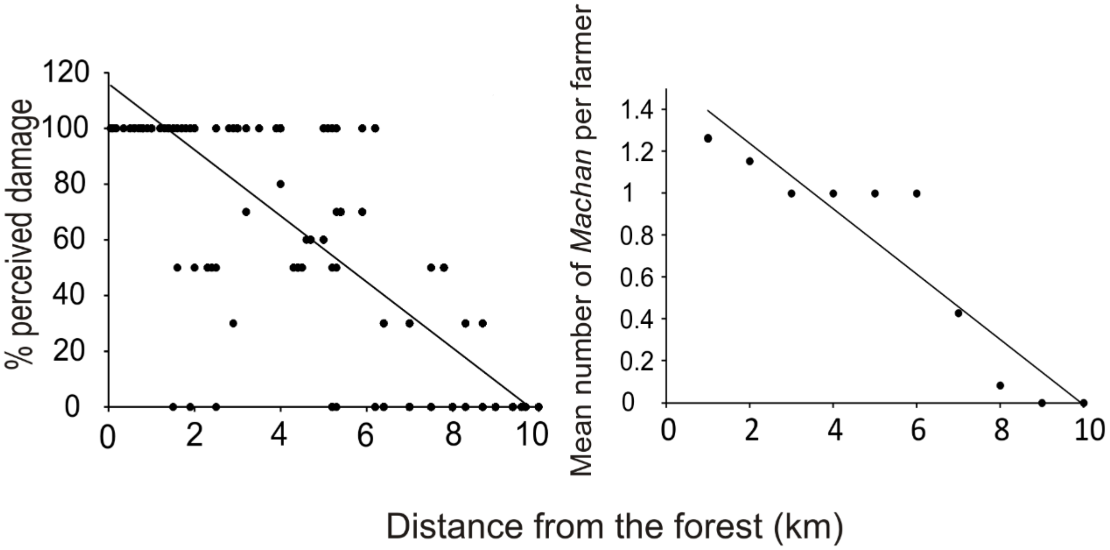
Farms along the three transect lines were monitored once a week during the kharif and rabi season of 2009-2010. Incidents of visible damage were recorded weekly along with the measurement of the area of damage. This damage could have been inflicted during one or more than one raids by wild herbivores during the week. In order to calculate the daily frequency of noticeable damage I assumed the damaging raids on a given farm to be a random process, giving rise to a Poisson distribution of number of raids per unit monitoring period. Based on the fraction of observations with no noticeable damage pooled over all crops in a given season, it was possible to back-calculate the mean frequency or probability of visible damage per night. Since a visible damage would mean one or more events of damage, $P_1, P_2 \dots P_n$ from the Poisson series could not be estimated empirically. But, since no crop raiding meant no damage, an empirical estimate of P_0 was possible. Using Poisson formula for $P_0 = 1/e^{\mu}$, the mean number of raids per week (μ) could be calculated, which when divided by 7 gave the mean frequency of damaging raids per night. The mean frequency per night, thus calculated, showed a decreasing trend with distance from the edge of forest (Figure 4.1). Although both seasons showed a declining trend with distance, the damage frequency in kharif (Figure 4.1A) was nearly twice that in rabi (Figure 4.1B) over the 10 km stretch. This difference is likely to be owing to active guarding by farmers, which is difficult during monsoon and therefore not practiced.

Figure 4.1: Trend of per day probability of damage pooled from three transect lines perpendicular to PA boundary. A: Trend in kharif season (r= -0.4525, p=0.0001, n=90); B: Trend in rabi season (r= -0.5455, p=0.0001, n=98).



It is important to note that the frequency of damage in Figure 4.1 is in spite of manual guarding efforts. Frequency of animal visits to a farm could be substantially greater than the frequency of inflicting visible damage, as raider animals are often driven away by the vigilant farmers. Consistent with the decreasing trend in the frequency of crop raiding, farmers' efforts at guarding declined with distance. Figure 4.2 shows the trend in % perceived risk of crop depredation decreasing with distance (Figure 4.2A) and the mean number of *machans* per farmer at one kilometre intervals made for night vigilance by farmers along the transect lines (Figure 4.2B). Farmers close to the forest often made more than one *machans* barring which one *machan* per farm was the modal trend. There appeared to be a threshold risk below which it was perhaps not perceived worth making a *machan* since there is a sharp decline in the number of *machan* after 6 km.

Figure 4.2: A: Trend in % perceived damage to crops (r= -0.82, p<0.0001, n= 352); B: Trend in number of machans per farm along transects (r= -0.9310, p<0.0001, n=10).



The agricultural lands that were infiltrated into the forested patches had higher frequency of visible damage than the farms along transects having forest from only one side. Table 4.1 gives probabilities per crop species with number of farms sampled per crop species (n). Kharif is represented by rice and soybean, and rabi is represented by chickpea and wheat. Cotton stands for more than 7 months, starting in kharif and harvested in rabi. Therefore, I did not pool the probabilities for cotton across season, rather calculated and represented for both seasons separately (Table 4.1). It is observed that per day probability of damage on farms infiltrated is twice than seen on farms along the transects having forest cover from only one side. It is important to notice that the distance between two opposite ends of infiltrated farm areas is nearly 2 km i.e. the forest cover is separated by just two km. Here in this situation the animals may come from all the directions to the farms and that would perhaps increase the probability of damage.

Table 4.1: Per day probability of damage on farms infiltrated in forest patches. (n= number of farms observed)

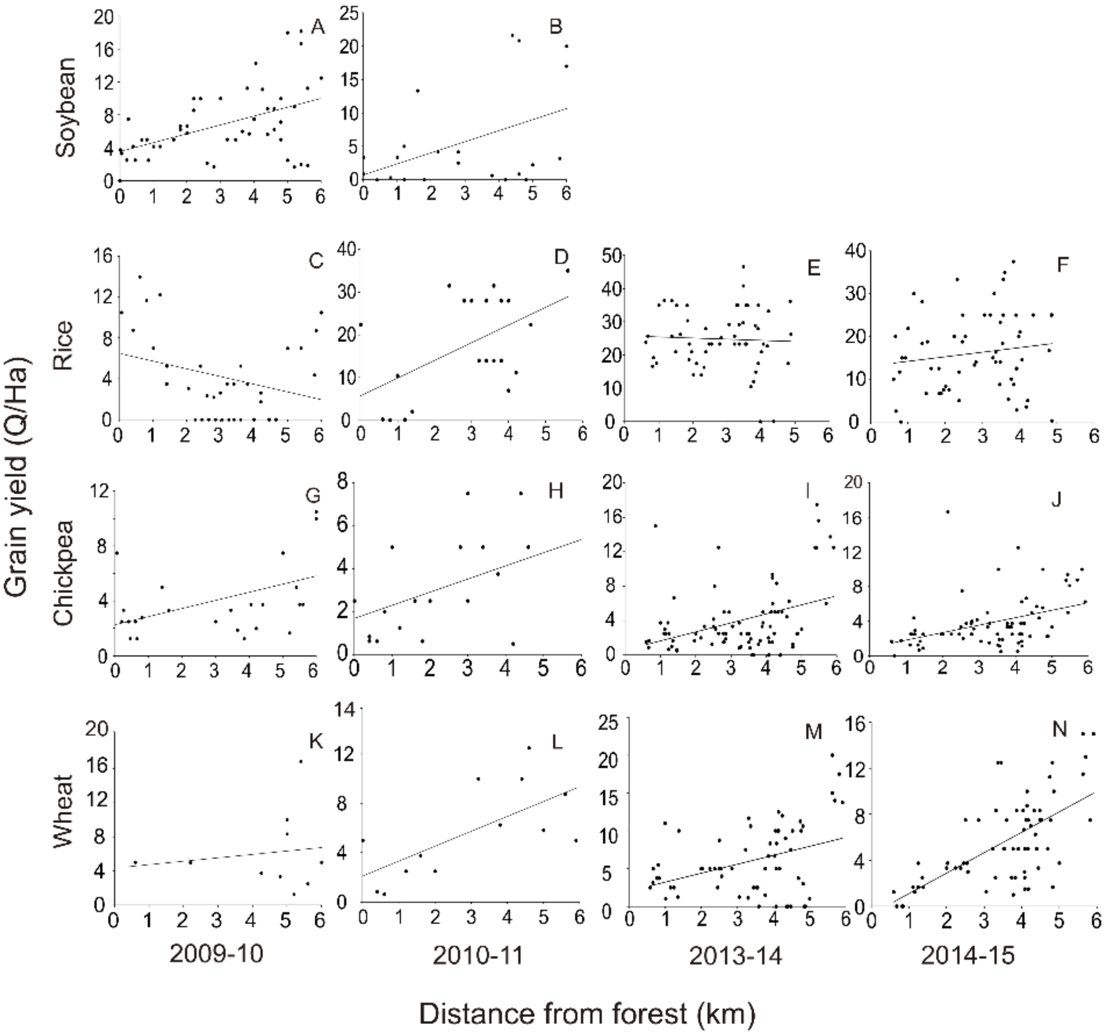
Crop species	Per day probability of damage (Mean ± SE)	n
Rice	0.044 (±0.004)	39
Soybean	0.0923 (±0.014)	16
Cotton (kharif)	0.11 (±0.0095)	21
Cotton (rabi)	0.27 (±0.018)	23
Chickpea	0.049 (±0.0077)	59
Wheat	0.098 (±0.0121)	39
Sorghum	0.17 (±0.0122)	43
Flax	0.11 (±0.009)	34

Grain yield along the transect farms

Corresponding to the decreasing trend of visible damage by herbivores, there was frequently an increasing trend in grain yield with distance from the park boundary along the transects (Figure 4.3). With the exception of rice, there was a consistent increasing trend with distance for different crops across different seasons.

Figure 4.3: Trend of grain yield at harvest with distance from PA boundary for 4 crops over 4 seasons. Soybean: A 2009 (r = 0.473, p = 0.0001, n = 95) and B 2010 (r = 0.448, p = 0.03, n = 22); Rice: C 2009 (r = -0.291, p = 0.08, n = 35), D 2010 (r = 0.53, p = 0.001, n = 20), E 2013 (r = -0.044, p = 0.73, n = 56) and F 2014 (r = 0.14, p = 0.28, n = 58); Chickpea: G 2009–10 (r = 0.466, p = 0.012, n = 27), H 2010–11 (r = 0.54, p = 0.01, n = 17), I 2013–14 (r = 0.378, p = 0.0029, n = 83) and J 2014–15 (r = 0.398, p = 0.0003, n = 78); Wheat: K 2009–10 (r = 0.147, p = 0.66, n = 10), L 2010–11 (r = 0.67, p = 0.01, n = 12), M 2013014 (r = 0.369, p = 0.004, n = 65) and N 2014–15 (r = 0.642, p = 0.0001, n = 67).

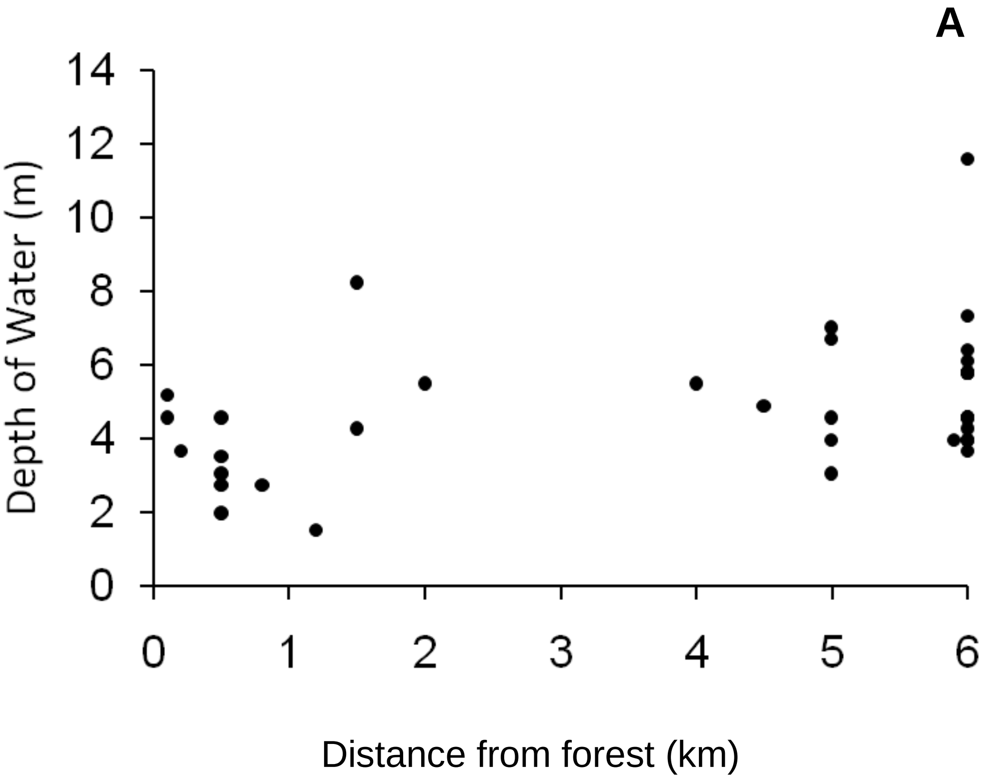
(See figure on next page)

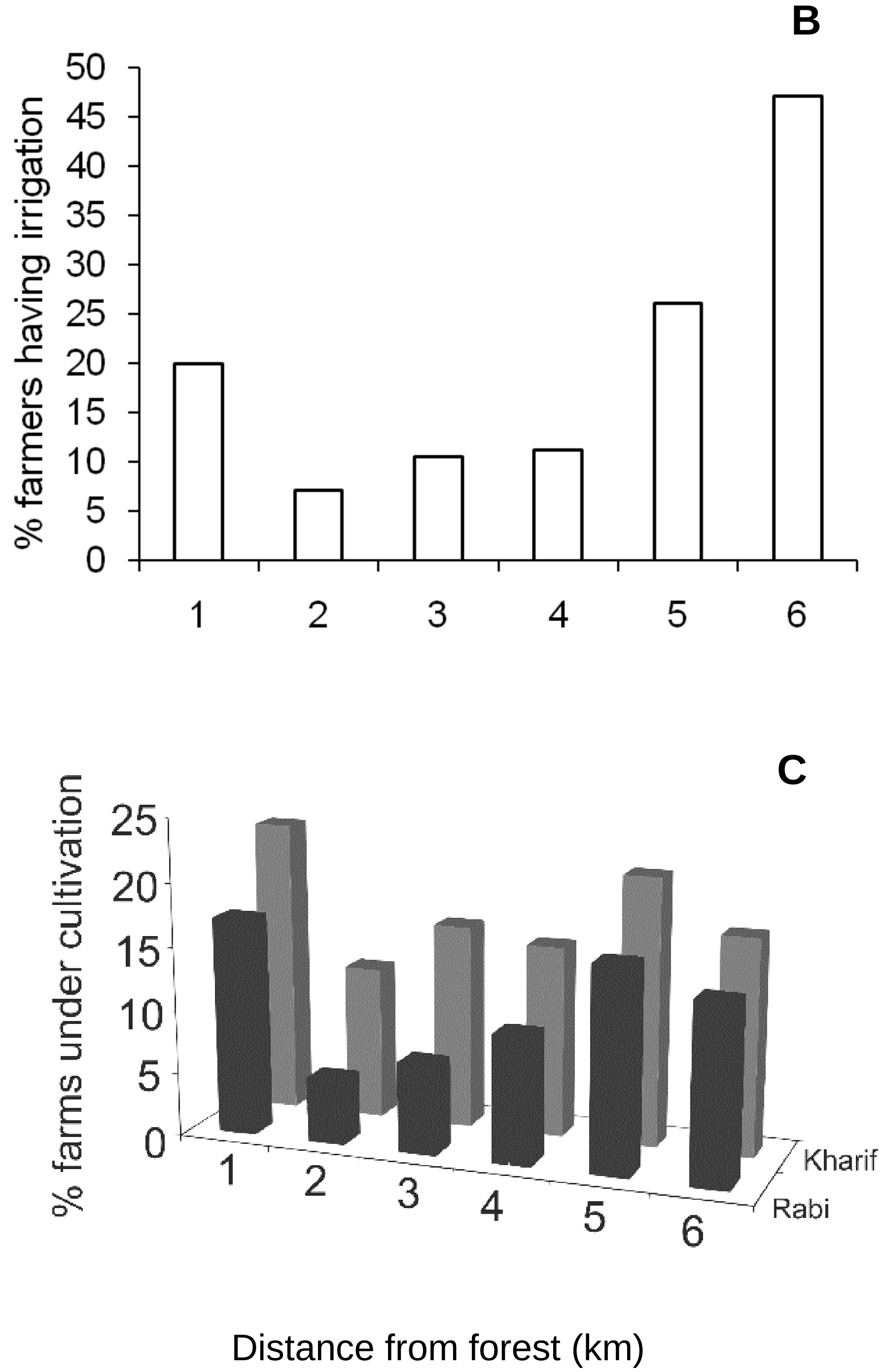


The trend in the frequency of animal raids between the first kilometre and the interval between 5th and 6th km showed about twofold decline in the frequency of raids. Compared to this decline the yield improved by 0.32 to 3.09 fold for rice 2.15 to 4.5 fold for soybean, 2.03 to 4.24 fold for chickpea and 1.37 to 2.85 fold for wheat with a pooled median at 2.24 fold. Thus, there is a fair match between the fold decline in the frequency of damaging visits by wild herbivores and the fold increase in net grain yield. However, there can be other possible reasons for an increasing trend in grain yield. (a) It is likely that there is a trend in the fertility, water availability, irrigation facility or any other agriculture related property of soil with distance from the park. (b) Farmers close to the park tend to invest less in intensive agriculture owing to the risk of damage. It is possible to assess the two possibilities from the available data.

(a) In experiments with fenced farms adjacent to the park (see below), the yields observed were comparable to those at a distance of 5-6 km from the park. For rice, the protected farm yield was 22.8 Q/Ha, and for wheat 24.8 Q/Ha both being close to the regression expected yield at 6 km. Since giving protection alone could increase the yield to a level comparable to the highest yielding areas, soil fertility was an unlikely reason for the trend in yield with distance. The trend in ground water levels (measured as water levels in open wells in the month of April) as well as the frequency of rabi crops with distance in a low rain fall year (2009) (Figure 4.4) showed that availability of ground water or water holding capacity of the soil did not correlate with the distance trend. The ground water level, the density of wells (Figure 4.4A), availability of irrigation (Figure 4.4B) and frequency of rabi crop in a low rainfall year all follow a similar trend (Figure 4.4C). There was greater water availability close to the forest, which declined at 2-4 km and again rose at 5-6 km. It is likely that close vicinity of forest had a positive effect on ground water and water holding capacity of soil. The second rise at 5-6 km is likely to be due to a perennial river flowing almost parallel to the park boundary at a distance of about 6 km. This trend is substantially different from the trend in crop yield at harvest and therefore these factors are unlikely to be causal to the increasing trend in yield with distance.

Figure 4.4: Indicators of the trend in availability of water with increasing distance from PA. A: umber of wells distributed at various distances from PA and the depth of water in the month of May (n=60). Note that between 2 and 4 km the density of wells is low and water levels low; B: The trend in proportion of farmers having any type of irrigation facility (n=334). Both the trends show good water availability near the forest followed by a drier zone at 2-4 km followed by increased water availability again. These trends do not match well with the trends in crop yields; C: Trend in proportion of farmers taking rabi crops in 2009-10. 2009 being a drought year the trend can be taken to represent the trend in water availability and water holding capacity of soil. This trend does not match with the general trend of increasing yield with distance from PA.

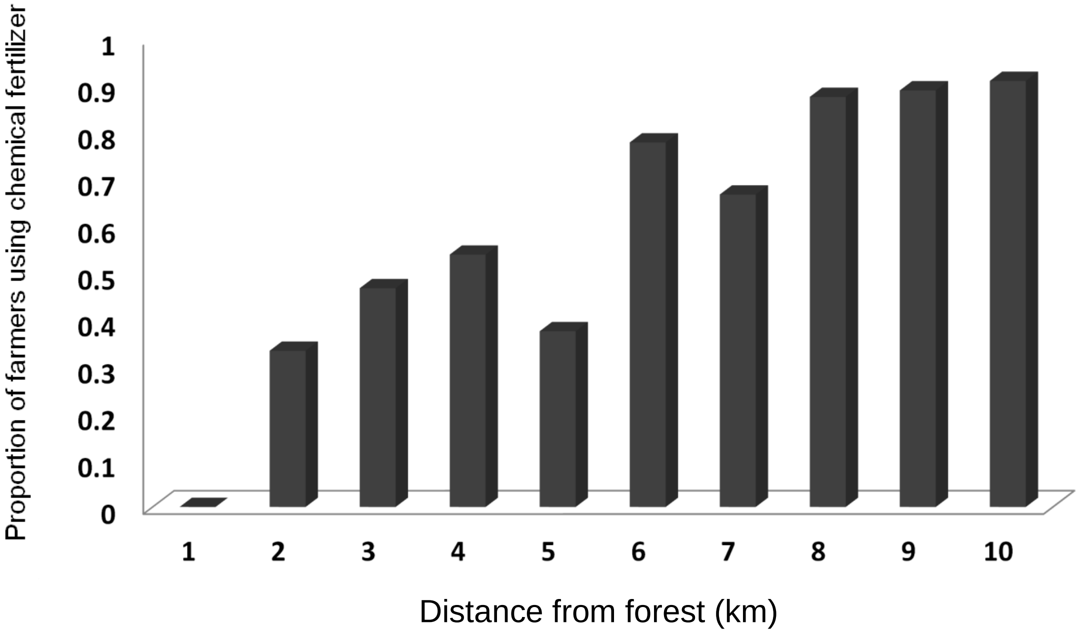



B
% farmers having irrigation
0
5
10
15
20
25
30
35
40
45
50
1
2
3
4
5
6
C
% farms under cultivation
0
5
10
15
20
25
1
2
3
4
5
6
Kharif
Rabi
Distance from forest (km)

The distance trends in rice appear to differ from those in other crops. Negative trend of rice yield along transects in the year 2009 could not be explained by frequency of damage as it included significant number of incidences of crop failure in the drought year. Trends in other years could be explained neither by raiding frequency trends nor by water availability trends. As rice is a rain-fed crop, effect of ground water availability was perhaps negligible except in a drought year. Additionally, rice was susceptible to herbivory at its fruiting stage alone that persists for one to two weeks before harvest. This implies that raiding incidences were rather sporadic for rice. This observation matches with people's perception that rice was the safest of the crops from herbivore damage point of view although it was more susceptible to rainfall variation. For all other crops the trend in the yields were better explained by the frequency of herbivore damage than by water availability or soil fertility.

(b) In contrast with (a) above, the possibility (b) was backed by some evidence. Farmers' interviews revealed an increasing trend in the use of multiple chemical fertilizers with distance (Figure 4.5). It is possible therefore, that farmers facing higher risk of herbivore damage invest relatively less in agricultural inputs and part of the reason for lower yields near the forest could be the trend in investment. In brief, greater accessibility and frequency of visits by wild herbivores and farmers' discouragement from investing in intensive agriculture appear to be responsible for the trend in grain yield. It should be noted that this loss is indirectly caused by herbivory itself, but it is unlikely to be recorded during visual inspection of damaged farms even if it is assumed that the visual vegetative damage estimates to be realistic.

Figure 4.5: Proportion of farmers using combinations of chemical fertilizers increased with distance from PA. This can at least partly explain the increasing trends in grain yield.



The trend lines of grain yield also give us a rough estimate of average damage close to the PA. For crops other than rice, the slopes of the trend lines range from 0.4 to 1.78. The average yields at 0-1 km are between 28 to 78% of the averages at a distance of 5-6 km.

Comparison between the averages in 0-1 km with that in 5-6 km indicates that the yield deficit due to all causes combined close to the PA, range from 22 to 72% for crops other than rice.

Experimental farms

Frequency of damage could be measured for four crops separately on experimental farms. It was observed that rice did not face severe raiding problems before seed setting, whereas wheat faced raiding at all stages except after seed setting. Post-harvest raiding was prevalent in rice stacks but not for wheat. Soybean and chickpea were susceptible throughout the season.

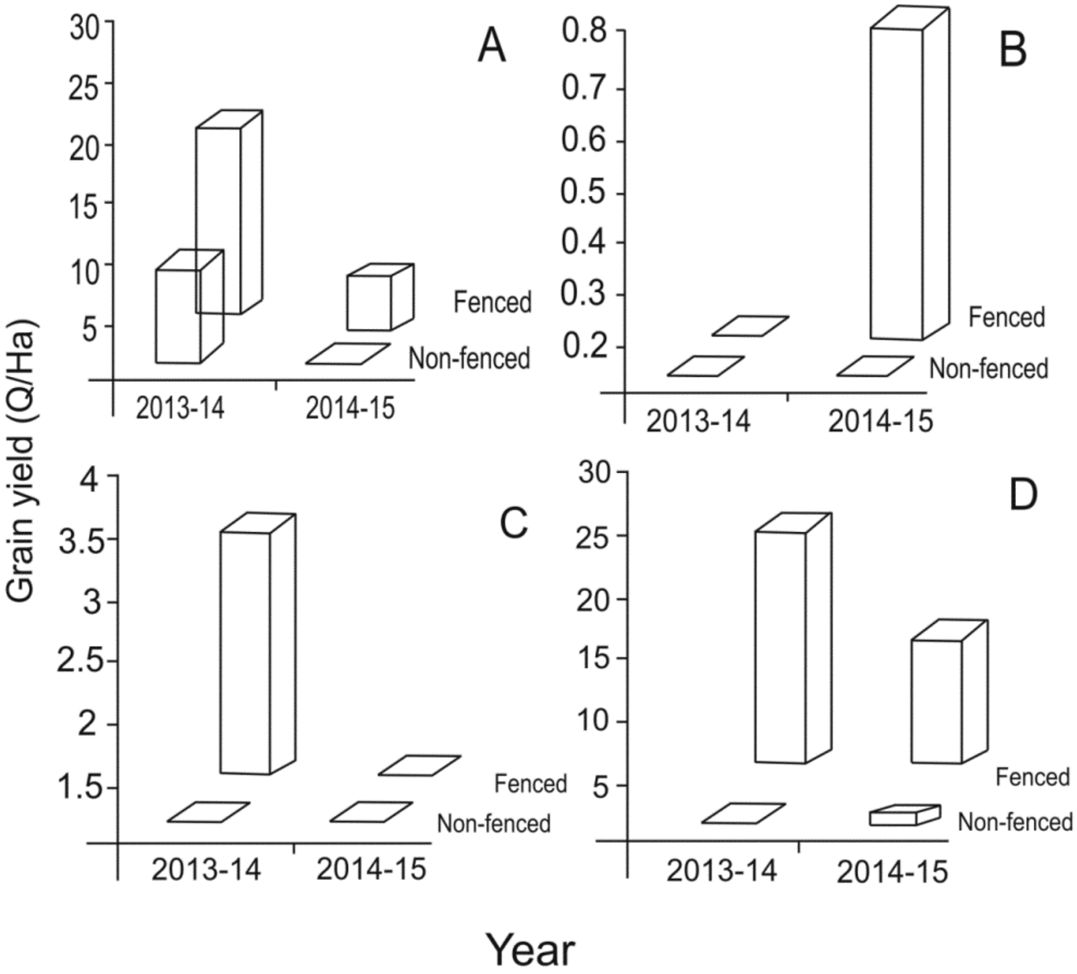
In all four experimental crops cultivated over two seasons, the non-fenced plots faced severe damage due to herbivory compared to the fenced plots. The fenced plots were not completely protected. Indian hare (*Lepus nigricollis ruficaudatus*) were observed to make their way through the fence routinely. Nilgai, chital and wild pigs demonstrated their ability to negotiate the fence on occasions although the frequency of their visits to fenced and unfenced areas was substantially different. Most instances of entering the fenced areas were after the crops on the neighbouring unfenced areas being almost completely devoured. Grain harvest at the end of the season revealed that wheat, soybean and chickpea faced 100% loss in the unprotected and unguarded farms. Rice was least damaged but still faced a 68% loss in the unfenced unguarded areas in 2013. In 2014 owing to unfavourable rainfall pattern accompanied by a disease, the overall rice crop suffered substantially. In this season, the unprotected area yielded nil whereas the protected area yielded 7.68 Q/Ha (Figure 4.6). It needs to be noted that when the damage is beyond a threshold (generally around 80%), the cost of harvesting becomes greater than the possible harvest and at that stage farmers decide to give up and the resulting yield is zero for practical purposes.

When night-time observations were compared with independent early morning visible evaluation of damage, I found that the frequency of visible damage was less than frequency of actual visits in unguarded farms (Table 4.2). The difference is likely to be much greater on guarded farms. This implies that on many visits the damage inflicted was either nil or small enough to escape visual inspection. The average damaged area per raid, whenever noticeable, was 34.088 ± 94.57 (277.4%) sq. m (Mean ± SD, CV) on unfenced and unguarded experimental farm for all crops pooled. High coefficient of variation shows severe occasional damage caused on certain raids. In one instance, an area as large as 900 sq. m (for Soybean) was damaged completely in one night by herds of wild pigs and nilgai.

Table 4.2: Per day frequency of damage, per day frequency of visits and average damage per night for rice (n=3), soybean (n=2), chickpea (n=4) and wheat (n=4) on experimental farm plots. (n is number of seasons of observations).

Crop	Per day frequency of damage (Mean ± SE)	Per day frequency of visits (Mean ± SE)	Per day visible damage sq. m.(Mean ± SE)
Rice	0.135(± 0.015)	0.135(± 0.015)	31.03(± 10.51)
Soybean	0.333 (± 0.067)	0.378(± 0.002)	80.81(± 25.45)
Chickpea	0.329 (± 0.10)	0.359(± 0.11)	20.97(± 4.25)
Wheat	0.32 (± 0.10)	0.39 (± 0.067)	19.81(± 3.07)

Figure 4.6: Comparison of grain yield at harvest in fenced and non-fenced plots for 4 crops in two seasons. A: rice, B: soybean, C: chickpea, D: wheat. Soybean in 2014-15 and chickpea in 2013-14 failed due to reasons other than herbivory.



Artificial herbivory

Since crops are living entities, partially damaged plants can regenerate. Plants can also show life history trade-offs on facing challenge of herbivory. Therefore, a realistic estimation of damage should also account for recovery by regeneration and altered life history traits if any. Artificial herbivory experiments by cutting the shoot tips at measured heights or at certain age of plants revealed that there was substantial regeneration after cutting. Nevertheless, there appeared to be a cost associated with regeneration reflected in deficient grain yield.

In wheat, I observed that plants cut at the age of 25 days from sowing substantially regenerated and gained a height comparable with the control at harvest. The grain yield was also comparable to the controls (Figure 4.7). However, when cut at later ages it did not recover sufficiently in height as well as seed number. If cut after the flowering stage, there was no regeneration and no seed formation. Thus in wheat damage at later stages of crop appeared to be more serious. When groups of plants were cut at different heights in a pre-flowering stage they recovered partially in terms of height and produced some seed but the yield was substantially lower. There was a decreasing trend in yield with the extent of cutting (Figure 4.8). Consistent with the experiment, the naturally depredated plants that were nibbled at different times and at different heights showed regeneration with a significant correlation between the height and number of seeds (Figure 4.9).

Figure 4.7: Artificial herbivory in Wheat: comparison of regeneration by wheat plants cut at different age. A: vegetative regeneration and B: number of seeds after regeneration (control, n=125; age 25, n=92; age 45, n=202; age 55, n=199). Early damage appeared to allow greater time for regeneration resulting in to better grain yield.

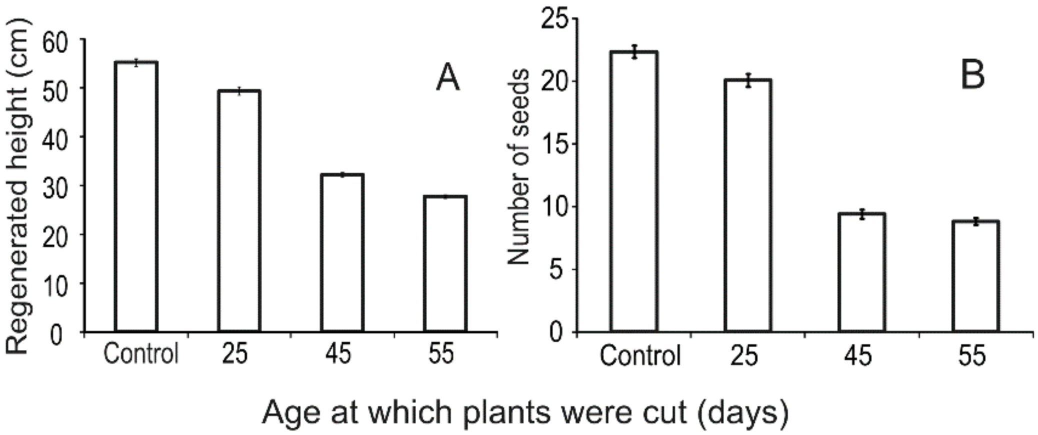


Figure 4.8: Comparison of regeneration of vegetative part in wheat plants cut at various heights at pre-flowering stage. A: vegetative regeneration B: number of seeds. (Control, n=125; height 5 cm, n=176; height 10 cm, n=178; height 15 cm, n=205)

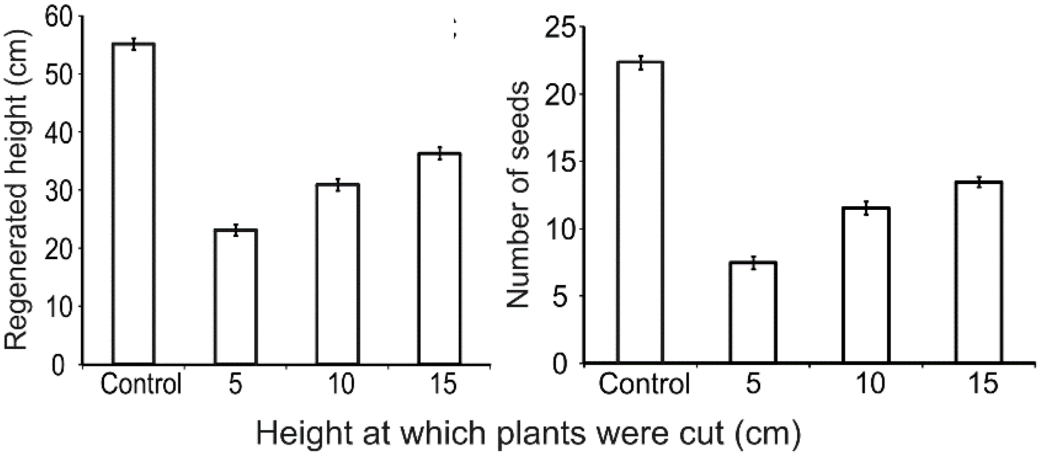
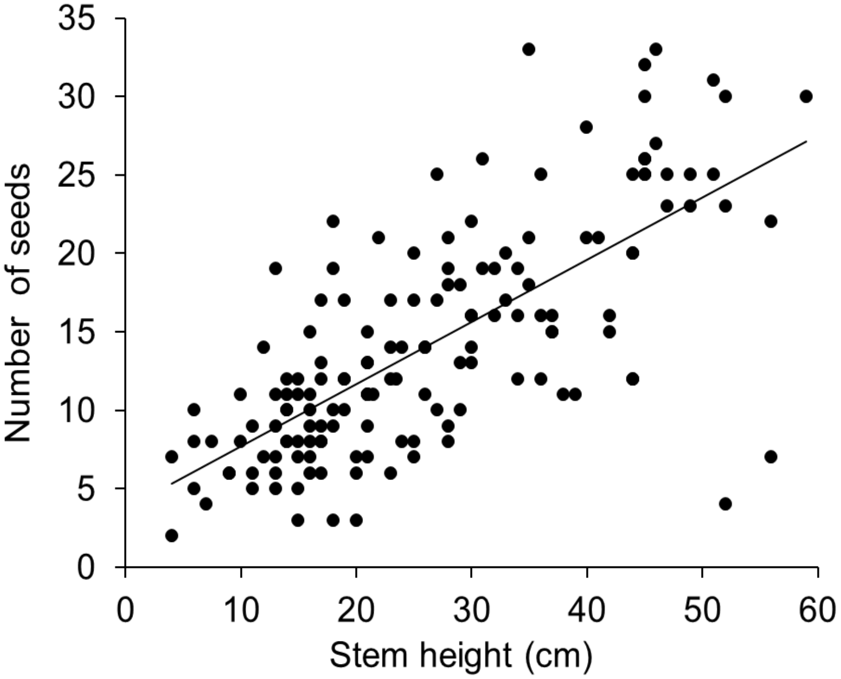


Figure 4.9: correlation of plant height and with number of seeds in naturally depredated wheat plants (r=0.7119, p<0.0001, n=150).



In soybean, the age trend in regeneration differed from that in wheat. Plants cut at a young age showed less regeneration in height, number of branches, number of pods and seeds (Figure 4.10). Early damage appeared to be more detrimental in this species. Different extent of cutting at the pre-flowering stage showed regeneration negatively correlated to the extent of cutting (Figure 4.11). In spite of regeneration, there was 40 to 80% loss in the seed number.

Figure 4.10: Regeneration after artificial herbivory in Soybean at different ages. A: regenerated height, B: number of branches, C: number of pods and D: number of seeds 20 days (n=87) and 45 days (n=107) with control (n=108).

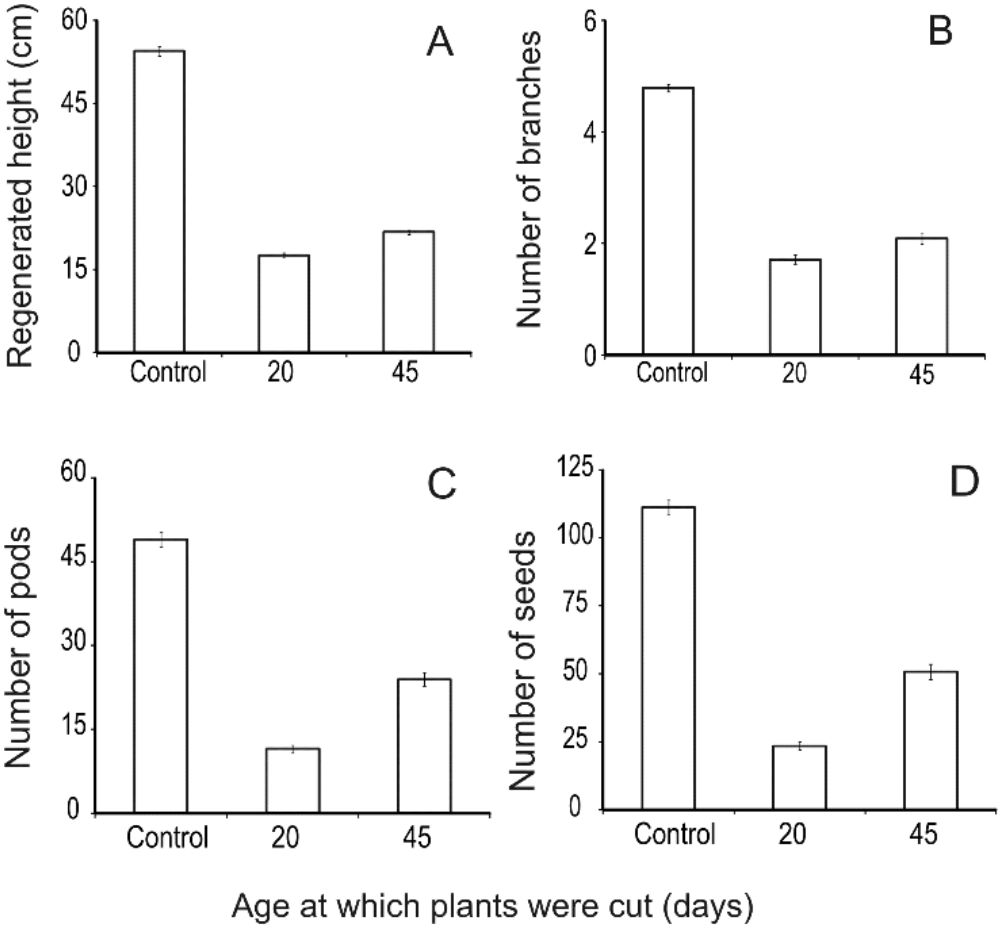
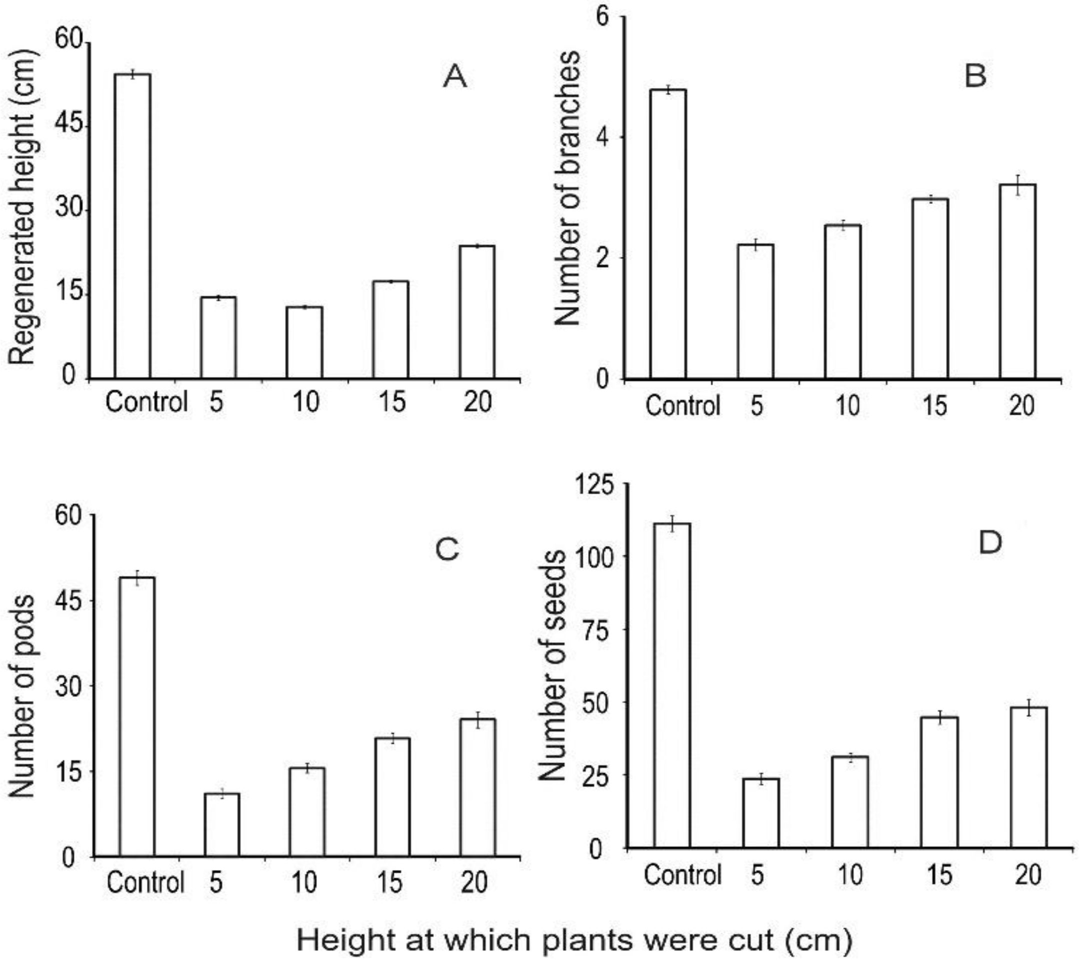


Figure 4.11: Regeneration after artificial herbivory at different heights in pre-flowering stage in soybean. A: regenerated height, B: number of branches, C: number of pods, D: number of seeds in plants cut at 5 cm (n=125), 10 cm (n=128), 15 cm (n=100), 20 cm (n=74) with control (n=108).



Artificial herbivory experiments on chickpea gave non-linear outcomes. Cutting at the age of 20 days led to greater branching ultimately resulting into increased number of seeds. Cutting at 45 days showed the same direction of effect but less pronounced (Figure 4.12). This phenomenon is known to farmers and some farmers practice controlled plucking to increase the yield. However, cutting down beyond a threshold was counterproductive and decreased regeneration as well as seed formation. A yield deficit of up to 67% was noted on cutting down a plant to 5 cm at a pre-flowering stage (Figure 4.13).

Figure 4.12: Regeneration after artificial herbivory at different ages in chickpea. A: canopy height, B: canopy width, C: number of branches and D: number of seeds in plants cut when 25 days old (n=51) and 45 days old (n=53) with control (n=50).

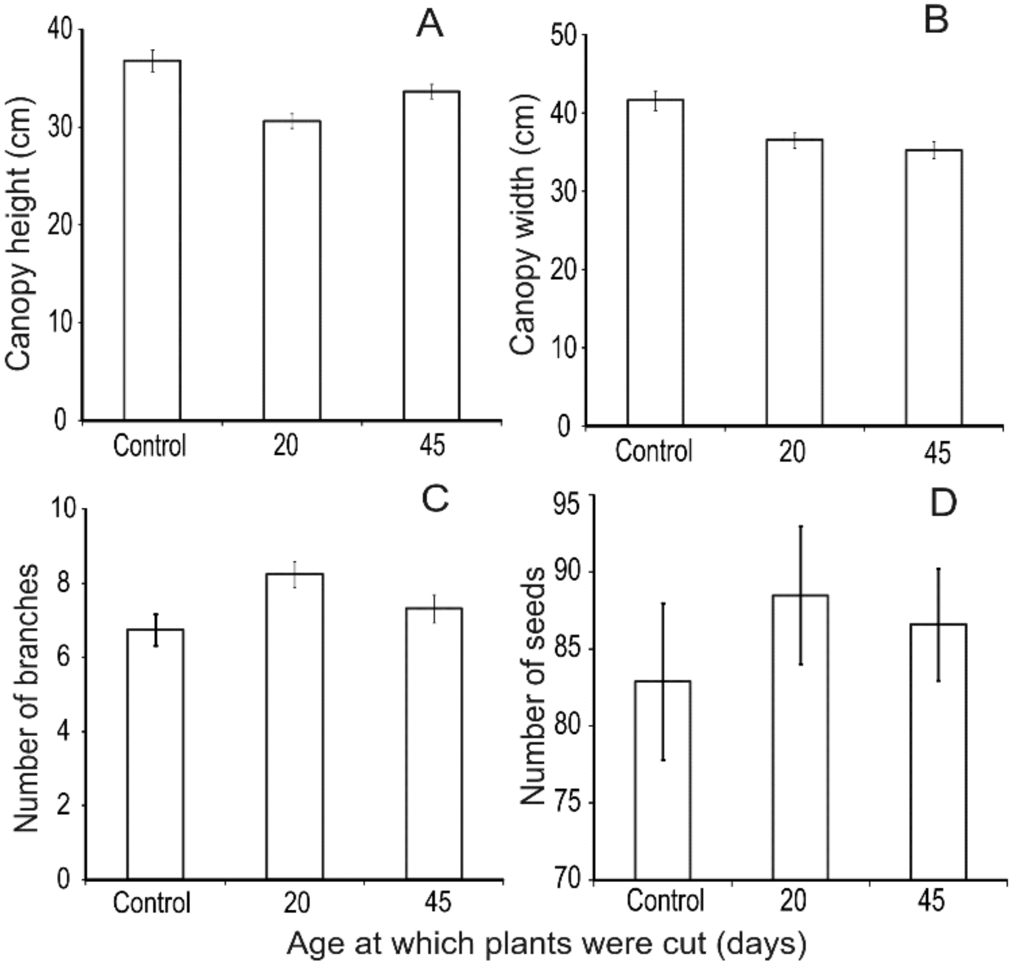
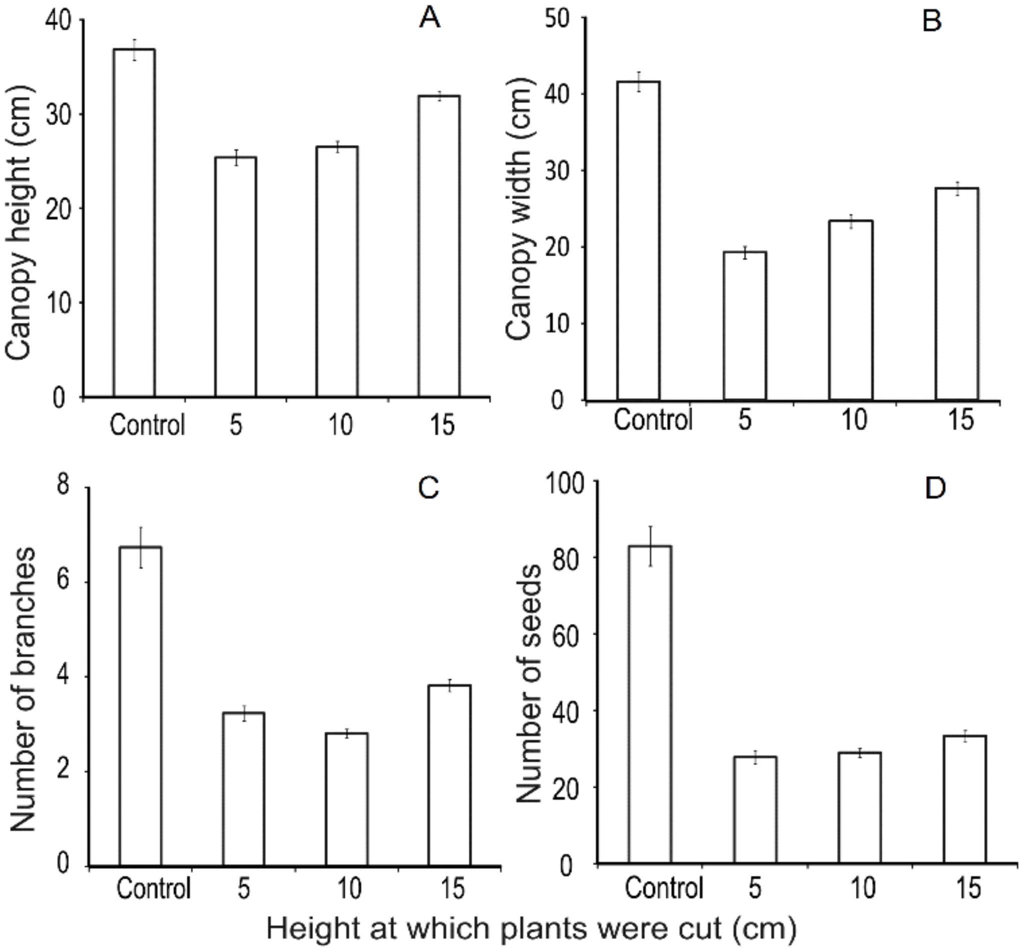


Figure 4.13: Regeneration after artificial herbivory at different heights at pre-flowering stage in chickpea. A: canopy height, B: canopy width, C: number of branches, D: number of seeds of plants cut at 5 cm (n=50), 10 cm (n=51), 15 cm (n=54) with control (n=50).



I did not perform artificial cutting in the case of rice but did observe that in the unfenced unguarded plot exposed to herbivory the number of tillers bearing seed was about 26% less and the number of seeds per tiller were 32% less than the protected plot. Since herbivory in rice prior to seed setting was infrequent this loss is unlikely to be a direct effect of damage at the pre-flowering stage. I suspect that some of the responses of different crop species to cutting are evolved life history optimization responses rather than the direct loss due to damage alone. For example, chickpea may have evolved to respond to herbivory by preferring greater investment in reproduction. Rice on the other hand belongs to grasses that have substantial root biomass, which can regenerate. Therefore, on facing greater threat of seed predation it may strategically invest more in root biomass and less in seed production. Such life history strategies of crop species (Adler et al., 2014) may explain some of the observed patterns. These are interesting hypotheses that need to be pursued separately. Our limited goals did not permit us to pursue these lines of investigations. Nevertheless, the artificial herbivory experiments demonstrated that although the plants showed the ability to regenerate, there was a substantial loss in the yield. This is important since after damage within a few days the farm as a whole looks intact and green due to regeneration and therefore the damage may not be noticeable on visual inspection, but a substantial loss is incurred. Regeneration is another likely reason why visual assessment of damage does not reflect on actual damage realistically.

Comparison of visual vegetative damage estimates

In an experiment performed in 2010, three farms that were raided the previous night were inspected independently by four persons each, who noted their own assessment of damage in terms of total loss in terms of the market value. This was to mimic the procedures followed during inspection for validating a compensation claim. The individuals who assessed the damage (whose identity will not be disclosed) included farmers other than the farm owner, agricultural experts, wildlife experts and forest officials. In all the three farms, it was observed that the variance in the assessed damage values was large. Although the number is small to draw a significant inference the coefficient of variation appeared to be inversely related to the mean damage. The means and CV (in bracket) for the three damage estimates in Indian rupees were 900/- (85.34%), 2, 857/- (67.77%), and 11, 250/- (50%). This demonstrates that assessment of crop damage by visual inspection is largely prone to personal judgment variation.

I also witnessed two cases of actual inspection followed by negotiations between the claimant farmer and the compensating authority. In both the cases, in spite of individual differences in assessment, after some negotiation all concerned individuals settled on a single number that ultimately got officially recorded. In one of the two cases, the estimate was settled at the residence of the claimant without actual inspection of the farm. Although this sample is very small, if it is representative, it demonstrates that the process is governed more by personal and social factors than by any objective and validated method of damage estimation.

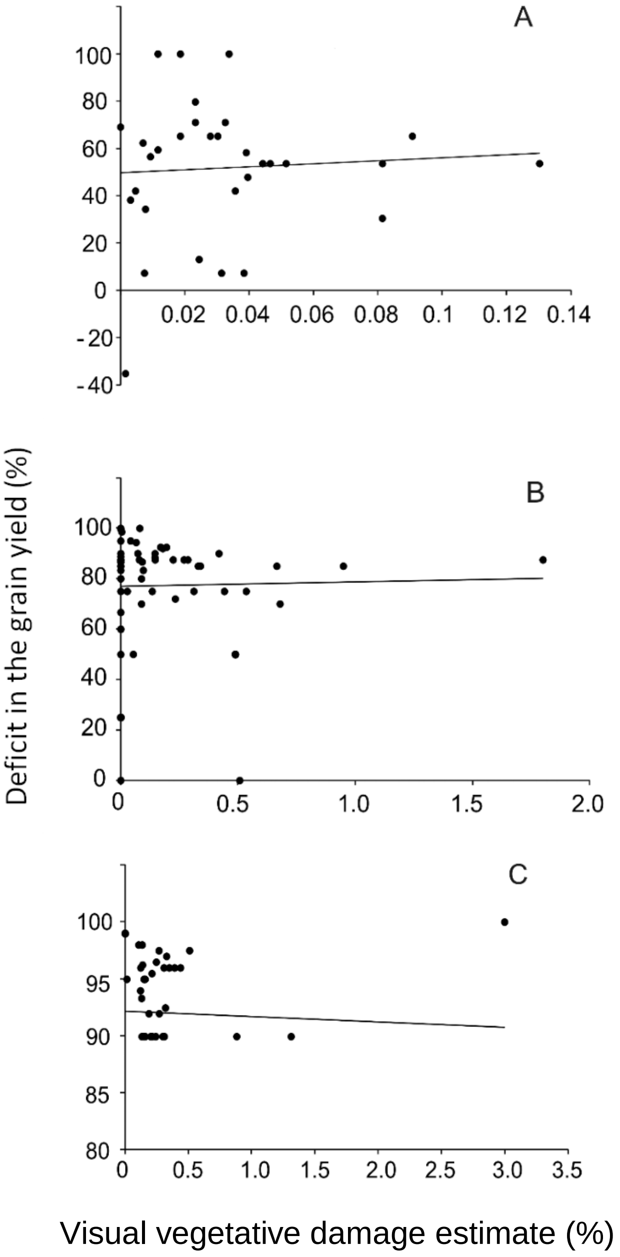
Information obtained from the forest department showed that during 2009-15 out of estimated 35,000 farmers in the susceptible area, between 61 to 2889 claims were processed in a financial year and the mean compensation paid per claim varied from ₹ 955 to 4244.

Correlation of visual vegetative damage estimates and actual deficit in yield

A comparison of grain yields with the visual estimates of the area damaged made during weekly visits to the transect farms as well as to the patch surrounded by forest (Figure 4.14), revealed a poor correlation between visual vegetative damage and the reduction in net yield from the expected. For this analysis, the expected was taken to be the average yield at a distance between 5 to 6 km. Also throughout the range, the deficit in grain yield was orders of magnitude greater than the estimates of visual vegetative damage. If the ratio of the two estimates was fairly consistent it would have been possible to rely on visual assessment after applying certain correction factor. However, the distribution of the ratio of visual vegetative damage estimate to harvest-based estimate was widespread and highly skewed. In addition, since the difference was in orders of magnitude, a small error in assessment would get amplified by orders of magnitude. This implies that estimates of visual vegetative damage are both unreliable and unrealistically below the mark.

(See figure on next page).

Figure 4.14: Comparison of visual vegetative damage estimates and actual deficit in grain yield at harvest. The visual assessment was based on the proportion of area with noticeable damage. A: Rice (r=0.062, p=0.73, n=32), B: Chickpea (r=0.022, p=0.86, n=63), C: Wheat (r=-0.0519, p=0.75, n=39). Apart from lack of correlation note the orders of magnitude difference in scales.



DISCUSSION

Estimating the damage caused by wild herbivores for the prevalent crop species does not appear to be a simple task. I observed that the currently prevalent method of assessing crop damage by visual inspection was grossly unreliable. It is possible that each of the five methods I used suffered from some flaw or shortfall. The net yield trends observed with distance from forest are likely to be affected by trends in soil quality, irrigation facility, agricultural practices or socioeconomic trends. Visual inspection is subjective and often misses subtle damage. Comparison of protected experimental farm and unprotected neighbouring farms with identical agricultural inputs and artificial herbivory experiments are scientifically sound but impracticable to employ routinely on a mass scale. However, since each method has a different possible flaw or shortcoming, if all of them converge on a similar inference, the inference should be treated as robust. The impression of farmers was that there was 50 to 70% loss in produce. The regression of grain yield with distance estimated between 22 to 72% deficit adjacent to the park as compared to the belt between 5-6 km. Experimental comparison of protected and unprotected farms revealed almost 100% loss for crops other than rice. In these experiments neither fencing nor guarding were employed. The farms neighbouring the experimental farm had unfenced farms but they were being actively guarded by farmers every night. These guarded but unfenced farms incurred about 50±10 % loss on an average. The difference between the unfenced unguarded experimental farms and unfenced but guarded neighbouring farms can be said to reflect the efficiency of manual guarding. By this measure, manual guarding was able to save about 50% of loss. Regeneration studies after artificial herbivory revealed that although regenerated plants did give some grain yield, the net grain deficit in the experiment ranged between 40% and 70%. All these evidences converge to over 50% loss near the PA. An important implication of the artificial herbivory and regrowth studies is that although the plants look green and recovered after damage, the grain yield is affected substantially. This means that the deficit is unlikely to be assessed by visual inspection.

There were only two mismatches in the independent assessments. The first one was that in the regression versus experimental estimation of damage in rice. Although the trend with distance was not consistent for rice and farmers agreed that rice was least prone to raiding through much of the season, the experimental plot showed substantial deficit in rice yield in the unprotected area as compared to the protected area. The deficit was unexpected since the observed frequency of raids was not very high. The difference can perhaps be due to post-harvest damage (e.g. depredation on stacks of harvested crop) by wild pig. The other major mismatch was that assessment of visual vegetative damage always gave substantially lower estimates compared to all other methods. This was consistent with farmers' impressions. There are various possible reasons why visual assessment always gives underestimates. (i) The prevalent herbivore species in the study area do more of nibbling damage, which is less noticeable than trampling or uprooting type of damage. (ii) Not all types of damages are noticeable at the same time. For example, root or stem base chewing by wild boar leads to slow drying of the individual, which becomes noticeable after a few days. On the other hand nibbling the tips may be apparent after a careful look immediately after the damage, but the plants regenerate soon and the damage becomes difficult to notice after a few days. By the current procedures the inspection happens only once after a claim and therefore it is unlikely to notice all types of damages together. (iii) In the study area, the frequency of damage was high but the modal extent of damage per night small. The current inspection and compensation procedures are better suited for low frequency high extent damage. (iv) Since, the frequency of damaging raids is of the order of 0.3 per night, if every damaging raid is to be inspected and assessed there is a need to inspect every farm twice a week on an average. The compensating authority would need tremendous manpower for the inspection-validation work which appears impossible in the current set up. In reality no farm was inspected more than once in a crop season. (v) I also observed that crops faced hidden and indirect damages owing to herbivory such as a tendency among farmers to disinvest from intensive agricultural practices when faced with high risk of damage. This is unlikely to be recorded in visual assessment. (vi) Even if it is assumed that all actual losses are compensated realistically, the cost incurred in the protection measures is an additional burden that remains unaccounted for. (vii) Post-harvest damage especially by wild pigs was substantial for rice. This is generally not covered by the compensation procedure. Thus for a number of reasons the currently employed method is unable to make a realistic reflection of actual damage.

Apart from the two mismatches, all other approaches appear to converge towards the inference that the farmers' impression of 50-70% loss in spite of active night-time guarding was realistic.

Other than the actual loss due to depredation, there are other indirect losses a farmer close to a wildlife area faces. There is a cost associated with protection of crops e.g. manual guarding, making fences etc. This cost may not always be in terms of money. Since substantial lopping is involved in fence making there is an environmental cost of crop raiding paid by the forest vegetation. Active guarding at night to drive away animals involves extensive manpower inputs. This has so far remained unaccounted in the crop damage records. All-night guarding for a few consecutive months is likely to have a high health cost that is yet to be estimated. In addition, there is risk to the farmers during night-time guarding in a wildlife rich area. There were no cases of tiger or leopard attack on guarding farmers in the study area during the study period. However, there were three cases of mauling by sloth bear during night-time guarding. The health cost and life threatening risks also need to be accounted in estimating damage by wild animals. To address these questions, sound theoretical basis is required. Microeconomics of agriculture and cost-benefit optimization of various aspects of crop-raiding can provide vital insights.

COLOUR PLATE 4.1

DAMAGE TO SOYBEAN

Damaged by wild pigs foraging on soybean farm plot (left). Damage by trampling by wild pigs (right).

Damaged plant individuals: Close inspection of damaged plants (left). The damaged parts which possessed floral buds did not develop flowers after herbivory. Note the development of flowers on undamaged part of same plant individual (right).

COLOUR PLATE-4.2

DAMAGE TO RICE

Damage to the farm by wild pigs. Note that the damage is diffused (left) and can be examined only after close inspection (right).

Damage to stack of harvested rice plants by wild pigs before husking. Pigs selectively eat the grains out of these piles of rice plants.

A) Before

B) After

COLOUR PLATE 4.3

DAMAGE TO RICE

Close inspection of damaged (left) and undamaged rice tillers (right). Selective damage to the fruiting body of rice tillers ensures lesser yield that remains unnoticed.

Damage to the lower stem parts of tillers at the early plant stage (before flowering and fruiting). Note the damaged and nibbled lower stem of rice tillers (A and B)

A)

B)

COLOUR PLATE 4.4

DAMAGE TO CHICKPEA

Fenced plot (before harvest), note the fully grown plants with fruits (left). Damaged unfenced plot, note the trampled and depredated plants that are not distinguishable from a distance (right).

Damaged plant individual nibbled by Chital.

COLOUR PLATE 4.5

DAMAGE TO WHEAT

Damaged unfenced farm plot (left). Herbivory by nilgai, left bottom of picture shows less eaten and/or regenerated plant individuals (right).

Close inspection of damaged wheat plants. The early leafy stgaes of wheat are attractive especialy for nilgai, chital and hares (left). Trampling by pigs and nilgai (the fallen plant individuals) (right).

COLOUR PLATE 4.6

DAMAGE TO WHEAT

Selective foraging on wheat fruiting body by wild pigs, note nibbled plant individuals (left).Selective foraging on mature fruiting body by parakeets shown by arrow (close examination of plants). Also note the other undamaged plant individuals (right).

Foraging on wheat farm by flock of parakeets (left). The difference between fenced and unfenced plot yield of wheat (left stack is from fenced plot whereas right one is from unfenced plot) (right).

CHAPTER 5

FORAGING BEHAVIOUR OF NILGAI

INTRODUCTION

Foraging is an essential part of life history of every animal as it is directly associated with its own survival (Stephens et al. 2007). Foraging involves energy and time costs as well as predation and other risks and animals tend to optimize foraging behaviour by making an appropriate choice of food patch, time of visit, time spent on a patch and time division between feeding and vigilance (Parker & Maynard Smith 1990, Frid 1997, Treves 2000, Beauchamp 2003). A different set of vigilance behaviours might be needed while facing ambush hunters such as tiger, leopard versus cursorial/endurance hunters like wild dogs and wolves. However, it is not known whether a give herbivore population shows different sets of vigilance behaviours in habitats with different risks. Since food resource is limited especially in terms of availability and distribution, ungulates face trade-offs while being vigilant; excessive vigilance ascertains invulnerability, nonetheless, reduces feeding opportunities (Frid 1997). This further leads to altering herding strategies, as it is observed that vigilance required by an individual reduces with herd size (Frid 1997, Shorrocks & Cokayne 2005, Namgail 2007).

A wide variety of herbivores feed on agricultural lands adjacent to wild habitats (Fernando et al. 2005, Rode et al. 2006, Chiyo 2011, chapter 4 and Bayani et al. 2016a). This has been studied as a patch choice problem in optimum foraging (See chapter 6 and Watve et al. 2016b). In addition to patch choice, herbivores have to optimize their vigilance strategies because of the difference in the nature of risks faced while foraging in the wild versus on agricultural lands. One way of optimizing is by careful choice of the time of visit. Animals are known to change feeding patches as per the photoperiod, and thereby showing significant change in habitat use during day and night (Brown 1999, Valeix et al. 2009). Nocturnal activity of herbivores is likely to be affected by lunar cycles and moon light intensity (Penteriani et al. 2011). Herbivores change their activity patterns mainly to avoid predators (Bender et al. 1996, Valeix et al. 2009, Thaker et al. 2010, Penteriani et al. 2011, Cozzi et al. 2012). Species such as elephant (*Elephas maximus*), nilgai

(*Boselaphus tragocamelus*), chital (*Axis axis*), blackbuck (*Antilope cervicapra*), wild pig (*Sus scrofa*), and Indian wild ass/khur (*Equus hemiones khur*) visit agricultural lands almost exclusively at night (Sukumar 1989, Chauhan & Singh 1990, Singh 1995, Isvaran 2004, Shah 2007, Mehta 2014, Bayani et al. 2016). White-tailed deer (*Odocoileus virginianus*) show significant use of open fields in the absence of moonlight so as to avoid ambush predators (Brown et al. 2011). Higher predation of snowshoe hare (*Lepus americanus*) was demonstrated on moonlit nights (Griffin et al. 2005). African elephant (*Loxodonta africana*) seem to feel safe for raiding crops on moonless nights (Barnes et al. 2006, Gunn et al. 2013). Raiding of cultivated crops by various species is demonstrated in numerous areas across India as well (Mathur et al. 2015).

STUDY ANIMAL SPECIES: NILGAI

Nilgai or Bluebull (*Boselaphus tragocamelus*, Pallas 1766) is the largest antelope in India (Leslie 2008). It is widely distributed from Himalayan foothills to Mysore (Prater 1948). They are endemic to Indian peninsula; however, being introduced in US state of Texas in 1920s for recreational purposes, they can be seen as free-ranging game animals in the southern parts of this state, Alabama, Florida, Mississippi and Mexican state of Tamaulipas (Leslie 2008).

Nilgai is a great ungainly ungulate that may resemble a horse in built with high withers and low rump. Sexual dimorphism in Nilgai is quite evident. Adult bulls have coarse iron-grey coat, a white ring below each fetlock and two white spots on cheek. Lips, chin, ears (from inside) and under-surface of tail, inner sides of legs and belly are white. They also have white throat bib and a narrow white stripe along the underside of the body that widens at the rear. They also possess a tubular-shaped ‘pennant’ of long stiff hair on the midsection of the throat. They possess two small conical black horns arising close together behind eyes. Bulls generally stand 1.5 m at shoulders and measure up to 2.1 m in head-body length, with tail measuring up to 50 cm. they generally weigh 109 to 288 kg. sub-adult males are tawny coloured with smaller body dimensions but horns (these horns often form the characteristic feature of sub-adults that helps one telling them apart from adults and sub-adult females) (See table 5.1).

Tawny brown coloured cows are much smaller in size and weight than bulls. They can also be told apart from bulls by not possessing horns and much smaller hair pennant on neck. Young females are similarly coloured as the females but smaller in size.

Table 5.1: Sex and age-class classification of nilgai. Identification of sex and age of a given individual in field was based on the visual morphological characters explained in following table

Age Class	Size	Colour	Horns	Remarks
Adult males (AM)	Fully grown	Grey-black	Yes	
Sub-adult males (SAM)	Smaller than AM	Tawny brown	Yes	
Yearling male (YM)	Half the size of SAM	Tawny brown	Yes (smaller than SAM)	
Adult Female (AF)	Fully grown	Tawny brown	No	
Sub-adult female (SAF)	Smaller than AF	Tawny brown	No	
Yearling female (YF)	Same size as YM	Tawny brown	No	
Calf	Very small (Can pass through under the belly of adult female	Tawny brown	No	Sex cannot be distinguished on field.

Habits: Nilgai although seem widely distributed in Indian peninsula, it is known to be an animal of grasslands and scrublands avoiding dense forests (Prater 1948, Johnsingh and Manjreker 2015). It prefers the forest edges and open grasslands associated with forests. Their usual refuge is hills with small and widely spaced trees, and scrubby and/or grassy undulating terrains.

Nilgai do not form clear harems. The adult bulls form their own bachelors' herds. Sometimes forming harems (mixed age-class herd owned by singular adult bull) but very rarely quasi-harems (mixed age-class herd with multiple adult bulls). Nevertheless, adult bulls keep away from matriarchal herds joining them only in breeding season (Leslie 2008).

Nilgai is chiefly a grazer but browses frequently when fresh grass in not available e.g. in summer. Thus, it is often seen sharing their habitats with spotted deer and wild pig, but very rarely with sambar deer and gaur (pers. obs.). They also co-exist with blackbuck in Velavadar NP and with hog deer in Terai regions (Johnsingh & Manjrekar 2015).

Tiger, Lion, Leopard, wild dogs, wolves, striped hyena are the main predators of Nilgai. In the study area, nilgai comprises 15% of the Tiger's diet as revealed by tiger scat analysis (Dandekar et al. unpublished data).

Since nilgai experiences two different types of habitats at the western boundary i.e. forest and agricultural lands and therefore two different set-ups of habitat variables such as vegetation, predation risk, type of predator(s), visibility etc., it becomes interesting to know whether nilgai show any plasticity in their behaviour while foraging in forests and agricultural lands. In this chapter I discuss some new insights obtained while studying herding, foraging and vigilance behaviour and compared the possible changes across seasons and habitats.

METHODS

General sampling methods

Transects

Three independent 4-km-long transects were laid which started from the forest edge and moved away into agricultural lands. Each transect was walked in night hours between 1800h and 0000h twice a month in November 2013–February 2014 and November 2014–February 2015 covering a total transect length of 192 km. GPS location was noted at every sighting (±2 m accuracy using Garmin60). If an individual (or a group of individuals) was seen >25 m away from the next neighbouring individual (or a group of individuals) it was considered as a different 'herd'. Transect sampling was not possible during monsoon months and was not relevant in the non-crop months of the year. On the same transects pellet heaps of nilgai were recorded. For every dung pellet heap, I measured the area in sq. ft. I also counted the number of different noticeable types of pellets in every heap based on individual pellet size and shape.

Observations on frequented wild foraging grounds

Initial *ad lib* observations identified four frequently used foraging grounds of nilgai in the forest, where they could be regularly observed without any hindrance or disturbance from cattle herders. These were used for documenting foraging behaviour in the forest during daytime i.e. 1300h–1900h in the period of November 2012–March 2013, November 2013–March 2014 and November 2014–February 2015.

Observations on an experimental farm

An experimental farm, marked to study the effect of wild herbivores on crop yields, was used for studying foraging behaviour on agricultural lands. Experimental farm was a cultivated land of area 0.4 hectare, approximately 600 m away from forest cover boundary and exposed to herbivores without any fencing or guarding. Nilgai herds were awaited every night between

1800h and 0100h, and observed from a 12 ft tall *Machan*. Since no crops are cultivated in summer i.e. March to June in this area, and observations at night on farms during monsoon were difficult to record, sufficient behavioural data could be recorded only during the winter seasons of the years 2012-2013, 2013-2014 and 2014-2015.

Since the general pattern of nilgai movement was that individuals spent the daytime in the forest cover and moved to agricultural lands at night, observations in the wild were possible between 1300h and 1900h. After 1900h, sighting of animals on the wild foraging grounds was less frequent. The experimental farm was visited almost exclusively at night and observations were made between time-period of 1800h to 0100h. For observations in forest as well as experimental farm, no artificial lights were used. Search lights were used during transects only but these data were used only for herd size and composition and its spatial trends.

Behavioural sampling methods

Herding behaviour

In all the three above approaches, instantaneous scans (Altman 1973) were used on first detection of animals to record herd size, sex and age structure, an index of 'compactness' (Ghuman 2009) and animal activity. For the nilgai herds observed in forest and experimental farm, I allowed a settling time of 5-10 min for every herd before beginning the observations. This was necessary to minimize a change in behaviour in response to possible detection of the observer.

For every herd observed in forest and on an experimental plot, sighting distance (from observer) to leftmost individual, rightmost individual, and sighting angle between those two arms were recorded using rangefinder and magnetic compass respectively. These measurements were used to calculate the diameter of the herd's spread and the area of the imaginary circle that can be thought of as the spread of a herd. The herd size divided by this calculated area of spread was used as an estimate of compactness to understand how closely the individuals are packed in a given herd at a given time. Higher compactness index reflected smaller inter-individual distance. Whenever possible, diameter was directly measured using measuring tape after individuals left the feeding place. Herding behaviour was studied during monsoon and winter seasons of years 2012, 2013 and 2014.

Foraging / Vigilance behaviour

Focal-animal sampling (Altman 1973) with continuous recording was followed wherein one individual from a given herd was observed for 15 min or until the focal individual went out of sight, whichever occurred first. Upon sighting a herd, first 5-10 min time was used as ‘settling time’ before beginning the observations. Any state of animal with ‘neck at or above shoulder level’ and not ‘browsing’ was recorded as vigilance behaviour (this included the behaviours *viz.* Alert, Alarming, Grooming, Scanning, Sniffing, Standing, and Walking see page no. 104 for details). Actual feeding included both grazing and browsing during which the time spent in feeding as well as bite count per minute was recorded. I abandoned observations whenever there was disturbance by any other anthropogenic activities. Time utilized for each behaviour was recorded using a digital wristwatch. The number of times the focal animal attained ‘head-up’ behaviour except browsing was recorded as the frequency of attaining an alert position per unit observation time (defined here as vigilance frequency) (see colour plate 5.1). The time for which an alert position was retained was also recorded (defined as unit scan duration). Since nilgai herds observed on agricultural lands were female-biased and occurrence of males on farms was relatively infrequent, I could not obtain sufficient number of foraging behaviour observations of males for comparison between forest and farm, and hence behaviour of only adult females is compared here. Based on the focal-animal sampling, I also calculated proportion (in per cent) of time utilized in vigilance, which is further expressed as ‘total scan duration’.

Lunar cycles and foraging during winter season

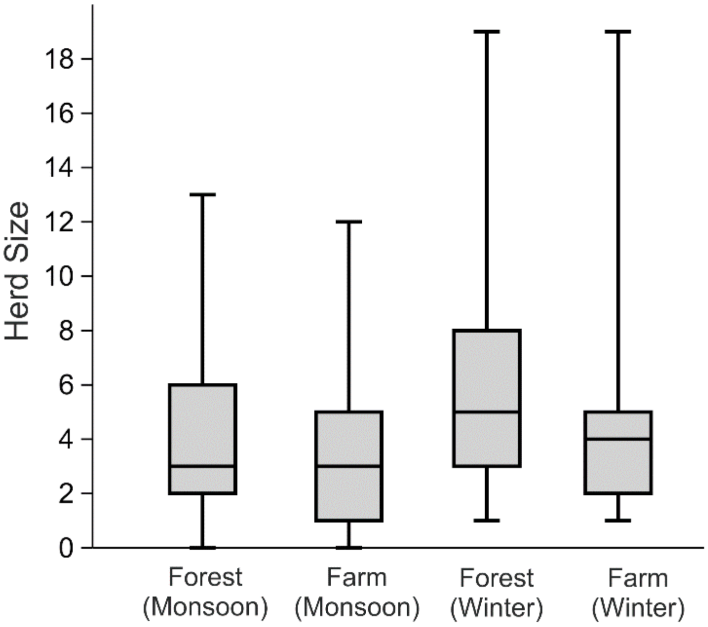
To study the effect of ambient light intensity on nocturnal activity of nilgai on agricultural lands, I studied crop-raiding frequencies as a function of lunar cycle (and in turn the ambient light intensity in night associated with each moon phase). All the lunar phases were ranked 0 to 16, 0 representing new moon, whereas 16 as full moon. Direct observation expressed as visiting frequency was done between the time-period of 1900h to 0100h. It was possible that the nilgai may visit farms other than the observation window thus to avoid any bias and deficit in the direct observations, I used indirect signs of presence/absence of nilgai by looking for fresh hoofmarks, fresh pellets (within 50 m in any direction of the experimental plot) and visible damage the following morning on the experimental plot (see colour plate 5.2). Since the ambient light intensity can be altered by presence of clouds, I did not take observations on cloudy nights and hence no observations in monsoon.

RESULTS

Herd size

Herd size of nilgai in forest and farm across two seasons showed marked differences (Figure 5.1). When compared forest with farm after pooling from both the seasons, herd size was significantly larger in forest compared to farm (Mann-Whitney U-test, $P < 0.0001$, $\text{Median}_{\text{forest}} = 5$, $n_{\text{forest}} = 176$, $\text{Median}_{\text{farm}} = 3$, $n_{\text{farm}} = 321$). Similarly when pooled over for two habitats, herd size was significantly larger in winter than in monsoon (Mann-Whitney U-test, $P < 0.0002$, $\text{Median}_{\text{monsoon}} = 3$, $n_{\text{monsoon}} = 146$, $\text{Median}_{\text{winter}} = 4$, $n_{\text{winter}} = 351$). While foraging in forest the herd size was larger in winter compared to monsoon (Mann-Whitney U-test, $P < 0.0003$, $\text{Median}_{\text{monsoon}} = 3$, $n_{\text{monsoon}} = 64$, $\text{Median}_{\text{winter}} = 5$, $n_{\text{winter}} = 112$) and the trend remained similar in farms (Mann-Whitney U-test, $P < 0.002$, $\text{Median}_{\text{monsoon}} = 3$, $n_{\text{monsoon}} = 82$, $\text{Median}_{\text{winter}} = 4$, $n_{\text{winter}} = 239$). When compared for the season of monsoon, forest and farm do not show difference in median herd size, but by Mann-Whitney U test the ranks for the forest are significantly higher than those in farm (Mann-Whitney U-test, $P = 0.024$, $\text{Median}_{\text{forest}} = 3$, $n_{\text{forest}} = 64$, $\text{Median}_{\text{farm}} = 3$, $n_{\text{farm}} = 82$). In the winter, herd size in forest was significantly larger than that on farms (Mann-Whitney U-test, $P < 0.0001$, $\text{Median}_{\text{forest}} = 5$, $n_{\text{forest}} = 112$, $\text{Median}_{\text{farm}} = 4$, $n_{\text{farm}} = 239$).

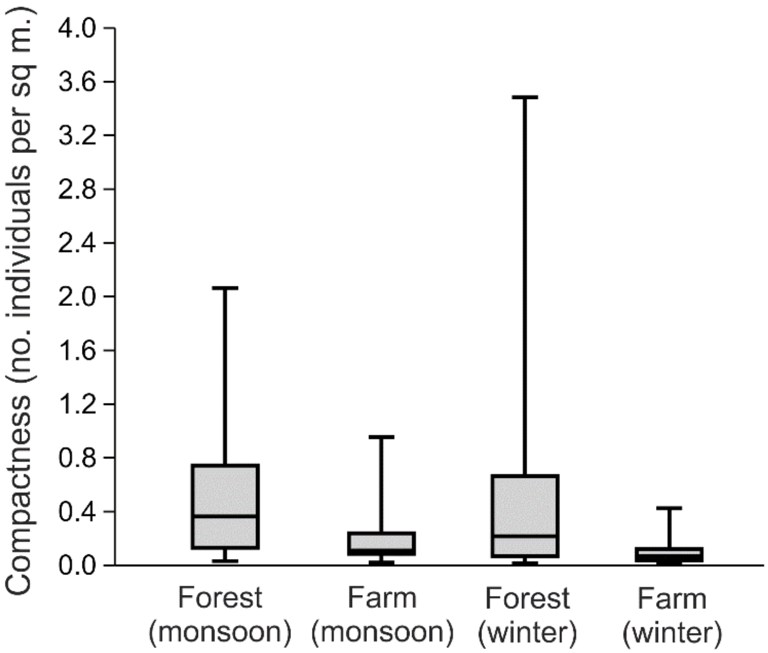
Figure 5.1: Changes in herd size (number of individuals per herd) in monsoon, winter and forest, farm.



Compactness across seasons and habitats

Nilgai herds seemed to keep greater inter-individual distance while foraging on crops compared to foraging in forests when pooled from both seasons, as reflected by the compactness index (Mann-Whitney U-test, $P < 0.0001$, $\text{Median}_{\text{forest}} = 0.27$ individuals per sq. m, $\text{Median}_{\text{farm}} = 0.09$ individuals per sq. m $n_{\text{forest}} = 83$, $n_{\text{farm}} = 117$). This difference is not only evident across two different habitats, but also across seasons. The compactness was higher in the monsoon than in the winter (Mann-Whitney U-test, $P < 0.0001$, $\text{Median}_{\text{monsoon}} = 0.141$ individuals per sq. m, $\text{Median}_{\text{winter}} = 0.095$ individuals per sq. m. $n_{\text{monsoon}} = 77$, $n_{\text{winter}} = 123$) (Figure 5.2).

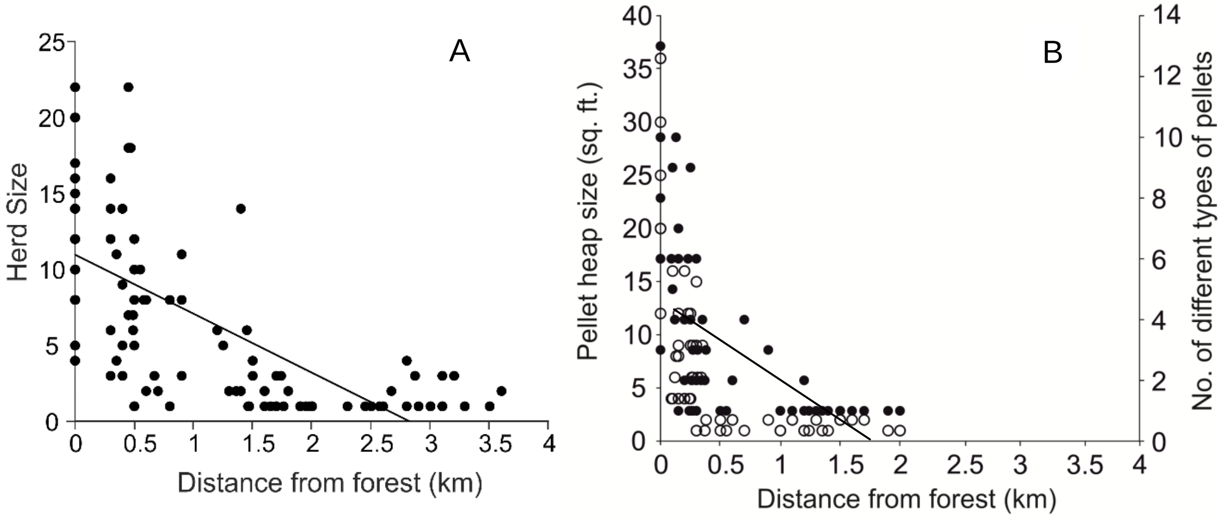
Figure 5.2: Difference in compactness index across seasons and habitats.



Spatial trends in herd size

In the transect data, the herd size (Kendall's τ = -0.61, n = 123, P < 0.0001) (Figure 5.3A), heap size (Kendall's τ = -0.67, n = 69, P < 0.0001) and the number of different types of pellets observed in a given heap (Kendall's τ = -0.69, n = 69, P < 0.0001) (Figure 5.3B) were observed to decrease with distance from the forest. This reflects greater dispersal tendency of nilgai while foraging on agricultural crops.

Figure 5.3: Trends in herd parameters with distance from forest. A: Herd size (number of individuals) (Kendall's τ = -0.61, n = 123, P < 0.0001), B: dung pellet heap size (hollow circles, Kendall's τ = -0.67, n = 69, P < 0.0001) and number of different types of pellets per heap (solid circles, Kendall's τ = -0.69, n = 69, P < 0.0001).



Herd composition across seasons and habitats

Nilgai population was always female-biased and the sex ratio was substantially different when compared across seasons and habitats (Table 5.2). When sex ratio was compared between two habitats it was found that in monsoon, there were 4.94 females per male (or 20 males: 100 females) in forest and 13.4 females per male (or 7 males: 100 females) on farm (two-tailed Fisher's exact test, P = 0.001, n_{forest} = 63 herds, n_{farm} = 81 herds). This difference was further more substantial in winter having 1.7 females per male (or 58 males: 100 females) in forest and 13.8 females per male (or 7 males: 100 females) on farm (two-tailed Fisher's exact test, P < 0.0001, n_{forest} = 124 herds, n_{farm} = 238 herds). In forest alone there were 4.94 females per male (or 13 males: 100 females) in monsoon but 1.7 females per male (or 23 males: 100 females) in winter (two-tailed Fisher's exact test P = 0.0001, $n_{monsoon}$ = 63 herds, n_{winter} = 124 herds). Whereas, on farm alone, there were 13.4 females per male (or 7 males: 100 females) in monsoon compared to 13.8 females per male (or 7 males: 100 females) in winter (two-tailed Fisher's exact test, P = 0.88, $n_{monsoon}$ = 81 herds, n_{winter} = 238 herds). This suggests that although males join female herds in winter, they seldom accompanied herds while raiding crops.

Table 5.2: Age and sex class structure of herds as observed in forest and experimental plot.

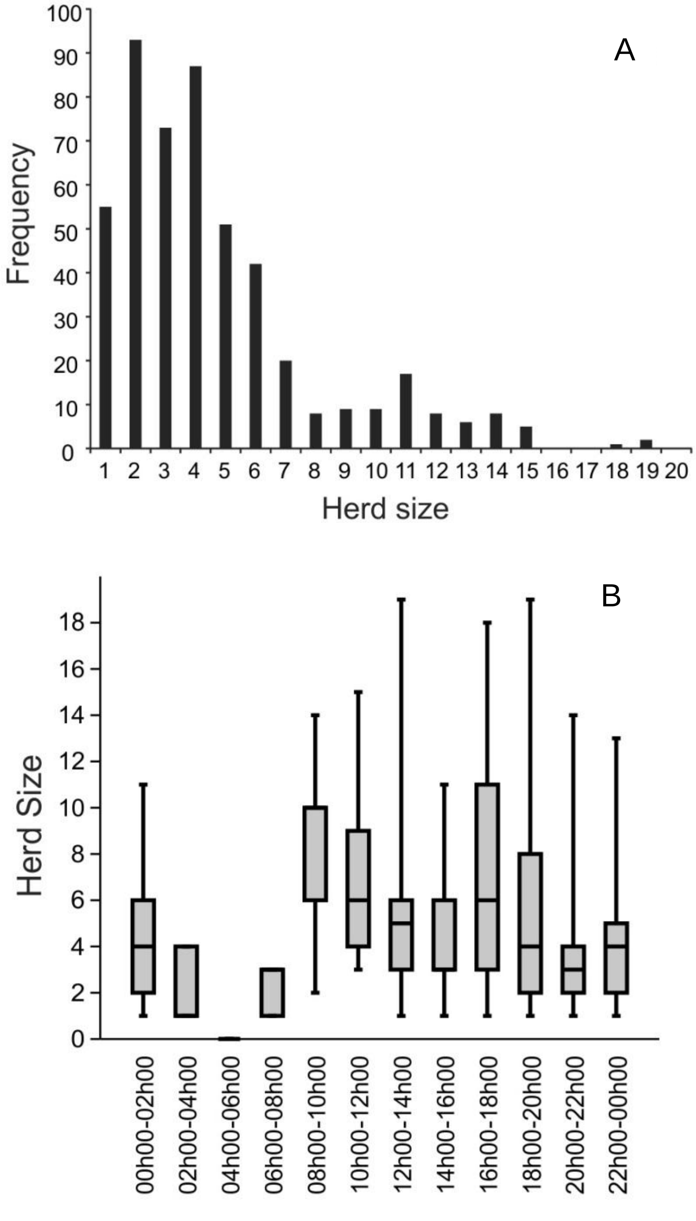
	Adults		**Sub adult**		**Yearling**	**Calf**
Monsoon	Male	Female	Male	Female		
Forest	25	132	13	56	34	13
Farm	16	176	-	38	8	28
Winter						
Forest	151	299	60	62	48	119
Farm	60	689	-	141	113	50

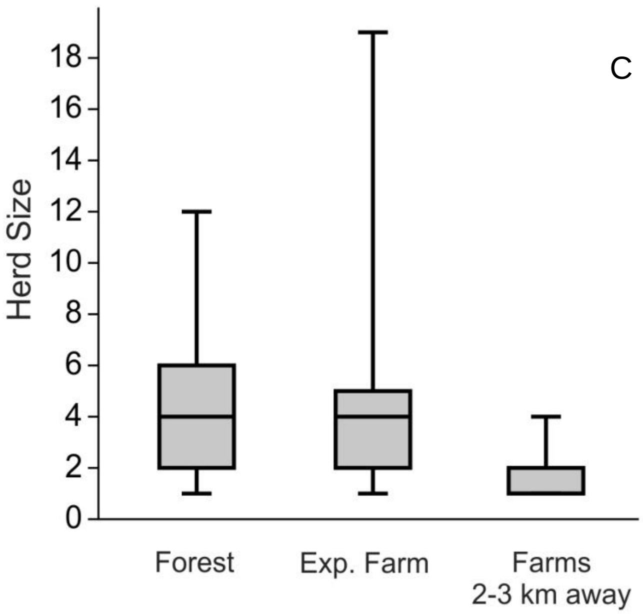
In the monsoon, the juveniles (yearlings and calves) and adults (adults and sub-adults) appear in farm in the same proportion as seen in forests (two-tailed Fisher's exact test P = 0.273, Juvenile:Adult ratio = 0.20 in forest and 0.15 in farm), however, this is substantially different in winter, in which juveniles visit farms less often (two-tailed Fisher's exact test, $P < 0.0001$, Juvenile:Adult ratio = 0.33 in forest and 0.18 in farm). In forest alone, the ratio of Juvenile:Adult in monsoon was 0.20 which was significantly lower than observed in winter i.e. 0.33 (two-tailed Fisher's exact test, P = 0.01). I observed no significant difference in this ratio when compared in farm alone between monsoon and winter, which in monsoon was 0.16 and in winter, 0.18 juveniles per adult individual (two-tailed Fisher's exact test, P = 0.5) (Table 5.2). Thus, it is evident that adults show a higher tendency of crop-raiding and presumably females with very young calves may avoid the risk.

Although observation on the experimental farm and the frequented wild foraging grounds were confined to limited space and I did not make any attempt to identify individuals or herds, the large variance in the herd size across observations [Mean herd size (CV%), 5.54 (65.7%) in forest and 4.14 (52.6%) in farm] and absence of conspicuous bi or multimodality in the distribution (Figure 5.4A) makes it unlikely that only one or a few herds were observed repeatedly. It is also necessary to understand whether the observed difference in herd size was an effect of time or that of habitat. Analysis revealed that the median herd size did have a significant temporal pattern (Figure 5.4B) showing larger herd sizes in daylight hours. Nevertheless, in the time window between 1800h and 1900h, there were sufficient observations in forest and agricultural lands and a comparison showed that the herd size difference remained significant (Figure 5.4C). Therefore, even if the difference in herd size seems governed by time of the day, the effect of the habitat is more significant.

(See figure on next page)

Figure 5.4: Distribution of the nilgai herds and effect of time and habitat: A) Frequency distribution of herd sizes demonstrating wide variance and continuous distribution indicating diversity of herds under observation; B) herd sizes were significantly different at the different times of the day (Kruskal-Wallis test, H = 39.68, n = 462, P < 0.001); C) herd sizes observed between 18h00 and 19h00 in forest, experimental farm and farms at 2-3km from the forest show significant difference (Kruskal-Wallis test, H = 26.3, n = 127, P < 0.0001) showing that herd size varied according to habitats independent of time.





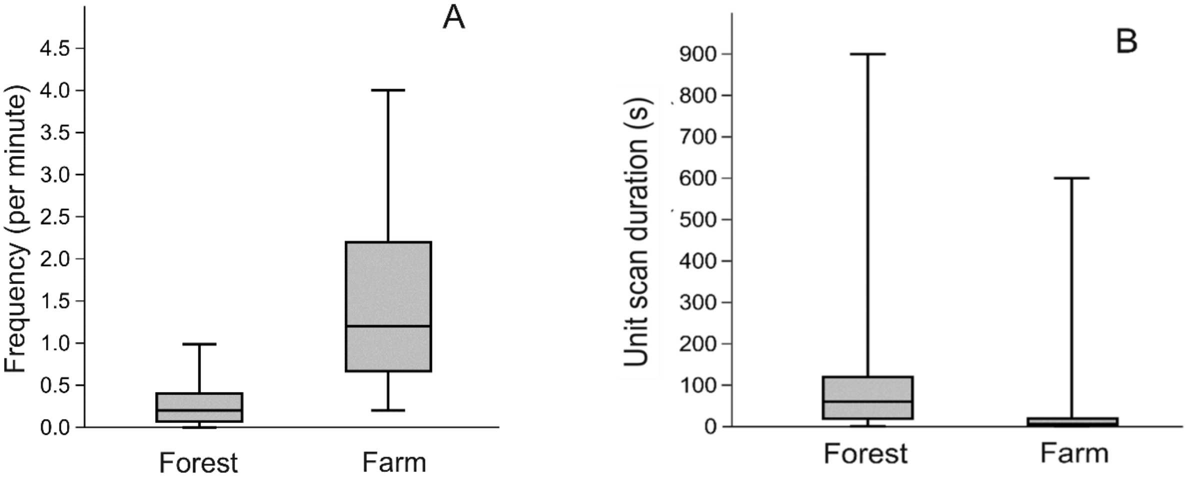
Variation in unit scan duration, total scan duration and vigilance frequency

In the instantaneous scan observations it was observed that, while foraging in forest, 78% of times (82 out of 105 scans) at least one individual was vigilant whereas, compared to only 32% (28 out of 85 scans) on farms (two-tailed Fisher's exact test $P < 0.0001$). On an average (± SD) 61.2% ± 26.8% individuals were seen feeding in forest, compared to 90.2% ± 19.3% on farm ($n = 105$ for forest, 86 for farm).

Focal animal sampling revealed that the total scan duration (%) on farm was higher than in forest. The total scan duration of focal individuals in forest (Median = 38.9%, $n = 91$, IQR = 5%-67.1%) was smaller than that observed on farms (Median = 53.1%, $n = 52$, IQR = 33.3%-76.8%).

A distinct difference in vigilance behaviour was that the vigilance frequency was significantly greater on farms (1.4 per minute) as compared to forests (0.205 per minute) (Figure 5.5A), whereas the unit scan duration (seconds) was significantly less on farm as compared to forest ($\text{Median}_{\text{forest}} = 60$ seconds, $n_{\text{forest}} = 269$, $\text{Median}_{\text{farm}} = 6$ seconds, $n_{\text{farm}} = 403$) (Figure 5.5B).

Figure 5.5: Difference in frequency of attaining vigilant stature (vigilance frequency, A) and unit time duration (B) in forest and farm in winter.



Since the time of the day when observations were made in forest and farm were not identical, the observed difference is likely to be contributed by the difference in time or that in habitats. In order to resolve between the two possibilities I compared the vigilance frequency and unit scan duration only during the overlapping time period i.e. between 1800h and 1900h. I also tested whether the vigilance frequency and unit scan duration were significantly different in the forest or farms between the overlapping time and non-overlapping time. It was found that, there was a significant difference in the vigilance frequency between forest and farms not only when data pooled over for all the time-periods, but also in1800h-1900h (Table 5.3). The difference in unit scan duration between farm and forest during the overlapping time window was also significant (Table 5.4). On the other hand no differences in either parameter were significant in the forest during 1300h-1800h versus 1800h-1900h. (Table 5.3, & 5.4). Similarly, no differences in either parameters were significant on the farm during 1900h-0100h versus during 1800h-1900h (Table 5.3, & 5.4). This clearly shows that the difference in vigilance behaviour was an effect of habitats independent of the effect of time.

Table 5.3: Log likelihood ratio for frequency of attaining vigilant postures (vigilance frequency) which explains that alteration in the vigilance frequency observed in two habitats is due to habitat and not due to photoperiod.

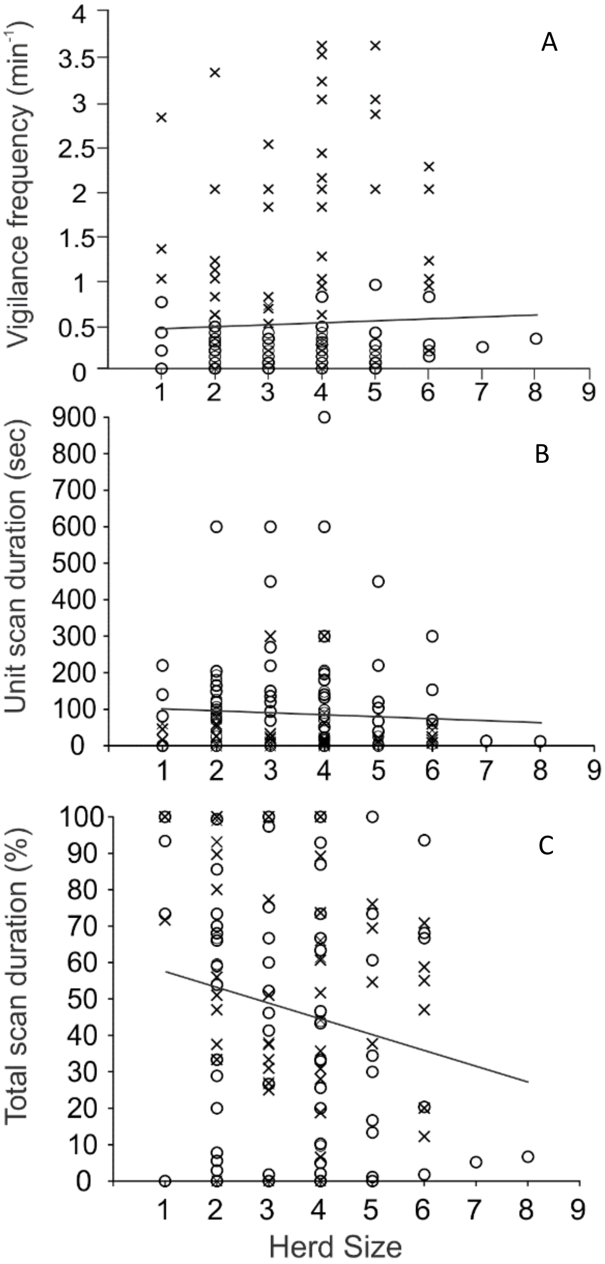
Forest versus Farm total data	Forest	Farm	2×(Log Likelihood ratio)	p value
Number of events	260	406	9.39	0.0022
Time (seconds)	76092	17312		
Forest & Farm only during 1800-1900h	Forest (1800-1900h)	Farm (1800-1900h)		
Number of events	69	278	9.39	0.0022
Time (seconds)	16200	11582		
Forest (1300-1800h) & forest (1800-1900h)	Forest (1300-1800)	Forest (1800-1900)		
Number of events	191	69	3.39	0.065
Time (seconds)	59892	16200		
Farm (1900-0100h) & Farm (1800-1900h)	Farm (1900-0100)	Farm (1800-1900)		
Number of events	128	278	0.79	0.37
Time (seconds)	5730	11582		

Table 5.4: Comparison of unit scan duration for forest and farm between overlapping and non-overlapping time of observation using Mann-Whitney U test. This result confirms that observed alteration in unit scan duration is not caused due to the photoperiod.

	Mann-Whitney U	Z	P value	Remarks
Forest & Farm	20539	-13.74	0.0001	Higher unit scan duration in forest
Forest & Farm only during 1800-1900h	3438.5	-8.4939	0.0001	Higher unit scan duration in forest
Forest (1300-1800h) & forest (1800-1900h)	6893.5	-0.24	0.8	No difference in unit scan duration
Farm (1900-0100h) & Farm (1800-1900h)	16875	-0.46	0.65	No difference in unit scan duration

In order to test whether the difference in vigilance between habitats was a result of difference in herd size, the relationship between herd size and vigilance behaviour was studied in data pooled from the two habitats. Vigilance frequency and unit scan duration did not correlate to herd size significantly (Figure 5.6A, B). It can be clearly seen that majority of the vigilance frequencies in forests lie below the best-fit regression line and those on farm above the line. Thus the difference in the two habitats exists independent of herd size. Unit scan duration had the opposite trend, the forest scan durations mainly lay above the line and farm scan durations below it. The total scan duration did correlate negatively to herd size (Figure 5.6C). In this case, there is no clear segregation along the y-axis according to habitat. It is possible therefore that the total scan duration is mainly influenced by herd size, but vigilance frequency and unit scan duration differ across the two habitats independent of herd size.

Figure 5.6: Effect of herd size on vigilance parameters, open circles represents forest and crosses represents farm. (A): vigilance frequency is not significantly correlated to herd size (Kendall's τ = 0.005, P = 0.9); (B): unit scan duration is not correlated with herd size (Kendall's τ = -0.08, P = 0.12); (C): total scan duration decreases significantly with herd size (Kendall's τ = -0.12, P = 0.03).

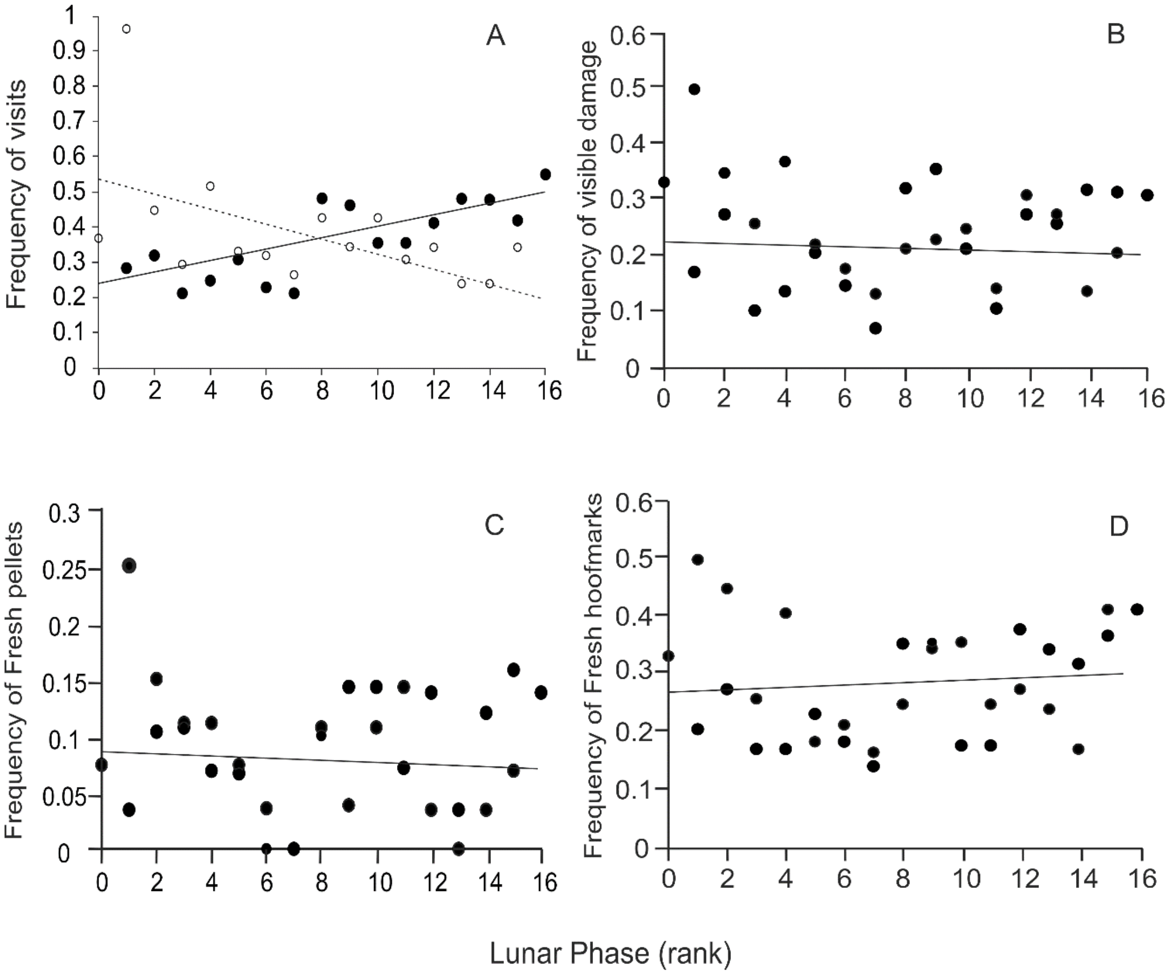


Effect of moonlight on crop-raiding

There were significant correlations between the lunar phase and the number of crop-raiding visits during the observation window (1900h to 0100h). In the waning phase, the correlation was negative (Kendall's $\tau = -0.38$, $P = 0.04$) and in waxing phase it was positive (Kendall's $\tau = 0.53$, $P = 0.006$) (Figure 5.7A). Since the observation window was in the first half of the night, in the waning phase there is progressively less moonlight whereas progressively more moonlight in the waxing phase. From the current observation, it appears that nilgai actually preferred moonlit hours for raiding the crops. However, there could be a bias in this trend since there were no direct observations other than time period between 1900h to 0100h. The indirect signs of nilgai visit seen the following morning, i.e. hoofmarks, fresh pellets and visible crop damage, no correlations were significant (Figure 5.7B, C, D). It is possible that the frequency of crop-raiding per night does not depend on the lunar phases but within a given night they prefer moonlit hours. In any case the patterns observed are marginal and inconsistent, therefore moonlight cannot be said to be a major factor in determining crop-raiding behaviour by nilgai.

(See figure on next page).

Figure 5.7: Trends in crop-raiding frequency with lunar phases (ranked) on experimental farm. A: Direct observations in terms of frequency of visits, where empty circles represent waning phase (Kendall's τ_{waning} = -0.38, n_{waning}=15, p=0.004) and solid circles represent waxing phase (Kendall's τ_{waxing}= 0.53, n_{waxing}=15, p=0.006). B: visible damage to the cultivated crops (Kendall's τ = -0.002, n=30, p= 0.98), C: fresh pellets (Kendall's τ = -0.025, n= 30, p= 0.83), D: fresh hoofmarks (Kendall's τ = 0.112, n=30, p= 0.36).



DISCUSSION

A number of behavioural parameters of nilgai were significantly different while foraging in forest versus farms. It is possible that while raiding crops nilgai herds break into smaller groups which presumably reunite when they take to forest cover again. Alternatively the smaller groups may have a greater tendency to raid crops. Farmers having their agricultural lands at the close proximity of forest actively drive away the raiders. In such cases breaking of a large herd into smaller herds is natural. This is perhaps reflected in the decreasing trend in nilgai herds while going away from the forest. Additionally, farmers were observed to be aggressive and actively chasing away the herds which are larger in number, however, less concerned when the herd size was less as 2-3. This response is perhaps learned by the raiders and hence they show alteration in their herding strategy.

The nilgai bulls are known to use common latrines to defecate (Mehta 2014, Singh 1995). However, at the study area I observed both sexes using such common latrines that could be found almost exclusively in or near forests. Large and composite dung pile heaps were never detected in agricultural land although a substantial part of foraging was done there. This indicates that they treat the two foraging grounds very differently.

A number of observations related to vigilance behaviour are remarkable. There is an apparent contradiction in the scan versus focal animal sampling data. Although individuals seemed to be spending more time in vigilant posture on the farms than in the forest, durations for which no animal in a group was vigilant were fewer in forest than on the farm. The contradiction is likely to be because of difference in herd size and also possibly because of different levels of synchrony in behaviours in the two habitats. In forest they appear to be vigilant more in a ‘turn by turn’ mode and on farms more synchronously.

Perhaps most interesting is the difference in the vigilance frequency and unit scan duration. The nature of risk between forests and farms is qualitatively different. In forest, tiger and leopard are the main predators which are ambush predators, whereas on farms the main threat is from guarding farmers. To detect the ambush predators in forest, high watchfulness is needed, thus individuals need to look for higher duration but since the predators are present in lesser density, a comparatively lower frequency of attaining vigilant postures could be an optimal strategy. On farms the situation is different, detection of guarding farmers and/or feral dogs or watch dogs, who make their presence conspicuous enough, needs a shorter duration but individuals need to look for such threats more frequently. Occurrence of tiger and leopard on the farms is quite infrequent therefore less likely to contribute to alter vigilance behaviour of nilgai.

For a well-camouflaged ambush predator there is safety in numbers since detection of predator by a single individual can alert the entire group. In contrast, detection of nilgai by farmers is more crucial in agricultural lands and by dividing into smaller groups this probability can be reduced. Therefore aggregating into larger and more compact groups in the wild and breaking into smaller groups and dispersing during crop-raiding can be an adaptive strategy.

Nilgai feeding on agricultural crops is a widespread phenomenon throughout the Indian peninsula and it is presumably an old phenomenon too. Therefore it is possible that the individuals might have developed strategies to the different nature or challenges. Individuals appear to perceive the risks as qualitatively different. In the last few decades, there are hardly any instances of farmers killing nilgai; however, such practices might have existed in history. The greater total scan duration and avoidance of bringing new born individuals to farmlands indicate that they do perceive a risk on agricultural lands although the probability of getting killed is currently negligibly small while foraging on farms as compared to forests.

Contrary to our expectation nilgai did not seem to avoid moonlight for crop-raiding in spite of the observation that farmers are more active in guarding their farms and driving away animals during moonlight hours. This is rather surprising since all other observations show that they make subtle changes in behaviour to adapt to a given context. With the exception of response to moonlight the study shows that nilgai have subtle behavioural plasticity in their adaptive response to the context of habitat and risk variations which is reflected in many different behavioural traits simultaneously. To the best of our knowledge, this is the first clear demonstration that a given population of herbivores gives different behavioural responses to two qualitatively different types of risks.

The relevance of a behavioural study for management of conflict is the realization that herbivore behaviour is plastic and they appear to optimize their behavioural strategies in order to adapt to given circumstances. Therefore while designing mitigation measures the plasticity of animal behaviour needs to be considered. Currently our understanding of behavioural plasticity of crop raiders is primitive but still gives some preliminary insights into how they can be incorporated in mitigating conflicts. The models of foraging optimizations that we developed are based on the assumption that herbivores optimize their foraging behaviour contextually. The nilgai behavioural study gives direct evidence in support of the assumption strengthening the applicability of the models. If some elements of optimization strategies of animals are studied, we may better understand why some of the mitigation measures succeeded or failed in particular contexts. Our models at least partly delineate the conditions under which given control measures would work or fail.

ETHOGRAM (BEHAVIOURAL INVENTORY)

Foraging/vigilance behaviour

1) Alarming (AL): Standing still; neck stiff and pointed forward; ears erect pointing front and making noise (forceful, guttural and coughing grunt roughly sounding "..*bwooaahh*..").

2) Alert (A): Standing still, looking at one particular direction; neck stiff and erect above shoulders; ears stiff and erect pointing in front; tail down.

3) Browsing (BR): Eating leaves from trees/shrubs neck and head forward; ears drooping down or pointing backwards; tail drooping down and wagging.

4) Grazing (GR): Eating grass with neck and head down in grass; ears drooping down or wagging; tail down and wagging.

(Note: Both 'grazing' and 'browsing' are the part of 'feeding' and distinguished so only while observed in forest. It was recorded only as 'feeding' on farms. Also, there were no browsing tree/shrub species in the experimental farm plot. In the forest, however, feeding on shrubs/trees below/above shoulder level was considered as 'browsing' while feeding on grass was termed as 'grazing'. The instances where grass growing taller than shoulder height of animal and trees/shrubs being available below shoulder level was infrequent).

5) Grooming (G): Licking and brushing the fur of self or calf or another individual in herd.

6) Sniffing (SN): Standing or walking one to two steps with head down at shoulders, sniffing with muzzle down to ground or in air; ears drooping down or pointing front; tail down. (Note: sniffing could be for danger and/or foraging, but its function was not detected during this study).

7) Scanning (SC): Standing still; neck held upright but moving at different directions within one second; tail down, ears may be held up or drooping down.

8) Standing (S): Standing still; neck straight, parallel either to ground or slightly above shoulders; ears drooping down or pointed backwards.

9) Walking (W): Walking through the feeding area with head at or above shoulders; ears drooping down or pointing backwards; tail wagging.

Miscellaneous behaviours

1) Defecating (DE): Defecating at common toilets or any place, head and neck at shoulders, tail held parallel to ground, hind legs spread and put backwards, and body bent down at pelvis.

2) Drinking (D): Drinking water at any water source; head, neck and tail down; ears down or pointing front. OR resting body on knees of forelegs and drinking.

3) Leaping (L): Jumping over a trench or fence or any barrier to cross.

4) Resting (R): Sitting down under tree or in grass with head and neck either down or erect, ears drooping down or wagging, tail kept flat on ground, wagging; animal may be masticating/chewing.

5) Running (RU): Running with neck and head held forward, ears pointing backwards, tail held either down or upright.

(Note: tail is held upright while ‘Running’ only when animal is chased by predator, which is often seen on farms, when chased away by farmers)

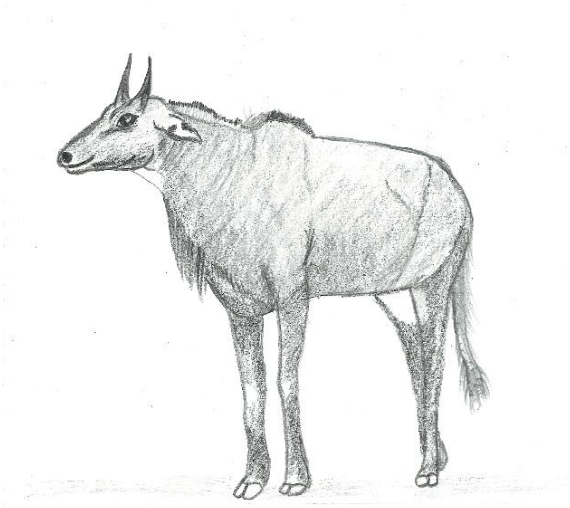
6) Threatened (T): Standing still; neck stiff and erect; ears stiff and erect pointing in front; looking at one particular direction with tail held upright.

7) Out of sight (O): Focal animal moved out of sight.

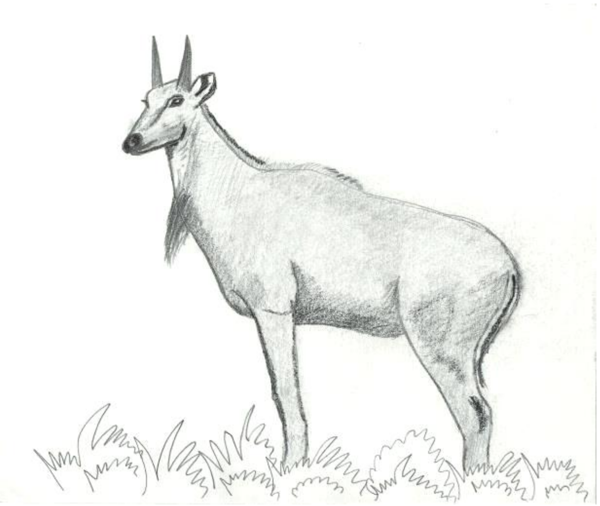
8) Checking carcass (C): An adult bull had escaped from tiger but eventually found itself dead of severe injuries. One adult bull from a herd (two adult bulls and four adult females) checked this carcass twice a day (early dawn i.e. 0400h to 0600h and night i.e. 2000h to 2300h) with head down at the body smelling it from different angles, touching it with forelegs for 6 days until feral dogs finished eating carcass.

COLOUR PLATE 5.1: BEHAVIOURAL POSTURES

Alarming

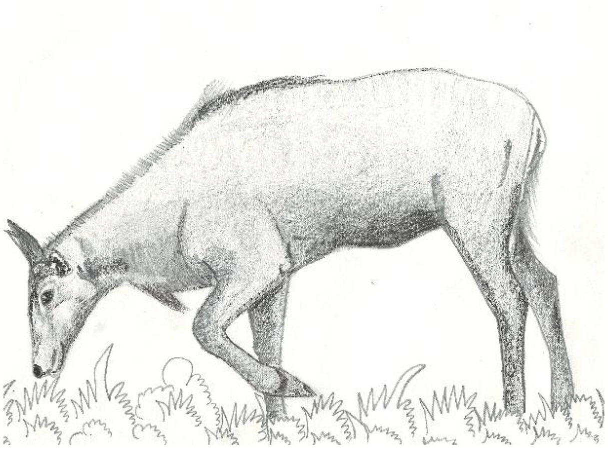


Alert

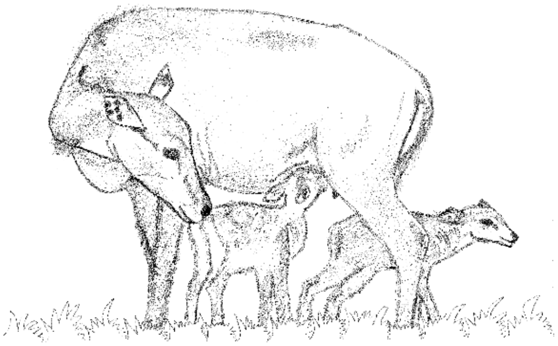


Browsing

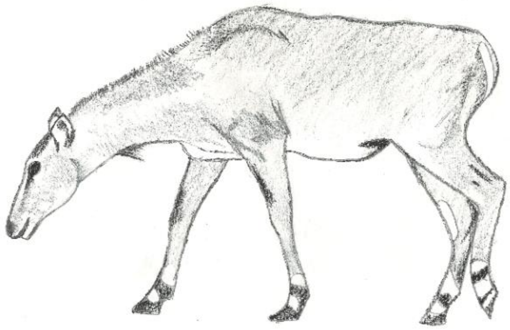
Grazing



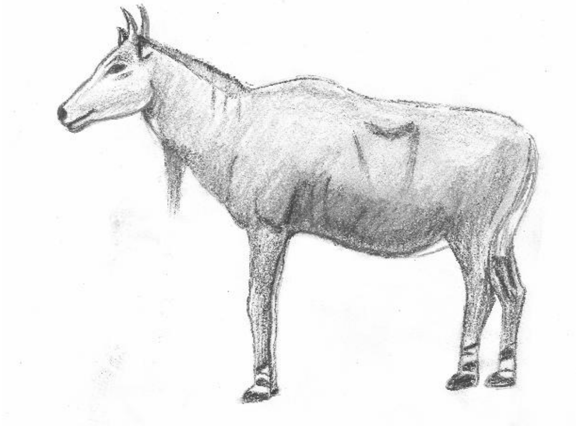
Grooming



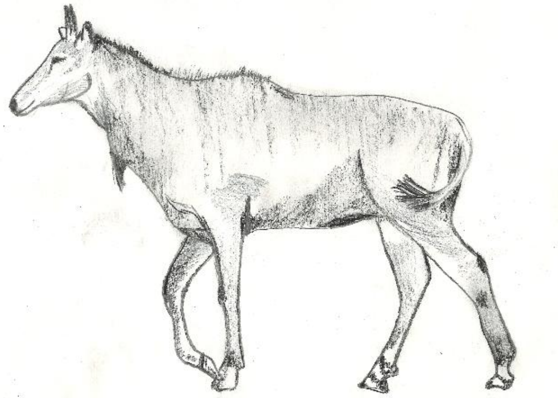
Sniffing



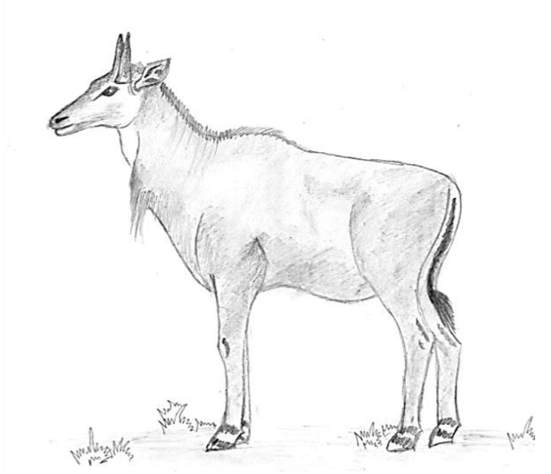
Standing



Walking



Scanning

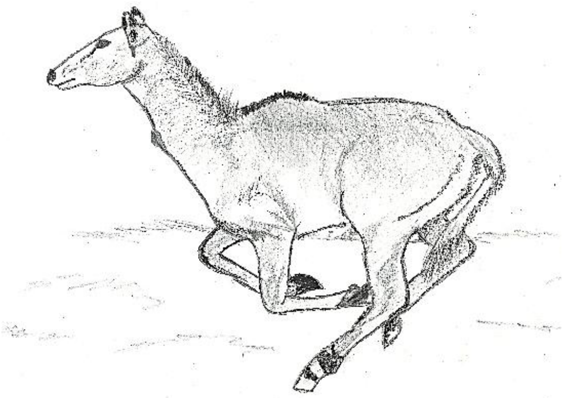


Scanning

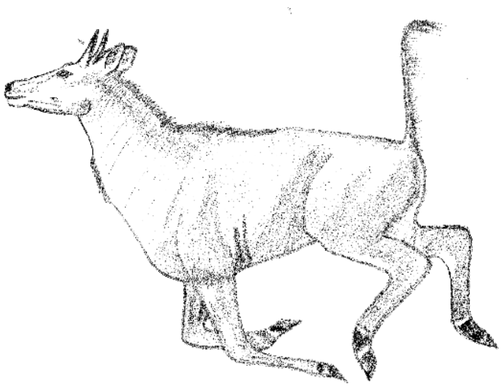
Drinking

Defecating

Running



Running (under threat or when chased)



Resting

Threatened

COLOUR PLATE 5.2

INDIRECT EVIDENCES OF CROP-RAIDING ANIMAL SPECIES

Regurgitated pellets of wild pigs after feeding on rice.

Fresh dung pellets (left) and hoofmarks (right) of nilgai in unfenced farm.

CHAPTER 6

COST-BENEFIT OPTIMIZATION MODELS FOR FARMERS AND WILD HERBIVORES

INTRODUCTION

Optimization models are based on the assumption that individuals choose behavioural strategies that are most likely to give them maximum benefit in comparison with the cost incurred. Individuals may achieve this through cognitive understanding, experiential learning or through evolved innate behaviours. Generalized optimization models have heuristic function and may use rather abstract quantitative parameters to derive qualitative inference of a given biological problem (Parker & Maynard Smith 1990). These models can then be converted to specific models to address a given problem based on empirical data and more specific parameters. General optimization models first developed for animal foraging have been extended to human behaviour (Perlan 1980, Hastrof 1983, Foley 1985) although the underlying cognitive basis might be different. My observations on nilgai foraging (chapter 5) suggest that they change their behaviour according to context. This is in support of the assumption in this chapter that herbivores optimize their strategy with required contextual plasticity.

An optimum can be defined either based on ratio of benefit to cost (benefit/cost) or subtracting cost from benefit (benefit – cost). Benefit-cost difference is typically termed as net benefit, whereas ‘cost-effectiveness’ is expressed in the ratio form (Boardman et al 1976). Both the approaches have been used in behavioural ecology. For example, models optimizing the amount of movement between foraging bouts maximize the benefit cost difference, but for optimizing the time spent in a patch they use maximization of the benefit cost ratio (Parker & Maynard Smith 1990). There are no clear indications as to which of the two is best suited in a given context. This is particularly important since the optimum obtained by difference maximization can be substantially different from that obtained from ratio maximization as shown below.

CHOOSING THE RIGHT OPTIMIZATION MODEL

The cost of agricultural production involves some overhead cost that includes baseline investment in land, equipment and basic land preparation. The produce scales linearly or non-linearly with the cost of seed/saplings, manure, fertilizers, pesticides, labour and other recurring costs. Since there is an upper limit on the productivity per unit area of any crop, the model assumes a relationship in which the benefit increases in a saturation curve beginning with an X intercept equivalent to the overhead costs (Figure-6.1). A saturation curve is typically used in optimization models where some limiting factor decides the upper limit that cannot be exceeded (Charnov 1976, McCleery 1977, Pyke et al. 1977, Sumpter & Beekman 2003). The curve can be captured by a simple mathematical expression (equation-1), which is a modified version of the Michaelis-Menten curve,

$$Y = \frac{Y_{max}(C-C_o)}{K+(C-C_o)} \qquad \text{Eqn. 1}$$

Where, C_o is the overhead cost and C the total cost incurred in agricultural inputs (See table 6.1 for all abbreviations). K, the equivalent of Michaelis-Menten constant is a half saturation cost ignoring the overheads. K will be decided by the default agricultural environment and the specific crop under consideration. Since the relation between cost and the yield is a saturating one, it is possible to ask what are the optimum inputs in agricultural practices that can maximize the benefit-cost ratio or their difference. The benefit to cost ratio can be maximum where a straight line starting from the origin becomes tangential to the curve (Figure 6.1 and 6.2). The net benefit (benefit – cost) is maximized where the vertical distance between the curve and the break-even line (benefit = cost) is maximum. This happens where the slope of the curve becomes exactly equal to unity. Since generally the overhead costs are imperative, one can optimize the costs with which the produce scales directly (C_s=C–C_o). It can be seen that for a saturation curve starting from a positive X intercept the ratio optimum and the difference optimum do not coincide.

Figure 6.1: Modified Michaelis-Menten saturation curve. The total agricultural inputs on the X axis, whereas Y depicts the grain yield obtained at harvest. Since there is an overhead cost, there is an X intercept C_0*. Long-dashed line is the one with slope=1, and short-dashed line is a tangent to the curve.* d_{opt} *and* r_{opt} *are the optimum inputs by the difference model and ratio model respectively.*

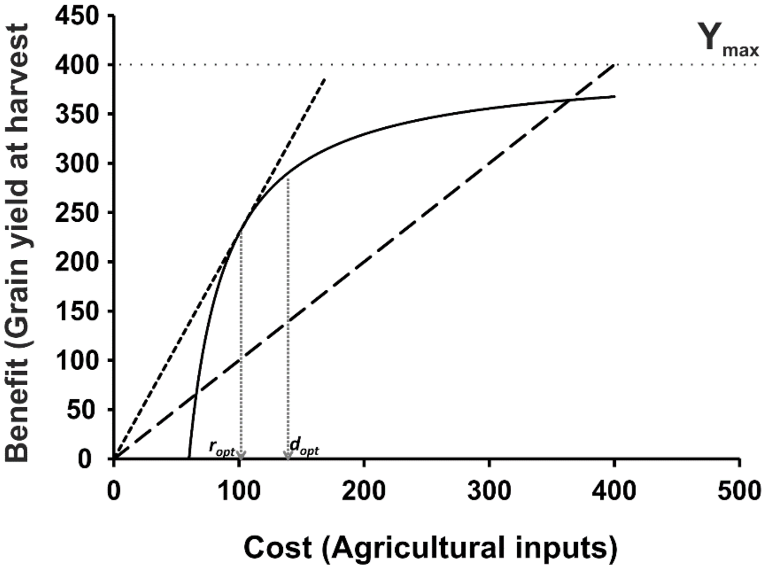


Table 6.1: List of abbreviations used in the models.

Parameter	Symbol
Grain yield	Y
Maximum grain yield	Y_{max}
Total Cost	C
Overhead Cost	C_o
Rate constant	K
Rate constant (forest)	K_1
Rate constant (agriculture)	K_2
Investable amount in agriculture	X
Sustenance cost	S

Probability/frequency of damage	P
Damage (measurable fraction of total land eaten)	F
Damage (measurable fraction of total land eaten) on guarding days	f’
Risk of predation in forest	Pr_1
Risk of predation on farms	Pr_2

The ‘ratio’ optimization

From equation1 the net yield is, $Y = \frac{Y_{max}(C - C_o)}{K + (C - C_o)}$. Therefore the benefit to cost ratio would be,

$$b_r = \frac{Y}{C} = \frac{Y_{max}C_s}{K + C_s} . \frac{1}{C_0 + C_s}$$

The benefit to cost ratio scales with C_s, therefore the benefit to cost ratio will be maximum when

$$\frac{db_r}{dC_s} = \frac{Y_{max}(C_0K - C_s^2)}{[(K + C_s)(C_0 + C_s)]^2} = 0$$

This condition is satisfied when $C_0K - C_s^2 = 0$ i.e.$C_s \;\; = \sqrt{C_0K}$.

Thus, the optimized total cost will be $C = C_0 + \sqrt{C_0K}$

In this model, optimum cost is dependent on both *K* and C_o and does not depend on Y_{max} (also see Figure 6.2A).

The difference optimization

Since the net yield at a given input is $Y = \frac{Y_{max}(C - C_o)}{K + (C - C_o)}$, the net benefit will be

$$b_n = Y - C = \frac{Y_{max}(C - C_o)}{K + (C - C_o)} - (C_o + C_s)$$

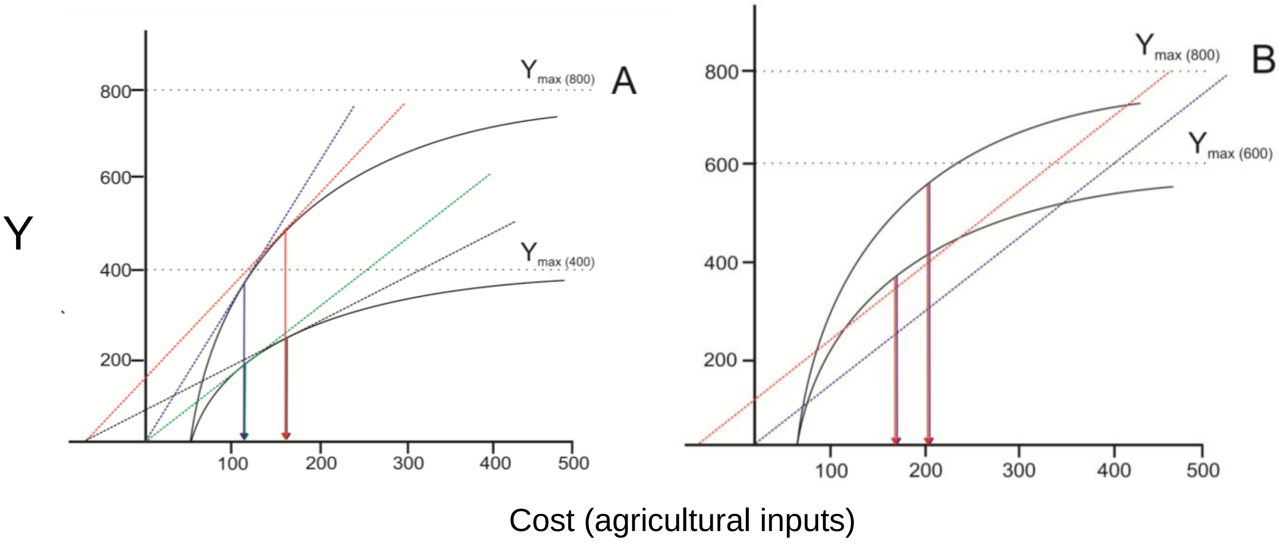
Since b_n scales with Cs, this will be maximized when

$$\frac{db_n}{dc_s} = \frac{K.Y_{max}}{(K + C_s)^2} - 1 = 0$$

This condition is satisfied when, $C_s = \sqrt{K.Y_{max}} - K$, which is the optimum input. Thus the total optimum investment will be, $C = C_0 + \sqrt{K.Y_{max}} - K$.

In this model the optimum C_s is dependent on Y_{max} and K but independent of C_o (also see Figure 6.2B).

Figure 6.2: Graphical representation of change in cost-benefit optimization with change in overhead and maximum benefit (Y_{max}). A: optimization of benefit to cost ratio, B: optimization of net benefit (Benefit-Cost difference).



Thus, it can be seen that the ratio optimum and its determinants are distinct and different from the difference optimum and its determinants. It is necessary therefore to select the appropriate model for addressing further questions. If an individual has an investable amount X and an investment opportunity whose optimum for both ratio and difference model is known, one can calculate which model gives greater returns on the investment. When, $Y_{max} > K + C_0$, i.e. for a sustainable or profitable venture $\sqrt{K.C_0} < \sqrt{K.Y_{max}} - K$ meaning that in a single venture, at any parameters in the sustainable or profitable range the total cost incurred as well as the total benefit for the difference optimum would be greater than that of the ratio optimum.

$$X + b_{d_{opt}} - C_{d_{opt}} - S > X + b_{r_{opt}} - C_{r_{opt}} - S$$

Where S is the sustenance cost, suffix d_{opt} denotes optimized for the difference model and r_{opt} optimized for the ratio model.

However, if the balance amount from X is invested in another venture with similar parameters, i.e. if multiple investments are possible then ratio optimization gives great total returns. When X is limiting $\frac{X}{C_{d_{opt}}}$different investments of the same type are possible. In that case it is seen that

$$\frac{X}{C_{d_{opt}}}\left(b_{d_{opt}} - C_{d_{opt}} - S\right) < \frac{X}{C_{r_{opt}}}\left(b_{r_{opt}} - C_{r_{opt}} - S\right)$$

This means that whenever alternative investment opportunities are limited, using a difference model is more appropriate but whenever investment opportunities are multiple, a ratio model is more appropriate. The ability to invest in multiple ventures is constrained by the nature of the limiting factor. For example money saved in one enterprise can be invested in another enterprise only when time or some other resource is not limiting. If the investor cannot manage two or more enterprises due to time or any other limit then multiple investments are not possible.

OPTIMIZATION IN AGRICULTURE: FARMERS' STRATEGIES

In sustenance agriculture often the piece of land owned by a farmer is limiting and multiple investments in agriculture not possible. If time spent in agriculture does not allow simultaneously running another enterprise, or limited skillset or any other cultural, social factors make it difficult, farmers have only one investment opportunity. The protected status of an area may put additional constraints on hunting, gathering or animal grazing as alternative livelihoods. Therefore, farmers close to protected areas should use difference optimization rather than ratio optimization. I show below that farmers indeed use the difference model inadvertently.

The problem of mega-herbivory necessitates two types of changes in the baseline model. One is that the total produce is reduced due to direct damage by animals and the other is the cost of protective measures against crop raiding needs to be included in the cost-benefit optimization. If we assume that wild herbivores damage some fraction of the total crop, the entire curve comes down proportionately. In the equation, a reduction in Y_{max} is sufficient to represent this change. Incorporation of the cost of protection measures is somewhat tricky. If the protection measure consists of a onetime operation such as making a fence of some kind, it can be taken as an overhead cost. Manual guarding or vigilance can potentially scale with the produce in a continuous curve but the nature of the curve needs to be examined carefully. Similar to the optimum investment question we need to ask whether there is an optimum guarding effort that can maximize yield per unit effort.

The cost of guarding as an overhead

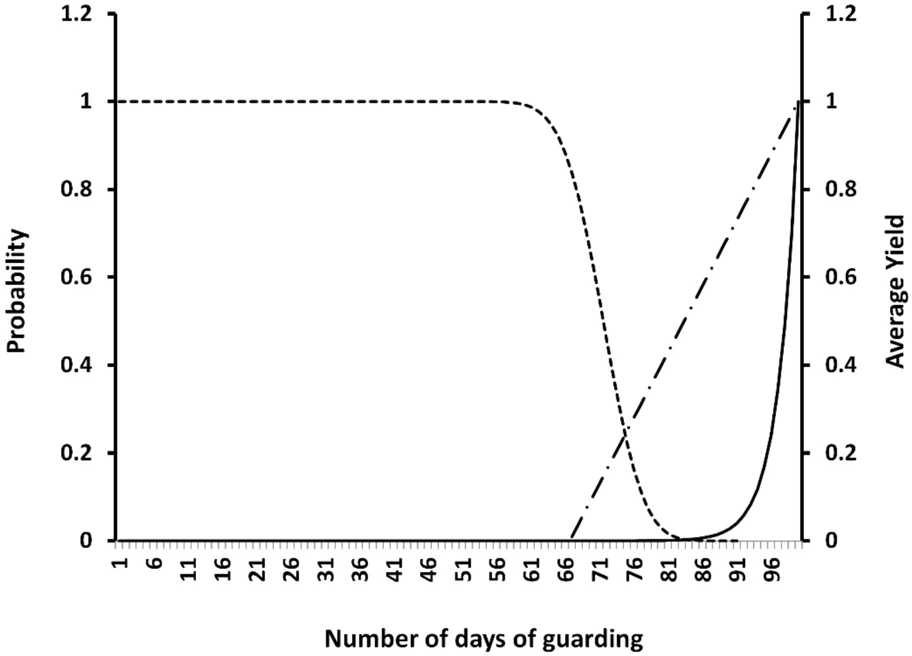
A given crop is visited by wild herbivores with a probability p per day and on an average they cause damage equivalent to a fraction f of the total produce in one day. The total expected damage over the season is $p.f.D$ where; D is the total number of days for which the crop is susceptible to damage. Since in many places, farmers actively guard the crops at night that can reduce or stop damage during vigilance, if d are the days on which active vigilance is observed and on days with active vigilance the damage in terms of fraction of the total produce is f', the total damage in the entire season can be written as $p.f.(D-d)+p.f'.d$. If guarding is highly effective so that f' is zero, the expression is simply $p.f.(D-d)$. In either case the mean damage should reduce linearly with d. The mean number of days needed to completely devour the unguarded crop will be $D/p.f$. Therefore, $D(1 - 1/p.f)$ will be the minimum number of days of guarding beyond which guarding efforts will have some positive effects on yield. Therefore guarding efforts up to $D(1 - 1/p.f)$ days is certainly an overhead cost. With an overhead input of d and a linear increase in yield with further guarding the optimum for benefit to cost ratio as well as for benefit-cost difference lies at $d = D$ i.e. active guarding throughout the susceptible period (Figure 6.3).

Furthermore, it needs to be appreciated that this is a probabilistic process. Although the mean per day damage will be decided by the product of p and f, if p is small and f large, the variance around the mean would be large. For an individual farmer, the risk of being at the higher end of the distribution is more threatening than the average damage. If we take a threshold risk tolerance, the trend is nonlinear. In an extreme case if we take the threshold to be zero damage, the probability of zero damage is given by $(1-p)^D$ assuming f' to be zero. This curve is non-linear and the only condition to ensure zero damage is $d=D$. That is all days are guarded. The other extreme, i.e. the probability of total loss is also highly non-linear (Figure 6.3). The minimum number of days required for total loss is $1/f$ since f is the mean fraction lost in a day. Probability of total loss becomes zero only when $D-d<1/f$. For values of d smaller than this threshold the probability of total loss can be given by addition of probabilities in the following binomial expansion until ($D-d-n$) reaches $1/f$.

$$(p+q)^{(D-d)} = {}^{D-d}C_0.p^{D-d}.q^0 + {}^{D-d}C_1.p^{D-d-1}.q^1 + {}^{D-d}C_2.p^{D-d-2}.q^2 + \ldots + {}^{D-d}C_n.p^{D-d-n}.q^n + \ldots.. + {}^{D-d}C_{D-d}.p^0.q^{D-d}$$

This curve is also highly non-linear in which Y comes down rapidly when d comes close to $D-1/f$ (Figure 6.3).The behaviour of these curves suggests that guarding all throughout the susceptible period is the only optimum guarding strategy. Because of the nature of the risk curves, the investment in guarding is better considered an overhead cost rather than a scaling cost. In reality f' is unlikely to be zero. Having a non-zero f' will bring down the maximum possible yield even after guarding, but all other inferences that we drew from the model remain unaltered.

Figure 6.3: Trend of Number of guarding days (d) against probability of no loss (solid line), probability of total loss (dashed line) and average yield (long-dash-and-dot line). The maximum possible yield is assumed to be 1 and the mean per day damage 0.03.



I will now incorporate the two effects of mega-herbivory in the optimization model. Direct damage by herbivores reduces Y_{max} and protecting-guarding efforts increase the overhead cost. The ratio and difference optima respond differently for these two changes. As it is shown above, the ratio optimum is independent of Y_{max} but it increases with C_o, when faced with herbivory, the optimum investment increases. As opposed to this in the difference model C_s is not affected by increase in overhead cost but it decreases with a reduction in Y_{max}. Therefore, one should decrease the investment in agricultural inputs when faced with mega-herbivory. Thus in order to optimize the ratio model one needs to increase agricultural inputs and in order to optimize difference model one needs to decrease it. The two models make diametrically opposite predictions. It was observed that farmers facing higher risk of herbivory were less likely to use combinations of chemical fertilizers (chapter 4, figure 4.5). This observation is compatible with the difference optimization model and the prediction that farmers should use the difference model over the ratio model. An important implication of this is that the actual loss due to herbivory is likely to be much greater than the direct loss due to damage. The risk of damage induces disinvestment further brings down the yield and this indirect loss should be counted as a loss due to herbivory. This is an important realization because in the current methods of crop damage assessment this loss is never accounted for.

If the disinvestment is due to the perceived risk of damage, it is expected that an assured realistic damage compensation should reverse the disinvestment trend i.e. compensating the actual damage would eventually also recover the indirect loss due to disinvestment. An efficient and realistic damage compensation scheme can thus have a dual advantage. On the one hand, it would reduce resentment and anti-conservation attitude among farmers and on the other, it would encourage better agricultural inputs and thereby productivity.

OPTIMIZATION IN FORAGING: HERBIVORES' STRATEGIES

A counterpart of the cost-benefit optimization by the farmer is the cost-benefit optimization by the herbivores. The animals have to take two important decisions, whether to forage in the forest or in the agricultural land and how much time to spend feeding in an area. It is assumed that both the decisions are based on cost-benefit optimization. A direct empirical evidence for this assumption can be taken from the behavioural studies of nilgai (chapter 5) where I show that nilgai do alter its behaviour significantly to optimize the cost of predation. I expect the benefit curve for animals to be similar to the one for farmers since there is a time and energy cost in moving to and entering a patch, scanning the surroundings for predators and other risks which can be considered as an overhead cost. Further foraging within a patch the tender, nutritious and palatable parts are most likely to be consumed first and therefore the cost benefit curve can be visualized as a curve of diminishing returns. In this curve Y_{max} is the maximum nutritive benefit that can be obtained from a given patch, C_o is the cost incurred in moving to the patch and scanning for potential risks, C_s is the time-energy cost incurred in actual feeding and K being inversely related to the palatability and nutrient density of forage. Unlike farmers who can invest in a limited piece of land, animals have a wide choice in foraging and therefore their optimization would be more appropriately based on benefit to cost ratio. According to the ratio model, the optimum time and energy actually spent in feeding (C_s) would be $C_s = \sqrt{C_0 K}$

In this time the total nutritive benefit would be $\frac{b_{max}\cdot\sqrt{C_0K}}{\sqrt{C_0K}+K}$ and the benefit to cost ratio would be

$$\frac{b_{max}\cdot\sqrt{C_0K}}{\left(\sqrt{C_0K}+K\right).\left(C_0+\sqrt{C_0K}\right)} = \frac{b_{max}\cdot\sqrt{C_0K}}{C_0.\sqrt{C_0K}+2C_0K+K\sqrt{C_0}}$$

With the risk of predation *Pr* the ratio would be

$$\frac{b_{max}\cdot\sqrt{C_0K}}{\mathrm{Pr}\ +(C_0.\sqrt{C_0K}+2C_0K+K\sqrt{C_0})} = \frac{b_{max}}{\mathrm{Pr}+(C_0+2\sqrt{C_0K}+\sqrt{K})}$$

Herbivores should choose the forest over the agricultural fields if

$$\frac{b_{max1}}{Pr_1+(C_{01}.+2\sqrt{C_{01}K_1}+\sqrt{K_1})} > \frac{b_{max2}}{Pr_2+(C_{02}+2\sqrt{C_{02}K_2}+\sqrt{K_2})}$$

Where the suffix 1 denotes forest and 2 denotes agriculture.

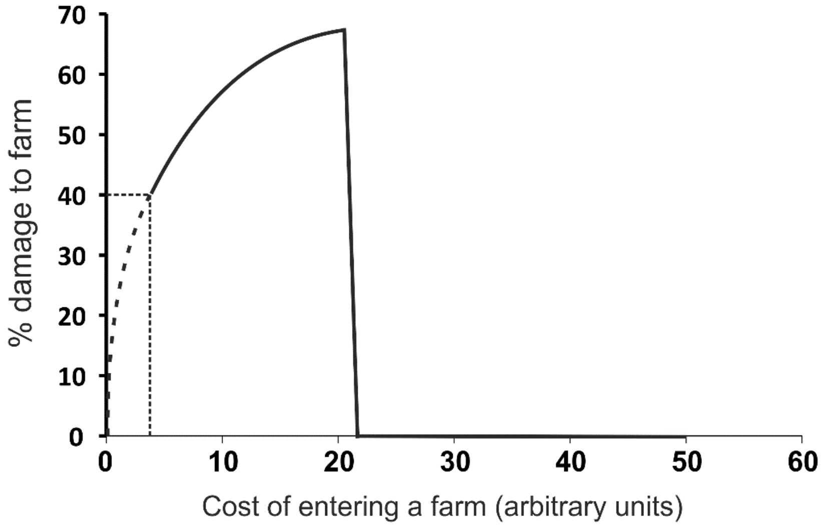
The decision thus should depend upon the relative total nutritional benefit, palatability, overhead costs and predation risk. Since for a given crop the nutritive value and palatability cannot be controlled, increasing the overhead cost by making fences, trenches etc. can be effective above a threshold increase in C_o, the threshold being decided by the nutritive content and palatability of the crop relative to wild forage. It is not necessary (and perhaps not possible or too expensive) to make a fence that is completely impenetrable to animals. It needs to increase C_o sufficiently so that the inequality in the above equation is true. Alternatively, the perceived risk in agricultural fields Pr_2 needs to be substantially greater than Pr_1 to make the inequality true. An alternative way of thinking is to increase the natural habitat quality or wild forage quality and quantity to discourage animals from crop raiding. For this to happen b_{max1}has to increase sufficiently to make the inequality true. From the equation, a change in b_{max1}will affect the left hand side in direct proportion of the improvement, but a change in C_{02} will have a greater than proportional effect on the relative quantities.

This is important since laws of some countries permit culling of the predominant crop raiding species (Lacy 1995, Linnell et al. 1991). However, effect of culling for reducing crop raiding is not demonstrated widely (Chauhan et al 2010). The inequality suggests that it would work like a threshold phenomenon. There is likely to be a sudden reduction in crop raiding if Pr_2 perceived by the herbivore is sufficiently greater than the perceived $Pr_1$to satisfy the above inequality. If this condition is satisfied there would be effective deterrence from raiding independent of the population density. However, for this to happen it would be essential that the animals associate the culling risk with the agricultural fields. This is possible if the culling is done only during crop raiding. If it is practiced over the wild land, the threshold phenomenon is unlikely to work and reduction in raiding, if any, would only be proportional to the reduction in population. The optimum level of culling Pr_2should be just sufficient to make the inequality true.

If herbivores chose the agricultural patch, the time they should optimally spend in feeding on a given patch is$\sqrt{C_0 K}$. This means that greater the difficulty in entering a patch, greater should be the time spent in feeding. Therefore, the possible effects of preventive fencing would be complex. Fencing is likely to decrease the probability of herbivores entering a field, but once entered they need to forage more for cost effectiveness. Thus, the efficiency of fencing would also act as a threshold phenomenon. Below the threshold, fencing may actually increase the damage whereas above the threshold it might suddenly become highly effective (Figure 6.4).

Figure 6.4: The non-monotonic effect of fencing on expected damage according to the model. The cost of fencing is assumed to increase linearly with the difficulty of crossing the fence. Contrary to simple belief, the damage increases with the difficulty of crossing the fence up to a threshold after which it reduced dramatically.

(See figure on next page).



The above inequality also gives an important insight into the efficiency of a protection measure. If a protection measure is applied to one farm, herbivores certainly have a better benefit to cost ratio in the unprotected neighbouring fields and they would avoid the protected field. However, if everyone applies the same protection measure, the inequality or the relative advantage is lost. If this happens animals are likely to resume raiding all fields albeit at a higher cost each. The higher cost may result into greater feeding effort and the actual damage could be more than the unfenced baseline damage, unless the fencing efficiency is above the threshold at which foraging in a forest is more beneficial. Therefore, a measure that is highly effective on an experimental scale is very likely to lose its efficiency when applied on a mass scale and in fact might prove counterproductive.

DISCUSSION

The generalized models provide many qualitative insights in the problem of crop raiding and raise many novel possibilities that need to be tested empirically. The explicit expression of the conditions when to use ratio model and when to use difference model has wide implications in microeconomics as well as in behavioural ecology and evolution. Apart from the theoretical general principle the model suggests many practical possibilities. The realization that actual loss of farmers can be greater than the direct damage done by animals is important in making justice to the farmers. The model warns against many simplistic beliefs such as a protection method that worked well on an experimental scale will work equally well on a mass scale. The most important realization is that the effects of fencing or culling can be highly non-linear and at times non-monotonic. Therefore, any effort to judge the efficacy of a mitigation measure without appropriate modelling may lead to misleading inferences. In addition to the generalized qualitative inferences, the model makes a foundation on which specialized models can be built. It is unlikely that a single solution would work for mitigating the crop damage problem. An integration of multiple measures might be appropriate (White 2010). The model can form the right platform on which such an integration can be attempted and evaluated.

Different species of herbivores differ in their population sizes, gregariousness, activity periods, qualitative and quantitative patters of damage and response to guarding and driving attempts (Sitati et al. 2005, Stankowich 2008, McComb et al. 2013). In cases where the probability of damage is small a crop insurance scheme can be a viable proposal even if the extent of damage is large. Insurance schemes are necessarily founded on the principle of small probability of disaster so that the insurance paid is less than the total premium paid by the pool of people. For smaller but more abundant herbivores crop insurance schemes are unlikely to be practicable since a large proportion of farmers in a damage prone area incur actual loss. Also for species which respond well to individual guarding crop insurance may turn counterproductive since it might cause partial discouragement from active guarding and thereby increase the damage.

In order to make locale and species specific useful quantitative predictions, more specific models using parameters measurable in field are needed (Parker & Maynard Smith 1990). The required modifications of the baseline model could be extremely context and question driven. They would differ according to the crop species, relevant agricultural practices, microeconomics of farmers, the major damaging herbivore species, their habits, habituation and prevalent law. The baseline generalized model described above can be used to make such specific quantitative predictive models. An insightful modelling approach is likely to lead a big way towards sustainable solutions.

In the context of the study area we certainly see some of the predictions of the model to be true. Farmers close to the forest and therefore subject to greater risk of herbivory invest less in intensive agriculture as shown in chapter 4. This is a part of their economic optimization and the reduced yields close to the park are substantially contributed by the disinvestment of farmers. The reluctance of farmers to invest in fencing can also be understood better in the non-monotonic returns of fencing predicted by the model. It needs to be appreciated further that the threshold of fencing efficiency depends upon neighbouring farmers too. If everyone makes a fence the threshold would be pushed further to the right. Perhaps having experienced this behaviour of the model, farmers do not consider fencing as a reliable anti-herbivory measure. Such insights are useful in understanding farmers' behaviour and a possible response they may give to any suggested mitigation measure. These are the useful insights obtained from qualitative use of the general model. In order to apply the model quantitatively to the farming in study area it is necessary to have realistic parameters of the saturation curve for each crop. This is a hard core agricultural economics problem going beyond the expertise of our research group. But for an effective long term solution to the conflict it is necessary to bring together expertise from different fields. The problem of crop raiding conflict is largely disowned by agricultural science and agricultural economics as a wild life problem and wild life researchers have inadequate expertise in agricultural science and agricultural economics. The model above can make a good platform on which such an interdisciplinary effort can be attempted.

CHAPTER 7

AN ALTERNATIVE COMPENSATION SCHEME

INTRODUCTION

I argued in earlier chapters that any protection measures implemented to reduce the crop damage have a limited efficiency when used on a mass scale. As a result with or without such measures it is necessary that some form of compensation or relief is offered to affected farmers.

The nature of conflict and accordingly the concept of damage compensation is considered as a part of wildlife management across the globe. Compensation by governmental and non-governmental organizations (NGOs) with a concern for wildlife is practiced in many areas (De Klemm, 1996). However, laws and compensation procedures vary widely across different countries and so do their execution (De Klemm 1996; Schwerdtner et al. 2007; Gordon, 2009; Agarwala et al. 2010). The cultural and political contexts often shape the compensation practices. Local people's perception and tolerance towards wildlife is highly variable across cultures and even locally across a small distance (Agarwala et al. 2010; Nagendra et al. 2010).

Among different types and levels of damages caused by wildlife, livestock killing by carnivores has received more attention; compensations schemes appear to work better for such cases since recording and assessment of damage is relatively easier and more objective. In reality the economic loss due to herbivore damage to cultivated crops is much greater in magnitude (Studsrod et al., 2009; Karanth et al., 2013a, 2013b) in most areas. However yet it received less attention of researchers and wild life managers as compared to carnivore conflict.

Compensation procedures in most countries involve assessment of visual vegetative damage done by a predefined team. Amount of damage is further negotiated between the victim and the compensating agency. It is usually not realized that often there is no correlation between the visible estimate of damage and the actual grain yield (Bayani et al. 2016). It is often difficult to decipher whether the damage is caused by the protected species or by something else. Additionally, whether compensation will ultimately benefit the conservation cause is also debated. Although the general thinking supports the compensation concept (De Klemm 1996), others think that compensation can become counterproductive in the long run. This fear is based on the assumption that it would encourage human activities in and around the protected areas (Bulte and Rondeau 2005).

It appears that, there is a lack of development of a sound theoretical platform on which the questions can be addressed (Schwerdtner et al. 2007). There are a few attempts towards developing objective, quantitative and validated methods for the assessment of damage but not for improving the compensation procedure *per se*. The social and managerial consequences of under, over or realistic compensation have not been thoroughly examined theoretically and empirically. Effective handling of the problem needs expertise from many fields including wildlife ecology, agriculture, economics, human behaviour and management. A number of problems on the interface of economics and human behaviour are addressed by game theory and other economic behaviour theories (Neumann and Morgenstern 1944; Aumann 1987; Myerson 1991; Roe 1996; Henrich et al. 2001). It is possible that a theoretical approach based on principles of human behaviour can give a conceptual solution that can be implemented in different parts of the world with an appropriate modification based on the local ecological, agricultural, and climatic conditions.

Problems in the currently practiced compensation schemes

A universal shortfall of all the compensation practices is that the laws and procedures all over the world do not provide accurate and comprehensive guidelines on how to estimate damage on field. Also, there are no reliable methods to differentiate damage caused by different wildlife species and domesticated or feral animals. Due to these inadequacies, system depends upon individual judgments, which invites conflicts as well as corruption (Ogra and Badola 2008). It is also important to realize that both under-compensation and overcompensation can have deleterious consequences for conservation. Under-compensation increases resentment and overcompensation can encourage human settlement and activities near the PAs (Studsrod and Wegge 1995; Sekhar 1998; Bulte and Rondeau 2005).

Farmers with high exposure to raiding tend to disinvest from intensive agriculture by cutting down the expenditure on quality seed, fertilizer etc. (Watve et al. 2016b). This decreases the yield qualitatively and quantitatively. An additional cost in fencing, guarding and other measures of protection decreases the benefit. In the currently practiced compensation procedures these indirect losses as well as additional costs are not covered. Almost all procedures involve verification of the damage claims by competent authorities. In the areas where the damage frequency is very high, large manpower will be required to assess the damage, which becomes impossible to handle. If there is a shortage of competent manpower, delay between the instance of damage and site inspection for validation would be inevitable. Since partially damaged plants start regenerating, assessment of damage becomes more and more difficult with increasing delay (see chapter-4). The frequency of raids by smaller herbivores with high population density can be very high. I observed frequency of detectable damage is approximately twice a week on a given field (chapter-4) and on the fringes of TATR which have over 10,000 susceptible farms, it would be physically impossible for appropriate park officers to carry out visual inspection for every event of damage on every farm.

Your animal syndrome: Indigenous farmers often have a considerable tolerance to wild animals and some extent of damage is accepted as natural (e.g. Hill 2004; Ogra and Badola 2008; Campbell-Smith et al. 2010; Canavelli et al. 2013). If the extent of damage is large, farming can no more be sustainable and this may bring in serious resentment. At this stage, it is thought that compensation would reduce the resentment (Sifuna 2010, Boven-Jones 2012). Nevertheless, when the PA management negotiates for paying the compensation for the damage caused by animals, there is a subtle change in the perception. Animals are no more perceived as a part of nature but as the property of park authorities and a cause of nuisance to farmers. This change in perception can be damaging to conservation efforts in the long run.

Characteristics of an ideal compensation scheme

The desirable characteristics of an ideal compensation scheme should be the following.

Fairness: The compensation package should cover both actual direct and indirect loss due to wildlife but should not overcompensate (Bulte and Rondeau 2005). For this to happen there should be realistic assessment of damage.

No free meal: The scheme should encourage farmers' efforts to increase agricultural productivity as well as in protecting it from damage using non-lethal techniques. The compensation benefits should go in proportion to the efforts and alertness of the farmers. If lack of efforts or alertness gets unduly rewarded, the individuals are likely to become lazy and lose agricultural productivity (Ogra and Badola 2008). In addition, if the scheme is too lucrative it will attract outsiders to settle near wildlife parks, which is an undesirable outcome. Therefore, the package should be such that it would not be viewed as free meal.

Free from corruption: The scheme should not leave any possible ways by which one individual can favour someone and gets bribed for it. The current need of validating damage claim is open for bribe driven favour. If the subjectivity in damage estimation is eliminated, and there are built in validation and crosschecking methods that do not depend upon a single person's judgment or certification, corruption can be arrested.

Behaviourally sound: If a system is designed based on the assumption that every individual is selfish, it is likely to work better than a system that assumes honesty or tries to impose it by policing. The design of the system should lead to a situation where "If everyone behaves selfishly there will be honesty and justice!!" If being honest is the most profitable strategy for any individual in the chain, corruption can be completely eliminated.

Minimum demand on personnel: The package should require minimal policing, validation and paper work by the park management. If the entire system is based on and operated by the local community, there would be minimum manpower demand on the park management.

Avoid 'your animal syndrome' and increase local community support to conservation: The package should avoid the psychological division between the victim and the compensator and the perception that the two have conflicting interests. If conflicts over compensation claims and the need for validation or negotiations are completely eliminated the psychological divide can be substantially reduced.

Sensitive to changing ecology: A number of variables including animal population densities, habituation to human presence, preferred crop species, their market values etc. change with time. The system should accommodate these changes naturally without any need to change legislation or implementation procedures.

THE PROPOSED PACKAGE OF COMPENSATION AND ITS IMPLEMENTATION

What matters for agricultural economics at any level is the net agricultural yield. The proposed package is based on the net harvest per unit area cultivated by a farmer. Since there is poor correlation between visible estimate of vegetative damage and the final grain or such other produce, it makes sense that the damage is estimated only once at the end of the season by the net produce rather than by looking at the vegetative damaged caused by herbivores from time to time during the season. The scheme is structured in such a way that the maximum benefit of the farmer community is in putting maximum efforts in agriculture and honestly reporting the yield. Both under-reporting and over-reporting of yield will cause a loss to farmers as explained below. Therefore, farmers would report honestly and based on the loss in total yield the due compensation can be calculated by an automated computerized system. The working of the proposed package will go in the following steps.

The conditions under which the scheme can work appropriately are that there is a group of farmers adjoining a protected wildlife area, who grow the same crop and share a comparable risk of depredation. The nature of the risk is such that there is high frequency of raiding with smaller one time damage. This is typically caused by small to medium sized herbivores including deer, antelopes or wild pig (Mehta, 2014). For small herbivores, the frequency of raiding can be high but the damage per raid is relatively small. In such cases, by statistical principles stochasticity becomes less important and farmers' efforts and alertness are better correlated to the net produce. For implementation of the scheme, farmers exposed to comparable risks form a cooperative group. Since the risk can be different for different distances (Geisser and Reyer 2004; Cai et al. 2008; Nath et al. 2015) and across geographic barriers such as rivers, the risk zones will have to be identified using local knowledge. Farmers in one group should belong to the same risk zone. For example, all farms within 1 km of a park can make one zone. 2 to 3 km may be another zone etc. The local geography and land use pattern needs to be considered while making such zones. Errors in risk level assessment while making such zones can be rectified later as described below. Since all farms in a group share similar levels of risk, the difference in damage would partly reflect the efforts and alertness of the farmer and partly the stochastic elements.

Out of the N farms in a group a random selection of 2-3 farms would be carefully fenced to prevent entry of the protected crop raider species. The nature of fencing will depend upon the damage causing species. The fencing expenditure is borne by the park authority. The fence would have a long life and can be used for many years with some maintenance if and when needed. These farms form the control group which is to be cultivated by the respective farmers with maximum care and intensity. Since these farms are protected from depredation, farmers are expected to have improved motivation for putting greater investment and efforts. Also getting maximum produce from control farms is beneficial for the entire community as described below. Therefore, there will be social pressure on these farmers to give maximum inputs. However, since these farmers are offered good protection, they will not get any other benefits of the compensation package.

All other farmers will leave their farms unfenced but are allowed to guard them by non-destructive means such as shouting, chasing away animals, scare devices etc. but destructive means such as fire arms, traps or poisons will be strictly banned. Such legislation already exists in most areas.

All farmers cultivate their farms through one cropping season. At harvest, the total yield of each farm per unit area is self-reported by each farmer and verified/endorsed by 4 other randomly chosen farmers from the group. The yield in the control farms is measured by the farmer and verified by 4 other randomly chosen farmers and an appropriate park official. The official at the most needs to examine the control plots and 2-3 additional randomly chosen non-fenced farms as a minimum necessary validation. The reported yield on all other farms need not be verified as the system encourages honesty and punishes cheaters as described below.

Calculation of compensation

After collecting harvest data from all farms in the group, the compensation is calculated as

X_{avg} = average yield per unit area of fenced control farms.

Y_{avg} = average yield per unit area of unfenced farms.

Y_i = i^{th} farmer's yield.

Compensation for the i^{th} farmer= $\left(\frac{X_{avg} - Y_{avg}}{Y_{avg}} \right) Y_i$

Compensation may be calculated and paid by to individual farmers by an automated software to avoid any personal favour.

After every 3 to 5 years the zones can be reorganized according to reported yields. For example if someone consistently reports yields substantially higher than the average for his group he will be shifted to lower risk group and vice-versa.

The implementation of the package can be undertaken by the park management itself or be entrusted to other agencies like cooperative banks or other local organizations that have a money handling infrastructure. All transactions should be done through such organizations so that all records are maintained and data get accumulated in long term.

Why the model is smart enough to prevent corruption and offer realistic compensation

The compensation package is designed using some of the principles of a mathematical theory in behavioural economics called "game theory". Game theory is a theory of human behaviour in the economic context. The theory assumes that every player in a game is selfish and will try to maximize his own benefit (Neumann and Morgensern 1944). If a system is designed in such a way that selfishness leads to honesty, such a system can function to be practically corruption free and with no need for policing. Since the compensation is based on the proportionate difference between control and average farms it gives full compensation on the damage on an average. However, it will not encourage laziness, carelessness or deliberate under-reporting of yield for the following reasons.

Those who invest more in agricultural practices and guard better get a better yield and since the compensation is proportionate to individual yields, they will get a greater share of compensation as well. Those who do not invest efforts and care for the crops will get low yield and proportionately lower share of the compensation. Thus, lazy or careless farmers are doubly punished. On the other hand, the requirement for endorsement by other farmers will not allow individual farmers to over-report yield to claim greater share of compensation. Any person showing higher yields reduces the average difference and thereby the total compensation amount. This is against the interest of the entire group. Therefore, the endorsing farmers should not allow anyone to over-report. Because of the conflicting interests of individuals versus the group there will be social pressure on individuals against over-reporting.

Whether the mutually contradicting selfish interests are likely to reinforce honesty in the system and whether any smart selfish strategies can take undue benefits of the system are examined below.

Possible smarter means of defying the system to extract more money

There are 3 potential ways of defying the system but counteracting measures are already built in the system and can be effectively enforced with minimum efforts.

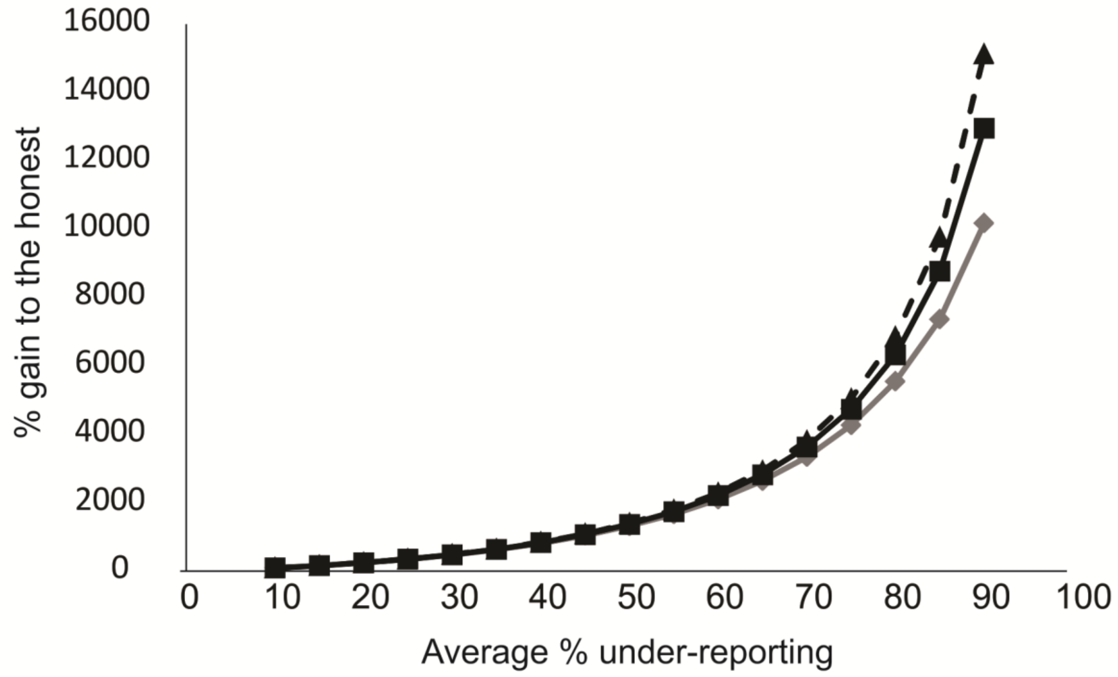
If the control yield is over-reported, everyone will get a greater than due compensation. This can be prevented by appointing an inspecting official of the park whose presence is mandatory for recording the control yield. Even if it is assumed that the inspecting officer is corrupt and can be bribed, there are multiple additional counter measures. The control yield can be compared to that in the agriculture data collection systems. For example, in India there are '*annewari*' or '*paisewari*' records for each district which document the percentage of average agriculture output for each district in a given season (Samra 2004; NABARD 2014). In addition, the maximum yield per unit area of any given crop is found in agricultural literature. The control yields cannot exceed these. Therefore, an exaggerated reporting of the control yield can be easily detected. Variation in average yield due to drought or other causes is accounted for in the control. Therefore, these losses will not be covered in the wildlife damage compensation calculation.

Even though over-reporting the control is possible there are two major hurdles in over-reporting. One is that the control farm owner has no benefit in over-reporting and the other is that the control produce is to be validated by a competent authority. If the validating authority is to be bribed, there is a problem in the stability of this type of bribery. Since the benefit of over-reporting is a community benefit the question is who pays the bribe. Everyone should contribute equally to bribe the inspecting person. However, such a system is open to free riding. An individual that does not contribute can still share the benefit of control over-reporting and therefore such a system is difficult to be stable. Also, since the compensation amount is a function of individual yield, everyone is not benefited to the same extent. Therefore, why should everyone contribute equally to the bribe? It is also not possible to contribute in proportion of the benefit since the benefit gets calculated after the control reporting and therefore the necessary data for proportionate contribution is not present at this time. All these factors make over-reporting of control yield highly unlikely.

If a group of farmers cooperates in such a way that everyone shows a lower yield in the same proportion, for example 20% each, then everyone will be overcompensated. This type of cooperation is inherently unstable because a single individual refusing to do so will get a disproportionately higher benefit, which is sufficient to break down the cooperation. Numerical simulations show (Figure 7.1) that when everyone cheats cooperatively by underreporting, the benefit to an honest individual increases exponentially with the extent of underreporting by the community. As the reward for honesty is huge and the benefit of cheating is marginal, cooperative underreporting is unlikely to be stable.

Also verification of just one or a few farms in the entire group by the park authorities is sufficient to break down the cooperative cheating since individuals whose farms have undergone such inspection will be reported factually and thereby will get disproportionately greater compensation. If honesty gives greater benefits, cooperative cheating is unlikely to sustain.

Figure 7.1: The benefits of honesty in a cooperatively underreporting group: Numerical simulations with group sizes 25(line with diamonds), 50(line with squares), and 100(line with triangles) and mean damage 50% show that an honest defector gets disproportionately large rewards that increase exponentially with the extent of underreporting. The reward increases with group size.



If the community reports honestly and one individual over-reports, he will get a disproportionately higher benefit. However, he will have to get endorsement from 4 other farmers which are members of the group that suffers a loss. For avoiding group loss, which is their individual loss too, the endorsing farmers should prevent over-reporting. In order to get their endorsement, the cheater will have to bribe them with amounts greater than the mean group loss. If the endorsers realize that the benefit to the cheater critically depends on their endorsement they may even demand more. This is an ultimatum game like situation where people are shown to give “fair” offers most frequently (Thaler 1988). If there are n endorsers, the possible extra profit will be shared amongst n + 1 individuals. This leads to two possible situations, in both of which the cheater is at a loss in the long run.

The endorsers demand the bribe in advance, which is a very likely situation. Since at this stage the average yield is not yet calculated, the cheater will have to use an estimated gain of cheating to optimize the bribery amount. However, the endorsers are farmers themselves and once they realize that this trick might increase their compensation too they will try to over-report their yields too by bribing their endorsers. This is a chain reaction by which the average difference will go on reducing so that the actual benefit to the cheater is substantially smaller than the estimated one on which bribery amount was decided. Thus the first cheater is likely to incur a net loss if the bribery amount turns to be greater than the net compensation obtained.

The second option is that the endorsers are only given a promise to share the benefit of cheating after getting the compensation amount. This can save the direct loss to the cheater as above. However, since the bribery is only promised at the time of endorsement, another channel for cheating is opened up in which the promised amount is not given. As a result a large proportion of farmers will over-report. This over-reporting will blow up the average so that at some stage the numerator in the compensation calculation formula becomes negative. This is a form of automated penalty and it can be seen that at this stage individuals that blow up their yields more will attract greater penalty. Thus although cheating by over-reporting may have short term benefits to individuals, ultimately the system punishes the cheaters proportionate to the extent of cheating.

An additional measure against this type of cheating comes during the periodic rezoning. Individuals that consistently report higher yields or little loss automatically move to the low risk zone during reorganization of zones. Since the average difference in this zone is small, they reduce their benefit in the long run. This is an additional discouragement to over-reporting.

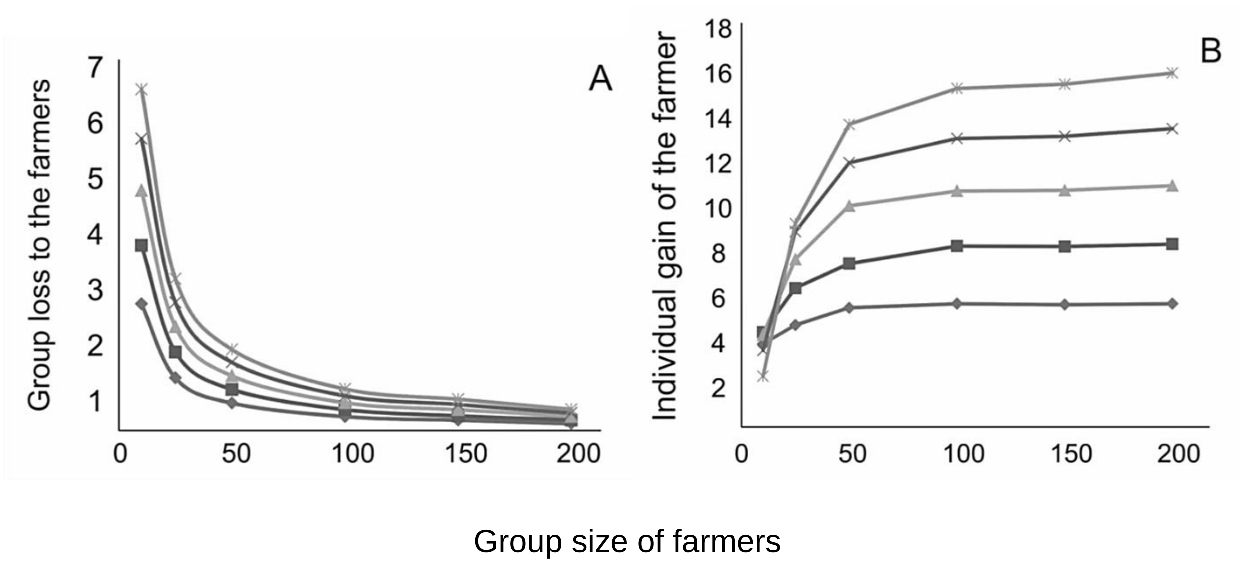
Optimizing group size

The relationship between individual gain by over-reporting and corresponding group loss is a function of group size (Figure 7.2A and B). Cooperation is easier in a smaller group since individual recognition, reputation and retaliation can play a major role. These cooperation-boosting measures become weaker as the group size increases. Also the reward to an honest defector is smaller in smaller groups. Therefore cheating by cooperative underreporting is more likely in small groups and will be increasingly unstable with larger group sizes. On the other hand, if the group size is large, group loss from a single over-reporting is smaller (Figure 7.2A). Therefore motivation for the endorsing farmers to prevent over-reporting could be proportionately less. Simultaneously individual over-reporting will be more beneficial with larger group sizes although this increase is in a saturation curve (Figure 7.2B). As a result the temptation for over-reporting is likely to be more common with increasing group size. Thus, there will be an optimum group size that would minimize cheating of both the types. The precise optimum could vary based upon local conditions including the market value of the crop, extent of damage, cultural norms and the cooperative nature of the society.

Figure 7.2: Effects of individual over-reporting with varying group sizes: Results of numerical simulations with mean loss of 50%. Different curves show different extent of over-reporting expressed as percentage of actual yield.

(A) Curve showing decrease in group loss with increase in group size at different percent of over-reporting [10 (diamonds), 15 (squares), 20 (triangles), 25 (crosses), 30(stars)]

(B) Curve showing increase in individual gain of the over-reporter with group size. [10 (diamonds), 15 (squares), 20 (triangles), 25 (crosses), 30 (stars)]



Characteristics of the model which will fulfil the expectations of an ideal compensation package

Fairness: Since reporting the produce honestly is the only stable beneficial strategy, realistic reporting is ensured. If the reporting is realistic, the compensation covers the entire loss on an average. One possible objection to the compensation formula is that if the difference in losses between farms is due to different raiding risks then the once raided more will get lesser yield as well as lesser compensation. The model assumes that variation in loss within a group is stochastic and therefore will average out eventually. For smaller herbivores with high frequency and small damage per visit, this is most likely to happen within a given season itself. For larger herbivores effective averaging might happen over a few seasons. If the variation in damage is non-random and some farms are genuinely at a higher risk, they would consistently show departure from the average based on which they would get regrouped during the periodic rezoning. As they are shifted to the high risk groups their compensation will increase automatically. Therefore in the long run the system offers justice to all.

No free meal: The proposed scheme is unlikely to make the farmers lazy and disinvest from agriculture. Uncertainty in returns is a strong discouragement in investment and efforts in agriculture (Watve et al. 2016b). With realistic compensation the uncertainty would be reduced substantially and the farmers would have a greater motivation to increase the investment and efforts. Also since the compensation is directly proportional to individual produce, there is a direct reward for greater investment and efforts. Therefore we expect the farming efforts to go up rather than go down with this compensation package.

Free from corruption: We have discussed above the possible ways of getting undue benefit by bribing someone and how all these ways are inherently unsustainable. Therefore we do not see any scope for corruption in the system.

Behaviourally sound: The system is designed based on the assumption that every individual is selfish. Since maximum long term selfishness lies in honesty, there is little need for policing to ensure smooth running of the system.

Minimum demand on personnel: It follows from the above statement that if the need for policing and verification is brought to a minimum the personnel demand on the management also comes down to a minimum.

Avoiding your animal syndrome: The compensation package is based on community self-reporting and deriving the benefits from an automated smoothly operating system with no face to face conflict or negotiations. This is likely to increase harmony and reduce the psychological divide between the victims of damage and the compensators. Human-wildlife conflict may give way to human-wildlife coexistence since the severity of conflict is expected to reduce substantially.

Sensitive to changing ecology: Changes in predominant crop species and their market values are accommodated in the calculations naturally. The risk zones can change with animal populations and their habituation and other behavioural changes. This can be taken care of during rezoning. Since the rezoning can be based on past few years' yield records, subjectivity can be minimized or eliminated from the rezoning procedure. Thus the main expected ecological changes can be easily accommodated in the system.

Other possible advantages of the compensation scheme

If the proposed scheme is implemented for and restricted to areas with a park status, farmers where there is significant animal population and therefore substantial crop damage will demand a park status on their own. At least the resistance of local people to park status, which is common in many areas, would reduce considerably (Badola 1998; Vijayan and Pati 2002; Ogra and Badola 2008; Karanth 2012).

In the proposed scheme damage estimation and its validation is intrinsically reliable. Therefore reliable data will keep on accumulating automatically.

In some areas wild animals are at least partially dependent on the crops for nutrition (Jhala 1993; Chiyo et al. 2011; Mehta 2014). The proposed scheme does not exclude animals from crop raiding and people's tolerance is expected to increase which would benefit wild herbivores, particularly Rare Endangered and Threatened (RET) species.

The scheme will exert a large financial burden on the park management. However it should be realized that this is the realistic cost of maintaining parks which was being overlooked so far. Although the cost would be high, since the package is expected to mobilize greater support from local people, policing for protection may become much less important. Poachers' support base among unhappy local people is likely to deteriorate rapidly which would ultimately serve the conservation purpose better.

Conditions where the system may fail to work

This system is perhaps not appropriate to use when animals like elephants damage farms. In such cases individual farmers would be unable to drive away the raiding animals and doing so is risky too (Nepal and Weber 1995). Also, if the frequency of raiding is low but the damage in one night is large, which is typical of elephants (Sukumar 1990), the scheme may suffer from serious statistical problems where stochasticity rather than farmer's alertness will be the major determinant of the total damage. In such cases averaging out of the damage is much more difficult and there would be injustice to some of the farmers.

The system is based on the assumption that individual farmers are free to take decisions and maximize their net benefits. If in any area individual decisions are under pressure due to terrorism, non-democratic political dominance and such factors, the system cannot ensure fairness. If a powerful landlord or a dominant lobby can coercively manipulate farmers, the system can be taken for a ride by the power holders (Ogra and Badola 2008). In a democratically run social organization with sufficient individual freedom the system can run in its full efficiency.

In an era where the pros and cons of the two philosophies of conservation namely people's displacement and enforced protection versus community based conservation are being debated (Zhang 2003; Berkes 2007; Agrawal and Gibson 2001), a community operated system of justice such as the one suggested here is likely to bring harmony and peaceful coexistence of people and wildlife.

HOW THE SYSTEM MIGHT WORK IN THE STUDY AREA: AN EXAMPLE

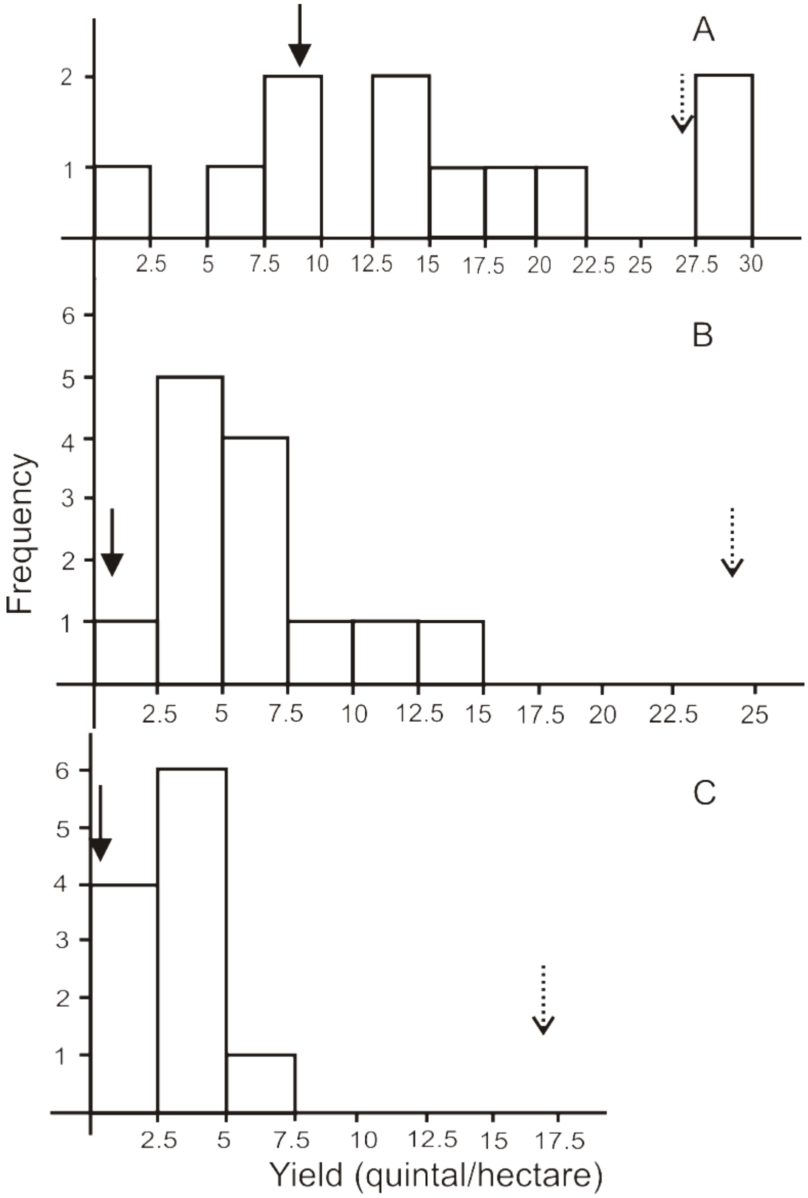
The need for alternative compensation scheme was realized during this study when we found that the compensation currently being paid is a tiny fraction of the actual loss estimated using six different approaches for damage assessment. I will illustrate here the calculation of compensation based on that data using the principles above and contrast it with the compensations actually paid to farmers in the area in the same season. The data on yields of rice and wheat comes from fields lying along three transect lines radiating from the park boundary. In this area the ecotone is rather sharp and there is no forest cover on the western side of the park boundary. Therefore the risk linearly decreases with distance along the transect lines going away from the park boundary. I take the first one kilometre on the transect lines to represent a comparable risk zone as suggested by the transect data.

In 2013-14 and 2014-15 an experimental comparison of yields in neighbouring fenced and non-fenced (and non-guarded) areas was done as one of the methods of assessing the extent of damage. Data from the fenced area can be used as the protected control (X_{avg}) of our model. Although the group size in this example is rather small, it can be used to illustrate the difference the proposed scheme makes. Figure 7.3 illustrates the frequency distribution of normalized per Hectare yields of farms in the sample along with the protected and unprotected controls for Rice in kharif season of 2013 and wheat in rabi seasons of 2013-14 and 2014-15. Rice in 2014 was badly affected by untimely rains followed by a disease therefore data for this year was not available. The following rabi was a bad season for wheat also but the crop did not fail completely. The calculations show that this loss is automatically discounted in the compensation calculation so that compensation becomes specific for herbivory damage. For all the three sets of results it can be noted that the unprotected control that was neither fenced nor guarded yielded the minimum. In the case of wheat in both seasons the unprotected farms were completely devoured. In the case of rice the unprotected control yielded non-zero amount and there were one or two farms with yields less than it. All farms by farmers who actively did night time guarding had yields somewhere between the protected and unprotected controls except two that were marginally above the protected control. This finding is compatible with the model assumption that yield is a function of guarding efforts. The calculated damage compensations are as follows.

For rice in 2013, a control plot yielded 26.07 Q/Ha (maximum yield having zero damage) and the average for 9 other farms was 15.67 Q/Ha, as a result the percent compensation was calculated to be 66.33 % over each farmer's yield. By the current market value the average compensation due per farmer was ₹ 17,523. For wheat in 2013-14 the protected control yielded 24.88 Q/Ha, the average of 13 others was 3.99 Q/Ha indicating substantial loss. As a result the percentage compensation due was 523.5 % and the average compensation due per farmers was ₹ 40,349. In 2014-15 wheat yield was lower throughout the area when the protected control yielded 16.48 Q/Ha, the average was 1.25 Q/Ha so that the percent compensation due was 1218.4%. Interestingly, in spite of every farmer's yield being lower and the percent compensation due being higher, the average compensation due per farmer was substantially lower than the previous year (₹ 23,260). This is because the main reason of crop loss this year was more climatic than herbivore related. This illustrates that the scheme could differentiate between different causes of loss and specifically focuses on herbivore loss. The average compensation per farmer calculated for all three crop seasons contrasts with the amounts actually paid by the government to farmers in these two year in the entire buffer zone of TATR. Only a small proportion of farmers (estimated at <1 %) were paid compensation and among those that were paid, the average per farmer was ₹ 4,244. This is compatible with the inference of the study that the current compensation scheme grossly underestimates damage.

Figure 7.3: The frequency distribution of farmers' yield in comparison with protected (dotted arrows) and unprotected controls (solid arrows): A. Rice in 2013; B. Wheat in 2013-14 and C. Wheat in 2014-15. All yields expressed as Q/Ha

(See figure on next page)



The above data on yield was collected from farmers who were not aware of the compensation scheme suggested by us. Therefore they are unlikely to have manipulated the yields for increasing their gains. Also about one fourth of the claimed yield was verified by research personnel on inspection based on the count of bags or the market price actually obtained.

CONCLUSION AND FUTURE PERSPECTIVES

This is the first comprehensive study of crop depredation involving multiple first-hand measurements of damage, aspects of herbivore behaviour, mathematical modelling of farmers as well as herbivores' optimal strategies, along with suggestion of an alternative damage compensation scheme. The main outcomes of this study are as follows:

(1) Communication with farmers revealed that crop-raiding by wild pigs and nilgai is their main livelihood problem, whereas livestock depredation by carnivores was not seen as a major problem. Although law enables compensation for both livestock depredation and crop damage by wild animals, people are satisfied with the former but not the latter. This suggests that it is not a general dissatisfaction or complaining nature of people, but some specific problem with the crop damage compensation procedure that is the cause of resentment.

(2) Measurements of crop damage by wild herbivores done using multiple methods revealed that the damage recorded during the last five years by government is a gross underestimate of actual damage. Further, visual vegetative estimates of damage were uncorrelated to the actual deficit in grain yield. Visual estimates made by different individuals were also substantially different. Therefore, the study raises questions about the reliability and validity of currently used damage estimation and compensation methods.

(3) The grain yields per unit area increased monotonically with distance from forest boundary for most of the crops under study. Yields close to the forest were also on an average half that of yields at a distance of 5-6 km. Experiments with fenced and unfenced plots, demonstrated that the difference was mainly contributed by herbivore damage.

(4) Artificial damage experiments demonstrated that through most of the crop period, plants show vegetative regrowth after damage. However, they have to pay a cost in terms of seed number. For all the three crop species examined, the regenerated plants had significantly lower seed numbers compared to control plants. This has an important implication that because of vegetative regrowth one cannot quantify the amount of

damage by visual inspection of damaged farms. And this is one of the reasons why visual vegetative damage estimates do not correlate well with actual loss.

(5) Nilgai showed a substantial difference in its herding and foraging behaviour between feeding on natural vegetation versus cultivated crops. They showed significant decrease in herd size while foraging on agricultural lands compared to forest. Most importantly, individuals showed significant increase in vigilance frequency and decrease in unit scan duration while foraging on crops. This suits well the difference in the nature of risk and accordingly better vigilance strategies in each of the habitats. This can be treated as evidence in support of contextual plasticity in vigilance behaviour in order to optimize foraging strategies.

(6) Assuming that both farmers and herbivores optimize their cost benefits in response to each other, we model the optimum behavioural strategies for both. We show that in sustenance agriculture, a farmer needs to optimize net benefit rather than benefit to cost ratio whereas herbivores need to optimize the benefit to cost ratio. The strategies for optimizing the net benefit are substantially different from those for optimizing benefit to cost ratio. Farmers' optimization shows that when threatened by depredation, farmers should disinvest from intensive agriculture. The model result resonates well with farmers' practice.

(7) Foraging optimization for herbivores showed that mitigation measures that are highly successful in deterring herbivores on an experimental scale are most likely to fail when used on a mass scale. Further, the effectiveness of mitigation measures such as fencing, trenching, culling will be nonlinear, being highly effective only beyond a threshold, below which some of them can be counterproductive.

(8) A model for assessing and compensating for herbivore damage is suggested. Realistic damage compensation can alter the behaviour of farmers towards agriculture as well as towards wildlife conservation, and the alternative compensation model suggested in this study can serve the purpose. As it is based on actual deficit in grain yield, it can do justice to farmers. The suggested procedure is community operated and the foundation of behavioural economics of the model ensures that farmers' self-reported yield will be honest. Both under-reporting and over-reporting leads to losses farmers and honesty is the only profitable strategy in the scheme. This can substantially reduce the need for

inspection, validation of the damage claims and make the entire procedure smooth for operation.

The methods standardized and principles emerged out of this study can be used in different conflicting areas in the state, country and beyond. The optimization models developed in this study should find a more general applicability across different habitats and species. The models can be modified according to specific needs of a habitat or species and used with empirical data to estimate the parameters. The alternative compensation model suggested here is an important conceptual novelty. So far there are few examples of successful implementation of any of the principles of behavioural economics towards designing robust management systems. This system has a potential of developing into one. The appropriate path to do so would consist of pilot implementation in one area. Through a pilot implementation it would be possible to build up the implementational and legal details, learn from experience and improve upon the protocols, build the necessary software and other infrastructure. A stepwise scale up can help avoid major mistakes in implementation and such an approach is likely to give a long term solution for just and peaceful co-existence of people and wild life.

At a more fundamental level a number of basic questions remain unanswered. Out of a large diversity of herbivore species a few species such as nilgai, wild pig and elephant are the main species of crop raiders. Within a species not all populations are equally troublesome. It is necessary to understand what makes some species, some populations and even some individuals notorious crop raiders. A good multidimensional understanding of the ecology of crop-raiding species is necessary. I could not address such ecological questions extensively because of restricted work permits. I took a ‘farm-centred’ approach for data collection. The other possibility is to take an ‘animal-centred’ approach to follow and study identified groups of raiders in the forest and agricultural lands to understand their nutritional ecology and behavioural preferences. This is likely to increase our understanding of the other side of the coin.

In any case it is only a beginning of a true understanding of the human-herbivore conflict and more insightful work is needed to understand the problem and find context specific practical and effective solutions that would make coexistence of human and wild herbivore populations peaceful and smooth.

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Appendix-1

Questionnaire base for farmers' interviews for crop-raiding

1. Name of Farmer:
2. Village:
3. Geological position of farm:

Height (msl)	Latitude	Longitude

4. Total Area of Farm:

Area under cultivation: Uncultivated land:

Other use:

5. Distance of Farm from Forest (km):
6. Type of farming: Rain-fed/Irrigated
7. Type of soil (local classification):
8. Crop species:

Crop	Area under cultivation	Season (kharif or rabi)	Average Grain yield	Crop raiding species, if any

9. Irrigation facility: present/absent

Type of irrigation	Distance of source from farm	Whether animals visit this water source	Which species are seen
Stream/ Canal/ Well/ Lake		Yes/No	

10. Use of Fertilizer: Chemical/ Organic/ both.

Types of manure/fertilizer used

11. Use of Pesticides:

12. Crop raiding: List of animal species in decreasing order of menace

Order	Animal species	Individual or herd	Male /Female	Adult/young ones	Preferred crop	Preferred Crop stage	Time of raid
1							
2							
3							
4							

13. How much area animals may eat in one night:

14. How many times animals come to farm in a week:

Guarding measures:

Fence	Type of Fence	For which crop	Cost of fence	Whether perceived useful
Yes/no				Yes/No

Machan	Number	Type	Cost of machan	Whether perceived useful
Yes/No				Yes/No

Other guarding measures (if any):

15. How much loss do you face due to herbivory:

Crop	Approx % loss

16. Are you aware that there is a crop damage compensation scheme by the government?
17. Do you know the procedure to file a compensation claim?
18. Have you claimed compensation so far?
19. If yes, what do you think was the actual loss? How much compensation you were paid?
20. If not, Reasons for not claiming compensation:

Appendix-2

Questionnaire base for farmers' interviews for carnivore-human conflict

21. Name of Farmer:
22. Village:
23. Geographical position of farm:

Height (msl)	Latitude	Longitude

24. Distance of farm from forest (km):
25. Distance of village from forest (km):
26. Type of farming: Rain-fed/Irrigated:
27. Annual income:

Agriculture:	Livestock:
Labour Work:	Other (if any):

28. Livestock species:

Livestock	Age	Sex	Number	Traditionally obtained/purchased	Purchase price (If purchased)	General expenses per annum (grazing/labour/maintenance etc.)
Cattle						
Buffalo						
Goat						
Sheep						
Dog						
Other						

29. Livestock grazing:

Season	Grazing starts at (time)	Grazing ends at (time)	Grazing ground (name of place/area)
Summer			
Monsoon			
Winter			

30. Protection/guarding of livestock at residence/village:

    Personal cattleshade/common cattleshade of village/other

31. Protection/guarding of livestock at grazing grounds:

    Manual guarding (vigilance)/watchdog/other

32. Awareness of large carnivore presence at the grazing ground : Yes/No

    If yes, which species: Tiger/Leopard/Dhole/Sloth Bear.

33. Is any of your livestock killed by wild carnivore in last 5 years?

    If yes,
    When (date):
    Which livestock species:
    How many:
    Which carnivore species killed it:
    Where was livestock killed: Grazing ground (name of area)/village.
    Carcass retrieved or not:
    What did you do with carcass after claim (left for the predator/burnt/buried/taken away to village for consumption)
    Did you claim compensation:
    How much amount obtained:

34. How frequently do you see carnivore near village and which species
35. How frequently do you see carnivore near grazing ground, which species
36. Are you ever attacked by any carnivore

    If yes, which species and where (name of place/area)

37. How do you protect yourself if carnivore attacks you or livestock
38. If carnivores are nuisance: yes/no.
39. Which animal is the most dangerous
    Do you go for firewood collection, If yes,
    How many times a week
    How many hours do you spend in forest collecting firewood
    How much amount (kg)
    What is the other source of fuel (LPG/gobar gas/other).
40. Meat consumption per week, per capita (kg), which species (goat/sheep/fowl/other):

Appendix-3

Datasheet for livestock kills

1. Date of interview:
2. Date of claim:
3. Name of livestock owner:
   Village:
4. Name of livestock herder:
   Village:
5. Time (approx.) of kill:
6. Place (name):
7. Place (GPS co-ordinate):
8. Species killed:
   Age:
   Sex:
9. Market price of the livestock killed:
10. Carcass retrieved or not:
11. If retrieved, description of markings on body: teeth/ claws/ others
12. How much part of livestock was eaten when carcass was retrieved?
13. Suspected carnivore species: Tiger/Leopard/Sloth bear/Dhole/Other
14. Details of carnivores (if seen):
    Number of individuals:
    Age:
    Sex:
15. Whether the carnivore is photographed: Yes/No.
    If yes, then manually/camera trap.
16. Specific id of carnivore (in case of tiger and leopard), if photographed:
17. Whether eaten at the place of kill/dragged away:
18. If dragged away, GPS co-ordinate of place:
19. Awareness about carnivore’s presence at the place of kill: Yes/No.
20. Whether carnivore was deterred/chased away from the carcass: Yes/no.

21. Whether carnivore returned back to carcass after being chased away: Yes/No.
22. Whether claimed for compensation: Yes/No.
    If yes, how much amount is assured?
    When do you expect the compensation amount will be paid?
23. Carcass burnt/buried/taken away from the place/let for carnivore to eat
24. Scavenger species (if any):
25. Remarks (if any):