


GOKHALE INSTITUTE OF POLITICS AND ECONOMICS, PUNE

Centre for Sustainable Development

# HUMAN WILDLIFE CONFLICTS

## An Estimation of Net Agricultural Losses in Maharashtra

JULY 2025



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Prepared by

Centre for Sustainable Development,
Gokhale Institute of Politics and Economics, Pune

**The Gokhale Institute of Politics and Economics** was established in 1930 by the Servants of India Society. It is the oldest research and training institute in economics in the country, dedicated to research in socio-economic dimensions of Indian society. It is deemed to be a university.

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## List of abbreviations

| ABBREVIATION | FULL FORM |
|---|---|
| **APMC** | Agricultural Produce Market Committee |
| **CACP** | Commission for Agricultural Costs and Prices |
| **CCEA** | Cabinet Committee on Economic Affairs |
| **CR** | Crore |
| **DIST.** | District |
| **ECO-ECONOGRAPHY** | Ecological-Economic Geography |
| **GDP** | Gross Domestic Product |
| **GR** | Government Resolution |
| **HA** | Hectare |
| **HWC** | Human-Wildlife Conflict |
| **IUCN** | International Union for Conservation of Nature |
| **KG** | Kilogram |
| **MSP** | Minimum Support Price |
| **MT** | Metric Tons |
| **NTFP** | Non-Timber Forest Produce |
| **PAS** | Protected Areas |
| **PCCF** | Principal Chief Conservator of Forests |
| **PMFBY** | Pradhan Mantri Fasal Bima Yojana |
| **RS** | Indian Rupees |
| **RTS** | Right to Services Act |
| **SPPU** | Savitribai Phule Pune University |
| **SQ KM** | Square Kilometre |
| **SUR** | Support cum Reward Method |
| **TATR** | Tadoba-Andhari Tiger Reserve |

# 1. Executive Summary

Over the last one year the Centre for Sustainable Development has been studying the problem, make estimates of the enormity of the problem and set out the steps for further action. Our study of crop damages by wild animals focuses specifically on the economic losses suffered by farmers due to wild herbivores. For the first time, we include visible and invisible damages, and the direct and indirect costs incurred by the farmers. While human attacks by carnivores, particularly tigers, receive significant media attention, the widespread damage caused by herbivores like wild pig, nilgai, and macaques is often understudied. Our study shows that this conflict is not limited to protected areas (PAs), as many species inhabit areas outside of them.

Improving agricultural productivity in forest villages is seen as key to reducing farmers' dependence on forests and minimizing dangerous wildlife encounters. However, farming in these areas is threatened by crop damage, that has led to farmers abandoning farming. This further increases HWC. Despite various mitigation measures attempted globally and in India, the **extent of the problem quantitatively and the specific reasons for crop raiding by wild animals remain understudies**.

The problem is aggravated by the historical philosophy of conservation in India that isolated wildlife from humans. This approach, described as a "do nothing and do not allow to do anything" framework, has led to a neglect of the inevitable human-wildlife interaction. Neither wildlife researchers nor agricultural scientists have seriously addressed the issue of quantifying crop damage.

The **practical definition of agricultural loss due to wildlife** is the difference between the net agricultural income with and without the presence of damage-causing animals. This includes increased costs like fencing. Compensation based on costs incurred before damage is not fair in agriculture because it does not account for seasonal delays or the loss of potential income. Furthermore, current compensation does not cover the substantial loss to the community, including farm labour and downstream stakeholders.

Prior attempts to estimate damage have limitations:

- **Farmer interviews** reflect perceptions and opinions but are not quantitatively accurate.

- **Visual estimates** miss subtle damages.
- **Compensation data** is the only state-wide data available but is highly unreliable due to lack of standardisation, farmers' lack of awareness/reluctance to claim, unprocessed cases, and compensation covering only visible damages. Studies indicate that only a small fraction of actual damage is compensated.

Based on different data sources and extrapolation methods, our study estimates the **net agricultural loss in Maharashtra state due to wildlife to be between Rs. 10,000 to 40,000 crore per year**. This figure is considered an underestimate as it doesn't include all forms of indirect losses. The time trend of damage is alarmingly increasing. Where ever there are uncertainties in the data, we have calculated very conservatively. Our estimates were based on six different approaches using data from two primary surveys, two published studies, and data sets from the Departments of Agriculture and Forest of the government of Maharashtra.

In addition, we also mention other costs borne by the community and the government that are not quantitatively estimated and included here.

Towards effective remedies, we propose the essential steps:

1. **Restructure compensation protocols** to be realistic, farmer-friendly, timely, and transparent, suggesting unconventional approaches like the Support cum Reward (SuR) method.
2. Use effective compensation protocols as a means to assess the effectiveness of any remedial measures.
3. Simultaneously initiate **fundamental research** to understand the true causes of crop damage, develop long-term mitigation measures based on these causes, design a long-term policy for coexistence, and create a practical, cost-effective, data-generating, self-correcting management system.

We stress the need for effective long-term solutions that reconsider conservation policies. We reiterate that this is not an economics vs. ecology conflict, as the two must complement each other for sound conservation in the Indian context, where humans and wilderness coexist.

# 2. Introduction

## 2.1 The imperative to address Farmer-Herbivore Conflicts

In India, human-wildlife conflict (HWC) has become a buzzword today. There are articles, discussions, and debates around this subject. The increased attention is due to the alarming increase in human attacks by carnivores, particularly tigers around the protected areas. Carnivore attacks attract media attention undoubtedly because of loss of human life, but also partly because tigers are a charismatic species. While human attacks by tigers is a serious issue for conservation biology, an equally or more serious issue is the economic loss suffered by farmers in areas inhabited by wild herbivores. Herbivores such as wild pig, nilgai or macaques are not as glamorous as tigers and therefore conflicts involving them do not get similar attention. Areas inhabited by wild animals is not restricted to “protected areas (PAs)” because many species occupy areas outside PAs. Both their numbers and the damage they cause is understudied.

While the problem of crop damage by wild herbivores is not restricted to India and is a global concern (Graham et al 2010, Mackenzie and Ahabyona2012, Yazezew 2022, IUCN 2023), the Indian context has certain dimensions that are unique. The way wildlife conservation is handled in India is different in its philosophy, legislation as well as implementation (Pabla 2015). The focus of this document is HWC in India. We have collected data from different regions of the state of Maharashtra and hence our quantitative arguments are specifically about Maharashtra, though qualitatively they apply to every part of India.

Further, agriculture has a huge potential in the co-existence of people and wildlife. People in forest villages have diverse traditional livelihood options; most of them are directly dependent on the wilderness. This includes livelihoods that depend on hunting, grazing animals, timber, bamboo and non-timber forest produce (NTFP). Farming, on the other hand, has minimum direct dependence on wilderness. If the economy of a forest village is turned into one that is agriculture centred, people’s dependence of forests can be reduced thereby reducing the chances of dangerous wildlife encounters.

It is thus important to ensure that agricultural productivity of villages in the vicinity of wildlife is improved to such an extent that almost entire economy of the village is agriculture driven.

Diversifying agriculture to include agro-forestry of mahua, fruit trees, bamboo and fodder can make a village nearly self-sufficient with little need to encroach the protected forests. Value addition to these products is possible and a potential booster to the village economy. In contrast, currently agriculture in forest villages is seriously threatened and farmers are giving up farming, which further increases HWC. Reversing this trend is vital for long term co-existence of people and wildlife. Pilot experiments (Joshi et al 2020) have shown that it is possible to reverse this trend with a small but appropriately implemented support. This potential has not been realized by wildlife researchers and managers and we believe, a change in paradigm is required for handling HWC in all forms in India. Agriculture is the key to resolution of HWC and that needs to be a focus of management efforts.

Although a number of mitigation measures have been suggested to avoid/minimize crop damage by wild herbivores and tried on a small scale in India as well as globally (Sitati and Walpole 2005, King et al 2009, Massei et al 2010, Hoare 2012,2015, Krivek et al 2020, Karanth and Wanamamalai 2020), two fundamental questions remain unanswered. One is that we do not know the extent of the problem quantitatively and the other is that we do not fully know the reasons why wild animals raid crops. Without these answers, mitigation measures are unlikely to be effective. Even planning any action on a large scale needs a quantitative understanding of the extent of the problem. Compensating the affected farmers has been shown to help maintain a positive attitude towards conservation (Karanth et al 2018, Johnson et al 2018, Joshi et al 2020) but in absence of a realistic method to assess damage, a practical and fair compensation is not possible. For any fundamental mitigation measure the cost of the implementation has to be weighed against the damage it is likely to prevent. Whether and to what extent a mitigation measure is effective can be assessed only if there is ongoing assessment of the extent of damage. How to quantify damage is the question we address in this document.

### 2.2 Why is Crop Damage understudied?

It is long known that wild animals eat, trample and otherwise damage crops, however, how much loss of agriculture is because of wild animals, remains quantitatively unanswered. Until now there have been no attempts to make a comprehensive estimate of the net cost of wildlife to the society and to its economy. One of the reasons we do not have studies addressing this question could be that the question has not been seriously asked. The sole focus of wildlife conservation in India has been to create protected areas, and implement a complete ban on hunting. Conservation practices in India have believed that wild animals can be protected only by isolating them in areas away from humans, particularly the indigenous people. An unscientific belief that nature has always been in a state of balance and only humans are responsible to disturb this balance, has been the central philosophy of conservation. A "do nothing and do not allow to do anything" framework (Sankhala 1977) has almost entirely guided conservation policies. As pointed out by Pabla (2015) many other questions important for wildlife conservation have never been asked with a serious intention to address and solve them. Since "all humans out" has been central to wildlife conservation, the inevitable human wildlife interaction has been understudied by wildlife researchers. Buzz words such as "coexistence" have been in fashion, albeit without quantitative backing. For a real coexistence it is necessary to understand at sufficient depth, both sides of the conflict. While HWC is well discussed and covered in media, most of it is about carnivore conflict. The problem of herbivore farmer conflict does not get the same attention.

This is evident from the toolkits of wildlife researchers. While a battery of contextually appropriate methods has been developed for estimating and studying the dynamics of populations, migrations, movement patterns, breeding, social behaviour and other aspects of wildlife, there are no methods scientifically developed to estimate the crop damage because of wild animals. Failure to develop quantitative methods indicates a neglect of the problem. Other than that, there is no reason why developing methodological rigor would not be possible. Furthermore, the question why animals feed on crops has not been seriously addressed by differentially testing possible alternative hypotheses (Prabhulkar and Watve 2025).

Realistic estimates of damage have not been attempted apart from a handful of studies with a small localized focus (Jayson 2013, Bayani et al 2016). The types of damages are highly diverse, direct and indirect and there is no inventory of the types of crop damages and the animals that cause them. Even among the scanty studies, most of them employ a visual inspection method (Kumar et al 2017) that covers only the prominently visible damages, such as uprooting of trees or crops trampled flat. Damage by mega fauna such as elephant and rhinoceros get disproportionately greater attention. This is despite wild pig and nilgai causing much more damage than elephants even in elephant populated areas (Kumar et al 2017).

Table 1 illustrates that damage can take many forms and most are difficult to quantify and compensate. The current protocols of compensation cover only a handful of them. Apart from the damages directly caused by animals, there are indirect forms of damages. For example, when faced with the risk of damage by animals the behaviour of farmers also changes. They often give up farming altogether or avoid certain seasons, change the cropping patterns in a suboptimal way, hesitate to invest in better agricultural practices. This leads to substantial loss to net agricultural productivity but this is never counted as loss caused by wild animals. There are no methods to estimate the subtle and indirect damages and they do not come on record anytime. Indirect losses are never considered while compensating farmers and therefore compensation given is not a realistic estimator of actual damage. In addition, there are multiple on ground reasons why the crop damage compensation does not work realistically.

| Sr. No. | Type of damage | Crops | Animals | Visibility | Ease of measurement | Compensation coverage |
|---|---|---|---|---|---|---|
| **Agricultural crops** | | | | | | |
| **1** | Eating up seeds and sprouts after sowing | Corn, pulses, vegetables | primates, wild pig, peacocks | Poor | Very difficult | nil |
| **2** | Eating young saplings, tender branches and leaves | Almost all | Wild pig, ungulates, langurs | Medium | Somewhat difficult | Poor |
| **3** | Gnawing selectively at tips, buds, flowers, edible parts | Cereals, pulses, vegetables, cotton | Ungulates, wild pig, parakeets and other birds | Poor | Very difficult | Poor |
| **4** | Trampling flat | Cereals, pulses, vegetables, cotton | Elephant, gaur, Wild pig | Good | Relatively easy | Better |
| **5** | Completely eaten up | Cereals, pulses, vegetables | Elephants, wild pig | Good | Relatively easy | Better |

| | | | | | | |
|---|---|---|---|---|---|---|
| **6** | Chewed bases of tillers causing delayed death of tillers | Rice | Wild pig | Poor | Very difficult | poor |
| **7** | Eating up during and after harvesting, before transport | Cereals, pulses, | Wild pig and ungulates | Medium | Difficult | nil |
| **8** | Breaking into and raiding storage spaces, warehouses | Mahua, grains | Elephants | Good | Good | Not covered |
| **Horticulture** | | | | | | |
| **9** | Early damage to saplings and grafts | All fruit trees | Primates, porcupine | Good | Relatively easy | Possible but rarely covered |
| **10** | Stunted growth due to eating up young shoots at any stage of growth | All fruit trees | primates | Poor | Most difficult | Nil |
| **11** | Damage to inflorescences, flowers affecting fruit yield | All fruit trees | primates | Poor | Most difficult | Nil |
| **12** | Fruits eaten up from inside | Coconut | Bonnet macaque, giant squirrel | Medium | Possible at a later stage | Done but inadequat ely |
| **13** | Fruits eaten up or destroyed at various stages | All fruit trees | Primates, giant squirrel, large ungulates | Medium | Difficult, except for coconut | Done for coconut inadequat e |
| **14** | Uprooting tree | All fruit trees | Elephants | Good | Good | Better |
| **15** | Major branches broken | All fruit trees | Elephants, primates | Medium | Difficult | Rare |
| **Indirect losses** | | | | | | |
| **16** | Farmers having given up farming because of repeated losses | All crops and horticulture | All commonly damaging species | Good but difficult to decide cause | Possible but not done | Nil |
| **17** | Given up seasons, (e.g. rabi season not utilized even when possible) | All rabi and summer crops | All commonly damaging species | Good but difficult to decide cause | Possible but not done | Nil |
| **18** | Shifted to suboptimal crops | All crops and horticulture | All commonly damaging species | Difficult | Difficult | Nil |
| **19** | Reduced investment in intensive practices | All crops and horticulture | All commonly damaging species | Difficult | Difficult | Nil |
| **20** | Lost opportunities for agri-based value-added products | Fruits and vegetables | Primates, wild pigs, birds | Good but difficult to decide cause | Possible but not done | Nil |

***Table 1:*** *Different types of agricultural and horticultural damages caused by wild animals*

Another reason why crop damage by wild herbivores is an orphan problem is because agricultural scientists have largely disowned this problem. In their perspective this is a wildlife researchers' responsibility. It does not figure in the major concerns and research themes of agricultural universities and organizations. On the other hand, wildlife managers do not consider agricultural productivity as an important parameter in their research. Their concern is that resentment amongst farmers should not go to a point where they destroy forests or kill wildlife. Their mandate is not about ensuring agricultural productivity, or livelihood and justice to indigenous people. They look at HWC only when it threatens wildlife. As a result, no scientific account of the farmer wildlife conflict is available anywhere in the world, despite international organizations like IUCN officially intending to address the problem (IUCN 2023). Even in their recent compilation of literature and thinking in HWC, there are no estimates of damage, no account of how it affects agricultural economics or no attempt even to develop methods to study these angles.

Researchers observe that people whose livelihood is affected by wildlife conservation are more likely to support poaching (Pabla 2015) but even when this happens, the problem is addressed at the level of policing and criminalizing, not at the level of the root cause. Effectively wildlife managers disown the problem as long as they can suppress people's rights easily. They are concerned only if and when people become overtly destructive.

Therefore, this is time to start from scratch. The first step needs to be estimating the extent of the direct and indirect damage to crops since that is the most important driver of human wildlife conflict. We attempt the quantitative question first in this document which has ramified consequences which will open up a set of new and relevant questions, badly needed rethinking and novel directions of action research. Knowing the problem quantitatively will enable us to decide how badly mitigation measures are needed, which fundamental questions we need to address with priority, which assumptions need rethinking and in which direction the conservation policy needs to move.

### 2.3 Definition and Assessment of crop damages by wildlife

Before discussing the precision, accuracy and fairness of the different attempts to quantify crop damage, we need a definition for damage/loss of agricultural production. The ultimate, useful and practicable definition of loss due to wild life is the difference between the net agricultural income in the absence of wildlife versus its presence. If, in the absence of potentially damage causing wild animals a farmer's net income would have been X and, in their presence, it turns out to be Y then X – Y is the loss. If the farmer has spent money to install fencing and this has effectively prevented damage, even then, the farmer has increased the costs, which translates to lower net agricultural income. From the agricultural perspective this is the only satisfactory definition of loss.

An alternative definition of damage that has been used at times to compute compensation payment is the cost incurred before the damage event. While compensations based on costs might be appropriate for certain kinds of damages, it does not fairly compensate in the agricultural context. Suppose I am a travelling salesman using a vehicle for business, and my vehicle is destroyed in an accident due to someone else's fault; I may be compensated for the cost of the vehicle and that is fair. This is because if I am compensated immediately, I can buy a new vehicle and my business starts wherever it stopped. This does not work for farming, which is season dependent. If my crop gets destroyed during mid growth, compensating the expenses incurred does not enable me to start the process where it stopped. I have to wait for the next year's appropriate season to sow again. The loss due to delay does not get covered by paying the expense incurred. Thus, agricultural loss must to be calculated by the net deficit and delay in the income. Compensating the cost incurred is not a fair and just way of compensating.

There is also a difference between the loss to the owner and the loss to the society. A significant portion of harvesting and post-harvest processing costs comprise of labour costs. This is a crucial source of income for many landless and land-owning individuals across India. When a crop is destroyed in mid-season, not only the farmer suffers a loss, the farm labour and other downstream stakeholders also suffer substantial loss. In effect the loss to the community is much greater than the loss to the farmer alone. But the current compensation protocols do not account for this.

### 2.4 Prior attempts to estimate damage:

We reviewed reports and research articles that attempted to quantify crop damage, across different parts of the world. Here we summarise them as follows:

#### 2.4.1 Based on farmer interviews

One type of study relies on interveiws (for example, SEKHAR, N.U. 1998, Rao et al 2002, Ogra and Badola 2008, Sumitha & Shaharban, 2022). This has limited use in reflecting the mindsets, beliefs and outlooks of people qualitatively. By human nature perceptions and opinions may reflect a problem qualitatively adequately, but humans are not very good in quantitative judgments.

#### 2.4.2 Based on visual estimates

Precise primary measurements are necessary for any reliable assessment. This is attempted by some studies using visual assessment (e.g. Kumar et al 2017). However, not every type of damage is immediately visible and measurable over a large area (figure 1).

***Figure 1:*** *Visible forms of damages*

***Figure 2:*** *Damages that are difficult to quantify*

#### 2.4.3 Based on Compensation paid to farmers

Data on compensation paid to farmers is the only state wide data available. However, this data suffers from multiple limitations, flaws and biases. Different norms have been used at different times and places to calculate damage; and compensation has been paid without any standardization of the norms. We describe in a later section why compensation paid is the most unreliable and misleading source of damage data. Therefore, although the only state wide available source of data, relying on it can be grossly misleading.

#### 2.4.4 Some inclusive methods

Bayani et al (2016) used a novel approach of using convergence of multiple methods to estimate net damage and this estimate is orders of magnitude greater than compensation claimed or paid on the same set of farmers during the same time. To the best of our knowledge, this approach has not been used anywhere else so far. Joshi et al (2020) showed that when given an assurance of returns and incentive for intensive agriculture, villages close to areas with heavy damage risk can increase their productivity between 2.5 and 4 fold. This means that only 25 to 40 % of the land capacity is being utilized. In other words, there is 60 to 75 % loss. Such intensive studies are methodologically sound and inclusive of different types of damages. But they are made on very small areas.

We did not come across any study that has tried to combine intensive and extensive data to arrive at a state wide estimate.

# 3. Estimating net losses from crop damages in Maharashtra

In this study, our approach is to estimate the net agricultural loss due to wild life in Maharashtra State. For this, we are guided by the definition of loss stated in section 1.2. We acknowledge that this is not an easy task, as there are many gaps in the data as of now.

Agriculture is a complex activity, with several factors that can affect the output. Thus, there is no single reliable way to collect appropriate data. As we pose our question for the entire state of Maharashtra, there are bound to be several data gaps. In order to be able to draw reasonable inferences from the inherently incomplete data we take two approaches. First is to use Fermi estimates to reasonably accommodate the data gaps. The second is to take multiple approaches using different data sources. Different data sources have different biases and limitations. Therefore, any of these methods in isolation may not be considered robust. However, if multiple approaches using different data sources converge on similar conclusions, they can be considered robust.

We will now describe the different data sources used, their known and potential biases and limitations, evaluation of their reliability and ultimately their contribution to answer our main question. For brevity and convenience of the reader we briefly summarize the underlying studies below, the detailed methodology and results of the original studies are available in the form of Annexure 1 to 6.

### 3.1 Based on data of compensation paid to farmers

In some states of India there are laws that enable farmers to be compensated for damage to their crops by wild animals. Agriculture being a state subject, each state has its own protocols of registering complaints, examining and paying compensation claims. In the state of Maharashtra, it has the status of a law and is included in the Right to Service (RTS) Act of 2015. This means that getting compensated for crops destroyed by wild animals is recognized as a legal right of farmers.

Data on the number of claims of compensation, and the amounts paid may be expected to reflect some trends and patterns in crop damage by wild life. However, this picture is incomplete owing to multiple reasons. Some of them are:

(a) Farmers across the state are not equally aware of their rights. The Forest Department has made no attempts to make the farmers aware and make the protocol farmer friendly. Many farmers are somewhat aware but do not know the protocol or are illiterate, unorganized and under fear or simply reluctant to claim compensation due to the lengthy bureaucratic procedures.
(b) only a small proportion of farmers apply for and receive compensation. A substantial percentage of cases remain unprocessed.
(c) The protocol for estimating damage and paying compensation is not standardized throughout the state.
(d) Furthermore, compensation covers only the direct and conspicuously visible forms of damage (table 1). Thus, many times the amount paid is meagre compared to actual damage.
(e) The GR related to compensation also has several flaws (Annexure 1).

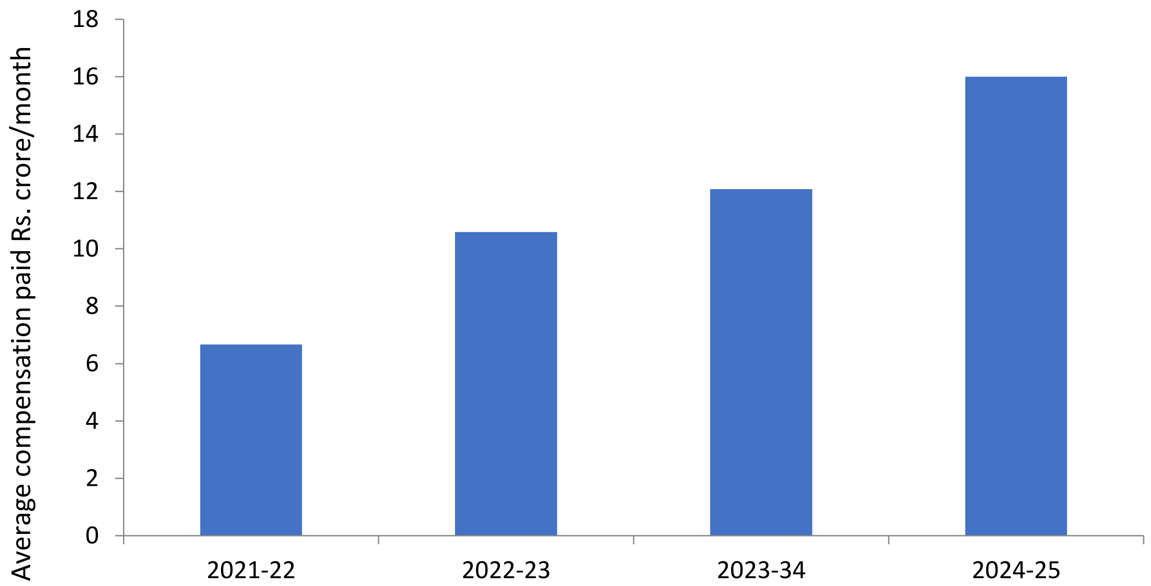



***Figure 3:*** *Trend in the net compensation disbursed in Maharashtra state over a 4-year period. (Average compensation paid in Rs crore per month) Data source: PCCF, Wildlife Department, Maharashtra.*)

Due to such problems the net compensation given throughout the state is a small fraction of the actual loss, and the data of compensation paid is not representative of the real problem in the state. Nevertheless, the compensation data reflects certain relative trends.

It can be observed that the compensation paid out has been increasing rapidly (Figure 3). The data also show that compensation is not restricted to circles having good forest cover and rich wild life.
Substantial compensation has been given in circles not having large protected areas known for rich large mammalian wildlife. In an earlier report (Naqvi et al 2013) maximum compensation has been given in Beed and Aurangabad areas demonstrating that crop damage is a state wide phenomenon not restricted to districts or circles with PAs having large wild mammalian fauna.

### 3.2 Based on farmers' perception of Crop Damages and compensation

Our study was undertaken on the background of some unpublished studies compiling farmer experiences and perspectives. One study conducted by Sagar Tonpe (Biodiversity, Wildlife Conservation and Management student, Mumbai University) in 10 villages in and around Radhanagari Wildlife Sanctuary in 2020 showed that in the preceding 3 years 48.95% farmers applied for the compensation at least once in last 3 years, and not every instance of damage was claimed by them. Damage estimated by farmers was on an average 51.62 times greater than the amount compensated. In other words, only 1.93 % of the estimated damage was being compensated. In another study conducted in the buffer zone of TATR (Bayani et al 2016) between 0.1 to 8% farmers received compensation during the years 2009 to 2015 while over 90% farmers suffered some loss. Also, farmers that received compensation, claimed that not more than 20% of the actual loss was compensated (Bayani et al, 2016).

Vijay Sambre (unpublished) interviewed 39 farmers from Ahilyanagar, Thane and Pune Districts to understand their perception about crop damage and the current compensation process. This study found that 44% farmers claimed for compensation at least once, not every instance of damage was claimed by them, out of the claims only 23% received compensation and the amount of compensation given was less than 50% of their perceived loss.

Since these studies are small and localized, our study examines the net income loss of farmers and impact of human wildlife conflict on agriculture in Maharashtra using a mixed-method approach that integrates both qualitative and quantitative data. A descriptive research design was employed to assess direct financial losses farmers and indirect impact due to wild animals (Annexure 2).

Sample population was selected on the basis of purposive and convenience sampling. Data was collected through a primary survey conducted among 1200 farmers, from all regions of Maharashtra: Konkan, Khandesh, Western Maharashtra, Marathwada and Vidarbha. A majority of the farmer respondents were contacted at: (i) Kisan 2025 agriculture exhibition, in Pune (ii) the Beejotstav, festival of seeds in Nagpur (iii) Through local organizations from different parts of Maharashtra. A structured questionnaire was used for data collection and the data were analysed with statistical techniques for quantitative data and thematic categorization for qualitative insights.

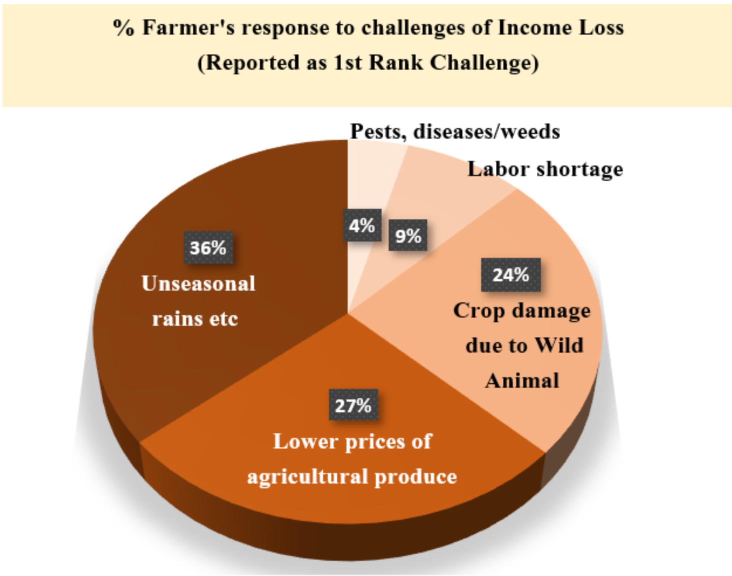



***Figure 4:*** *Magnitude of the problem and Farmers perspective about challenges of Income Loss*

From the farmers' perspective, the magnitude of the problem was significant, as 24% respondents ranked "crop damage due to wild animals" to be their foremost causes income loss. Similarly, 54% farmers said that they had to discontinue taking at least one crop due to wild animal damage. There is some heterogeneity across regions on this response.

| Region of Maharashtra | Percentage of Farmers who discontinued at least one crop |
|---|---|
| **Khandesh** | **58%** |
| Konkan | 67% |
| **Marathwada** | **72%** |
| Vidarbha | 24% |
| **Western Maharashtra** | **58%** |

***Table 2:*** *Discontinuation of at least one crop due to wild animals. Percentage of farmers by region*

But surprisingly farmers from districts without large wilderness areas like Marathwada region also reported giving up some or the other crop because of destruction by wild animals. Further 62 % farmers said they had to reduce the area under cultivation because of repetitive damage and protecting a larger area from wild animals was not practicable.

Regarding compensation for damage by wild animals, only 28% of the farmers in the sample claimed compensation, that too not every time there was an event of damage. On an average these farmers launched a damage complaint only 25 % of the times they suffered damage. In effect only about 5 % of damage cases were registered. Not all registered complains were paid compensation and when paid it was much lower in amount than the farmers' own estimate of damage. In only 4 % of the cases farmers thought the compensation amount paid was realistic. In effect only 1 to 2 % of actual damage appears to have been compensated. This is compatible with the findings of earlier surveys mentioned above. Our survey also unearthed the reasons for not claiming compensation. 78% farmers did not know the protocol for getting compensation. Those who tried were discouraged by complete absence of any response, the procedure being too complex and bureaucratic and not getting realistic compensation. This is in complete agreement with Annexure 1.

Furthermore, we noted that farmers are implementing mitigation measures like Guarding, Scarecrow, Electronic sound devices / Lights, Electric shock machines / Solar fencing to protect their crops. In spite of such devices manual guarding day and night was thought essential in many regions. The man-hours required for guarding, expenditure towards other measures and the non-visual losses are not covered in the current compensation process.

| Region of Maharashtra | Number of responses | Area Under Cultivation (Hectares) | Direct Loss per year (Rs) | Loss in Rs Per Year Per Ha |
|---|---|---|---|---|
| **Khandesh** | 76 | 373 | 77,66,500 | 20,822 |
| **Marathwada** | 315 | 1,483 | 3,54,38,000 | 23,896 |
| **Vidarbha** | 254 | 1,158 | 3,24,32,000 | 28,007 |
| **Western Maha** | 149 | 449 | 1,29,14,500 | 28,763 |
| **Konkan** | 128 | 367 | 1,55,99,000 | 42,504 |
| **Total** | **922** | **3830** | **10,41,50,000** | **27,195** |

***Table 3:*** *Per Ha Annual Income loss due to wild animals in farmers' perception (Regional Distribution)*

When asked about a judgement of the net loss per year due to wild animal damage, the perceived average loss was Rs. 27,195/- per hectare per year with a large variability around the mean. Small and marginal farmers report much higher damage per unit area. As stated earlier, opinions and judgments of people are not quantitatively accurate but they reflect trends.

An important realization is that damage due to wild animals is not restricted to areas with large protected areas or forest cover. The damage is well spread across the states even in districts without well-known wildlife reserves. In farmers' perspective, the loss per hectare in Marathwada and Khandesh, that does not have large wilderness areas, is not too small compared to Vidarbh and Konkan regions which have good forest cover and wildlife presence.

### 3.3 Based on a detailed agricultural eco-econography of farmer families from Ratnagiri and Sindhudurg districts

Estimating the damage in areas where farmers cultivate a diversity of Agri-horticultural products is a more challenging task. Konkan region is particularly characterized by mixed and diverse cultivation practices and therefore we focused on this region. Farmers in Konkan are often well educated and therefore can give a much-detailed account of the turnover also farmers from Konkan region reported highest loss in our previous survey (Tables 2 and 3) Therefore, we did a detailed study of the net agri-horticultural economics of 15 farmer-horticulturist families in Ratnagiri and 10 in Sindhudurg district cultivating a diversity of products. The objective was to include direct as well as indirect losses including the crops given up or replaced by other suboptimal ones, reduction in areas under cultivation and the loss of opportunities for value addition.

Selection of farmer families was based on snowball sampling. The inclusion criteria used were the following (i) Having a mixed agri-horticultural cropping pattern (ii) Educated families who keep reliable records of their agricultural activities in detail (iii) Covering various landscapes as Konkan has both costal and hilly areas. The study adopts a mixed-method approach, combining both qualitative and quantitative data to ensure a comprehensive analysis with detailed assessment of farmers' experiences and quantitative measurement of economic losses. Data were collected through guided interviews and participant farmer was interviewed at their residential place or on the farm and the duration of each interview was 30 to 45 min (See Annexure 3 for detailed methods and results).

While in our previous study (Annexure 2) annual loss reported by farmers from Konkan region was Rs 42,502/- per Ha per year; the detailed estimation-based data in this study revealed the net annual loss per hectare per year to be Rs 1,33,000/- from Ratnagiri district and Rs 1,17,000/- from Sindhudurg district. This indicates that the farmers' perceived loss was a substantial underestimate. If this is considered representative, the net loss is likely to be much more than what table 3 indicates.

| District | Number of Farmer Families interviewed | Respondents' Area Under Cultivation in Hectares | Net Annual Loss Rs | Loss Per Hectare per year |
|---|---|---|---|---|
| **Ratnagiri** | 15 | 45 | 6025433 | 133862 |
| **Sindhudurg** | 10 | 64 | 7564535 | 117734 |

***Table 4:*** *Net annual loss per hectare calculated for the sampled farmer families of Ratnagiri and Sindhudurg districts*

Total area under cultivation in Ratnagiri dist. is 2,750 sq km and 1370 sq km in Sindhudurg dist. That makes a net loss of Rs 3681 crore and Rs 1612 crore per year in Ratnagiri and Sindhudurg districts alone, the total being Rs 5293 crore per year. These estimates include direct and many types of indirect losses but do not include farmers that have completely given up farming and migrated to cities or adopted other livelihood options.

Apart from farmer families, most households in rural Konkan region have sufficient spaces around in which growing a kitchen garden was a common practice. In our survey (section 2 above) **83% respondents** from Konkan region opined that they have given up this practice mainly because of macaques, langurs and wild pig eating up the vegetables (Annexure 2). Now vegetables have to be necessarily bought from the market. Taking a very conservative estimate of Rs 200 per family per week, this amounts to a loss close to Rs 10,000 per family per year. From 2011 census, there are estimated 2.7 lakh families in Rural Ratnagiri district and their net loss is estimated to be 270 crores. For Sindhudurg district a similar estimate is about 148 crores. Thus, the net agricultural loss including kitchen garden loss of the two districts together is estimated to be Rs 5677 crore per year.

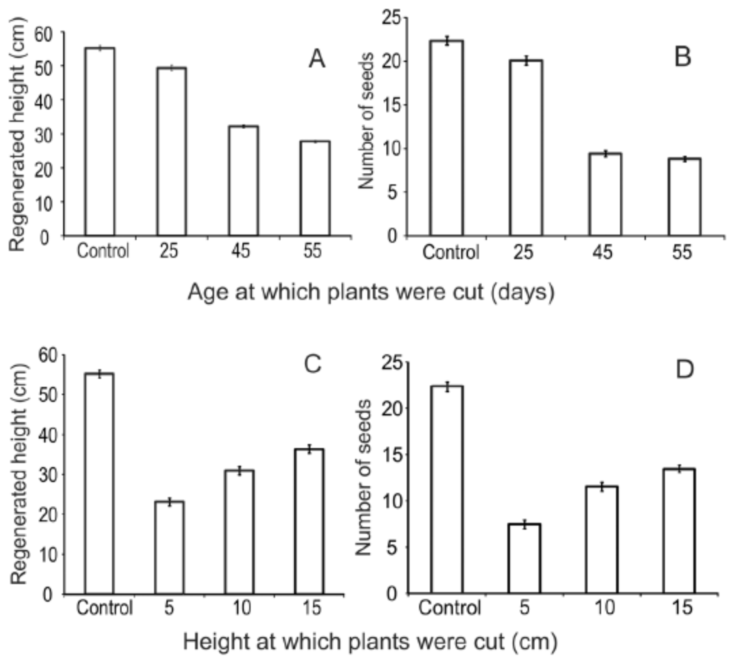
### 3.4 Using a multi-approach estimates of crop damage from around TATR

Perhaps the only study on the global platform that used multiple approaches to quantify net crop damage was by Bayani et al (2016) (Annexure 4) in a cluster of villages on the western boundary of TATR. It drifted from the common approach of assessing the damage by visiting a farm following an episode of damage and looked at the net yield per hectare coming from the farms. It carefully compared the net crop yield at the end of the season along transect lines going away from the forest edge. The study showed that, the crop yield increased more or less linearly going away from the forest. For most crops in many seasons the average yield nearly doubled at a distance of 5 Km from the forest boundary, as compared to the yields in farms facing the forest border.

When a control farm was meticulously fenced to prevent the entry of any herbivore, and a neighbouring farm was kept unfenced and unguarded, for rabi season the unguarded crop was completely destroyed (i.e. 100 % loss) whereas Kharif rice suffered 60-70 % loss. The experiment was done in a high-risk area next to the forest boundary and the yield of the control plot was comparable to the yields 5 km away. This indicates that the trend of doubling yield at a distance of 5 km is not due to difference in soil fertility, but due to wild animal damage itself. Similar experiment in Kerala by Jayson (2013) showed 47% reduction in paddy yield in the open plot as compared to control plot preventing the entry of peafowl and other birds.

A common argument has been that when only a part of a plant is gnawed at, it regenerates naturally and therefore compensation needs to be paid only when the plants are dead and flat. The suggestion for including wildlife damage compensation as add on to the PMFBY (Revamped guidelines 2020, www.pmfby.gov.in) also recommends that whenever regeneration is possible, the damage should not be counted. The Bayani et al (2016) study compared plants cut at pre-decided heights and phases of growth and allowed to regenerate with plants without any damage. The comparison showed that although the plants regenerated rapidly, the grain yield suffered substantially (figure 3). Thus, the policy of only considering completely destroyed plants for compensation is not justified. Although plants have the capacity to regenerate, a plant once damaged does not give the expected yield in spite of regeneration.

***Figure 5***: Artificial herbivory in wheat: Adopted from Bayani et al (2016). Comparison of re-growth by wheat plants cut at different age. **A:** vegetative re-growth, **B**: number of seeds after re-growth (control, n = 125; age 25, n = 92; age 45, n = 202; age55, n = 199) and comparison of re-growth of vegetative part in wheat plants cut at various heights at pre-flowering stage **C:** vegetative re-growth, **D:** number of seeds. (Control, n = 125; height 5, n = 176; *height 10, n = 178; height 15, n = 205).*
**(Reproduced from Bayani et al 2016)**




**The extent of disinvestment with distance from forest**: The study also showed that the use of fertilizers differs with the distance from forest. It is reasonable to expect that when faced with a risk of complete destruction, farmers may hesitate to invest more in their farms. Compatible to this expectation the study noted that farmers close to the forest make minimum use of fertilizers whereas the use of combination fertilizers increases monotonically with distance from the forest.

By comparing net yields, this study covered direct and some forms of indirect damage. It did not cover some other forms of indirect loss such as farmers giving up farming or giving up rabi crops entirely. It also did not include the cost of fencing and guarding. The multiple methods used in this study can be put together to get an estimate of 50 % crop loss near the farm-forest interface as compared to a distance of 5 km away from the forest. Inclusion of the cost of fencing and guarding would add to the net loss further.

### 3.5 Based on estimates from Support cum Reward (SuR) method

Joshi et al (2020) employed a behaviour based, game theory supported design of supporting farmers affected by wild animal damage. The model called support cum reward (SuR) was implemented in two villages on the western boundary of TATR over three years i.e. 6 cropping seasons covering 4 types of crops. Prior studies in this area had indicated that indirect loss due to decreased inputs by farmers facing risk of damage was greater than the crops actually destroyed by animals.

The pilot scale experiment demonstrated that when an assurance of returns was obtained, farmers' inputs increased. Coupled with incentive for increased production farmers could increase their crop output by 2.5 to 4-fold (Figure 6). If 2.5 to 4-fold increase (i.e. 150 to 300 % greater yield) was possible in heavy damage areas (Annexure 5) it means that in high risk areas only 25-40 % agricultural potential was being utilized. The rest needs to be considered as loss due to wild animals. The prevalent wildlife policy and the ineffective compensation protocols prohibit utilization of the full potential.

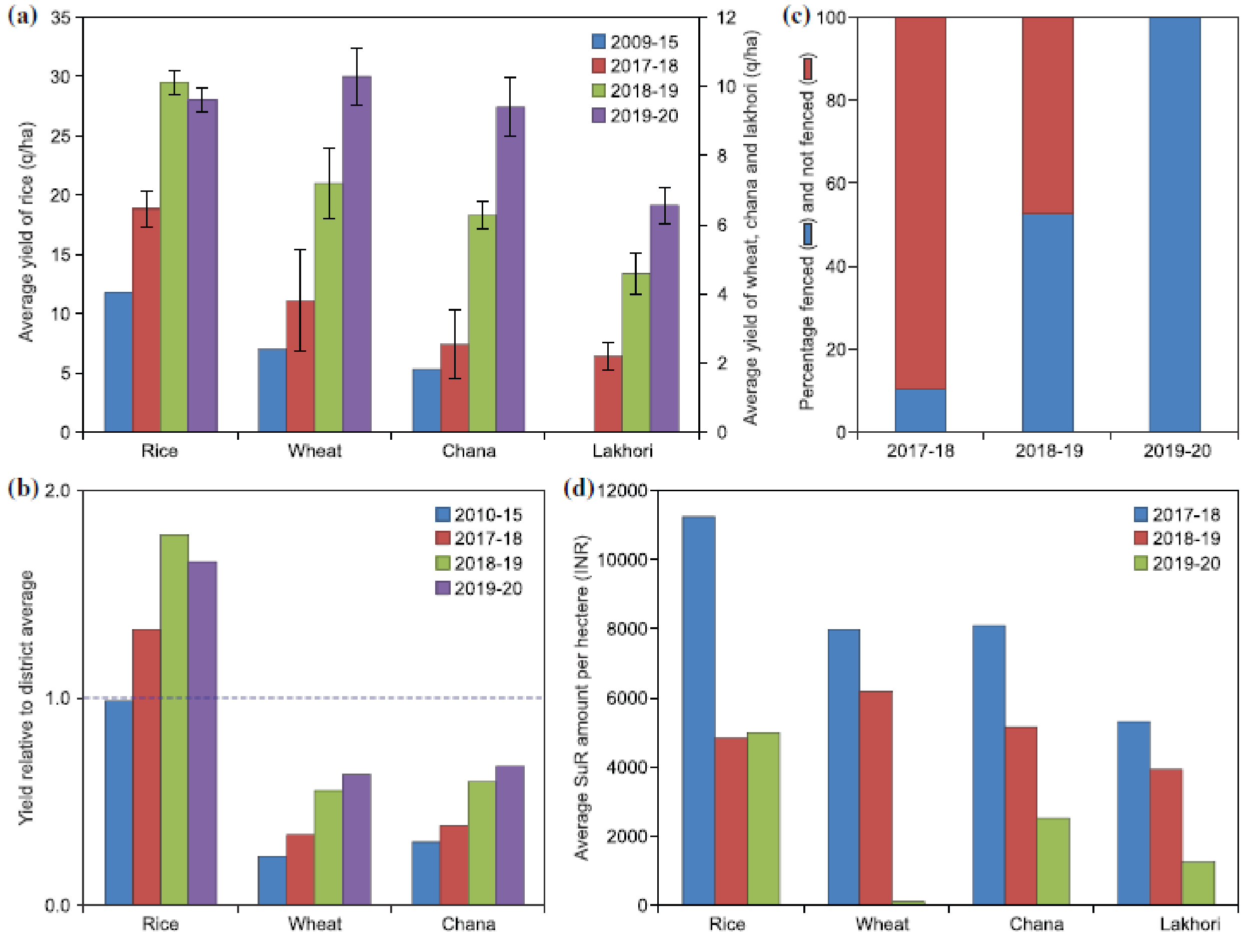
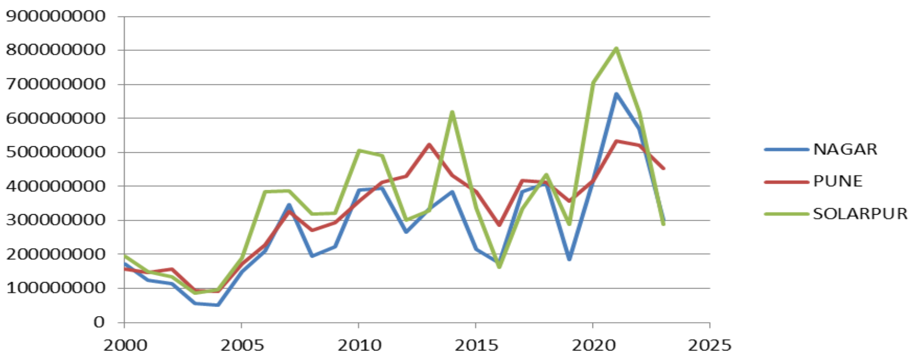



***Figure 6:*** *Trends in **(a)** absolute rice, wheat, gram, and lakhori production, weighted mean Q/He and standard deviation, **(b)** production relative to district average of that year (lakhori not included), **(c)** proportion of farmers using solar fences for crop protection, and **(d)** combined compensation for damage and reward for crop productivity (SuR) paid per hectare over 3 years. Adopted from Joshi et al (2020).*

The case of Pitezari village bordering Nagzira wildlife sanctuary also demonstrates that under the threat of wild herbivores, the agricultural potential of an area is grossly underutilized and given assurance of return the output more than doubles. The Pitezari village has good protective irrigation facility and their crops have been less prone to rainfall fluctuations. The main cause of crop failure had been wild herbivore attacks. In an attempt to help the farmers, close to protected areas, the village and cluster of farms of Pitezari was surrounded by chain link fencing prior to the kharif crops of 2024. The expenditure for the fencing was supported by Corporate Social Responsibility funding of Bharat Forge. Although fences do not keep all herbivores out all the time, a well-constructed fence generally offers a fair amount of protection until animals learn to overcome the barrier. At least in the first year the fence gave a moral boost to the farmers of the village who cultivated their lands with greater enthusiasm and inputs. There was an increase in the area sown in kharif as well as rabi season, the diversity of crops increased and so did the net productivity. Although data were not systematically kept prior to and after the fencing, Tekam and Purandare (Personal communication) interviewed 28 farmers of the village who could give their precise quantitative record prior to and after fencing. For these 28 farmers the net agricultural output increased over two-fold (from Rs 12.33 lakh in the pre fencing year to Rs 25.24 lakh in the post fencing year) and the average types of crops taken by a farmer increased from 1.25 to 2.21. This matches with the Bayani et al (2016) and Joshi et al (2020) estimates of 50 % or greater loss in villages close to protected areas. It also demonstrates that agricultural revival near protected areas is possible and given an appropriate solution farmer respond positively and the results are astonishing.

### 3.6 Correlating district wise agricultural productivity trends with wild life and forest cover

Kolape and Komkar, Master's degree students of the Department of Statistics, SPPU, Pune, analyzed district wise agricultural data available from the government of Maharashtra website [https://krishi.maharashtra.gov.in/](https://krishi.maharashtra.gov.in/) . They addressed the question how the trends in districts with rich versus poor wildlife and forest cover compare (Annexure 6). Directly comparing productivity across districts is prone to multiple confounding factors since the area under cultivation, soil characteristics, rainfall patterns and cropping patterns are widely different across districts. Therefore, avoiding such comparisons, they put the net output of all crops expressed in terms of current MSP (or market value for crops where MSP wasn't available) and plotted a time trend with data available from 2000 to 2023. This avoids comparisons between districts but represents the progress of agriculture in that district (Fig. 7). MSP or market rates of 2023 have been used throughout the calculations so that the trend seen is independent of inflation.



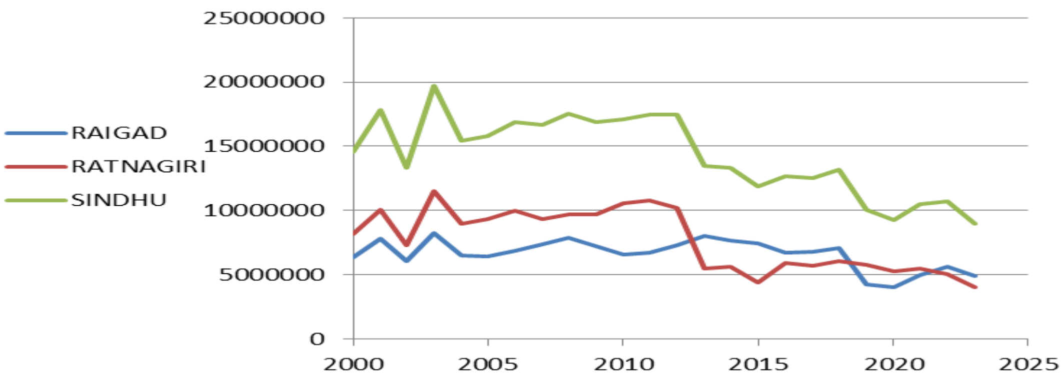



***Figure 7:*** *Trends in the net agricultural output between 2000 and 2023. Some districts have an upward trend and some districts have downward trend.*

The slope of this trend line in every district is correlated with forest cover data obtained from India State of Forests Report (fsi.nic.in). No district wise quantitative data on wild herbivore populations is available, therefore it is not possible to correlate but categorization of districts into rich or poor in wildlife could be made.

The analysis showed that there was a significant negative correlation between forest cover and progress of agricultural output. The progress of net agricultural productivity was stunted or even negative in districts with greater forest cover. Agricultural lands not surrounded by forests showed better progress. Similarly districts without rich wildlife have progressed significantly more than the ones with rich wildlife presence (Fig. 8). This difference is robust because selectively deleting one district at a time does not affect the trend qualitatively. Some forested districts including Sindhudurg, Ratnagiri, Raigad have a negative progress, in that their net agricultural output has deteriorated instead of improving. This is likely to be largely because of a significant proportion of farmers giving up farming and migrating. The difference in the average net linear trend between rich and poor wildlife districts is 4 % per year. The analysis suggests that forest cover and wildlife presence appear to have substantially hindered net growth in agricultural productivity.

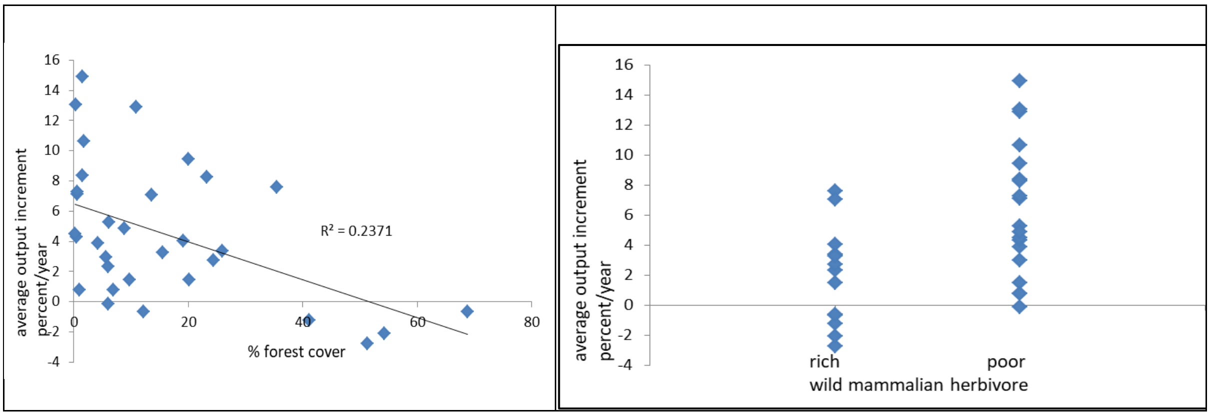



***Figure 8:*** *(Left) A negative correlation between forest cover and progress in agricultural productivity. (Right) Comparison of districts with and without rich large herbivore flora with respect to agricultural productivity trend.*

This analysis has many limitations in that only the crops available on the official government website are considered and this does not cover the entire agricultural landscape. The main source of data appears to be land records and APMC data and not all crops are marketed through APMCs. Nevertheless, the trend is qualitatively robust and suggests that forests and wildlife have a significant negative impact on agricultural trends.

### 3.7 Fermi calculations based on the data sources

The studies 1 and 2 from the above represents state wide data. But the data are not complete and not representative of the state owing to several limitations stated above. The studies 3 to 5, on the other hand, are carefully designed and intensive studies but are conducted on small sets of farmers in restricted areas.

Estimating the net loss for the state is a challenging task because of the large gaps in the data. Nevertheless, combining the reliable sides of all the studies and using different methods of extrapolating the data we can arrive at reasonable estimates. The advantage of using multiple methods is that if they converge on the inferences, the inferences can be said to be substantially robust. If they contradict each other it reflects on the unreliability of the estimates. This is a first and unprecedented attempt to estimate a state wide agricultural impact of wild animal damage anywhere in the world and therefore has important implications in spite of its limitations. More precise data and alternative approaches can be added as and when more systematic studies are undertaken. But since the problem is serious and related to the livelihood of a large number people, an action plan needs to be designed at the earliest. The action plan can be refined from time to time as more data accumulate.

The first approach for obtaining a state wide estimate of damage is to combine data from sources 1 and 2 of the above. The farmer surveys implicate that only of about 1 % of actual damage gets compensated. The intensive localized studies (3,4 and 5) compared to the compensation paid in that area over that time also indicate that compensation paid is a fractional percent of the actual. A simple projection from this is that if the compensation given annually in Maharashtra State in the last few years averages about 100 crore and it is about 1 % of the total, the net damage can be estimated to be of the order of Rs. 10,000 crore per year in the entire Maharashtra state. This estimate is a projection from 1 % and therefore is subject to a large error, but gives a good idea of the order of magnitude. Further compensation includes only direct and visible damage. Non-visual and indirect losses are not included and therefore this projection is likely to be an underestimate.

The farmers' perceived annual loss averaged to Rs 27,000/- per hectare in study 2. This is a perception and therefore also subject to errors and variability but gives us an order of magnitude judgment. The state of Maharashtra has an area of 165 lakh hectares under cultivation. If the farmers in the survey sample are representative enough, the state wide annual estimated damage becomes around Rs. 45,000 crores. In Konkan area the comparison of farmers' perception and detailed calculations based on data show that farmers' perception is an underestimate. If this is representative enough, the actual loss can be much greater than Rs 45,000 crore per year.

Ratnagiri and Sindhudurg districts together suffer from a net loss of Rs 5677 crore per year by our study described above. These two are elite output districts mainly because of mango, coconut and other high market value fruits. Conservatively we assume other districts to have an average loss of only 20% of that, the net loss of the state turns out to be around Rs. 25,000 crore.

By the Bayani et al (2016) study, the net estimate is 50 % crop loss near forest front coming down to 10-20 % at a distance of 5 km from forest. This estimate did not include the fencing and guarding cost. The estimated 10 to 50 % loss happens in spite of guarding for 12-16 hours a day. If we calculate the guarding cost for the sensitive period of a crop which is typically 3 months per season or 6 months per year, taking the minimum wages act the cost is of the order of Rs. 50,000 per hectare per year. This makes the net cost close to the forest as Rs 1,00,000 per hectare per year. The guarding cost does not reduce proportionate to the distance but the damage may and as a result the net loss comes down to Rs 50,000/- per hectare per year at a distance of 5 km and more. Using Fermi calculations, we can have rough estimates of net loss for the state as follows.

The above estimate is for farms in proximity to protected areas (PAs). The total area under PA in Maharashtra State is 6733 sq km. Fringe area of PAs where there is heavy loss can be assumed to be 5-10 % of this, i.e. 350 to 700 sq km suffering a loss of Rs 50,000 to 1 lakh per hectare makes a net annual loss of 175 crore to 700 crore in the close vicinity of PAs alone. Forest areas other than PAs are 61,579 sq km, but the non-PAs are a mosaic of forest and human habitation therefore the proportionate area of interaction is expected to be much larger i. e. bet 20,000 to 30,000 sq km, here too fencing and guarding cost is expected to be similar but actual destruction can be assumed to be somewhat less. A net loss of 25-30,000 per hectare is a conservative but reasonable assumption for this area. That makes an estimate of Rs 5000 to 9000 crore for non-PA forest areas. Agricultural areas not directly in contact with forests are of the order of 2,00,000 sq km. They are not free of wild life damage as shown by the Naqvi committee report (2013), compensation data (1) and farmers' interviews (2), but it is patchy and less common. Some areas harbour good populations of nilgai and other antelopes, wild pig and monkeys despite not having any PAs around. Some areas are relatively free of wild animal damage. These areas may not have to be guarded all the time. But the farmer survey as well as the compensation data show that these areas are not free from wild animal damage. The net loss per hectare here may average Rs 1000 to 5000 as a very conservative estimate. This amounts to further Rs. 2000 to 10,000 crores. The total estimate therefore is between Rs. 5175 to 26,000 crore per year. This estimate does not include many forms of indirect losses.

The implementation of Support cum Reward (SuR) on a pilot scale in a high-risk area resulted in 2 .5 to 4-fold (150 to 300 % difference) increase in agricultural productivity of farmers. This means only 25 to 40 % of productivity potential was being utilized. Given an adequate support along with incentivization, much of the true productivity potential could be realized. In low risk areas, the difference between potential and actual can be assumed to be substantially smaller. If we conservatively take only 10 % of that in heavy damage areas, it makes 15-30 % potential increase. The annual agricultural market by APMC data is around Rs 50,000 crore, a 15-30% of it amounts to Rs. 7,500 to 15,000 crores. This means that giving assurance of making up for the wildlife damage along with incentives for increasing productivity could increase the net yields by Rs. 7500 to 15000 crores. This estimate includes direct and indirect losses. However, since these calculations are based on APMC data and not all agricultural products are marketed through APMCs, the actual number is expected to be much greater.

The analysis by Kolpe and Komkar (Annexure 6) showed that there is an average 4 % difference in the linear annual increment in agricultural income between wildlife rich versus wildlife poor districts. The wildlife rich districts are progressing less than others by a linear difference of 4 %. With a 4 % increment in 23 years the net income should have increased by 92%. If we look at the total net agricultural produce by the market rate of the wildlife rich districts by APMC records of 2023 it is Rs 16,400 crore per annum. Since a 92 % increase was expected, Rs 15,000 crore can be considered a net loss of the state per year. Again, since this calculation is based on APMC data, it is an underestimate of the actual loss.

In effect, it can be seen that the different sources of data and the different ways of calculating converge surprisingly well to estimate the net agricultural loss of Maharashtra state because of wildlife to be between Rs. 10,000 to 40,000 crore per year. This is not a stagnant figure but has an alarmingly increasing trend.

### 3.8 Other approaches to recheck and strengthen the estimates

There are other ways of cross-checking and strengthening the estimates using different data sources. Some of these are listed below:

(i) The number of farmers who have given up agriculture entirely and migrated to other areas. In certain regions such as the Konkan, this pattern is observed, but needs a quantitative analysis. Reduced farm output due to wildlife raids is at least one important reason for giving up farming.

(ii) Because of the wildlife menace, many families cannot cultivate kitchen gardens. They have to buy vegetables from the market. Often the vegetables are transported across hundreds of kilometers. This transport has its own environmental cost.

(iii) We accounted for the cost of manual guarding of the farm, in terms of person-days. But guarding day and night is stressful and could have a health cost, particularly for those who cannot afford to employ paid guards. In the Konkan, the bigger landowners usually employ guards who have commonly arrived here for work, from Nepal. The Nepalis are separated from their families, and this has resulted in some form of mild social tension due to increased social heterogeneity in many Konkan villages.

### 3.9 Other social costs from crop damages

Farmers who cultivate around areas that are rich in wildlife suffer greater losses. In our study we found that such families have to buy their daily vegetables from the market. This has resulted in greater inequality among farmers, which is a significant social cost.

The young generation is rapidly moving away from agriculture since they view it as a non-profitable activity. With the more talented and motivated youth moving away, the agricultural sector would be left with an aging population, less capable and less motivated. This is a slow and silent national disaster. Wildlife damage is a substantial if not sole causal component of this change. In many areas youth who have chosen to be farmers find it difficult to get a suitable spouse.

A possible radical change owing to this trend is that the traditional farmer families would eventually give up farming, selling off their lands. The farmlands would eventually be acquired by the rich. The end result might be oligopoly and corporatization of agriculture. Unlike the small farmers the large players can easily “manage” the forest department and take care of the wild animal menace by illegal and unregulated means. The agricultural productivity may be restored this way but both wildlife and the poor sector of the society would be at an irreversible loss. A large sector of the rural society will have to migrate and settle in slums and ghettos. The pressure on urban planning, crowding and subsequent effects will be intensified further because of the inevitable migration.

There are alternative possibilities. People are observant and they realize that agriculture in non-forest areas has been prospering at a much greater speed than the forest areas. This is a large disincentive for the environmental movement. In worst case, people may burn or otherwise destroy forests and kill wild animals because that is the only option left to make a living. Such are the potential long-term costs of the farmer - wild herbivore conflict.

It is not only the farmers who bear the brunt and pay the costs of wildlife raids. The forest department also pays heavy costs from their budgets, to compensate for the human wildlife conflicts. There is a cost involved in processing the compensation claims, verifying every claim by panchanamas and the bureaucracy involved. In areas with elephants, the forest department incurs costs of controlling animal movements, monitoring their paths, and alerting people. In areas with large menace by langur and macaques, a monkey capture program is sporadically being undertaken. Capture and relocation of large animals is also needed and that involves high cost although the frequency may be smaller. These costs have not been included in our current study.

Wildlife and the entire biodiversity is precious and priceless. However, it is important to work out the costs of conservation for two reasons. (i) Although the species might be priceless, there is a practical aspect of management which needs a budgetary provision and therefore the cost of conservation is a relevant question. Wildlife policy needs to address the question whether conservation of species and ecosystems can be optimized with respect to its cost, without compromising on survival of species. (ii) The second important question is that even if we accept that the society should bear the cost of conservation, which section of the society bears the actual cost and how much? We need a realistic estimate of the net cost to plan a more equitable distribution of the cost over the society in such a way that no section of the society disproportionately pays the cost and thereby suffers injustice.

Ultimately, we need to design remedies effective in the short as well as long run. This is possible only when we have a realistic estimate of the net cost and its distribution over the society. Without knowing the patterns of damage effective mitigation is not possible. Current practices are superficial attempts to show that “we are doing something”. There is no mechanism to check whether and to what extent any of the mitigation measures employed is really effective. This analysis again is not possible without having methods to follow up on the realistic assessment of net loss.

**A warning against polarity of perception**: This document, in our best knowledge, is the first attempt to estimate the true cost of wildlife conservation. Economics and ecology are equally important aspects of conservation. The debate should not be perceived as an economist versus ecologist war, nor a value assessment of wildlife. The two need to complement each other rather than conflict. Sound ecological action is not possible without a balanced economic view, particularly in India where wilderness exists necessarily as a mosaic with human livelihood.

# 4. Towards effective remedies

## The essential steps for effective remedies

A quantitative assessment of damage that takes into account all the direct and indirect costs that farmers incur, is essential to show urgency of an effective action plan to address this problem. However, urgency does not imply hasty decisions based on unsupported assumptions. We need to move in definite steps as under.

I. Restructure compensation protocols that compensate realistically, are farmer friendly, and disburse the compensation without any delays and costs to the farmers. The current protocols have proved hurdle infested and ineffective. There is a need to consider unconventional approaches. One such approach is demonstrated with pilot implementation, i.e. the support cum reward (SuR) method (Joshi et al 2020). The SuR method needs minimum state infrastructure and personnel for implementation. It can be made completely AI driven, realistic, reliable and transparent.

II. Although paying compensation is not the ultimate solution to the increasing trend in damage, it gives us a breathing time for research making a sound basis for planning. Having sound methods for realistic damage compensation automatically provides a means to assess the effectiveness of any remedial measures. Therefore, a smoothly running compensation protocol is required in all phases of management.

III. Simultaneously initiate fundamental research towards: (i) Elucidating the true causes of crop damage by wild animals by testing the differential predictions of the alternative hypotheses (Prabhulkar and Watve 2025). (ii) Long term mitigation measures directed towards the causes identified by in-depth studies. (iii) Chalk out a long-term policy on how to achieve long term co-existence of farmers with wild life (iv) Design a practicable and cost-effective working system that needs minimum state machinery, has no loopholes that might allow corruption, has a built-in mechanism of data generation and is self-correcting based on the feedback data. The emerging concepts of behavior informed policy make such systems possible. We elaborate on such a system design in a separate document.

In the absence of fundamental research on these lines, effective long-term solutions are not possible. Moreover, in the absence of fundamental research, a conservation action with good intention might turn out to be harmful in reality. There are documented examples of such upside-down effects of conservation actions (Balmford 2025). Therefore, rethinking of the conservation policy optimizing the multiple dimensions of costs and benefits of it is urgently required. The intrinsic value of species and the ecological benefits need to be weighed against the cost paid by people in planning effective conservation strategies. Our analysis shows that the cost paid by people is much greater than what has been assumed so far and that needs to be integrated in the holistic picture of conservation.

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# Annexure 1

### Calculating Compensation

### [A] Compensation Provided by Forest Department

The Forest Department records the compensation paid against cases of crop damage by wild animals. This is mandatory under the provisions of the **Wildlife (Protection) Act**, 1972, Section 11 and Section 12, which empowers the authorities to manage human-wildlife conflict and provide relief. However a GR defining the norms of compensation was effective only from 2004, which was amended from time to time.

In the state of Maharashtra compensation for wild animal damage was included in the Right to Service (RTS) Act of 2015. This means that getting compensated for crops destroyed by wild animals is recognized as a legal right of farmers.

To understand and analyze compensation process and its time trends, geographic trends, correlations with forest cover and wildlife presence, we sent a written request addressed to the PCCF Wildlife, Maharashtra to share damage compensation data in Maharashtra for the last five years. Based on our request, the Forest Department sent us the following data:

1. Number of Cases filed: Accepted, Rejected, Disposed from 2020 to 2024 at the aggregate (state level) and at the level of forest circles.
2. Amount of compensation disbursed
3. Category of Cases filed for Compensation
    a. Crop Damage
    b. Human Killing/ Damage
    c. Livestock Killing

**मनुष्य हानी/पशुधन हानी शेत पिकाचे नुकसान बाबतची माहिती.**

| आर्थिक वर्ष | मनुष्य | | पशुधन | | पिक नुकसानी | दिलेली नुकसान भरपाई (रू. कोटीत) |
|---|---|---|---|---|---|---|
| | मृत | जखमी | मृत | जखमी | | |
| 2021-22 | 86 | 553 | 10317 | 343 | 56402 | 80.00 |
| 2022-23 | 111 | 762 | 12517 | 640 | 54036 | 127.10 |
| 2023-24 | 64 | 799 | 4648 | 11819 | 104436 | 145.00 |
| 2024-25 Till 04.12.2024 | 40 | 490 | 8743 | 3205 | 40261 | 132.59 |

***Table 1:*** *Compensation data on damage to Human, live stalk and crop damage*

From Table 1, it is observed that the compensation paid out has been increasing rapidly (Figure 1).

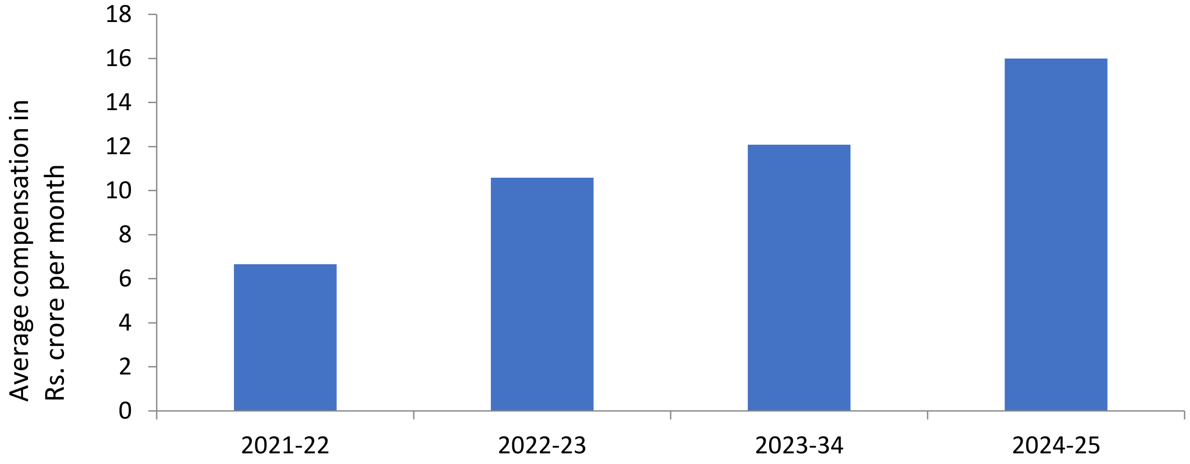



***Figure 1:*** Time trend in the net compensation given in Maharashtra state (average Rs in crore per month), as per the data supplied by PCCF, wildlife office

Furthermore, the data in Table 2 shows that compensation is not restricted to circles having a good forest cover and rich wild life. Substantial compensation has been given in circles not having large protected areas known for rich large mammalian wildlife. In an earlier report (Naqvi et al 2013) maximum compensation has been given in Beed and Aurangabad areas demonstrating that crop damage is a state wide phenomenon not restricted to districts or circles with PAs having large wild mammalian fauna.

शेतपिक 01/01/2020 ते 09/12/2024 मधील प्रगती अहवाल विहीत दिलेल्या प्रपत्रात सादर करण्यात येत आहे.

| Sr. No. | Circle Name | Subcategory Name | No. Of Cases | Accept | Reject | Disposed | Paid Amount (in Rs.) |
|---|---|---|---|---|---|---|---|
| | | ऊस | 267 | 185 | 82 | 145 | 8,33,362 |
| | | पिक | 231297 | 150497 | 80800 | 121604 | 60,53,16,951 |
| 1 | Amravati | फळझाड | 2254 | 1633 | 621 | 1263 | 1,03,61,582 |
| Total | | | 233818 | 152315 | 81503 | 123012 | 61,65,11,895 |
| | | ऊस | 43 | 32 | 11 | 27 | 2,41,250 |
| | | पिक | 113102 | 96472 | 16630 | 68618 | 40,58,89,897 |
| 2 | Chandrapur | फळझाड | 30 | 20 | 10 | 14 | 2,00,750 |
| Total | | | 113175 | 96524 | 16651 | 68659 | 40,63,31,897 |
| | | ऊस | 5069 | 2702 | 2367 | 1716 | 55,34,374 |
| | Chhatrapati | पिक | 34125 | 19658 | 14467 | 12663 | 3,94,85,230 |
| 3 | Sambhajinagar | फळझाड | 846 | 510 | 336 | 327 | 28,12,128 |
| Total | | | 40040 | 22870 | 17170 | 14706 | 4,78,31,732 |
| | | ऊस | 813 | 497 | 316 | 463 | 36,89,583 |
| | | पिक | 20112 | 13434 | 6678 | 11657 | 6,82,45,763 |
| 4 | Dhule | फळझाड | 595 | 422 | 173 | 348 | 41,51,719 |
| Total | | | 21520 | 14353 | 7167 | 12468 | 7,60,87,065 |
| | | ऊस | 14 | 9 | 5 | 8 | 1,13,800 |
| | | पिक | 9157 | 7997 | 1160 | 7072 | 7,82,06,136 |
| 5 | Gadchiroli | फळझाड | 6 | 4 | 2 | 4 | 26,140 |
| Total | | | 9177 | 8010 | 1167 | 7084 | 7,83,46,076 |
| | | ऊस | 14751 | 13030 | 1721 | 11474 | 7,59,53,287 |
| | | पिक | 42795 | 39255 | 3540 | 34582 | 18,41,12,943.96 |
| 6 | Kolhapur | फळझाड | 3320 | 3005 | 315 | 2843 | 5,43,26,535 |
| Total | | | 60866 | 55290 | 5576 | 48899 | 31,43,92,765.96 |
| | | ऊस | 813 | 654 | 159 | 558 | 59,68,905 |
| | | पिक | 49438 | 40749 | 8689 | 34322 | 25,77,99,496 |
| 7 | Nagpur | फळझाड | 732 | 601 | 131 | 570 | 43,88,169 |
| Total | | | 50983 | 42004 | 8979 | 35450 | 26,81,56,570 |
| | | ऊस | 83 | 59 | 24 | 54 | 3,56,160 |
| | | पिक | 1480 | 1267 | 213 | 1109 | 67,11,369 |
| 8 | Nashik | फळझाड | 88 | 76 | 12 | 72 | 20,35,335 |
| Total | | | 1651 | 1402 | 249 | 1235 | 91,02,864 |
| | | ऊस | 269 | 228 | 41 | 165 | 16,04,409 |
| | | पिक | 2981 | 2671 | 310 | 2330 | 1,66,52,042 |
| 9 | Pune | फळझाड | 41 | 37 | 4 | 30 | 5,80,460 |
| Total | | | 3291 | 2936 | 355 | 2525 | 1,88,36,911 |
| | | ऊस | 2 | 2 | 0 | 2 | 25,600 |
| | | पिक | 901 | 768 | 133 | 581 | 32,10,865 |
| 10 | Thane | फळझाड | 23 | 16 | 7 | 11 | 1,09,460 |
| Total | | | 926 | 786 | 140 | 594 | 33,45,925 |
| | | ऊस | 4 | 2 | 2 | 0 | 0 |
| | | पिक | 4709 | 3754 | 955 | 2888 | 1,69,09,695 |
| 11 | Wildlife East | फळझाड | 23 | 20 | 3 | 14 | 1,00,487 |
| Total | | | 4736 | 3776 | 960 | 2902 | 1,70,10,182 |
| | | ऊस | 11 | 5 | 6 | 0 | 0 |
| | | पिक | 4434 | 2107 | 2327 | 580 | 33,89,347.60 |
| 12 | Wildlife Melghat | फळझाड | 99 | 56 | 43 | 41 | 2,90,136 |
| Total | | | 4544 | 2168 | 2376 | 621 | 36,79,483.60 |
| | | ऊस | 1221 | 914 | 307 | 847 | 53,37,592 |
| | | पिक | 2035 | 1431 | 604 | 1092 | 54,47,694 |
| 13 | Wildlife West | फळझाड | 37 | 17 | 20 | 15 | 1,39,280 |
| Total | | | 3293 | 2362 | 931 | 1954 | 1,09,24,566 |
| | | ऊस | 1333 | 1068 | 265 | 827 | 38,53,101 |
| | | पिक | 121426 | 103363 | 18063 | 67754 | 22,82,75,890 |
| 14 | Yavatmal | फळझाड | 291 | 217 | 74 | 168 | 15,01,099 |
| Total | | | 123050 | 104648 | 18402 | 68749 | 23,36,30,090 |
| | | ऊस | 24693 | 19387 | 5306 | 16286 | 10,35,11,423 |
| | | पिक | 637992 | 483423 | 154569 | 366852 | 1,91,96,53,319.56 |
| | | फळझाड | 8385 | 6634 | 1751 | 5720 | 8,10,23,280 |
| Grand Total | | | 671070 | 509444 | 161626 | 388858 | 2,10,41,88,022.56 |

***Table 2:*** *Compensation data on crop damage (2020 to 2024*

| Compensation Data 2020 to 2024 (Forest Department of Maharashtra) | Reported by Farmers | Accepted for Compensation by Forest Department | Rejected by Forest Department | Disposed by Forest Department |
|---|---|---|---|---|
| Number of Cases for Compensation | 10,59,928 | 5,09,444 | 1,61,626 | 3,88,858 |
| | | 48% | 15% | 37% |
| **Total Compensation paid (2020 to 2024)** | | **₹ 210.42 Crore** | | |

***Table 3:*** *Total Cases reported by Farmers for compensation (Crop Damage) in 2020 to 2024 and Compensation Paid for state of Maharashtra*

Net compensation given throughout the state is a small fraction of the actual loss, and the data of compensation paid is not representative of the real problem in the state. (Annexure 2)

## [B] Problems faced by farmers and Forest Department personnel in dealing with Crop damage cases

*"Only when crop destruction stops, we can talk about being non-destructive." Farmers and horticulturalists, Taluka Dapoli, Dist. Ratnagiri, Maharashtra*

The Maharashtra Forest Department and TATR had organized a conference on "Novel non-destructive strategies for population control of locally abundant herbivores and large carnivores outside protected area". Titled the WildCon 2025, this was a two-day conference in Chandrapur. Although the conference was to discuss and debate the wild herbivore conflict affecting farmers, no farmer was invited. However, one poster sent by farmers was accepted and one farmer attended and presented it (Figure 2).

After the conference Dr. Milind Watve conveyed to the PCCF (Wildlife) over email a detailed report of the problems faced by farmers and the forest department personnel in implementing crop damage compensation. The report is also enclosed below. This gives some idea about why the compensation protocol fails to give justice to famers by paying realistic compensation.

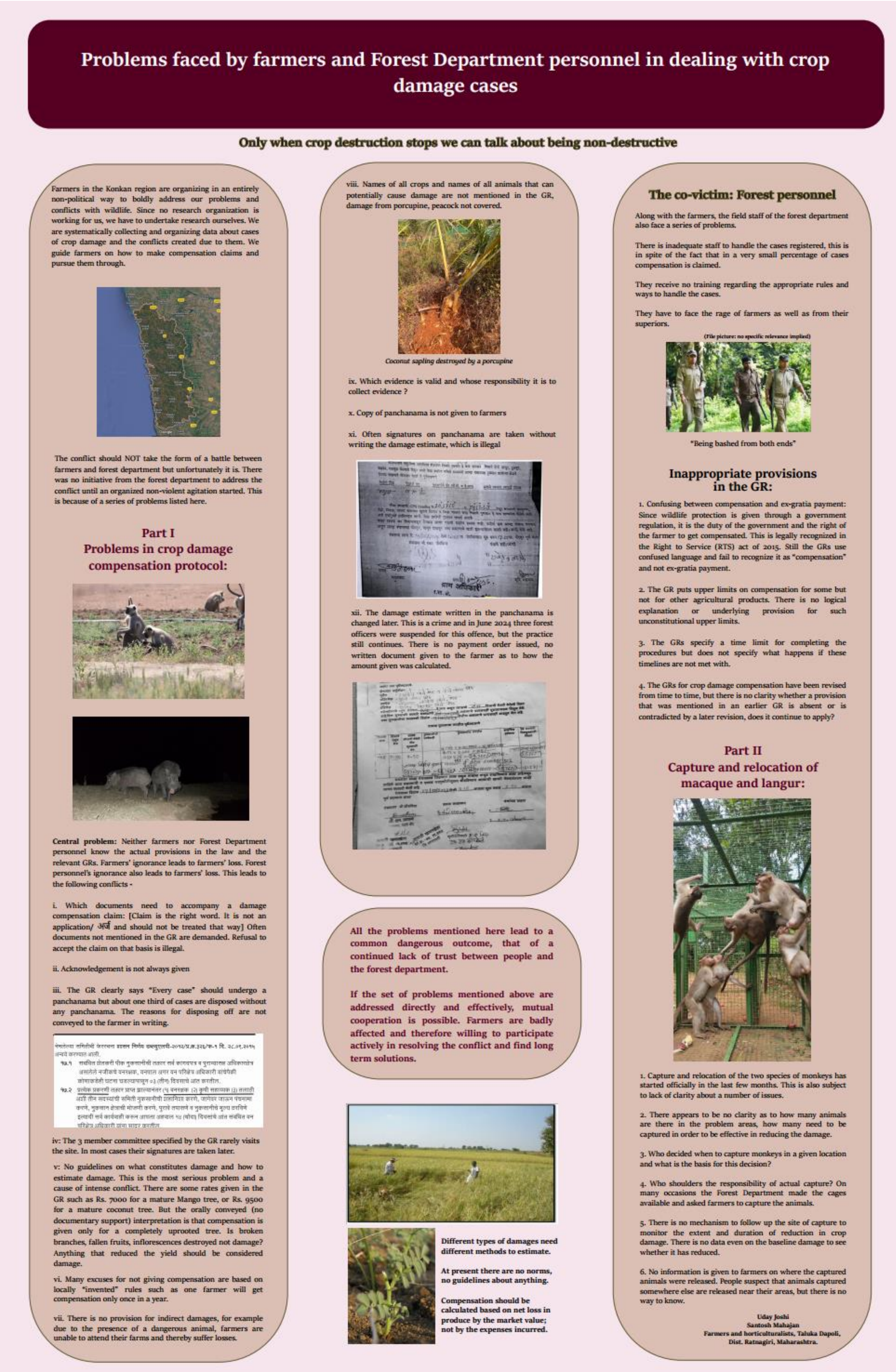



***Figure 2:*** *Poster submitted by farmers in WildCon 2025.*

**Copy of report submitted by Dr. Milind Watve to the PCCF (Wildlife).**

**Problems faced by farmers and the forest department personnel in implementing crop damage compensation.**

The problem of crop damage by wild animals is getting increasingly serious. Although long term solutions are being worked out, an immediate relief is very crucial in keeping the conflict limited. A legal provision for compensating affected farmers exists which can effectively defuse the tension but is largely underutilized. We have identified the following problems in the protocols which prevent realistic, smooth and efficient implementation of the provision.

**Central problem**: Our study revealed that neither farmers nor many Forest Department officials know the actual provisions in the law and the relevant GRs. Hence, the farmers' ignorance leads to farmers loss and the forest officials' ignorance exacerbates the loss. We noticed that this ignorance leads to the following conflicts:

i. Confusion about which documents need to be attached to the compensation claim: [Claim is the right word. It is not an application/ अर्ज and should not be treated that way] Often documents not mentioned in the GR are demanded by Forest officials. However, refusal to accept the claim on that basis is illegal.

शासन परिपत्रक क्रमांक: **डब्ल्यूएलपी-२०१६/प्र.क्र.२९०/फ-१**

नेमलेल्या समितीची फेररचना **शासन निर्णय डब्ल्युएलपी-२०१२/प्र.क्र.३२६/फ-१ दि. २८.०९.२०१५** अन्वये करण्यात आली.

१७.१ सबंधित शेतकरी पीक नुकसानीची तक्रार सर्व कागदपत्र व पुराव्यासह अधिकारक्षेत्र असलेले नजीकचे वनरक्षक, वनपाल अगर वन परिक्षेत्र अधिकारी यांचेपैकी कोणाकडेही घटना घडल्यापासून ०३ (तीन) दिवसाचे आंत करतील.

१७.२ प्रत्येक प्रकरणी तक्रार प्राप्त झाल्यानंतर (१) वनरक्षक (२) कृषी सहाय्यक (३) तलाठी अशी तीन सदस्यांची समिती नुकसानीची शहानिशा करणे, जागेवर जाऊन पंचनामा करणे, नुकसान क्षेत्राची मोजणी करणे, पुरावे तपासणे व नुकसानीचे मूल्य ठरविणे इत्यादी सर्व कार्यवाही करून आपला अहवाल १४ (चौदा) दिवसांचे आंत संबंधित वन परिक्षेत्र अधिकारी यांना सादर करतील.

१७.३ समितीने सादर केलेला अहवाल संबंधित वन परिक्षेत्र अधिकारी संबंधित सहाय्यक वनसंरक्षक / विभागीय वन अधिकारी / उपवनसंरक्षक यांना ०४ (चार) कामाच्या दिवसांच्या आंत सादर करतील.

ii. When farmers submit the compensation claim, they rarely get an acknowledgement of the claim form.

iii. The GR clearly says "Every case" should undergo a *Panchanama* but we noticed that 37 % of cases are disposed/rejected without any *Panchanama* (Table 3).

iv. A three-member committee comprising of forest guard, krishi sahayak and Talathi is mandated by the GR. However, we found that the three members often do not visit the site for the *Panchanama*.

v. The absence of guidelines on what constitutes "damage" and how to estimate the damage is the most serious problem, and a cause of intense conflict between farmers and forest officials. The GR gives arbitarary compensation rates from Rs.500 to Rs.7000 for a Mango tree and Rs 500 to 9500 for a coconut tree. But the verbally conveyed interpretation without documentary support, is that compensation is only given for a completely uprooted tree. However, broken branches, fallen fruits, destroyed inflorescences and more such events are also damage to the farmer. Anything destruction by wildlife that has reduced the income possibility to the farmer must be considered in the damage calculations.

vi. The GR does not mention all the crops and all animals that can potentially cause damage. For example, damages from porcupine and peacock are not covered, and the Rose crop is not covered in the GR.

vii. There is no clarity about which evidence is valid, and whose responsibility it is to collect the evidence.

viii. A common problem we encountered was that the farmers do not get a copy of the *Panchanama*. This hampers their ability to appeal for delays and other issues.

ix. Often signatures on *Panchanama* are taken without writing the Rupee estimate of the damage. This is an illegal practice.

x. There are several cases where the damage estimates written in the *Panchanama* were later changed. This is a crime and in June 2024 three forest officers were suspended for this offence. But this practice continues. There is no payment order issued, no written document given to the farmer as to how the amount given was calculated.

xi. Often, excuses for not giving compensation are based on "invented" rules. A farmer can be compensated only once in a year, is one such 'invented' rule.

xii. There is no provision for indirect damages. For example, when there is a presence of a dangerous carnivore farmers are unable to attend to their farms. Thus they suffer losses. This is not provided for in the GR.

xiii. Many farmers are afraid of some vindictive action by the Forest Department officials. There is no clarity on what is considered a crime under the wild life act and the lack of clarity creates an unnecessary fright that is detrimental to resolving the conflict.

**The co-victim: Forest personnel**

It is not just the farmers, but the field staff of the forest department also face a number of problems.

1. There is inadequate staff to handle the cases registered, this is in spite of the fact that in a very small percentage of cases compensation is claimed.
2. They receive no training regarding the appropriate rules and ways to handle the cases.
3. They have to face the rage of farmers as well as from their superiors.

**Inappropriate provisions in the GR**

1. Lack of clarity between compensation and ex-gratia payment: Since wildlife protection is given through a government regulation, it is the duty of the government and the right of the farmer to get compensated. This is legally recognized in the Right to Service (RTS) act of 2015. Yet, the GRs use confusing language and fail to recognize it as "compensation" and not ex-gratia payment.
2. The GR puts upper limits on compensation for some but not for other agricultural products. There is no logical explanation or underlying provision for such unconstitutional upper limits.
3. The GRs specify a time limit for completing the procedures but does not specify what happens if these timelines are not met with.
4. The GRs for crop damage compensation have been revised from time to time, but there is no clarity whether a provision that was mentioned in an earlier GR is absent or is contradicted by a later revision, does it continue to apply?

**Capture and relocation of macaque:**

Bonnet macaque captured by forest department at Sindhudurg (Koldhar)

The capture and relocation program for two species of monkeys was officially started in 2024. This is also subject to lack of clarity about a number of issues.

1. There appears to be no clarity as to the population of animals in the area, and how many need to be captured for effectively reducing the damage.
2. Who decides when to capture monkeys in a given location and what is the basis for this decision?

3. Who shoulders the responsibility of actual capture? On many occasions the Forest Department made the cages available and asked farmers to capture the animals.
4. There is no mechanism to follow up the site of capture to monitor the extent and duration of reduction in crop damage. There is no data even on the baseline damage to see whether it has reduced.
5. No information is given to farmers on where the captured animals were released. People suspect that animals captured somewhere else are released near their areas, but there is no way to know.

All the problems we note here lead to a common dangerous outcome, that of a **continued lack of trust between people and the forest department**. However, if these issues are addressed directly and effectively, it could pave the way for greater collaboration. Farmers, who are among the most affected and therefore are willing to participate actively in resolving the conflict and find long term solutions.

# Annexure 2

## Farmers' perception of net losses from wildlife in Maharashtra

In this Annexure, we present the data from our primary research, collected from 1151 farmers across Maharashtra. We documented the perceptions of farmers about the losses they incurred. We collected data only from farmers whose output was affected by wildlife raids. Hence, we do not have estimates of the proportion of farmers who suffer losses. We noted patterns of losses among the ones who do.

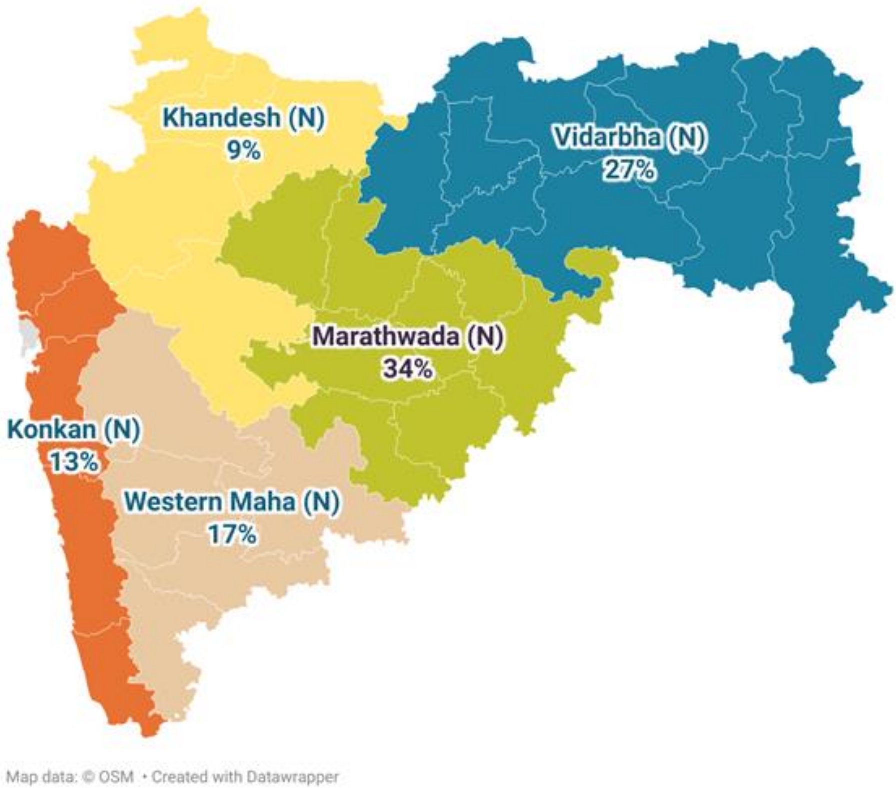



***Figure 1:*** *Distribution of respondent farmers (%) across six landholding categories in different regions of Maharashtra: Vidarbha, Marathwada, Khandesh, Western Maharashtra and Konkan.*

| Farmer category by land holding | Respondent percent |
| --- | --- |
| Marginal | 13% |
| Small | 19% |
| Semi-medium | 31% |
| Medium | 29% |
| Large | 8% |

***Table 1:*** *Respondent farmers by land holding*

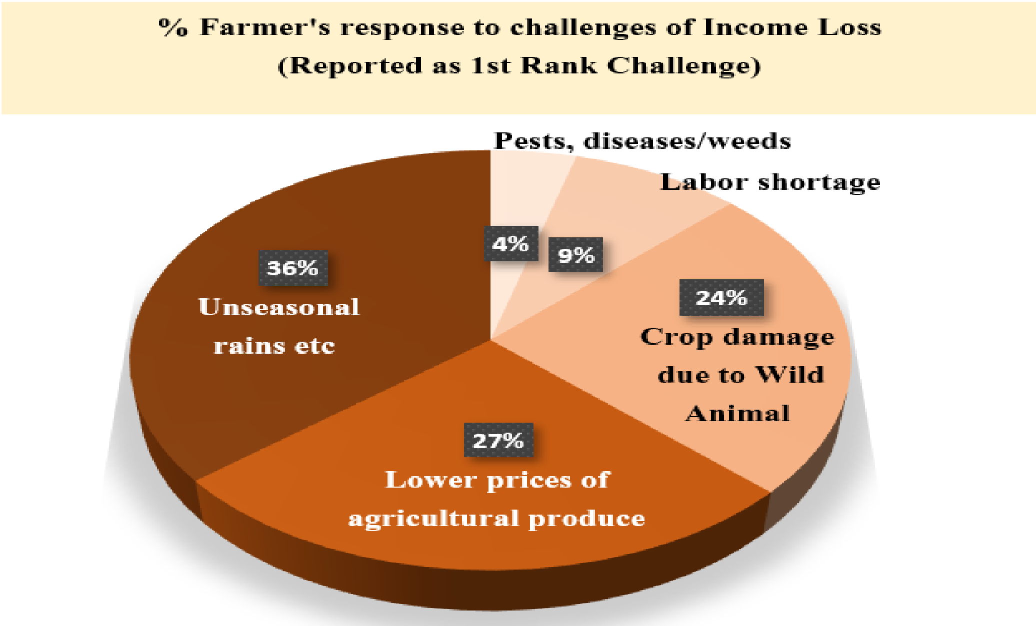



***Figure 2:*** *What are the main reasons for loss of farm incomes?*

**Perception of farmers about crop damage by wild Animals**

A significant proportion of farmers (24%) identified crop damage caused by wild animals as the primary challenge contributing to their income loss

**Estimation of Crop Damage caused due to wild animals based on Farmers Perception**

Based on judgment of 922 farmers from sample population the per hectare annual income across Maharashtra due to wildlife-related crop damage stands at ₹27,195.

| Geographical Region | Number of Farmers | Area Under Cultivation in Ha | Direct Loss per year | Per Year Per Ha Loss |
|---|---|---|---|---|
| Khandesh | 76 | 373 | 77,66,500 | 20,822 |
| Marathwada | 315 | 1,483 | 3,54,38,000 | 23,896 |
| Vidarbha | 254 | 1,158 | 3,24,32,000 | 28,007 |
| Western Maha | 149 | 449 | 1,29,14,500 | 28,763 |
| Konkan | 128 | 367 | 1,55,99,000 | 42,504 |
| **Total (N=922)** | **922** | **3,830** | **10,41,50,000** | **27,195** |

***Table 2*** *- Estimation of Net Farmer Income Loss due to crop damage caused by wild animals*

**Wild animals responsible for crop damage across different regions of Maharashtra.**

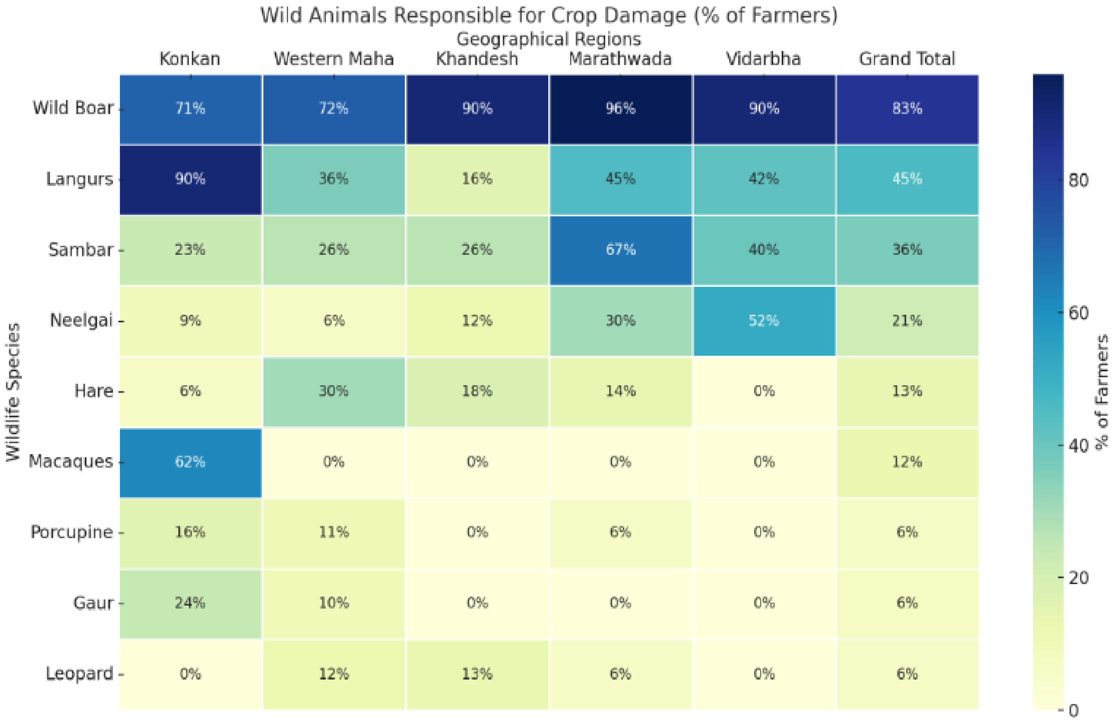



***Figure 3** – Wild Animals Responsible for Crop Damage and % of Farmers reported across all regions*

Wild pigs are the most damaging overall and affecting the highest percentage of farmers in all regions, especially in Vidarbha (96%), Marathwada (90%) and Khandesh (90%). Langurs are a major issue in Konkan (90%) while Sambar significantly affect Marathwada (67%). Nilgai are particularly problematic in Vidarbha (52%). Other species like macaques, hares, gaur, and leopard impact fewer farmers with notable macaque presence in Konkan (62%).

| **% of Farmers across Maharashtra** | **Number of different wild species attacking one Farm** | | | | | | |
|---|---|---|---|---|---|---|---|
| | One Species | Two Species | Three Species | Four Species | Five Species | Six Species | Seven Species |
| Khandesh | 41% | 34% | 18% | 6% | 2% | | |
| Konkan | 15% | 18% | 36% | 19% | 8% | 5% | 1% |
| Marathwada | 16% | 28% | 34% | 18% | 4% | 2% | 1% |
| Vidarbha | 29% | 28% | 24% | 14% | 4% | 1% | |
| Western Maha | 31% | 35% | 16% | 13% | 4% | 2% | |
| **Total (N=1154)** | **24%** | **29%** | **27%** | **15%** | **5%** | **2%** | **1%** |

***Table 3:** Percentage of Farmers reported the Number of different wild animal species responsible at one farm*

Majority of farmers face damage from multiple animal species. Overall, 76 % of farmers claimed that they are affected by more than one species, indicating multi-species crop damage.

**Spread of Farmer – wildlife conflict**

Despite having very low forest cover, the Marathwada region of Maharashtra faces significant human-wildlife conflict. Farmers have reported crop damage caused by as many as seven different wild animal species. Notably, 34% of farmers indicated that three different species were responsible for damaging crops on a single farm. This highlights that wildlife conflict is not confined to areas with dense forests but is increasingly affecting regions with limited forest cover as well.

| | Percent of responses: We reduced area under cultivation due to wildlife raids | Percent of responses: We discontinued at least one crop due to wildlife raids |
|---|---|---|
| Khandesh | 59% | 58% |
| Konkan | 80% | 67% |
| Marathwada | 64% | 72% |
| Vidarbha | 50% | 24% |
| Western Maha | 55% | 58% |
| **Total** | **62%** | **54%** |

***Table 4:*** *Reduction in area of cultivation and discontinuation of crops by farmers*

More than 50% of farmers from sample population reported that they have reduced their areas under cultivation due to frequent crop raiding by wild animals and 54% farmers discontinued atleast one potential crop.

**Discontinuation of Kitchen gardens**

Based on field observation every house in the konkan region use to have kichen garden due to terrain and spaces around houses and they are most common source of vegetables and fruits for them. But in current situation 83% of farmers from Konkan region said that they have to buy vegetables and fruits from the market due to damage caused by wild animals in their kitchen gardens.

**Mitigation measures implemented by farmers to protect their crops from wild animals**

Farmers reported mitigation measured applied by them and according to farmers, these mitigation measures are only 25% effective in protecting crops from wild animals also this cost is not included in compensation.

| Mitigation Measure | Percentage of respondents |
|---|---|
| 1. Guarding | 67% |
| 2. Scarecrow | 61% |
| 3. Electronic sound devices / Lights | 28% |
| 4. Electric shock machines / Solar fencing | 24% |
| 5. Use of chemical repellents | 10% |
| 6. Pit | 5% |
| 7. Fencing | 3% |
| 8. Installing cameras | 3% |
| 9. Firecrackers | 1% |

*Table 5: Mitigation measures that farmers use to protect their crops from wild animals*

**Compensation Provided by Forest Department**

| Why farmers Not report their crop damage for compensation | % Farmers (Out of 72%) |
|---|---|
| 1. Farmers are not aware of the compensation process | 56% |
| 1. They did not get any assistance after reporting | 6% |
| 2. Farmers reported that, paper work needed in current compensation process is time consuming and not easy to collect. | 4% |
| 3. Farmers reported that they did not get the compensation | 4% |
| 4. Farmers are not satisfied with the amount given as Compensation | 2% |

***Table 6:*** *Reasons claimed by farmers for not claiming compensation*

**Farmers Applications for Compensation for crop damage based on Primary Survey**

- 28% of farmers reported that they applied for compensation in only 25% of the total instances of crop damage, indicating a significant gap between actual losses and reporting.
- Out of 28% farmers who have applied for compensation, only 4% farmers get compensation as per there judgment of loss
- 72% farmers were going through losses but do not apply for compensation because majority of them are not aware of this process.

| **Compensation Data 2020 to 2024** (Forest Department of Maharashtra) | **Reported by Farmers** | **Accepted by Forest Department** | **Rejected by Forest Department** | **Disposed by Forest Department** |
|---|---|---|---|---|
| Number of Cases for Compensation | 10,59,928 | 5,09,444<br>(48%) | 1,61,626<br>(15%) | 3,88,858<br>(37%) |
| **Total Compensation paid (2020 to 2024)** | | **₹ 210.42 Crore** | | |

***Table 7:*** *Total Cases reported by Farmers for compensation (Crop Damage) in 2020 to 2024 and Compensation Paid for state of Maharashtra*

### 5.3 Comparison between Assumption of farmer income loss estimated from our study compensation provided by forest department

Assumptions for annual Income loss for Maharashtra, due to crop damage by Herbivores

- Based on primary survey: Per Ha Annual Income loss of Farmers due to crop damage by wild animals is 27,195/-
- Total Cultivated Land in Maharashtra = 21.32 Million Ha (Economic Survey of Maharashtra 2024-25
- Total Amount of Compensation given to farmers for Crop Damage by forest department = ₹ 210.42 crore. (2020 to 2024)

If we assume only 20% of cultivated area is damaged by wild animals annually then based on data given by forest department shows that compensation paid against income loss of 11,594 Cr is less than 1% only.

***Table 8*** *- Assumptions for annual Income loss for Maharashtra, due to crop damage by Herbivores*

| Assumption % Damage of Area under cultivation | Income Loss (₹ Crore) | Damaged Land (Million Hectare) |
|---|---|---|
| 20% | ₹11,594 | 4.26 |
| 40% | ₹23,187 | 8.53 |
| 60% | ₹34,781 | 12.79 |
| 80% | ₹46,374 | 17.06 |
| 100% | ₹57,968 | 21.32 |

Farmers opinion /expectations for Mitigation measures and supported by Government of Maharashtra

| Mitigation measures – Farmers Expectations | Percentage of Farmers |
|---|---|
| Compensation | **53%** |
| Subsidy for fencing solar wires/ Fencing | **48%** |
| More concrete measures from the government | **41%** |
| Subsidy on jhatka machines (subsidy) | **39%** |
| Permission to kill animals | **13%** |

***Table 9*** *- Farmer expectations on mitigation measures and % of farmers Reported*

**Conclusion**-

According to our study only less than one percent damage is compensated and amount of agricultural income loss is in between range of 11,000 crores to 57,000cr annually for state of Maharashtra (Table No 8). Compensation amount is misleading to understand magnitude of this problem as majority of farmers are not aware of this process and process is not farmer friendly, (Table No 6)

62% of Farmers reduced area under cultivation due to wild animal raiding and 54% of Farmers discontinued at least one potential crop due to wild Animals raiding. Farmers are implementing mitigation measures as mentioned in table no 5, they have only 25% effectiveness as per farmer opinion. 83% of farmers from Konkan region said that they have to buy vegetables and fruits from the market due to damage caused by wild animals in their kitchen gardens. These non-visual losses are not considered in the any compensation.

Compensation data shared by forest department and our primary data shows that farmers from across Maharashtra irrespective of dense forest areas are going through income loss due wild animals raiding. There are total nine wild animal species responsible for crop damage across six regions of Maharashtra. These species include wild pig, langur, sambar, nilgai, hare, macaque, porcupine, gaur and leopard. (Graph 2) Majority of farmers face damage from multiple animal species. Overall, 76 % of farmers claimed that they are affected by more than one species, indicating multi-species crop damage. (Table No2)

**Stakeholder Consultation meetings conduted across Maharashtra with farmers,forest department officials,local organization. To aware farmers about current compensation process and to uderstand Challenges about this process.**


# Annexure 3

### Agricultural ecological economic-geography (eco-econography) of Farmer families from Ratnagiri and Sindhudurg districts

The Konkan region, located along the western coast of India, is known for its rich biodiversity and unique cropping pattern influenced by its coastal climate, high rainfall and lateritic soil. The farming is diverse and highly dependent on monsoon. Rice, cashew, mango, coconut, and arecanut are the dominant crops, while pulses, millets, spices, and vegetables add to the variety.

Human-wildlife conflict in Konkan is a complex issue influenced by challenging terrain, seven different wild species including Gaur, wild pig, elephants, porcupine and giant squirrel, with dominant species of monkey (Macaques, Langurs). In Konkan, incomes depend on agroforestry and cash crops. Measures to mitigate animal conflicts are limited. Fencing around farm is difficult because of the terrain. Moreover, the crop damage loss is not near the vicinity of protected forest areas. We interviewed farmers and took their perception of net farm losses. The average farm loss is ₹42,504 per hectare, highest compared with the other regions in Maharashtra (Annexure 2). We noted the estimated damages per hectare per annum, and included visual and non-visual losses. The study was conducted in the Ratnagiri and Sindhudurg districts of Konkan region.

We adopted a mixed-method approach combining qualitative and quantitative data to ensure a comprehensive analysis with detailed assessment of farmers' experiences and quantitative measurement of economic losses. We conducted guided interviews with 25 farmer families, 10 from Sindhudurg and 15 from Ratnagiri district. The respondents were selected by snowball sampling. The inclusion criteria were (i) Having a mixed Agri-horticultural cropping pattern. (ii) Educated families who keep reliable records of their agricultural activities in detail (iii) Covering various landscapes as Konkan has both costal and hilly areas.

### 2.1 Study Area and Sample Selection

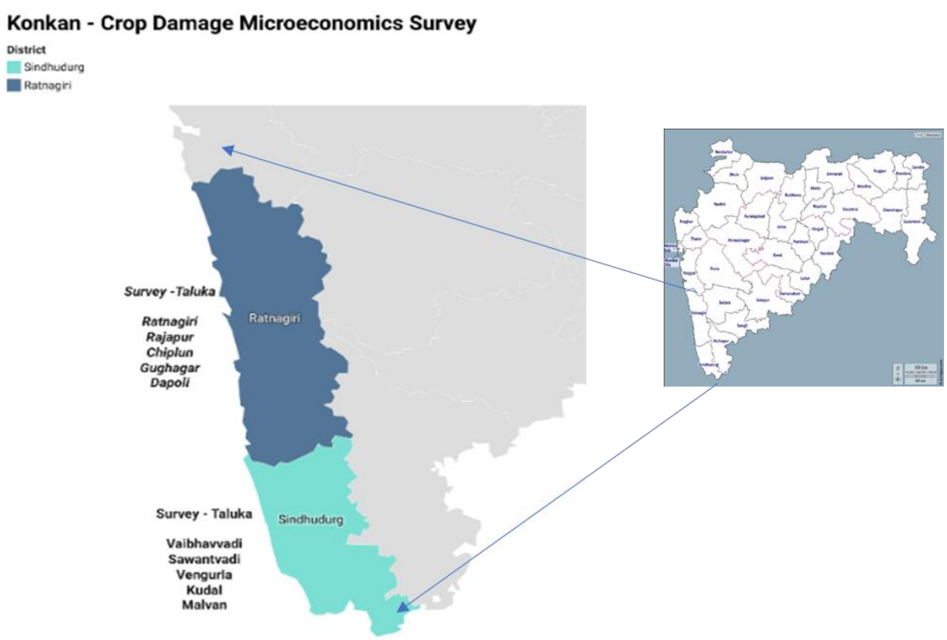



Figure 1: Study Area within Maharashtra Ratnagiri and Sindhudurg District

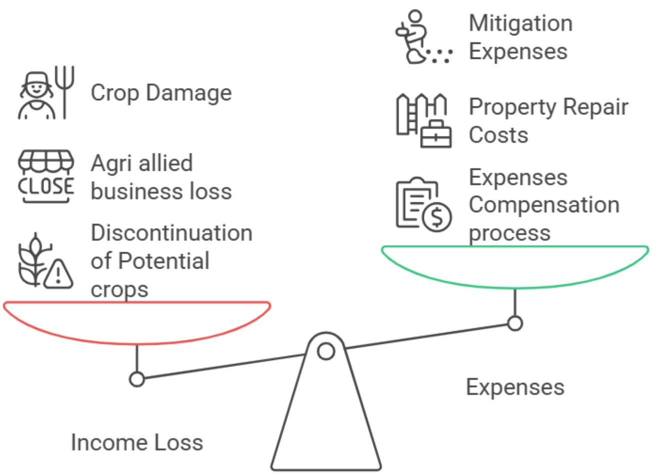
## 1. Sample Distribution and Demographic of farmer families

Table 1 : Sample Distribution and Demographic profile of Farmer Families

| | Ratnagiri | Sindhudurg |
|---|---|---|
| Total Number of Farmer Families | 15 | 10 |
| Blocks – Study Locations | Ratnagiri,Rajapur, Chiplun, Guhagar, Dapoli | Vaibhavwadi, Sawantvadi, Vengurla, Kudal, Malvan |
| Total Area Under Cultivation (Ha) | 45 | 64 |
| **Land Holding Category** | **Number of farmers (Sample distribution)** | |
| Marginal (Below 1 ha) | 3 | 0 |
| Small (1 to < 2 Ha) | 2 | 2 |
| Semi Medium (2 to < 4 Ha) | 5 | 3 |
| Medium (4 to < 10 Ha) | 5 | 3 |
| Large (10 Ha and Above) | 0 | 2 |

## 2. Visual and Non-Visual Net Per Ha Income Loss Due to Wildlife

The impact of crop damage by wild animals on farmers includes both visual and non-visual aspects, leading to significant income loss and additional expenses. Visual impacts, such as direct crop damage and property destruction are immediately observable and result in tangible losses. However, non-visual impacts—like the loss of Agri-allied businesses, discontinuation of potential high-value crops, ongoing mitigation expenses and costs involved in navigating compensation processes—often remain unaccounted for despite their long-term financial burden. Together, these factors not only reduce farm income but also increase economic stress on farmers




**Income Loss and Expenses of Farmers (Visual and Non Visual Impacts of Crop damage by Wild animals)**

***Fig 2-*** *Visual and Non-Visual Impacts of Crop Damage by Wild animals*

***Table 2 -*** *Crops cultivated by Sample population and Value-added Products with average rate shared by farmers*

| **Crops cultivated by respondents** | **% Respondents $N_1$ Ratnagiri $N_2$= Sindhudurg** | **Yield** | **Average Rate realized by farmers** | **Allied Value added Products** | **Average Rate realized by farmers** | **Other uses Non-quantified** |
|---|---|---|---|---|---|---|
| | | | **Fruit Crops/Horticulture** | | | |
| Arecanut | $N_1$=40%, $N_2$=30% | Nuts | Rs 311/kg | - | - | Stem used for water carrying |
| Banana | $N_1$=7%, $N_2$=0% | Fruit | Rs 40 /Dozen | - | - | Flower - vegetable, Leaves - plates, Stem - replantation |
| Cashew | $N_1$=60%, $N_2$=80% | Nuts | Rs 112/Kg | - | - | - |
| Coconut | $N_1$=53%, $N_2$=70% | Fruits | Rs 18/Per Coconut | - | - | - |
| Jackfruit | $N_1$=27%, $N_2$=0% | Fruits | Rs 43/Per Fruit | Jackfruit chips | Rs 600/Kg | - |
| Mango | $N_1$=73%, $N_2$=60% | Fruits | For Box Quality 328/Dozen and For Canning Rs 35/ Kg | | | - |
| Kokum | | Fruits | - | Aamsul | Rs 283/Kg | - |
| **Crops cultivated by respondents** | **% Respondents I Ratnagiri $N_2$= Sindhudurg** | **Yield** | **Average Rate realized by farmers** | **Allied Value added Products** | **Average R realized b farmers** | **Other uses Non-quantified** |
| | | | **Agri Crops** | | | |
| Black Eyed Bean (Chawli) | $N_1$=13%, $N_2$=20% | Grain | Rs 112/kg | - | - | - |
| Horse gram (Kulith) | $N_1$=40%, $N_2$=30% | Grain | Rs 95/kg | - | - | - |
| Kadve (Lima beans vari | $N_1$=7%, $N_2$=10% | Grain | Rs 120/kg | - | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mash melon (Chibud) | $N_1$=0%, $N_2$=10% | Grain | Rs 40/kg | - | - | - |
| Moong | $N_1$=13%, $N_2$=0% | Grain | Rs 80/kg | - | - | - |
| Pawta (Lima Beans) | $N_1$=13%, $N_2$=0% | Grain | Rs 125/kg | - | - | - |
| Ragi | $N_1$=33%, $N_2$=30% | Grair | Rs 50/kg | - | - | - |
| Rice | $N_1$=73%, $N_2$=80% | Grain | Rs 22/kg | - | - | - |
| Tuber crops (Kan SweetPotato) | $N_1$=0%, $N_2$=10% | Grain | Rs 70/kg | - | - | - |
| Udid (Black Gran | $N_1$=0%, $N_2$=20% | Grain | Rs 100/kg | - | - | - |
| Varai | $N_1$=7%, $N_2$=0% | Grain | Rs 120/kg | - | - | - |
| **Other** | | | | | | |
| Bamboo | $N_1$= 0%, $N_2$ =50% | Stem | Rs 59 per Stick | - | - | - |
| Turmeric | $N_1$=7%, $N_2$=0% | Root | Rs 300/kg | - | - | - |

**4.2 Discontinuation potential high-value crops (Crop list and % of farmers)**

A notable percentage of farmers have stopped cultivating following crops due to consistent damage by wild animals. Earlier, farmers used to grow them for both **household consumption and income through sales**, but now they are **forced to buy these from the market**. This leads to increasing their dependency and expenses. The most discontinued crops include **cowpea, ragi, and groundnut (24% each)**, followed by **chilli (20%), field beans and brinjal (16%)**, and several others like **okra, radish, green gram, and bitter grains (12%).** Even fruits like **banana and coconut (8%)**, as well as various vegetables and coarse grains (4–8%), are being abandoned.

***Table 3** – List of Discontinued crops due to frequent wildlife raiding and % Farmers*

| Crop | Crop Type | % of Farmer Families |
|---|---|---|
| Chawli (Cowpea) | Grain | 24% |
| Nachni (Ragi) | Grain | 24% |
| Groundnut | Other | 24% |
| Chilli | Vegetable | 20% |
| Pavta | Grain | 16% |
| Brinjal | Vegetable | 16% |
| Kadve | Grain | 12% |
| Moong | Grain | 12% |
| Okra (Bhendi) | Vegetable | 12% |

| | | |
|---|---|---|
| Radish | Vegetable | 12% |
| Banana | Fruit | 8% |
| Chikoo | Fruit | 8% |
| Coconut | Fruit | 8% |
| Kulith (Horse Gram) | Grain | 8% |
| Tomato | Vegetable | 8% |
| Snake Gourd | Vegetable | 8% |
| Pineapple | Fruit | 4% |
| Watermelon | Fruit | 4% |
| Udid (Black Gram) | Grain | 4% |
| Toor (Pigeon Pea) | Grain | 4% |
| Phajav (Cowpea type) | Grain | 4% |
| Coarse Cereals | Grain | 4% |
| Rice | Grain | 4% |
| Varai (Millet) | Grain | 4% |
| Areca Nut | Other | 4% |
| Bamboo | Other | 4% |
| Turmeric | Other | 4% |
| Cucumber | Vegetable | 4% |
| Coriander | Vegetable | 4% |
| Cluster Beans | Vegetable | 4% |
| Bottle Gourd | Vegetable | 4% |

## Estimation of annual income loss per family, based on farmers perception

We computed the income loss by wildlife raids using the following formula:

*Annual income loss Rs. per family = (A. Loss by Crop Damage) + (B. Loss by Crop Discontinuation) + (C. Loss in agri-allied businesses) + (D. Property Repair Cost) +(E. Expenses on Mitigation measures)*

### A. Loss by Crop Damage

| | Details of Information | Estimation of Net Income loss |
|---|---|---|
| **Current cropping pattern** | List of current crops (Horticultural and seasonal grain crops)<br><br>Area Under Cultivation and Number of trees for a horticultural crop<br><br>Current production (Quantity)<br><br>Potential production in absence of wild Animals (Quantity)<br><br>Percentage of per crop loss due to wild animals<br><br>Rate of produce | Per Crop visual Income Loss = (Potential production*current rate) - (Current production*Current Rate)<br><br>By adding per crop loss Per farmer family total direct loss is calculated |

**Example of loss** Estimation by Crop Damage

| Farmer from Rajapur Taluka (Current Crops) | Cashew | Coconut | Mango* | Kulith | Rice | Total Annual Loss |
|---|---|---|---|---|---|---|
| **Category** | Fruit Crop | Fruit Crop | Fruit Crop | Grain | Grain | |
| **Area (Acres)** | 3 | | | 3 | | |
| **No. of Trees** | 125 | 30 | 125 | – | – | |
| **Current Production** | 320Kg | 900 nos. | – | 200 Kg | 2800 Kg | |
| **% Loss Claimed (Due to Wild Animal Raiding)** | 20% | 50% | – | 50% | 20% | |
| **Loss** | 80 Kg | 900 nos. | – | 200 Kg | 700 Kg | |
| **Potential Production (Absence of Wild animals)** | 400 Kg | 1800 nos. | – | 400 Kg | 3500 Kg | |
| **Current Market Rate (₹)** | 110 Rs /Kg | 15 Rs/nos. | – | 80 Rs/Kg | 20 Rs/Kg | |
| **Annual Loss (₹)** | **8,800** | **13,500** | **3,68,667*** | **16,000** | **14,000** | **4,20,967** |

Estimation Details for Mango Crop *

| Crop Name | Mango |
|---|---|
| i. Number of Trees | 125 nos. |
| ii. Current Quantity for Box Quality in Kg | 1800 Kg |
| iii. Quantity Mango for Pulp in Kg | 200 Kg |
| iv. Total Quantity in Kg | 2000 Kg |
| v. % of Mangoes in Box | 90% |
| vi. % of Mangoes for Canning | 10% |
| vii. Loss % claimed by Farmers | 70% |
| viii. Loss in Kg | 4667 Kg |
| ix. Total Potential Production in Kg (In absence of Wild animals) | 6667 Kg |
| x. Loss for Box Quality Mango in Kg (based on "v.") | 4200 Kg |
| xi. Loss for Box Quality Mango in Dozen (Assumption: 3kg = 1 Dozen, 1kg = 4 mango) | 1400 Dozen |
| xii. Loss for Canning Quality Mango in Kg (based on "vi") | 467 Kg |
| xiii. Rate for Dozen (Box Quality) shared by farmers | Rs. 250 /Dozen |
| xiv. Rate for Kg (Canning Quality) shared by farmers | Rs 40/Kg |
| xv. Amount of Loss for Box Quality (Total) | Rs 3,50,000 |
| xvi. Amount of Loss for Canning Quality (Total) | Rs 18,667 |
| **Annual Loss for Damage to Mango (xv+xvi)** | Rs 3,68,667 |

### B. Loss by Crop Discontinuation

| | Details of Information | Estimation of Net Income loss |
|---|---|---|
| Discontinued potential crop details, loss of Agri residue for livestock<br><br>(Condition applied- If this discontinuation is caused by wild animals) | ▪ List of crops that have been discontinue due to damage caused by wild animals<br>• Quantity of production in Past<br>• Rate of produce in Past<br>• Quantity of produce purchased for domestic consumption<br>• Market Rate<br>• Agri residue requirement (due to crop discontinuation) and market rate | Total loss due to discontinuation of crops = Per crop Extra expenses paid for Agri produce for domestic purposes (Current Quantity required * Market Price)<br>+<br>Per crop Extra expenses paid for Agri residue used for pet animals (livestock) |

**Example: Estimation of Income Loss due to discontinuation of Potential crop**

| | Discontinued Crop : Ragi |
|---|---|
| Area under cultivation | 3 Acre |
| Number of years for discontinuation | 10 |
| Quantity of production in Past | 500 Kg |
| If Farmer need to buy this produce from Market for House hold (Yes/No) | Yes |

| | |
|---|---|
| If yes then Quantity required | 50 Kg |
| Rate (Market Rate) | Rs 40/Kg |
| **Total for Extra Expenses/ Income Loss due to Discontinuati of Crops (Rs)** | **Rs 2000** |

(Data Gap: For all farmer families We do not have data of, if currently this land is fallow or under cultivation of different crops)

### C. Loss in agri-allied businesses

| | Details of Information | Estimation of Net Income loss |
|---|---|---|
| Per year loss of Agri allied home based Business<br><br>(Condition applied - home grown Agri produce is used for production of value-added products) | • List of products<br>• Current production and rate<br>• Potential production and rate in absence wild animals<br>• If business is discontinued due to freque damage | Agri allied business loss = Potential production*Rate - current production*Rate<br><br>By adding per product loss Per farmer family total Agri allied business loss is calculated |

**Example - Income Loss of value-added products (Agri-allied business Loss)**

| Crop Name | Kokum |
|---|---|
| **Value added product** | Aamsul |
| Form of damage | Damage to fruits due to Macaque |
| Quantity of Production | 100 Kg |
| Loss due to Wild animals claimed by Farmer | 100 Kg |
| % Loss claimed by farmer | 100% |
| Rate of Value-added product | Rs. 300/Kg |
| **Total Loss due damage to Agri allied business** | **Rs. 30000** |

### D. Property Repair Cost

| | Details of Information | Estimation of Net Income loss |
|---|---|---|
| Property damage including (e.g. Irrigation Pipe, Ceiling etc.) | Types of property and per year Repairing cost | Per year cost required for property repair damaged by wild animals |

**Example – Property Repair Cost (Loss due to Property Damage)**

| Damage causing Wild animals | Number of Wild Animals present at a Time | Frequency of sightings per Week | Season of Maximum Damage | Type of Damages | Annual repair cost claimed by farmers |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Langur | 50-60 | Every week | throughout the year | Damage to roof of the house, Damage to "Panhal" (Pipe made from arecanut stem for water supply) | Rs 3000 |
| Macaque | 15-20 | 2 to 3 times per week | throughout year | | |

### E. Expenses on Mitigation measures

| | **Details of Information** | **Estimation of Net Income loss** |
|---|---|---|
| **Expenses on mitigation measures** | Types of mitigation measures | Total Expenses spent on mitigation measures per year |

**Example- Farmers Expenses on Mitigation measures**

| **Mitigation Measures Eg. Guarding, Solar Fencing, Sound Devices, alarms etc.** | **Details** | | | **Annual Expenses on Mitigation Measures** |
|---|---|---|---|---|
| Guarding | Number of labours | Salary per day | Period | 72000 |
| | 1 | Rs 400 | 6 months | |

**Conclusion**

**We now compute the estimated income losses per farmer per annum as:**

1. *Annual income loss Rs. per family = (A. Loss by Crop Damage) + (B. Loss by Crop Discontinuation) + (C. Loss in agri-allied businesses) + (D. Property Repair Cost) +(E. Expenses on Mitigation measures)*

   Calculating for one family from examples given above:

   *Annual income loss Rs. per family = Rs. 4,20,967 + 2000 + 30,000 + 3000 + 72,000*
   *Annual income loss Rs. per family = Rs. 5,27,967*

2. With the above amount, we calculated the annual income lost by each of the respondent families per hectare of land holding *= Total Loss / Total Area under Cultivation in Ha*

3. With these calculations, we made an estimate of the total losses incurred by the respondent farmer families in Ratnagiri and Sindhudurg districts (Table 1)

***Table 4*** *– Summary of estimates of net annual loss per hectare in Ratnagiri and Sindhudurg*

| District | Number of Farmer respondents | Area Under Cultivation in Ha (Sample Population) | Net Annual Loss (Rs / annum) | Per Ha Annual Loss (Rs/ Ha/ annum) |
|---|---|---|---|---|
| Ratnagiri | 15 | 45 | 60,25,433 | 1,33,862 |
| Sindhudurg | 10 | 64 | 75,64,535 | 1,17,734 |

While in our previous study (Annexure 2) annual loss reported by farmers from Konkan region was Rs 42,502/- per Ha per year; the detailed estimation-based data in this study revealed the net annual loss per hectare per year to be Rs 1,33,000/- from Ratnagiri district and Rs 1,17,000/- from Sindhudurg district (From Table 4), including all losses.

Taking an average of the total losses for Ratnagiri and Sindhudurg: **Rs. 1,25,798**

Total Area under cultivation in Ratnagiri and Sindhudurg Districts: **4,13,204 Ha**

Based on these two figures, we made an estimation for both the districts, assuming various percentage of losses (Table 5).

***Table 5 –*** *Estimation of total annual income losses in Ratnagiri and Sindhudurg. (Based on the sampling data, by assuming percent damage area)*

| Percentage of Area Damaged | Damaged Area (Ha) | Average Per Ha Loss (Ratnagiri +Sindhudurg) (₹) | Total Loss (₹) | Total Loss (₹ Cr) |
|---|---|---|---|---|
| 20% | 82640.8 | 125798 | 10,396,066,864 | **1039.61** |
| 40% | 165281.6 | 125798 | 20,792,133,728 | **2079.21** |
| 60% | 247922.4 | 125798 | 31,188,190,592 | **3118.82** |

According to these calculations based on 20-40-60 percent damage assumptions, the total income loss of farmer Families from Ratnagiri and Sindhudurg districts can vary between **Rs. 1039.61 Crore to Rs. 3119 Crores every year**.

Due to horticultural crops, Argo forestry cropping and langur, Macaques presence guarding remains only option for farmers to protect crops from wild animals. Farmers spend significant time and effort guarding their fields, diverting labor from other productive agricultural activities (Hill, 2000). In the case of perennial crops like coconut and cashew, mango damage can affect productivity for several years, leading to long-term income loss (Mehta et al., 2011)

Fig 3- Coconut Damage by Macaque

**Wild Animals Reported by Farmers responsible for Crop Damage**

In Ratnagiri and Sindhudurg macaques being the most damaging species responsible for affecting 17 crops, followed by langurs impacting 14 crops. Other species such as gaur, wild pig, and elephants damage 4 to 5 crops each while porcupines and flying giant squirrels have a relatively limited impact. Staple and high-value crops like rice, ragi, cashew, and coconut are among the most affected, often targeted by multiple animal species

**Table: Cultivated Crops and Wild Animals responsible for damage**

| Crops | Macaques | Langurs | Gaur | Wild Pig | Elephants | Porcupine | Flying Giant Squirre | Number of Animals Responsible |
|---|---|---|---|---|---|---|---|---|
| Rice | Yes | Yes | Yes | Yes | Yes | | | 5 |
| Cashew | Yes | | Yes | | Yes | Yes | | 4 |
| Ragi | Yes | Yes | Yes | Yes | | | | 4 |
| Coconut | Yes | | | Yes | Yes | | Yes | 4 |
| Grains | Yes | Yes | | Yes | | | | 3 |
| Banana | Yes | Yes | | | Yes | | | 3 |
| Mango | Yes | Yes | | | | | | 2 |
| Pineapple | Yes | Yes | | | | | | 2 |
| Vegetables | Yes | Yes | Yes | | | | | 2 |
| Papaya | Yes | Yes | | | | | | 2 |
| Kokum | Yes | Yes | | | | | | 2 |
| Jackfruit | Yes | Yes | | | | | | 2 |
| Bamboo | Yes | Yes | Yes | | | | | 2 |
| Kitchen Garden | Yes | Yes | | | | | | 2 |
| Water Melon | Yes | Yes | | | | | | 2 |
| Groundnut | | | | Yes | | Yes | | 2 |
| Warai | Yes | | | | | | | 1 |
| Arecanut | Yes | | | | | | | 1 |
| **Total Crops** | **17** | **14** | **5** | **5** | **4** | **2** | **1** | |

Out of 25 Farmer families only 6 farmer families reported only once for compensation and remaining 19 families not applied for compensation due to difficult Process, time consuming and amount given is not sufficient as reported by farmers.


"Alu" Local Vegetable in Kitchen Garden. Farmer's attempt to protect the last crops of Alu from Macaques) in Diveagar

**Losses from damaged Kitchen gardens (परसबाग):**

Kitchen gardens are traditionally nurtured in homes in the Konkan region. These are fruit and vegetable gardens that are meant for use by the family. By providing fresh produce year-round, especially in remote areas with limited market access, these gardens support the family with the needs for food and nutrition, and preserve cultural practices.

86% of respondents from Konkan region reported that their kitchen gardens are routinely raided by macaques, langurs and wild pigs. Thus, they are forced to buy vegetables and fruits from market (Annexure 2). This imposes costs on the family that are part of wildlife crop damages.

Estimation of annual losses due to Kitchen Garden damage

1. Per family annual loss is calculated based on data from the sample population. This amounts to Rs 200 per family per week.
2. Total number of rural households in Ratnagiri and Sindhudurg (3,35,318+ 1,83,201) = 5,18,519 (from the Census data https://censusindia.gov.in/census.website/data/population-finder )

Table 6: Estimation of net annual loss due to kitchen garden damage

| Assumed percent damage of Kitchen Garden | Number of Rural Households (Ratnagiri and Sindhudurg) | Total loss from damaged Kitchen Gardens, assuming Rs. 200/week/family (In Rs crores) |
|---|---|---|
| 20% | 1,03,704 | ₹99.56 |
| 40% | 2,07,408 | ₹199.11 |
| 60% | 3,11,111 | ₹298.67 |

Thus, the annual net income loss of the two districts together is **between Rs 99.56 crore to Rs 298.67** and the net agricultural loss including kitchen garden loss of the two districts together is estimated to be **between 1139.17 crore to Rs 3417.49 crore** per year

Coconuts damaged by Wild Pigs - Konkan

# Annexure 4

**Assessment of Crop Damage by Protected Wild Mammalian Herbivores on the Western Boundary of Tadoba-Andhari Tiger Reserve (TATR), Central India**

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RESEARCH ARTICLE

# Assessment of Crop Damage by Protected Wild Mammalian Herbivores on the Western Boundary of Tadoba-Andhari Tiger Reserve (TATR), Central India

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## Abstract

Crop raiding by wild herbivores close to an area of protected wildlife is a serious problem that can potentially undermine conservation efforts. Since there is orders of magnitude difference between farmers' perception of damage and the compensation given by the government, an objective and realistic estimate of damage was found essential. We employed four different approaches to estimate the extent of and patterns in crop damage by wild herbivores along the western boundary of Tadoba-Andhari Tiger Reserve in the state of Maharashtra, central India. These approaches highlight different aspects of the problem but converge on an estimated damage of over 50% for the fields adjacent to the forest, gradually reducing in intensity with distance. We found that the visual damage assessment method currently employed by the government for paying compensation to farmers was uncorrelated to and grossly underestimated actual damage. The findings necessitate a radical rethinking of policies to assess, mitigate as well as compensate for crop damage caused by protected wildlife species.

## Introduction

Agricultural lands close to protected areas (PAs) often face crop raiding by wild herbivores, which can be a serious problem for farmers whose livelihoods depend on agricultural produce [1–4]. In order to avoid economic loss, farmers apply a range of protective measures. They include manual guarding, various types of fences, trenches and other devices [5–13]. However, these measures often come with high associated costs [14] and risks [11, 15–19]. The traditional fences are made using wooden poles and thorny branches lopped from nearby forests causing substantial damage to the forest. Destructive measures such as traps can kill or injure animals. Highly sophisticated means such as electric fences are expensive and need continued maintenance [14, 20]. Although a number of measures have been developed and shown to be

**Competing Interests:** The authors have declared that no competing interests exist.

effective on an experimental scale, there are reason why they achieve limited success when employed on a wider spatial scale (Watve et al, manuscript under review).

Economic loss due to wildlife is a considerable threat to animal conservation due to increasing resentment among the residents that may result into retaliation [21–27]. Appropriate compensation is thought to reduce conflict, making conservation efforts more effective [27, 28]. At least in one case, that of wolves in Yellowstone national park, compensation was shown to be an effective conservation policy [27]. Even if we make no assumption of compensation helping conservation, from social justice point of view the government may accept it as its duty to compensate farmers' loss. In many countries, including our study area, the laws enable compensation of damage to the suffering farmers [26]. Although a number of studies on crop raiding are published addressing the problem in different habitats and caused by different species of wild animals, few utilize rigorous methods for primary estimation of damage and attempt to cross check or validate the methods [4, 29–32]. Some rigorous methods for damage estimation are suggested in the context of rodent damage [33] which are highly man-power intensive and no such methods have been used in compensation protocols in the study area. Since, the legal protocols in our study area have no clear guidelines on how to estimate the extent of damage, a visual inspection and assessment of damage is made accompanied by negotiations between the farmer and the compensating authority. This leads to a subtle ongoing conflict between farmers and park officials. It also brings about a change in perception of the farmers. Animals that were once perceived to be a part of nature are now perceived as a property of the park and a cause of menace to them. This "your animal syndrome" is likely to be more injurious to conservation in the long run than the actual damage to crops and the compensation paid [34].

Patterns of damages caused by different herbivores can be substantially different and estimating them using a single method may not be possible. For example, raiding by Asian elephant (*Elephas maximus*) and African elephant (*Loxodonta africana*) leads to visibly obvious damage over a measurable area whereas smaller to medium sized herbivores like, blackbuck (*Antilope cervicapra*), nilgai (*Boselaphus tragocamelus*), chital (*Axis axis*), wild pig (*Sus scrofa*) etc. may chew or nibble some specific parts of a plant such that the damage is not obvious at a glance [27, 35] but yields can be affected significantly [1].

Even if we assume that there is some way of accurately estimating the damage during an inspection following the raid, there are more complications. The crop species are also living entities that respond to inflicted damages in an adaptable manner. If the damage is not lethal to a plant, it regrows and tries to make up for the loss at least partly. Thus, the net damage at the end of the season may be substantially different from what appears immediately after a raid. One study that addressed this question showed that the visible damage was not correlated well with the grain yield at harvest [36].

Government records show that between 0.1 to 8% farmers received compensation during the years 2009 to 2015. This was in contrast with farmers' perception that over 90% farmers in the buffer zone suffered some loss. The farmers that received compensation, claimed that not more than 20% of the actual loss was compensated (Bayani et al, manuscript under preparation). Out study was motivated mainly by this difference. We used in this study, four different methods of damage estimation in the study area to address the question, whether the farmers' perception was more realistic or the compensation records of the government, or both were biased in different ways. Since different methods of damage estimation have different sources of errors and biases, if they converge on a similar inference, the inference can be more reliable. If they do not converge, a comparison would show whether some of them give consistent under or overestimates as compared to others [37–38]. This can be used to choose appropriate methods towards offering realistic compensation in near future.

## Study Area

The Tadoba-Andhari Tiger Reserve (TATR, 19° 59'–20° 29' N and 79° 11'–79° 40' E) is located in Chandrapur district of Maharashtra, India. The Tiger Reserve extends over 1727 sq. km out of which 625.5 sq. km is the core zone (Fig 1). TATR is a Teak (*Tectona grandis*) dominated mixed forest of deciduous trees including *Diospyros melanoxylon*, *Terminalia elliptica*, *Butea monosperma*, *Chloroxylon sweitenia* and bamboo (*Dendrocalamus* sp. and *Bambusa* sp.), supporting good faunal diversity. We selected the western boundary buffer (of the core) where through most of the length, the transition between forest cover and agriculture lands creates a sharp ecotone. Only in certain areas outside the western boundary, there is a mosaic of agricultural lands and forest patches. Crops are cultivated in two seasons, *viz*. kharif (monsoon crops) and rabi (winter crops). Rice (*Oryza sativa*) and soybean (*Glycine max*) are the primary kharif crops whereas wheat (*Triticum aestivum*) and chickpea (*Cicer arietinum*) are primary rabi crops. We selected these four crop species for all of our observations and experiments as they are the most abundant crops in the study area. Apart from these, cotton (*Gossypium arboreum*), turmeric (*Curcuma longa*), flax or linseed (*Linum usitatissimum*), and grass pea or sweet blue pea (*Lathyrus sativa*) are other secondary crops taken in comparatively lesser extent. The mammalian fauna of the western periphery of TATR is dominated by herbivore species including nilgai (*B. tragocamelus*), chital or spotted deer (*A. axis*), wild pig (*S. scrofa*) and carnivore species including tiger (*Panthera tigris*), leopard (*Panthera pardus*), dhole (*Cuon alpinus*) and sloth bear (*Melursus ursinus*).

## Materials and Methods

We used four independent methods to directly or indirectly estimate crop damage. (1) periodic visual examination of crop damage along transect lines going away from forest boundary; (2) the net grain yield per unit area along the same transect lines, measured at the time of harvest; (3) comparison of yields on protected and exposed neighboring farms; (4) comparison of grain yields after controlled artificial herbivory. Across the four methods one or more of the three parameters were monitored namely, (i) Frequency of visits by wild herbivores (ii) Visual estimate of apparent 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. We report the results of 6 years of study form 2009 to 2015 in this paper. Owing to manpower limitations, each of the four methods could not be employed across all the six years but we ensured that each method was replicated sufficiently to ensure reproducibility (Table 1). Whenever analysis compared the results of two or more of the methods, the comparison was made in the same season and same area.

### 1. Visual estimates of frequency of raids and area damaged

Three transect lines each 10 km long were laid going away from the boundary of the core area of TATR. Since there was no forest cover available to animals outside this boundary, we expected the raiding frequency to be a monotonic decreasing function of distance from forest. Geographical location of the center of each farm that was cut by the line was recorded using handheld GPS device (Garmin 60). Baseline information about the owners and the cropping season, crop species, total area of farm, area under cultivation of each crop, irrigation facility and other agriculture related information was noted. A total of 137 farms along the transects were then visited once every week by our research personnel during daytime to observe whether there were visible areas of damage. Whenever damage was noted, the approximate area with visible damage was measured in meter squares. This mimics the currently employed method of visual inspection to estimate damage. The weekly observations continued until the

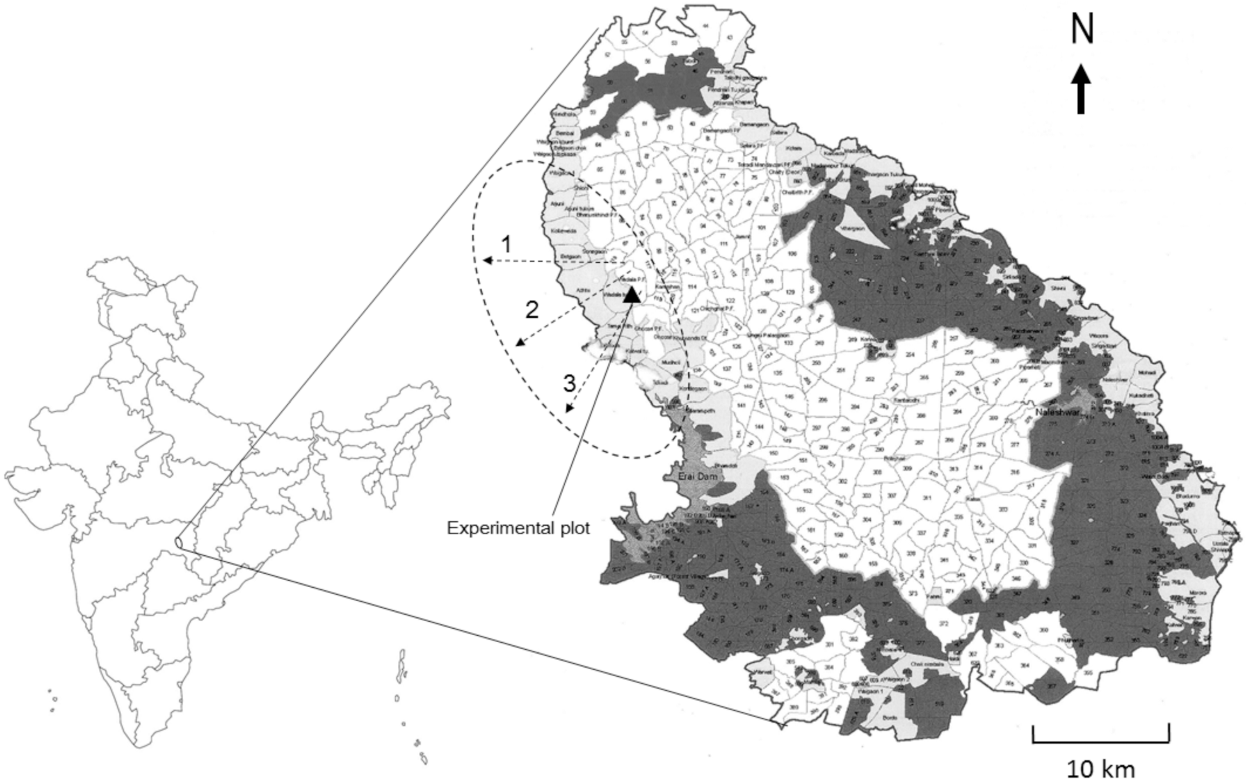


**Fig 1. Map and location of study area.** Light gray shaded zones denote villages and dark gray denote Division Forest area; both together constituting the buffer zone. The buffer area comprises over 70 villages with agriculture as the main livelihood. The dotted ellipse represents our study area. Location of the experimental plots is indicated by the dark triangle and the three transect lines extending from forest boundary into agricultural lands are shown by dotted arrows.

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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. Since a visible damage would mean one or more events of damage, $P_1$, $P_2$ . . . $P_n$ 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 ($\mu$) could be calculated, which when divided by 7 gave the mean frequency of damaging raids per night.

## 2. Grain yield at harvest

The farms along the transect lines up to 6 km mentioned above were visited at the time of harvest to note the total grain yield for each crop per unit area. Since the harvesting operations were at various stages at the time of visit by research personnel, the actual yield was not directly accessible for inspection every time. However, in at least 20% of cases, the research personnel

**Table 1. Temporal overlap of methods.**

| Year | Methods used |
|---|---|
| 2009–2012 | Method-1, 2 |
| 2012–2013 | Method-2 |
| 2013–2015 | Method-2, 3, 4 |

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could physically verify the grain yield at the time of harvest in terms of number of bags or at the time of sale in terms of actual weight in quintals. We studied the farms along transects for subsequent years and recorded yields at 180 farms for both kharif and rabi season. Grain yield was normalized with individual farmer's land area under cultivation and expressed as quintals 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 the first from the forest along one of the transect lines. The experimental area 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 neighboring 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, locally termed as '*mara*' or '*machan*'. 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 on harvest per unit area was recorded.

## 4. Artificial herbivory

To study the effect of levels of damage on individual plants, particularly their regrowth after damage and the resultant grain yield, the plants were manually cut 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 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 (see Table 2). 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 species).

# Results

## 1. Periodic monitoring of farms along transects

The mean frequency per night, calculated using Poisson probabilities, showed a decreasing trend with distance from the edge of forest (Fig 2A and 2B). Although both seasons showed a declining trend with distance, the damage frequency in kharif (Fig 2A) was nearly twice that in rabi (Fig 2B) 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.

It is important to note that the frequency of damage in (Fig 2A and 2B) is in spite of manual guarding efforts. Frequency of animal visits to a farm could be substantially greater than the

**Table 2. Experimental design for artificial herbivory of wheat, soybean and chickpea.**

| Crop species | Plot area (sq. m.) | Height at which plants cut (cm) | Number of plants (n) | Age at which plants cut (days) | Number of plants (n) |
|---|---|---|---|---|---|
| Wheat | 1 | Control | 125 | Control | 125 |
| | 1 | 5 | 176 | 25 | 92 |
| | 1 | 10 | 178 | 45 | 202 |
| | 1 | 15 | 205 | 55 | 199 |
| Soybean | 1 | Control | 108 | Control | 108 |
| | 1 | 5 | 125 | 20 | 87 |
| | 1 | 10 | 128 | 45 | 107 |
| | 1 | 15 | 100 | | |
| | 1 | 20 | 74 | | |
| Chickpea | 2 | Control | 50 | Control | 50 |
| | 2 | 5 | 50 | 25 | 53 |
| | 2 | 10 | 51 | 45 | 51 |
| | 2 | 15 | 54 | | |

doi:10.1371/journal.pone.0153854.t002

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. Fig 2C shows the trend in the mean number of *machans* per farmer at one kilometer intervals along the transect lines. 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 we see a sharp decline in the number after 6 km.

## 2. Grain Yield along transect farms

Corresponding to the decreasing trend of visible damage by herbivores, there was an increasing trend in grain yield with distance from the forest boundary along the transects. With the exception of rice, there was a significant and consistent increasing trend with distance for soybean, chickpea and wheat (Fig 3).

The distance trends in rice appear to differ from those in other crops. For all other crops the trends in the yield were consistent with the frequency of herbivore damage. The trend in the frequency of animal raids between the first kilometer and the interval between 5$^{th}$ and 6$^{th}$ km showed about twofold decline in the frequency of raids. Compared to this decline the yield improved by 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. The trend lines of grain yield also give us a rough estimate of average damage close to the forest. 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 average yields at a distance of 5–6 km. This comparison indicates that the yield deficit due to all causes combined close to the PA, range from 28 to 78% for crops other than rice.

A comparison of grain yields with the visual estimates of the area damaged made during weekly visits to the farms, revealed a poor correlation between visually estimated damage and the reduction in net yield from the expected (Fig 4). For this analysis done on four seasons' (2009–2011) data, a cumulative of the weekly visual estimate of damage was correlated with the deficit from expected yield. The expected was taken to be the average yield at a distance between 5 to 6 km for a given crop and given season. All the correlations were non-significant and throughout the range, the deficit in grain yield was orders of magnitude greater than the cumulative visual estimate of damage.

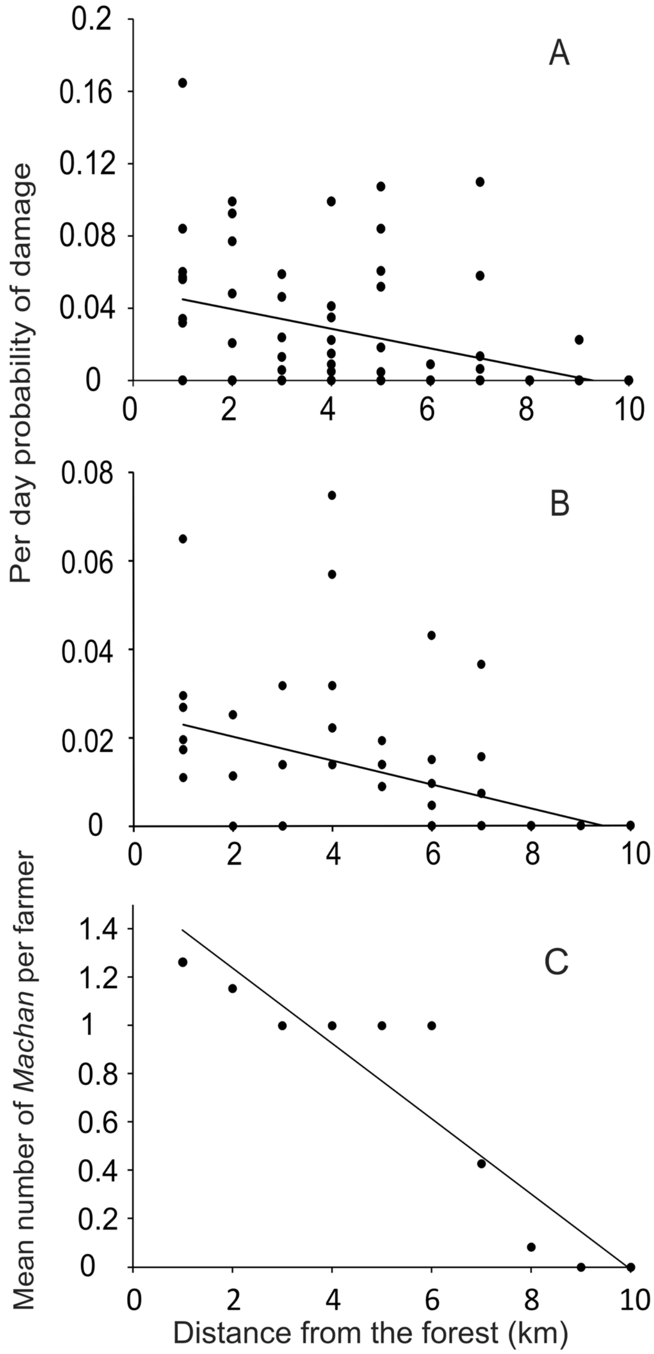


**Fig 2. Trend of per day probability of damage pooled from three transect lines.** For each of the observed weeks, per day Poisson probability of raid between every one kilometer interval was calculated from the fraction of undamaged farms from all the three transects. A: Trend in kharif season ($r = -0.4525$, $p = 0.0001$, $n = 90$); B: Trend in rabi season ($r = -0.5455$, $p = 0.0001$, $n = 98$). C: Trend in average number of *machans* per farm along the transects ($r = -0.9310$, $p<0.0001$, $n = 10$).

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## 3. Experimental farms

Frequency of damage could be measured for four crops separately on experimental farms. We observed that rice did not face severe raiding problems before seed setting, whereas wheat

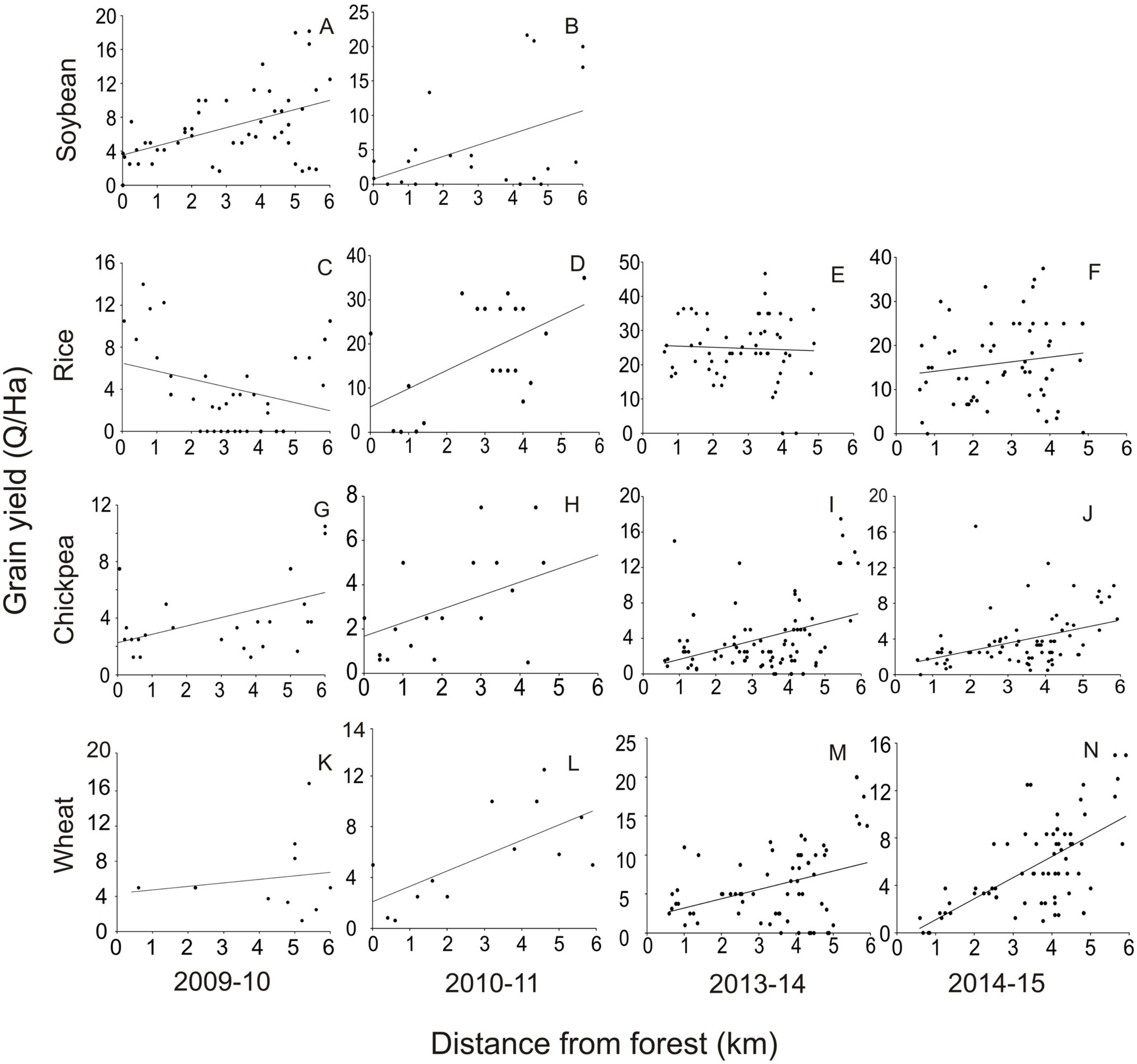


**Fig 3. Trend of grain yield at harvest with distance from PA boundary for 4 crops over 4 seasons.** Soybean: A 2009 ($r = 0.473$, $p = 0.0001$, $n = 95$) and B 2010 ($r = 0.448$, $p = 0.03$, $n = 22$); Rice: C 2009 ($r = -0.291$, $p = 0.08$, $n = 35$), D 2010 ($r = 0.53$, $p = 0.001$, $n = 20$), E 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 ($r = 0.642$, $p = 0.0001$, $n = 67$).

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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*) were observed to make their way through the fence

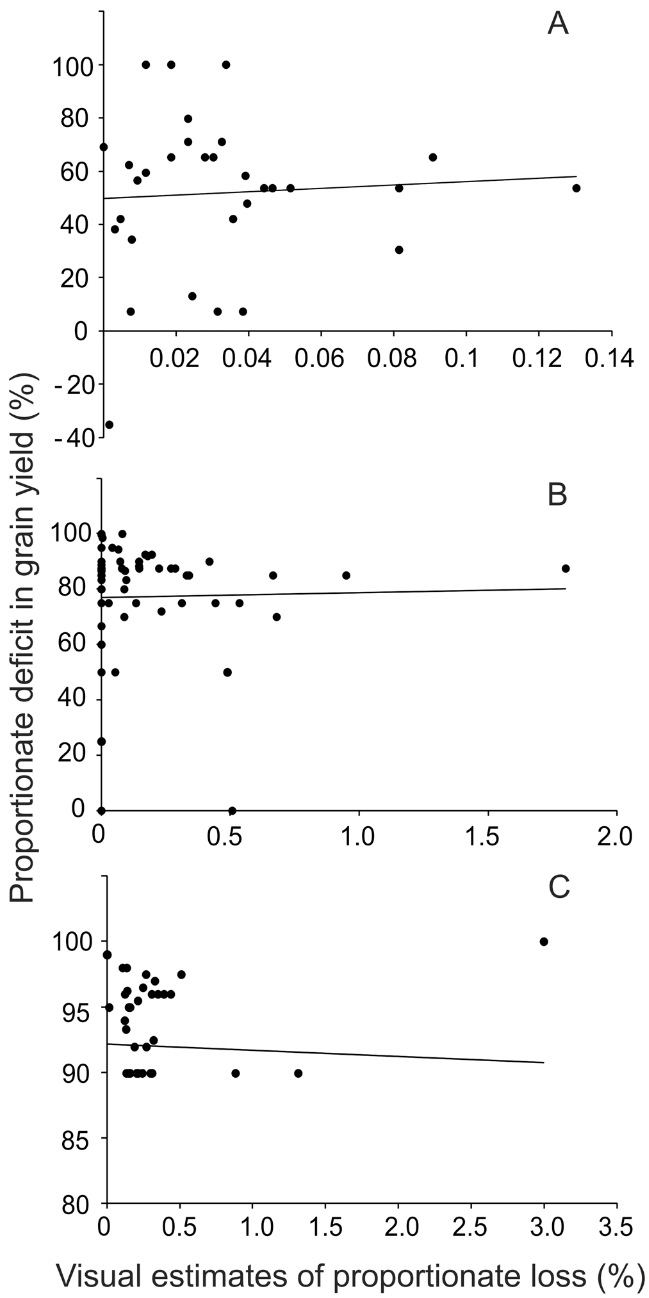


**Fig 4. Comparison of visually estimated loss and actual deficit in grain yield at harvest as compared to fenced control plots (both expressed in percentage).** A: Rice (r = 0.062, p = 0.73, n = 32), B: Chickpea (r = 0.022, p = 0.86, n = 63), C: Wheat (r = -0.0519, p = 0.75, n = 39). All trends remained non-significant even after removing outliers. Apart from lack of correlation, note the orders of magnitude difference in scales. Cumulative visual assessment was dramatically lower than yield deficit.

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frequently. 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 neighboring unfenced areas were 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

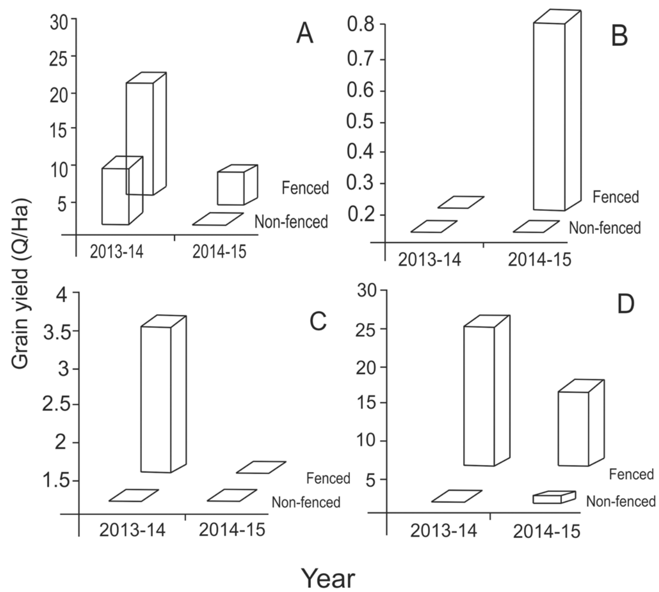


**Fig 5. Comparison of grain yield at harvest in fenced and non-fenced plots for 4 crops in two seasons.** A: rice, B: soybean, C: chickpea, D: wheat. Soybean in 2013–14 and chickpea in 2014–15 failed due to reasons other than herbivory.

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farms. Rice was least damaged but still faced a 68% loss in the unfenced unguarded areas in 2013. In 2014, owing to unfavorable 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 (Fig 5).

## 4. Artificial herbivory

Since crops are living entities, partially damaged plants can regrow [33, 39]. Plants can also show life history trade-offs on facing challenge of herbivory [39]. Therefore, a realistic estimation of damage should also account for recovery by compensatory growth 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 growth after cutting. Nevertheless, there appeared to be a cost associated with compensatory growth reflected in deficient grain yield.

In wheat, we observed that plants cut at the age of 25 days from sowing regrew substantially and gained a height comparable with the control at harvest. The grain yield was also comparable to the controls (Fig 6A & 6B). However, when cut at later ages it did not recover sufficiently in height as well as seed number. In other words, early damage appeared to allow greater time for regrowth resulting into better grain yield. If cut after the flowering stage, there was 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, the deficit in yield being proportional to the extent of cutting (Fig 6C & 6D).

In soybean, the age trend in compensatory growth differed from that in wheat. Plants cut at a young age showed less growth in height, number of branches, number of pods and seeds (Fig 7A to 7D). Early damage appeared to be more detrimental in this species. Different extent of cutting at the pre-flowering stage showed compensatory growth negatively correlated to the

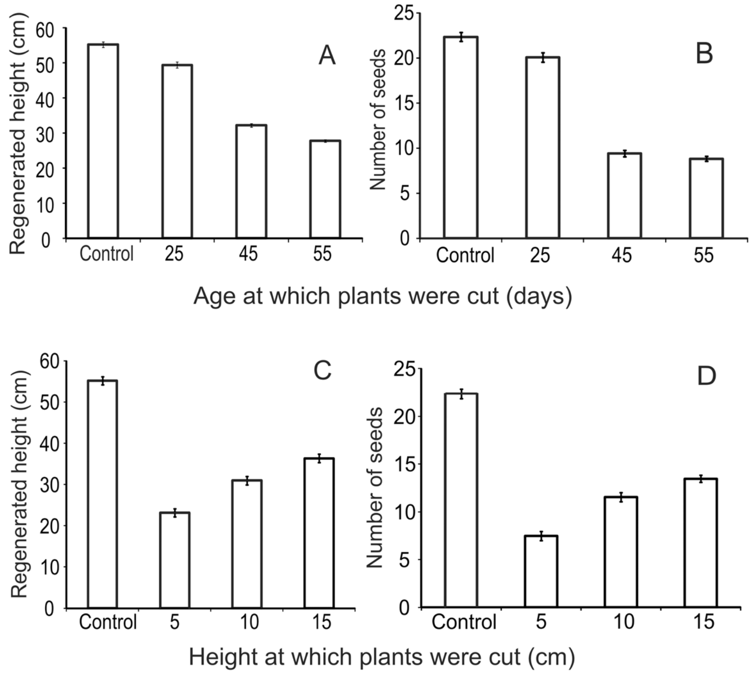


**Fig 6. Artificial herbivory in Wheat: comparison of regrowth by wheat plants cut at different age.** A: vegetative regrowth, B: number of seeds after regrowth (control, n = 125; age 25, n = 92; age 45, n = 202; age 55, n = 199) and comparison of regrowth of vegetative part in wheat plants cut at various heights at pre-flowering stage: C: vegetative regrowth, D: number of seeds. (Control, n = 125; height 5, n = 176; height 10, n = 178; height 15, n = 205).

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extent of cutting (Fig 7E to 7H). In spite of regrowth, there was 40 to 80% loss in the seed number.

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 (Fig 8A to 8D). 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 regrowth as well as seed formation. A yield deficit of up to 67% was noted on cutting down a plant to 5 at a pre-flowering stage (Fig 8E to 8H).

We did not perform artificial cutting in the case of rice, but did observe that in the unfenced and 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.

## Discussion

Many studies have pointed out the large difference between the amounts compensated and the perceived losses [32, 40–41]. However, attempts to make a reliable third party assessment of actual damage are few, most studies depending upon questionnaire surveys and oral impressionistic information. The uniqueness of our study lies in the attempts towards a first-hand assessment of damage using multiple methods.

We employed four different approaches to assess and compare crop damage in the study site. It is possible that each of the methods suffers from some flaw or shortfall. The net yield trends observed with distance from forest are likely to be affected by other factors. (a) It is likely that there is a trend with distance from the park in the fertility, water availability, irrigation

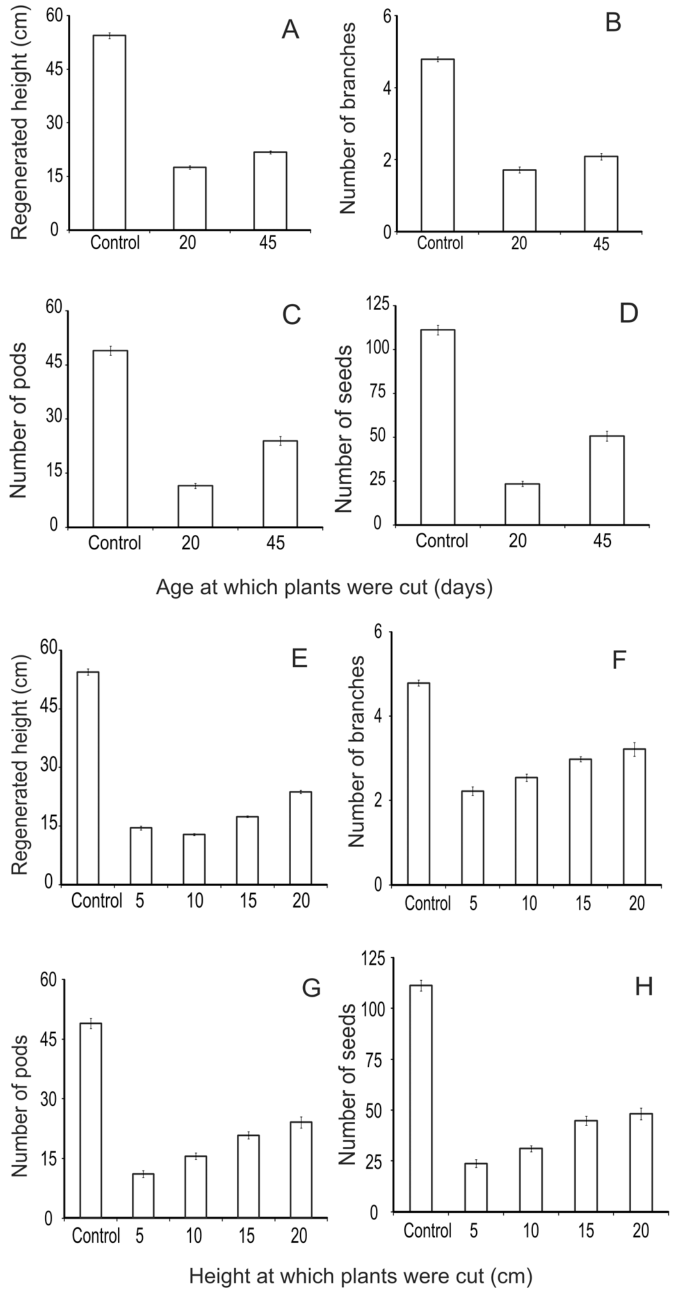


**Fig 7. Regrowth after artificial herbivory in soybean at different ages.** A: regenerated height, B: number of branches, C: number of pods and D: number of seeds 20 days (n = 87) and 45 days (n = 107) with control (n = 108). Regrowth after artificial herbivory at different heights in pre-flowering stage in soybean. E: regenerated height, F: number of branches, G: number of pods, H: number of seeds in plants cut at 5 (n = 125), 10 (n = 128), 15 (n = 100), 20 (n = 74) with control (n = 108).

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facility or any other agriculture related property of soil. (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.

In experiments with fenced farms adjacent to the park, the yields observed were comparable to those at a distance of 5–6 km from the park. For rice, the protected farm yield was 21.66

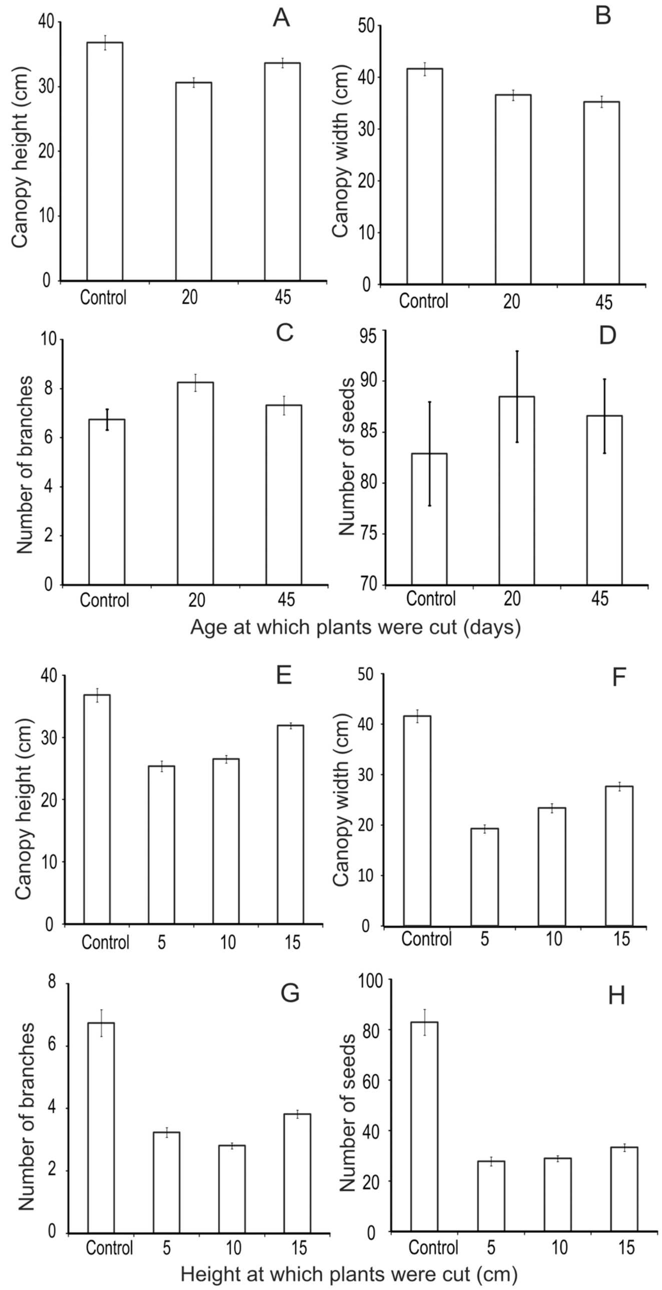


**Fig 8. Compensatory growth after artificial herbivory at different ages in chickpea.** A: canopy height, B: canopy width, C: number of branches and D: number of seeds in plants cut when 25 days old (n = 53) and 45 days old (n = 51) with control (n = 50). Compensatory growth after artificial herbivory at different heights at pre-flowering stage in chickpea. E: canopy height, F: canopy width, G: number of branches, H: number of seeds of plants cut at 5 (n = 50), 10 (n = 51), 15 (n = 54) with control (n = 50).

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Q/Ha, and for wheat 24.88 Q/Ha both being close to the regression yield expected at 5–6 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.

In contrast with (a) above, the possibility (b) was backed by some evidence. Farmers adjacent to the boundary hardly used chemical fertilizers, whereas at 10 km 90% farmers used more than one types of chemical fertilizers in combination. This trend is expected by optimization models of farmers' economic (Watve et al manuscript under review). 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 to 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 (Watve et al manuscript under review). It should be noted that loss due to farmer's disinvestment is indirectly caused by herbivory itself, but it is unlikely to be recorded during visual inspection of damage even if we assume the visual estimate to be accurate.

The poor correlation between visual estimate of damage and net loss in grain yield demonstrates that visual inspection is unable to reflect on realistic loss. If the ratio of the two estimates was fairly consistent it would have been possible to rely on visual estimates after applying certain correction factor. However, the distribution of the ratio of visual 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 visual damage estimations are both unreliable and grossly underestimating.

Results of simulated herbivory are important because a potential cause of mismatch between a visual estimation of damage and grain yield deficit is regrowth of plants after damage [33, 39, 42–43]. The vegetative parts of plants regrow to a considerable extent after herbivory [39]. There are claims of herbivory being beneficial for plants owing to stimulated regrowth [39, 42–43]. We observed some positive effect on chickpea after limited cutting. However, barring this exception the effects of herbivory on net yield were negative in our study. We 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 [44–45]. For example, chickpea may have evolved to respond to limited herbivory by preferring greater investment in reproduction. Rice on the other hand belongs to grasses that have substantial root biomass, which is long lived and can regrow in the following season. 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 [45] 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 regrow, 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 regrowth and therefore the damage may not be noticeable on visual inspection, but a substantial loss is incurred.

For crops other than rice, the regression of grain yield with distance estimated between 28 to 78% deficit adjacent to the park in comparison with 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 neighboring 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. The difference between the unfenced unguarded experimental farms and unfenced but guarded neighboring farms can be said to reflect the efficiency of manual guarding. By this calculation, manual guarding was able to save about 50% of loss. Compensatory growth studies after artificial herbivory revealed that although plants did give some grain yield, the net grain deficit in the experiment ranged between 40% and 70%. All the evidence converges to over 50% loss close to the park boundary. This matches the farmers' perception closely and differs from the government records of damage.

There were two prominent 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 and therefore damage could not be calculated from the trend, 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 or differential strategic investment by the plants as discussed above.

The other major mismatch was that visual assessments always gave substantially lower estimates compared to all other methods. There are a multitude of possible reasons why visual assessment always gave 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 regrow soon and the damage becomes difficult to notice after a few days. By the current compensation protocols the inspection happens only once after filing a claim and there are variable delays between damage and inspection. Therefore it is difficult to notice all types of damages together in a single inspection. (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. This puts an unrealistically large demand on competent and authorized personnel for inspection-validation work which appears impossible in the current set up. In reality no farm was inspected more than once in a crop season. Therefore in effect only a small part of damage was actually inspected (v) Farmers tend to disinvest from intensive agricultural practices when faced with high risk of damage (Watve et al, manuscript under review). This is unlikely to be recorded in visual assessment. (vi) Even if we assume 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, is likely to be substantial for rice. This is generally not covered by the compensation procedures. Thus for a number of reasons the currently employed method of visual assessment is unable to make a realistic reflection of actual damage and thereby offer adequate compensation.

Previous research on crop raiding by wild animals in India is heavily biased towards damage by large herbivores such as elephants. In this case, the damaged area is measurable and the net loss is likely to be directly proportional to the fraction of the visibly damaged area. However, the case with smaller to medium sized herbivores that do not kill the plants is very different. It is possible that visual assessment of damage works for certain species of damaging animals, but fails completely for others. There is a need for alternative methods of damage estimation where a visual assessment fails. We suggest that it should be based on the grain yield or net produce at harvest rather than visually assessed vegetative loss. A model for compensation based on community data collection is suggested by Watve et al [34] that takes into account all possible flaws of such a system and an operating design that can overcome these flaws. This principle can be a potentially effective solution to make realistic damage compensations.

It is in the interest of PAs to address the conflict problems realistically to avoid growing resentment that can potentially mount over time to explode at some stage. The problem needs to be addressed at multiple levels including measures to reduce the damage, encouraging alternative crop species non-palatable to herbivores, alternative livelihood along with realistic damage compensation [27, 46–48]. The main concern is prevention of social damage more than economic damage. Anticipatory and preventive solutions need to be implemented rather than looking for remedies after a major episode of unrest [27, 47].

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## Author Contributions

Conceived and designed the experiments: AB MW. Performed the experiments: AB DT AD APD RP. Analyzed the data: AB MW RP. Wrote the paper: AB MW.

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# Annexure 5

**Combining payment for crop damages and reward for productivity to address wildlife conflict**

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CONTRIBUTED PAPER

# Combining payment for crop damages and reward for productivity to address wildlife conflict

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**Article impact statement**: A novel scheme of payment for damage and reward for productivity helped resolve farmer–wildlife conflict.

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**Abstract**
Conflict caused by wild herbivores damaging crops is an almost universal problem in conservation. We designed and implemented a game-theory-based system for supporting farmers whose crops were being heavily damaged by wild herbivores. In this community-operated system, farmers self-report their production, which is endorsed by neighboring farmers. The average deficit in production is compensated for by a payment that is directly proportional to the average deficit in production of the group and to the individual farmer's productivity. As a result, farmers are compensated for the average damage (support) and rewarded for individual productivity (reward) (i.e., support cum reward [SuR]). The design of the game is such that only honest reporting gives maximum returns. Farmers who under-report receive less payment because the SuR amount is proportionate to their self-reported productivity. The endorsing farmers, in their own self-interest, prevent overreporting. The system involves multiple game situations, the combined result of which is a stable strategy based on honesty and hard work. In 2 villages along the western boundary of Tadoba Andhari Tiger Reserve in central India, we tested the system with 75 farmers over 6 crop seasons. After a few initial attempts to cheat, honesty prevailed throughout the group. Average crop productivity increased 2.5-fold, in spite of damage, owing to increased effort by farmers. Apart from wildlife conflict resolution, the model offers a promising alternative to crop insurance and a potential behavioral green revolution in agriculture.

**KEYWORDS**
crop insurance, evolutionary game theory, experimental socioeconomics, human–wildlife conflict, support cum reward

Combinación entre el Pago por Daños a Cultivos y la Recompensa por Productividad para Abordar el Conflicto con la Fauna

**Resumen:** El conflicto causado por herbívoros silvestres que dañan los cultivos es casi un problema universal para la conservación. Diseñamos e implementamos un sistema basado en la teoría de juegos para apoyar a los agricultores cuyos cultivos estuvieran siendo dañados considerablemente por los herbívoros silvestres. En este sistema operado comunitariamente, los agricultores reportan por sí mismos su producción, la cual es endosada por los agricultores vecinos. El déficit promedio en la producción se compensa con un pago que es directamente proporcional al déficit promedio en la producción del grupo y a la productividad individual del agricultor. Como resultado, los agricultores son compensados por el daño promedio (apoyo) y recompensados por la productividad individual (recompensa) (es decir, apoyo con recompensa [SuR]). El diseño del juego es tal que solamente la declaración honesta otorga la máxima ganancia. Los agricultores que declaren menos de lo dañado reciben menor pago porque la cantidad SuR es proporcional a su productividad auto declarada. Los agricultores que los endosan, por interés propio, previenen que haya declaraciones por encima de lo realmente producido. El sistema involucra varias situaciones de juego, cuyo resultado combinado es una estrategia estable basada en la honestidad y el trabajo duro. En dos aldeas ubicadas a lo largo de la frontera occidental de la Reserva de Tigres Tadoba Andhari en el centro de la India, pusimos a prueba este sistema con 75 agricultores durante seis temporadas de cultivo. Después de algunos intentos iniciales por hacer trampa, la honestidad prevaleció en todo el grupo. La productividad promedio de cultivos incrementó 2.5 veces su cantidad inicial a pesar del daño, esto debido al incremento en el esfuerzo de los agricultores. Además de la solución del conflicto con la fauna, el modelo ofrece una alternativa prometedora al aseguramiento de cultivos y una potencial revolución verde en el comportamiento agrícola.

**PALABRAS CLAVE:**
apoyo con recompensa, aseguramiento de cultivos, conflicto humano-fauna, socioeconomía experimental, teoría de juegos evolutiva

## INTRODUCTION

Crop damage by wild herbivores is a major human–wildlife conflict wherever agriculture coexists with wildlife. In India, high human density and agriculture coexist, increasing the intensity of the problem (e.g., Bayani et al., 2016; Karanth & Vanamamalai, 2020; Karanth et al., 2013). Along the western boundary of the Tadoba Andhari Tiger Reserve, Maharashtra, India, farmers lose on an average 50% of their crop to wild herbivores in spite of active guarding (Bayani, 2016; Bayani et al., 2016; Watve et al., 2016a). Indian law allows compensation to the affected farmers. Currently, the procedure for implementing the law is highly inefficient (Johnson et al., 2018; Karanth et al., 2018); therefore, it has largely failed to mitigate the problem. However, attempts to implement realistic compensation have had positive effects (Karanth & Vanamamalai, 2020). In a prior study, we found that, faced with the risk of damage, farmers are reluctant to spend money on crop intensification (Bayani et al., 2016; Watve et al., 2016a). The deficit in productivity due to reduced investment is greater than the actual damage inflicted by animals. Such indirect losses are not covered by the current compensation law, and there is a need for a better alternative to support farmers along the forest–agriculture interface.

Existing compensation law requires verification of damage by a set of government officials. In areas with frequent damage, verification of every farmer's claim is practically impossible. We devised a community-operated system for collection of data on wildlife damage, assessment of average damage in a community, and provision of compensation for damage along with a reward for increased productivity in spite of the risk of damage. The entire system is operated by the farming community with little, if any, need for government personnel. Farmers collect the data, determine the average damage, and upload the data to a website, after which they receive payment. However, the system is intended to work in a way that only honest reporting maximizes benefits to farmers. The system can be described as an n-person game. We considered the theoretical solutions of the game and observed behavior of farmers in a test of the system over 6 crop seasons.

The evolution and stability of cooperation among egotists is a long-standing conundrum. A variety of strategies based on reciprocity, policing, and punishment to arrest cheating have been suggested, mostly based on the prisoner's dilemma as the paradigm (e.g., Axelrod & Hamilton, 1981; Dahanukar & Watve, 2009; Nowak & Sigmund, 2005). Relatively little attention has been given to the question whether the game itself may evolve or be designed to make it immune to cheating. Real-life social systems are likely to be more complex, with multiple social dilemmas at work simultaneously. The ultimate goal of game theory is to design stable and robust cooperative systems for use in real life. Game theory has been used to address problems in business (Remeikiene, 2017) and politics (Wolitzki, 2013), but attempts to design institutional or community governance structures (Jiang et al., 2020; Young, 1998) are yet to reach their full potential. In the field of environmental and conservation science, appropriate use of behaviorally designed interventions has been suggested (Watve et al., 2016b; Zabel & Roe, 2009), but its potential for practical use remains underutilized.

The support cum reward (SuR) system originated from a modification of a theoretical model by Watve et al. (2016b) that evolved through several rounds of collective thinking with farmers, social workers, wildlife ecologists, and park managers. The main modification to model is that we changed the objective from compensation for damage to assurance of returns and incentives for increasing crop production in spite of the risk of damage.

In the SuR system, each farmer is paid an amount (SuR amount) proportionate to the average crop loss in the entire group and to an individual farmer's productivity. The estimate is based on farmers' self-reporting and endorsement by other farmers. Therefore, honesty is critical to successful functioning of the system. Underreporting productivity is against the interest of individual farmers; therefore, out of self-interest, they are unlikely to underreport (Watve et al., 2016b). However, overreporting productivity can increase the relative benefit of an individual farmer but reduce the average deficit, thereby reducing the percent payoff of the entire group. Therefore, the farmers validating the self-reporting are unlikely to allow overreporting. Thus, honesty is ensured due to the self-interest of individual players in the n-person game. Further, because the reward is proportionate to an individual farmer's productivity, there is an incentive for increased productivity.

Owing to the background belief systems and cultural practices, Indian forest dwellers and farmers are traditionally and generally tolerant of wildlife, a perception that started changing with the establishment of wildlife reserves (Rangarajan, 2001). Nevertheless, moderate to high levels of tolerance of wild animals is still prevalent in India (e.g., Bhatia et al., 2016; Hall, 2011; Senthilkumar et al., 2016). However, it is difficult to sustain heavy losses to crops and other livelihood options, and this creates resentment. We did not undertake a comparative evaluation of people's perceptions of wild animals in the SuR participant farmers versus nonparticipant farmers, but in group meetings and individual interactions, the issue was discussed repeatedly.

Using a combination of theoretical and experimental approaches, we examined for the SuR system whether honest behavior can be theoretically stable and whether the theory was supported by farmer behavior in real life. We also studied farmers' collective analysis of and reasoning behind their own behavior; whether the combination of compensation and productivity incentives increased crop production as predicted; and whether the farmers' perception of wildlife was changed by SuR.

# METHODS

## Ethics considerations

The farmer group was involved in the design of the implementation plan. An institutional study protocol was not imposed on the farmers. We did not have prior institutional ethics committee approval because the protocol's validity could have been challenged if farmers were to suggest changes to the protocol. After the farmers agreed to the implementation protocol, a Paryavaran Mitra (organization handling the field component of the study) committee reviewed the ethical aspects of the study and approved its implementation. At the beginning of the study itself, every farmer provided informed consent to participate.

## Theoretical work

Following classical game theory, we modeled SuR as a game (Appendix S3). In the baseline model, the payoffs of honest farmers and farmers underreporting and overreporting damage were considered at a constant efficiency of validation $\mu$ (i.e., the probability at which an overreporter could be detected and prevented from overreporting). Evolutionary dynamics and Nash equilibriums of the game were analyzed using replicator dynamics (Appendix S3). Because $\mu$ is decided by the validators in the system, we designed an adaptive dynamics model to examine the coevolution of honesty and validation (Appendix S4).

## Empirical component

The empirical component of the work was executed with a group of 75 farmers from the area surrounding the Tadoba Andhari Tiger Reserve in central India. The agroecology of the study area and the details of the farmer group are described in Bayani (2016), Bayani et al. (2016), and Appendix S1. The farmers had heavy direct and indirect losses from wild herbivore damage and therefore were under great distress when the experiment began. Details of the prior and preparatory work, working protocol of SuR system, and the evaluation of the outcome are detailed in Appendices S1 and S2.

## Evolution of and consensus on the implementation protocol

Although the central idea of the scheme was based on Watve et al. (2016b), we allowed the detailed implementation protocol to evolve from collective thinking by the farmers. We also allowed refinements during implementation. Watve et al.'s (2016b) model was explained to the group, and participants were asked to discuss and devise an implementation plan. Four main modifications of the model evolved from farmers' and researchers' collective thinking. First, the objective was changed from monetary compensation for the damage to encouraging productivity in spite of the risk of damage. Second, the farmer group worked out the procedure for validation of self-reports (*panchanama*), which was an optimization between the objectives to be fulfilled and practical constraints. The consensus procedure was that 2–3 farmers coordinated the validation activity for the entire group and ensured that at least 3 other farmers from the group were present when the crop from any given farm was harvested, threshed, and packaged. Farmers decided 3 validators were required. It was thought that if it became difficult to ensure honesty of reporting, the number of validators could be increased, but the need did not arize throughout the 6 seasons.

Third, to select validators, no formal randomization procedure was followed, as in the original model. Farmers either volunteered to be validators or the coordinating group asked them to be. After collecting all self-reported and validation data, results were shown to the entire group. The efficiency of the data transparency was inadvertently demonstrated when there was an error in computer entry that was pointed out during the following group meeting and corrected.

The SuR amount for the $i$th farmer was calculated as follows (Watve et al., 2016b):

$$SuRamount_i = y_i \cdot \frac{S - R}{R}, \qquad (1)$$

where $S$ is the expected crop yield per unit area, $R$ is the mean yield per unit area of the farmer group, and $y_i$ is the total productivity of farmer $i$ expressed in terms of monetary value at the current market rate.

Fourth, unlike in the original model (Watve et al., 2016b), we did not maintain fully protected control plots to get a working estimate of $S$. Instead, the average yield of agricultural lands away from the forest in that season was used as $S$ in the model. The problems associated with having control plots were related to determining whose land should have control plots and whether the motivation in tending the control plots would be

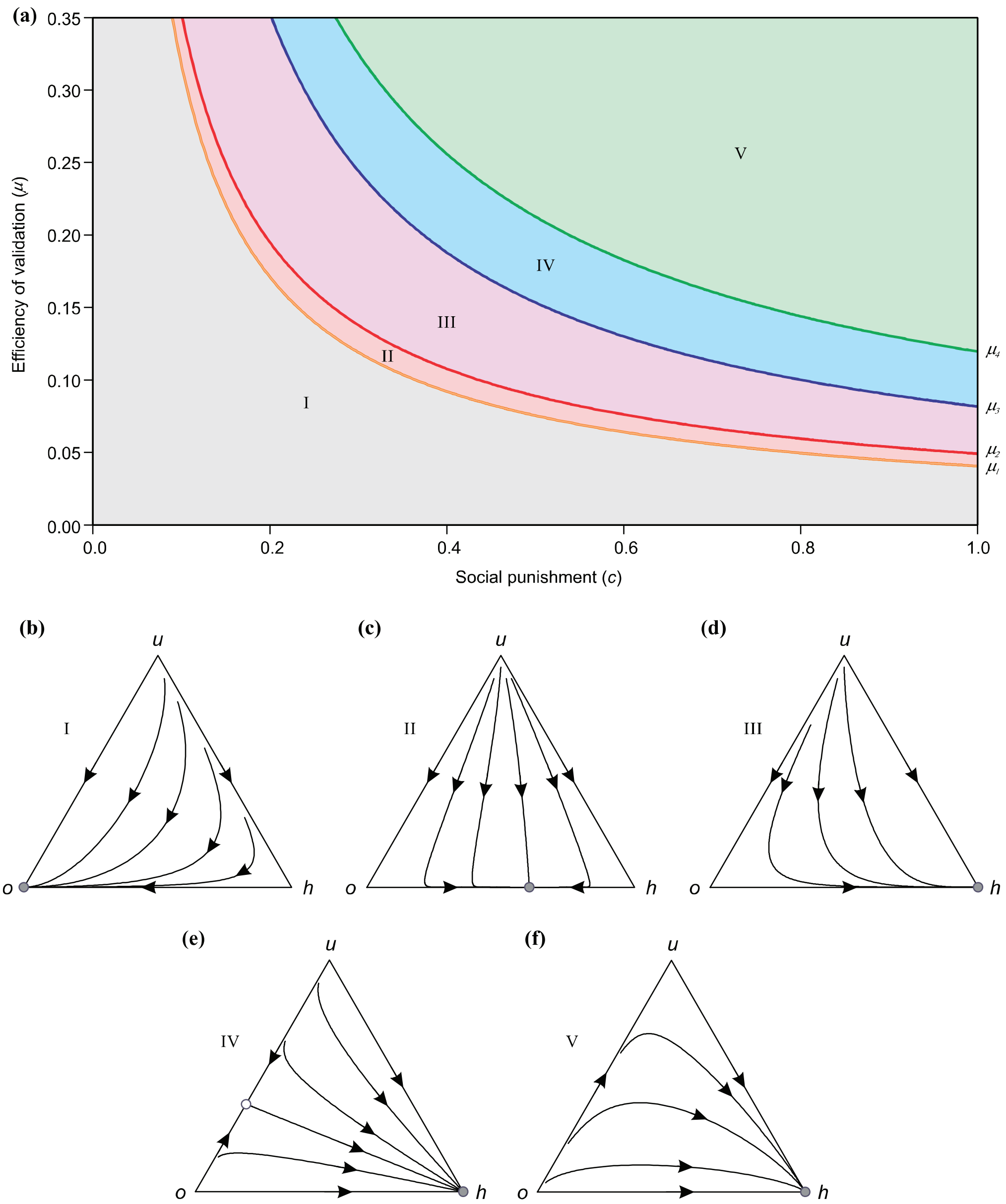


**FIGURE 1** Evolutionary dynamics (I–V) of the support cum reward game (i.e., farmers compensated for average damage [support] and rewarded for individual productivity [reward]) at different efficiencies of production validation and social punishment: (a) parametric space of dynamics and (b–f) simplexes of the dynamics (gray circles, stable Nash equilibriums; white circles, unstable Nash equilibrium; $\mu_1$–$\mu_4$, range of probability at which a farmer overreporting damage can be detected and prevented from overreporting; *u*, underreporting; *o*, overreporting; *h*, honest reporting). Other simulation conditions: *S* (expected yield = 1*y* (observed yield) = 0.5, $\varepsilon$ (amount of over- and underreporting of yield) = 0.05

different from the motivation in tending the experimental plots, and so on.

## RESULTS

### Honesty in game theory considerations

Replicator dynamics of the basic model suggested that Nash equilibrium depended on the efficiency of validation ($\mu$). Underreporting was unstable because it could be invaded (i.e., replaced in the population) by honest as well as overreporting individuals. Overreporters, in contrast, had a short-term advantage over honest individuals when the efficiency of validation was low. If an attempt to overreport was exposed, the overreporter was embarrassed and thus was subjected to a social punishment *c*. There were 5 possible results associated with different values of $\mu$ (Figure 1 & Appendix). For $\mu > \mu_2$, honest reporting was the only Nash equilibrium. For $\mu_1 < \mu < \mu_2$, a mixed strategy Nash Equilibrium existed with coexistence of honest and overreporters. Overreporting was stable only when $\mu < \mu_1$.

The critical parameter $\mu$ was not a constant but rather a function of the proportion of honest validators in the population. Because overreporting reduced pay-offs to the entire group, preventing overreporting was of common interest. However, overreporters could bribe validators to approve the

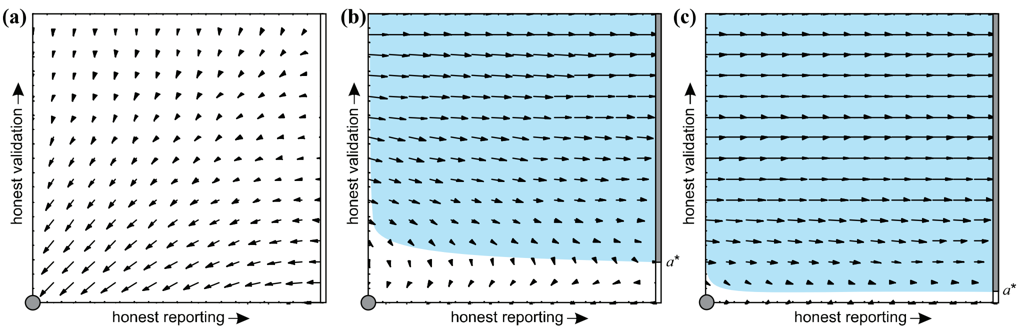


**FIGURE 2** Adaptive dynamics between reporters and validators of self-reported yield for different values of $c$ (social punishment) and $v$ (number of validators) (gray circles and bars, stable Nash equilibriums; white bar, unstable Nash equilibrium; blue, stable honest reporting): (a) $c = 0.0$, $v = 2$, (b) $c = 0.05$, $v = 2$, (c) $c = 0.05$, $v = 5$. Other simulation conditions: $S$ (expected yield $= 1$ $y$ (observed yield) $= 0.5$, $\varepsilon$ (amount of over- and underreporting of yield) $= 0.05$

overreporting. Validators could be corrupt or honest. However, just 1 honest validator in a group of validators was sufficient to prevent overreporting. Bribing all the validators was comparable to the ultimatum game in which a fair distribution of the benefit is the most acceptable outcome (Debove et al., 2016). Therefore, we assumed that for a successful bribe, the overreporter would have to distribute equally the benefit among himself and all the validators (Appendix S4). As the number of overreporters ($r$) and the amount overreported ($\varepsilon$) increased, the mean yield per unit area of the farmer group $R$ became large and the benefit of overreporting declined (Eq. 1). However, when overreporting was exposed, overreporters lost respect within the group and were subject to a social punishment ($c$). Thus, the cost–benefits of a validator strategy depended on the frequency of overreporters, and the stability of overreporters depended on $\mu$, which was a function of the number of honest validators. This resulted in a dynamic relationship between the fraction of overreporters and the frequency of honest validators ($a$) as captured by adaptive dynamics (Appendix S4). In the absence of social punishment of overreporters, overreporting and corrupt validation was the only stable Nash equilibrium. But with a social punishment, above a threshold $a^*$, honest reporting was stable with a large basin of attraction (Figure 2). Thus, validation by 1 or more individuals and social punishment for exposed overreporting were essential components for the stability of honesty.

## Additional factors stabilizing honesty

The following features of the SuR model additional to the basic game theory model stabilized honest reporting and validation synergistically. Typical game theory dynamics considers the relative benefits of different strategies and assumes that the one with the better pay-off increases in frequency. However, we had a situation in the SuR dynamics in which one could choose between absolute versus relative pay-offs. When the proportion of overreporters increased, $R$ increased and thus the SuR amount decreased. By preventing this, an honest validator benefitted along with everyone else in the population. In contrast, the bribe that a corrupt validator got from an overreporter decreased as the fraction of overreporters increased. The rise in SuR amount by preventing overreporting could be greater than the bribe one might get by approving overreporting when,

$$r > \frac{S - y}{S.(v + 1) + \varepsilon}. \tag{2}$$

Therefore, when validators were rational and flexible and maximized their absolute pay-offs, they were predicted to become honest above a critical $r$ (Appendix S5). Thus, at large $r$, $\mu$ tended to 1 and thereby encouraged honest reporting. So, when farmers made decisions based on their absolute pay-offs, the overreporter and corrupt validator Nash equilibrium (Figure 2a) was impossible. This critical $r$ above which $\mu$ tended to 1 was small when $y$, $v$, or $\varepsilon$ was large. This could be achieved by increasing the number of validators. In contrast, $\varepsilon$ was predicted to become larger on its own because a larger $\varepsilon$ always gave an advantage to an overreporter over a smaller $\varepsilon$. This additional factor stabilizing honesty operated independent of the social punishment to the overreporter.

We assumed for simplicity in the baseline model that everyone has the same yield. In reality, there is substantial variance across farmers, which can control dishonesty through known behavioral principles. Because this was not a zero-sum game, coalition for underreporting brought higher payoff to everyone. However, reporting lower yields was a complex issue. In a group, if everyone contributes to a lie in order to get a benefit, everyone would expect the same gains. When everyone decided to report yield as $y_i - \varepsilon$, the SuR amount increased by a constant percentage, but the ones with lower $y_i$ could complain of getting disproportionately lower benefit of the dishonesty. When, however, they reported $\frac{y_i}{\varepsilon}$, where $\varepsilon > 1$, the ones with lower yields could still complain about lower absolute benefit of dishonesty. Cooperation for dishonesty is unlikely to be stable unless everyone perceives to have gained the same benefit of dishonesty and has a feeling of fairness. Refusal to cooperate on seeing an unfair outcome is a fundamental trait in human as well as nonhuman primates, owing to which, underreporting with a wide variance around $y$ is unlikely to be stable. The model predicted that if the entire community decides to generate a fair benefit of cheating to everyone, the statistical distributions generated will be substantially different from natural distributions, making it easy to detect the fraud.

Unlike the assumptions of the game theory model, there is considerable individual variability in rationality in real life. Individual responses are also shaped by subtle factors in relationships between individuals and affected by subtle rivalries and friendships. Because volunteering for panchanama was permitted, individuals might come forward to prevent their rivals from taking advantage of overreporting. When close friends cooperated, these coalitions were unstable. Because even 1 honest person among the validators could prevent or expose cheating, control by rivals is very likely to be effective. Owing to such sources of behavioral variance and intraindividual dynamics, some validators keen to prevent overreporting will always be present. Above a threshold $v$, $\mu$ became sufficiently large to prevent overreporting.

When the farmer's self-report is to be validated, the group's average yield is not yet calculated. Therefore, the possible benefits of overreporting were unknown. Bribing the validators at this stage is, therefore, not practicable. Making futuristic promises is also not possible with incomplete information. Even if a promise were made, its credibility would be questionable. Therefore, although the model considered this possibility, bribing validators is not stable in real life.

Farming operations were an open act, and farmers were good judges of each others' success. Harvesting, threshing, and packaging were done in the open. These were prolonged operations, and there was substantial time between packaging and transport. Therefore, there was plenty of opportunity for farmers to know other farmers' net yield. Also, neighboring farmers and their family members helped each other and did manual labor on each other's farms. It was not possible to harvest in secret. Therefore, overreporting one's yield without the knowledge of other farmers was difficult. The cues of being watched induce honesty (Bateson et al., 2006), even in situations where secretive cheating is possible. For operations in the open, one is unlikely to dare to cheat the system when it is against others' interests.

The organization providing the support cum reward to farmers is an important player in the game. The interest of this player is to provide a realistic solution to affected farmers and keep them satisfied with minimum cost incurred. It is easy to visualize that when the farmers behave honestly, the government need not intervene, except making the SuR amount available. When farmers overreport on an average, they cannot blame the government for the smaller than realistic benefit obtained. However, the government needs to worry about a coalition of farmers underreporting. Game theory shows that such a coalition is inherently unstable. However, in our model, the government could be more cautious and could achieve this by participating in only one or a few harvesting and validation operations from a group. When everyone is underreporting, the one whose validation is independently checked gets a disproportionately large pay-off, resulting in unfair outcomes that destabilize cooperative cheating.

## Honesty as observed among the community

In the first monsoon crop season, 38 farmers participated out of which 31 self-reports matched exactly with other independent sources of data. Six farmers appeared to attempt manipulation. Of these 5 overreported and 1 underreported, and their endorsers did not carefully verify their honesty. The research group did not interfere or expose the dishonest reporting, but farmers themselves realized the consequences and corrected themselves or corrected each other before finalizing the data for calculations. In the second season, there was only one overreporting attempt to which other farmers objected. The overreporting farmer apologized and corrected himself. In the following 4 seasons, no incident of dishonesty was reported. This real-life experiment was consistent with earlier imaginary game trials (Watve et al., 2016b) in which players tried to manipulate initially and then realized that any departure from honesty led to loss. They played honestly in subsequent iterations of the game.

## Farmers' perception about the factors contributing to honesty

Because the initial attempts by a few individuals to manipulate the system for selfish interests failed and all farmers started reporting honestly, we encouraged a group discussion on which factors, in their perception, were important in ensuring honesty. Participants agreed the following 3 factors were the most important: high price of cheating (in terms of loss of respect), data transparency, and perceiving absolute benefit to be more important than relative benefit.

## Increase in yield

Relative to the baseline average yield from 2010 to 2015, during the study period, there was a monotonic rise in yield of all the crops, and the maximum increase was >4-fold for wheat and gram and about 2.5-fold for rice (Figure 3a). This dramatic increase was at least partially due to good rainfall in the 2018 and 2019 monsoons. But the 2017 monsoon was unfavorable to crops, and we still observed an increase in yield over the previous years' average.

Because annual variation in rainfall was shared by the entire district more or less equally, we compared the yield of our group with the district average data obtained from Department of Agriculture, Government of Maharashtra (2020). In the indices relative to the district average, there was a similar monotonically increasing trend (Figure 3b), indicating that the increase was more than could be explained by the monsoon. The prediction of the model of an increase in yield appeared to be fulfilled beyond our expectations.

The SuR amount per hectare decreased substantially as yield increased (Figure 3d). The success of the SuR model was indicated further by the inputs to produce ratio. When the SuR amount of INR 1.14 million (approximately US$ 15,000) was paid to the farmers and subsidies on solar fences worth INR 0.5 million (US$ 6800) were made available during the intervention period, the market value of their yield increased by INR 6.96 million (US$ 95,000). This demonstrated that apart from being a relief to farmers affected by wildlife damage, SuR

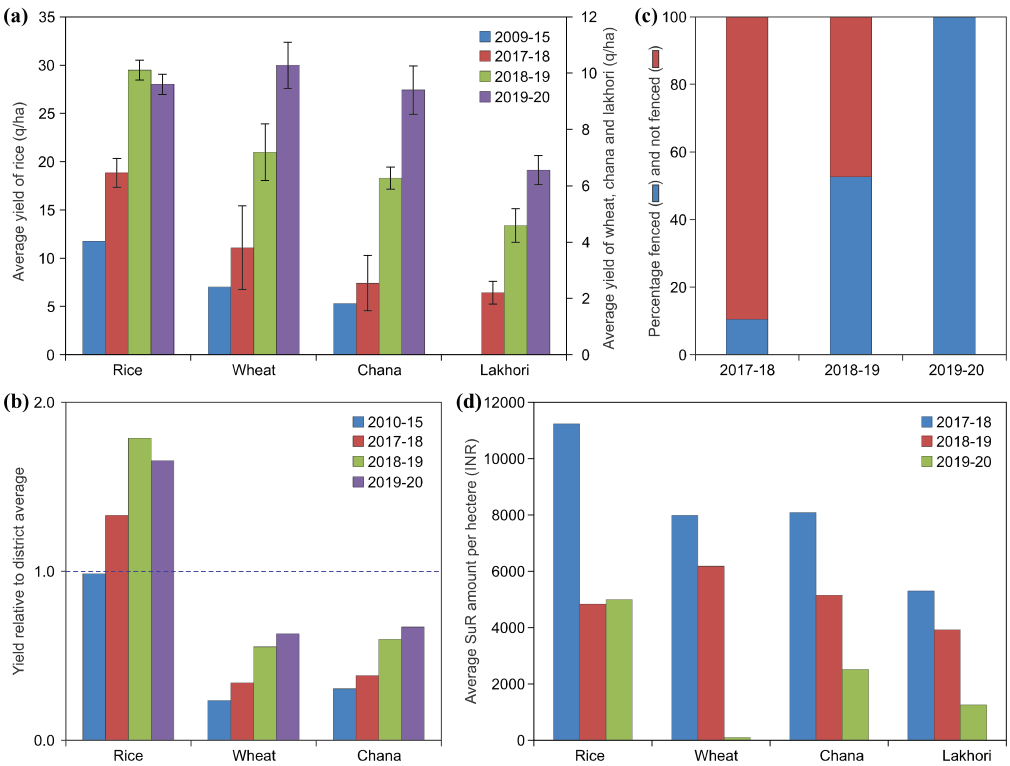


**FIGURE 3** Trends in (a) absolute rice, wheat, gram, and lakhori production, weighted mean Q/He and standard deviation, (b) production relative to district average of that year (lakhori not included), (c) proportion of farmers using solar fences for crop protection, and (d) combined compensation for damage and reward for crop productivity (SuR) per hectare over 3 years

actually worked as an effective investment in improving agricultural yield in the area in spite of the damage.

## Inputs and efforts

An expectation of the SuR model was that farmers' inputs in agriculture would increase. Such an increase occurred based on at least 2 indicators. Solar powered fences help prevent animals from entering the farms. In the study area, solar fences offered significant, though not complete, protection from wild herbivores. Prior to our intervention, the forest department and ecodevelopment committees offered farmers solar equipment either free of cost or at high subsidy levels, but only 15% farmers in the group were using them. During the 3 years of implementation, the percentage of farmers using solar fences in the intervention group increased to 100%, whereas it did not reach 30% in nonparticipant farmers from the same area. We did not collect quantitative data on fertilizer use but qualitatively the diversity of fertilizers used by the participant group increased during the intervention period. In the year 2019–2020, 21 of the participant farmers decided to use bacterial inoculants for the first time. These 2 examples demonstrated that farmer's inputs in agriculture increased qualitatively as well as quantitatively during the intervention period.

Because the benefits of the scheme were proportional to individual farmer's yield, the benefits differed substantially among the group. We thought lesser beneficiaries might be disappointed or resentful and might thus drop out from the scheme. However, this did not happen. In the group meetings, the causes of lower yield for some farmers were discussed, and farmers wanted to improve on their yields rather than complain about the provisions in the scheme.

## Causes of variability within the group

Although the principle of the scheme specified that farmers with comparable risk should form a group, there was always substantial variance in productivity of different farmers. When the assumption of comparable risk was not complied with, those with higher risk were at a disadvantage and those with lower risk received an undue share of the benefit. Therefore, it was important to know the causes of the variability in yield. In a prior study in the area (Bayani, 2016; Bayani et al., 2016), the risk of damage reduced approximately linearly with distance from forest over a span of 5 km. Our farmers were approximately 0–1 km from the forest. Therefore, we looked at correlation with distance from the forest (Appendix S6). In 2017–2018, there were positive trends between distance and produce for the 4 crops, 2 of which were statistically significant. However, in all the subsequent seasons, the trend with distance vanished completely for all crops. This indicated that difference in wildlife damage was not a predominant cause of the variance within the group. This was reassuring because it validated the assumption of comparable risk across the group.

The variance in yield was discussed in the farmers' meetings, and they agreed that animal damage was not appreciably different among the group, particularly after everyone acquired solar equipment. Their interpretation was that irrigation facility and individual farmer wisdom and effort were mainly responsible for the variance. Wisdom and effort were not quantifiable, but we classified the irrigation available into good, medium, and poor, and this classification explained 7–50% variance along the crop-year matrix for postmonsoon crops (Appendix S6). For the monsoon grown rice, there was no correlation with irrigation facility as expected. Farmers' own interpretation that the difference in wisdom and inputs was responsible for the difference in yield was likely to have been a big motivating factor because there was increased awareness and readiness to learn about new agricultural technologies among the group. This was demonstrated by the use of bacterial inoculants for the first time. In short, the prediction that rewards for productivity would provide an effective incentive for increased inputs appeared to be true.

The frequency distribution of productivity (Appendix S6) showed that the increase in average productivity was not solely due to some outliers achieving very high productivity. The entire distribution shifted to the right, indicating that there was improvement in low-productivity farms as well.

## Perception of wildlife

Group meetings with farmers gave us the impression that given the SuR assurance, people were ready to give up hostility toward wild animals almost entirely. During the study period, there were documented instances in which injured wild herbivores were found in human-inhabited areas. Instead of killing, bothering, or hurting them further, people helped and even initiated rescue operations.

# DISCUSSION

The results of our experimental implementation of the n-person-game-based community-operated support cum reward scheme for farmers affected by wild herbivore damage were as predicted by the model: honesty was the only prevalent and stable strategy; the combination of compensation for damage and reward for increased productivity increased the productivity markedly, and the perceived human–wildlife conflict decreased.

The SuR system is a complex game, and a single game-theory model does not capture the entire dynamics of the system. Multiple game-like situations are involved, including prisoner's dilemma, volunteer's dilemma, and ultimatum game. Also, multiple behavioral principles are involved, including punishment, reputation, rejection of unfair outcomes, and cues of being watched, all of which promote and reinforce honesty in mutually compatible or synergistic ways.

A major problem in the prevalent compensation protocol is mutual mistrust among farmers and park managers (Johnson et al., 2018). The compensation protocol has become painful and unwieldy mainly because of mistrust. The government wants to ensure that no false claims are entertained. If compensation is made liberal, there is no guarantee that farmers will not cheat. In fact, cases of cheating are on record. Honest farmers, however, believe that in spite of their claims being true, the government intends to harass farmers on purpose. The honesty-ensuring principle of SuR is likely to break this vicious cycle and create an atmosphere of trust between park management and forest villages, which would aid conservation success in multiple ways.

Particularly remarkable is the spectacular increase in productivity in the absence of any detectable change in the reported animal density in the park. There are 3 possible reasons for the trend. When farmers were assured they would be protected from total loss, their investment and inputs increased. Simultaneously, there was an incentive for increased yield. The third important factor was that they came together and discussed a variety of issues. During these discussions, they exchanged information on the one hand and developed a competitive spirit on the other hand. The uniqueness of this experiment was that there was no technological or biological intervention. No new seed, variety, fertilizer, or agricultural practice was introduced by the researchers. Only a behavioral economics intervention was responsible for the observed 2- to 4-fold increase in productivity. Stimulated by the dual facilitation of assurance and incentive, they made use of technologies and facilities available to them already. Making good use of solar fences is a good example. The technology was available at considerable subsidy even before the implementation of SuR. Farmers knew its usefulness as well as limitations. The use of solar fences, better quality fertilizers, and better seed quality certainly contributed to the increased production. The periodic farmers' meetings likely boosted their motivation and awareness. These factors were not independent of each other and worked as in a network. Therefore, it is difficult to segregate their contributions to increased productivity. But these technologies, facilities, and practices were not newly available. The SuR was the novel intervention, and it appeared to have brought about substantial change in other factors.

An important parameter in our model is the social punishment of overreporting, which affects the evolutionary dynamics and equilibrium of the game. Interestingly, social punishment was also identified by the farmer group as an important deterrent for overreporting. Such social punishment, which can include ostracism, boycotting, or shame, has been observed as an important driver of social cohesion (Mahdi, 1986; Zippelius, 1986). We assumed that there was no cost of punishment for the punisher. However, it has been shown that even when the punishment is costly, group members are willing to pay such costs (Henrich et al., 2006).

Our small-scale experiment has the potential to be scaled up. The system is behaviorally sound and robust. Even if everyone behaves selfishly, honesty and good conduct are expected to ensue. Therefore, the entire system can be operated by the farmers themselves, and convenient mobile apps and software can be developed through which they can upload the data they collect, based on which the monetary transactions can be automatically processed. Because there is no intermediary required, there is no scope for corruption in the system. Because selfishness itself ensures honesty, realistic data on agricultural yield can be automatically generated year after year with little centralized efforts. This will put minimum pressure on government agencies for implementation on a wider scale. Substantial alleviation of a major human–wildlife conflict can make coexistence and conservation easier. But the real potential of SuR model goes beyond human–wildlife conflict in that it offers a promising alternative to crop insurance, given the serious limitations of current crop insurance policies (Gulati et al., 2018), and boosts agricultural yield particularly for small farmers in the developing world.

## ACKNOWLEDGMENTS

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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# Annexure 6

## The Impact of Forest Cover and Wild Herbivore Presence on Agricultural Productivity in Maharashtra State

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Abstract:

The problem of wild animals damaging agricultural crops in well known but we have no information on to what extent it affects Maharashtra's agricultural economy. We look at whether how it is reflected in the district wise agricultural data of the state. Since the distribution of forest cover and wildlife is heterogeneous, we can compare districts with small versus large forest cover and wildlife presence. Since the districts differ in the cultivable areas, soil and climatic conditions, preferred crops and other factors a direct comparison of net output or productivity could be confounded. Therefore we consider the slope of the temporal trend in net productivity of every districts which represesnts agricultural "progress". We observe that the progress is negatively correlated with forest cover, districts with large forest cover often having a negative progress. Since quantitative data on animal densities being unavailable we compare districts with and without rich wildlife abundance. Here too we see that districts with abundant wildlife progress slowly or negatively as compared to the ones with poor wildlife presence. The districts with rich wildlife showed a mean 4 % linear deficit in progress so that there was about two fold difference in the two categories of districts over 23 years. Sensitivity analysis showed that the trends are robust and unchanged by omitting one district at a time from the data. Forest and wildlife are likely to have a significant negative impact on agricultural productivity in Maharashtra state.

## INTRODUCTION

Maharashtra, one of India's leading agricultural states, has been witnessing significant changes in its agricultural productivity over the years. These changes are influenced by a multitude of factors, both natural and anthropogenic. One of the underrated factors has been crop damage by wild animals. Some studies have quantified the extent of crop damage in certain areas which is alarmingly large. Bayani et al (2016) estimated that farmers close to forest boundary suffered on an average 50 % loss in spite of active guarding throughout the season. Moving away from forest the damaged reduced to 10-20 %. We have no information on how wild animals affect the net agricultural economics of the state.

Agricultural productivity in Maharashtra is a vital aspect of the state's economy, impacting the livelihoods of millions of farmers and contributing significantly to the state's GDP. Multiple factors affecting agricultural productivity have been studies extensively. However, a damage to crops by wild animals and birds is a factor on which studies are scanty. Wildlife has been considered a different area of research and agricultural universities and institutions have not focused their investigations on it. Wild life research , on the other hand, recognizes this problem qualitatively but the effect on agriculture is neither their focus, not their expertise. As a result we have no studies assessing its impact on agriculture. We attempt to see whether there is a correlation between the forest cover and agricultural output in the district wise data. A negative correlation would suggest that as forest cover and herbivore populations increase, the rate of growth in agricultural productivity tends to decline.

The intricate relationship between agriculture, forest cover, and wildlife is complex and multifaceted. Forests play a crucial role in maintaining ecological balance, supporting biodiversity, and regulating climate. However, they also serve as habitats for wild herbivores, which often venture into agricultural lands in search of food, leading to crop damage and reduced yields. Facing the risk of damage farmer may give up farming altogether or hesitate to invest in better agricultural practices. This dynamic poses a significant challenge for farmers and policymakers alike, as they strive to balance agricultural productivity with ecological conservation.

This report aims to delve into the changing patterns of agricultural productivity in Maharashtra, examining the factors contributing to these trends and exploring potential strategies for sustainable agricultural practices.

The findings of this report will contribute to a better understanding of the challenges faced by the agricultural sector in Maharashtra and inform the development of policies and practices that can enhance productivity while preserving the state's rich natural heritage. By addressing the interplay between agriculture and the environment, this study aims to support the creation of a sustainable and resilient agricultural system in Maharashtra.

## OBJECTIVES

**The primary objectives of this report are:**

- To examine the relationship between the average percent increment in agricultural productivity and the percent forest cover.
- To investigate the impact of wild mammalian herbivores on agricultural productivity.

- To analyse the shift in farming patterns from forested areas to non-forest areas in Maharashtra and its impact on crop productivity.
- To examine the correlation between forest cover and cultivated areas, and identify other significant factors influencing farming trends, such as migration and socio-economic changes.

**DATA DESCRIPTION:**

- **Time Frame:** The data covers estimates from 2000 to 2023.
- **Data Source**: Obtained from **mahakrishigov.in**
- **Measurement Units:** **Area:** Reported in lakh hectares (ha).
- **Production:** Measured in lakh metric tons (MT).
- **Yield:** Expressed as kilograms per hectare (kg/ha).
- **District-wise Insights:**
- We can explore specific districts within Maharashtra to understand localized variations.
- For example, districts like Thane, Palghar, Raigad, Ratnagiri, Sindhudurg, Nasik, Dhule, and Nandurbar contribute significantly to crop production

| **Crop Category** | **Crop Name** | **Seasons (Growing Period)** | **Types** |
|---|---|---|---|
| Food Grains | Rice | Kharif, Summer | Cereals |
| | Wheat | Rabi | Cereals |
| | Jowar (Sorghum) | Kharif, Rabi | Cereals |
| | Bajra | Kharif | Cereals |
| | Ragi | Kharif | Cereals |
| | Maize | Kharif, Summer, Rabbi | Cereals |
| | Tur | Kharif, Summer | Pulses |
| | Mung | Kharif, Summer | Pulses |
| | Udid | Kharif, Summer | Pulses |
| | Gram (Chickpea) | Rabi, Summer | Pulses |
| Oilseeds | Groundnut | Kharif, Summer | Oilseeds |
| | Sesamum | Kharif, Rabi | Oilseeds |
| | Nigarseed | Kharif | Oilseeds |

| | | | |
|---|---|---|---|
| | Sunflower | Kharif, Summer, Rabi | Oilseeds |
| | Soybean | Kharif, Summer | Oilseeds |
| | Safflower | Kharif, Summer | Oilseeds |
| | Linseed | Kharif, Summer | Oilseeds |
| | Other Oilseeds | Varies | Oilseeds |
| Other Crops | Sugarcane | Varies | |
| | Cotton | Kharif, Summer | |
| | Tobacco | Kharif, Summer | |

**METHODOLOGY**

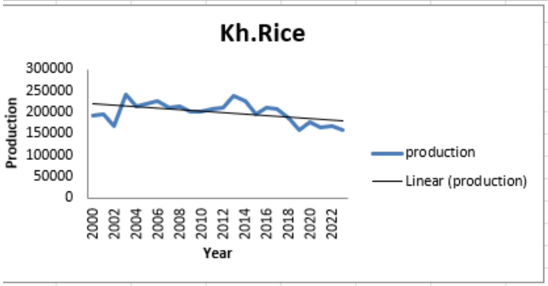
In our research, we utilized agricultural data obtained from the Maharashtra government's Krishi-Vibhag website. Our main focus was on the crop production dataset, which encompasses information on 26 different crops. We collected and organized datasets from various years, highlighting key data points such as year, area, productivity, and production to facilitate our analysis. Through our examination of the data, we were able to discern discernible patterns of both increase and decrease in crop production over the years.

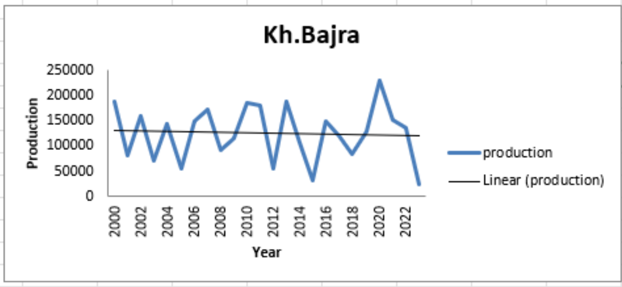
Furthermore, our analysis encompassed a detailed study of crop production in every district of Maharashtra, considering the influence of different seasons. Employing statistical techniques such as regression, time series analysis, and correlation, we were able to extract valuable insights from the data. Our findings unveiled a persistent downward trend in production within forest area divisions, signifying agricultural losses. To delve deeper into the changes in crop production, we accessed minimum support prices (msp) to gauge total production. Our investigation suggested that the diminishing forest cover is associated with agricultural losses, attributable to the presence of herbivorous mammalian diversity within the high forest area.

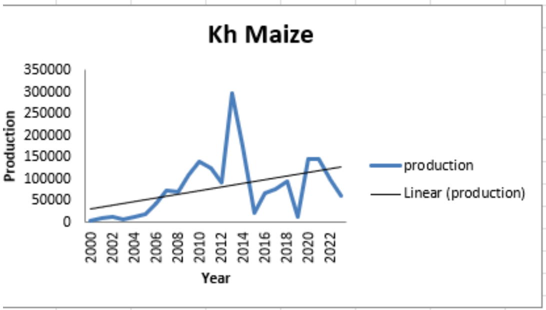
The decline in agricultural productivity undoubtedly raises concerns, prompting us to urge the government and forest department to take proactive measures to address the issue. Based on our analysis, we concluded that the agricultural losses caused by herbivores also may be linked to the deforestation of forest trees. Investigate trends in the area under cultivation to determine if challenges like crop destruction by animals (e.g., monkeys) and farmer migration to cities (e.g., Mumbai, Pune) are reflected in the data. Farmers in forested regions have reported such issues, and we want to examine whether these trends are evident in the data. This research project holds promise for future endeavours aimed at preventing or mitigating agricultural losses stemming from herbivores

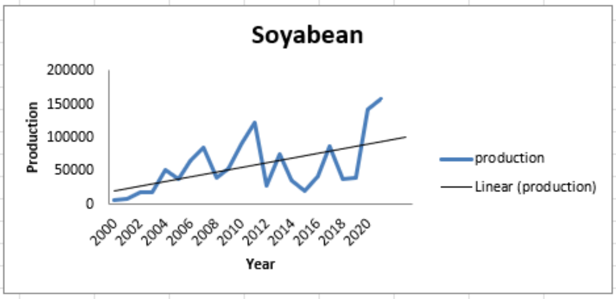
**CROPS ANALYSIS:**

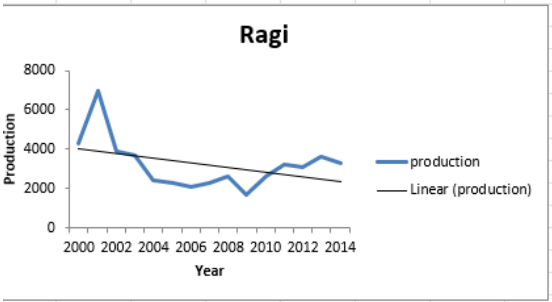
**Kharif Season Crops**

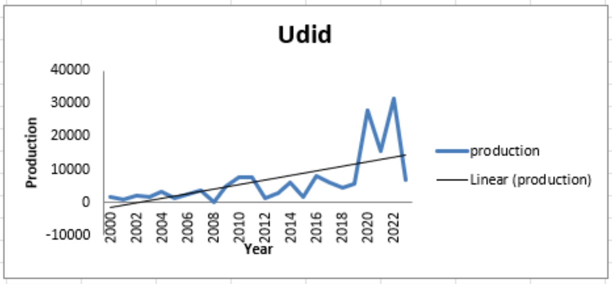


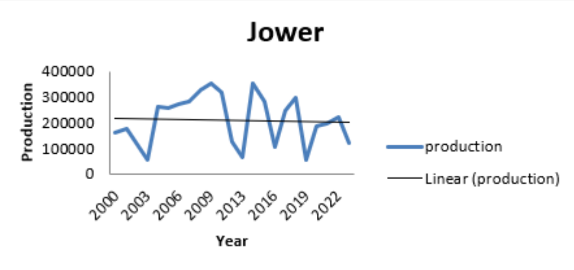



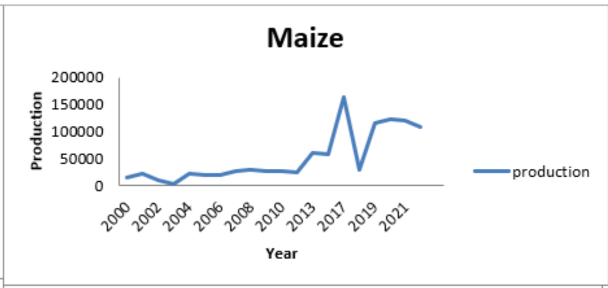



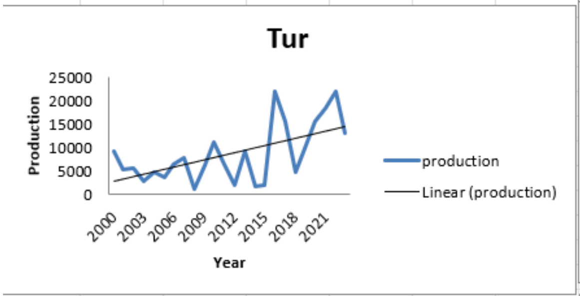



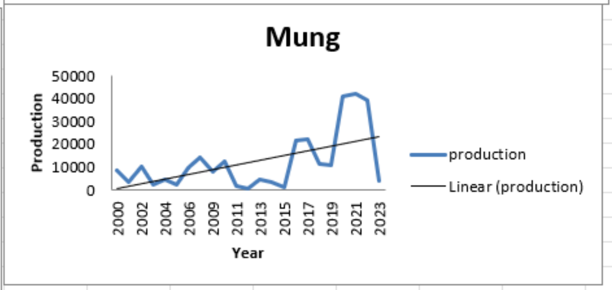

We have analysed the production trends of various crops during the kharif, rabbi, and summer seasons. Our analysis revealed that during the kharif season, there has been an increasing trend in the production of crops such as kharif Bajra, kharif maize, soyabean, and udidfrom the years 2000 to 2023. On the other hand, crops like Ragi, kharif Bajra have shown a decreasing trend in production over the same period.

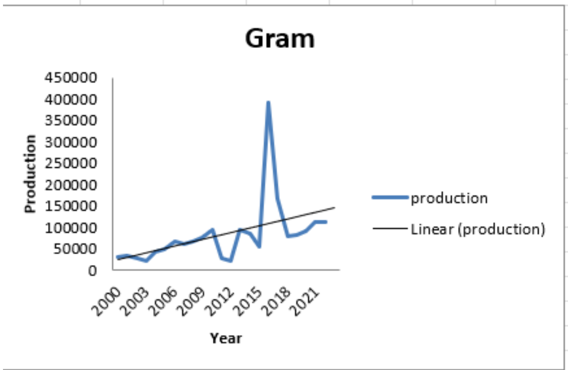
**Rabbi Season Crops:**

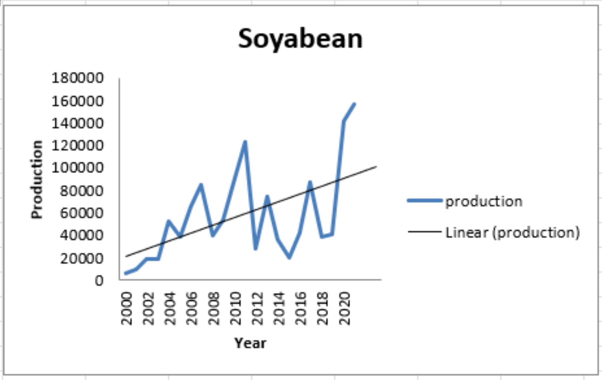


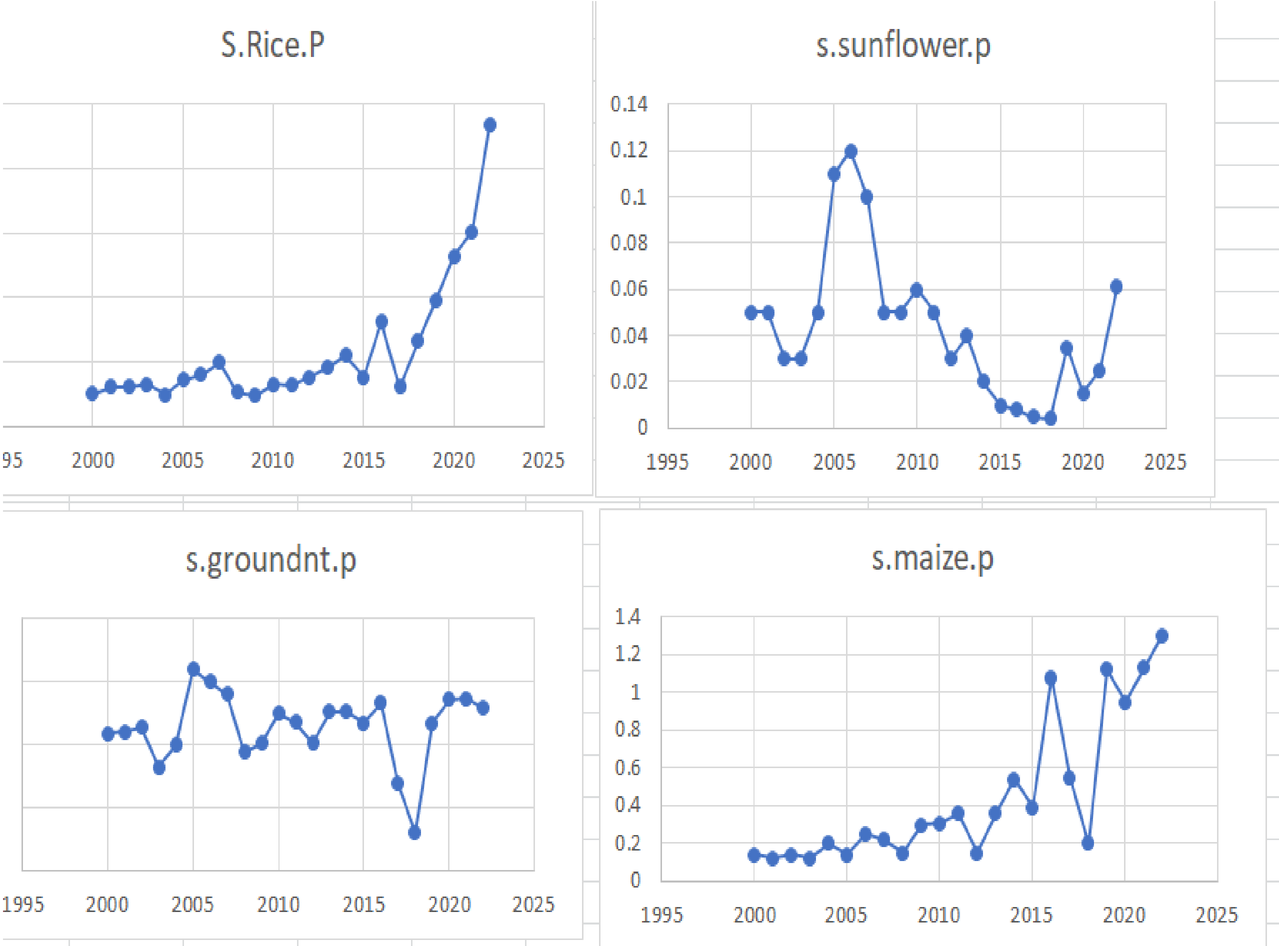




In crops like Jower,maize,Mung,Soyabean,Tur,Gram has increased in trends in production over the years 2000-2023

But some plots like sunflower, linseed etc. have decreased trends in production over the years 2000-2023

**Summary Season Crops (Production in tonnes)**




For the summer season, a wide range of crops including rice, sunflowers, groundnut, and maize are cultivated. Rice and maize production have been increasing, whereas sunflower production has remained relatively stable. We want to investigate the reasons behind the decrease in agricultural production of these crops. Furthermore, we need to focus on other contributing factors and analyze specific districts to determine which ones are causing the decline in agricultural output.

**DISTRICT WISE ANALYSIS:**

We have used data for all Maharashtra districts and separately analyzed crop production for each district. We have used some time plots analysis and regression analysis and calculated the slopes for each crop for different districts in Maharashtra for better understanding.

**Slopes of trends in crops production for Maharashtra districts:**

| | kh rice | wheat | total rice | kh jowar | Total kh. Cereals | Total kh. Pulses | Total Kh.Foodgrains | rabbi jowar |
|---|---|---|---|---|---|---|---|---|
| Thane | -50.8 | | -1.6099 | | -63.657 | -4.229 | -70.04 | |
| raigad | -15.12 | | -5.994 | | -11.88 | -0.89 | -21.64 | |
| ratnagiri | -3.74 | | -2.648 | | -10.37 | -0.904 | -13.28 | |
| sindhudurg | -7.64 | | -1.554 | | -8.759 | -0.745 | -9.593 | |
| Ahmednagar | -9.593 | -18.55 | 0.989 | | -36.8 | 41.96 | 3.365 | -93.56 |
| Pune | -1.37 | -3.133 | 5.549 | -1.361 | -48.29 | -1.459 | -50.4 | -161.9 |
| Solapur | | 12.19 | | | 21.7 | 37.6 | 60.03 | -119.8 |
| Aurangabad | | 5.193 | | -10.69 | -74.15 | -9.045 | -80.05 | -62.93 |
| Jalna | | -1.513 | | -17.48 | -52.86 | -17.13 | -67.22 | -38.73 |
| Beed | | -4.038 | | -31.48 | -97.95 | 17.95 | -79.25 | -40.24 |
| Buldhana | | 16.47 | | -55.92 | -61.14 | -58.24 | -117.8 | -3.306 |
| Akola | | 5.45 | | -45.21 | -48.88 | -25.52 | -72.55 | |
| Washim | | 9.792 | | -30.95 | -33.66 | -41.68 | -73.8 | |
| Amravati | -1.652 | 17.44 | | -49.93 | -34.01 | -25.12 | -72.755 | |
| Yavatmal | | 14.09 | | -65.83 | -72.67 | -23.21 | -93.77 | |

| | rabbi jowar | tur | rabbi maize | kh maize | ttl maize | kh bajra | Oth kh.Cereals | Oth kh.pulse |
|---|---|---|---|---|---|---|---|---|
| Thane | | -0.3934 | | | | | -5.4863 | |
| raigad | | | | | | | | |
| ratnagiri | | | | | | | | |
| sindhudurg | | | | | | | | -0.58 |
| Pune | -161.9 | -1.261 | -50.28 | 5.66 | 10.17 | -50.28 | -0.672 | -3.396 |
| Solapur | -119.8 | 19.24 | 22.16 | 13.5 | 16.75 | 8.885 | | |
| Aurangabad | -62.93 | -0.914 | 18.35 | -3.955 | -26.31 | -57.01 | | |
| Jalna | -38.73 | 2.567 | | -3.381 | 13.59 | -36.94 | | |
| Beed | -40.24 | 7.264 | 1.168 | 4.884 | | -66.67 | | |
| Buldhana | -3.306 | 14.13 | | 1.346 | 36.81 | -2.285 | | |
| Akola | | 3.476 | | | | | | |
| Washim | | 8.288 | | | | | | |
| Amravati | | 10.49 | | | | | | |
| Yavatmal | | 10.49 | | | | | | |

After calculating the slopes of all crops for each district in Maharashtra, we discovered that most districts experienced a decline in crop production between 2000 and 2023.

The negative slopes indicate a decreasing trend in crop production. Many of the districts in Maharashtra are covered by forest areas such as Sindhudurg, Raigad, Ratnagiri, Amravati, Aurangabad, Chandrapur, etc.

We need to find out the reasons behind this agricultural loss.

**How to estimate net agricultural loss?**

**Types of agricultural loss**

**Direct observable loss:** crops eaten, trampled, treesuprooted, broken, denuded, early flowering stagedestruction.

**Immediate indirect loss**: total give up, giving up season, reducing input costs, increased cost of protection, stress and health implications, fear and anxiety, nutritional implications, microeconomic implications.

**Long term indirect loss:** Changing cropping patterns, suboptimal choice of crops, altered microeconomic choices.

**MINIMUM SUPPORT PRICES**

The **Minimum Support Price (MSP**) is the rate at which the government purchases crops from farmers. It is calculated based on at least one-and-a-half times the cost of production incurred by the farmers. The Commission for Agricultural Costs and Prices (CACP) recommends MSP for 22 specific crops and a fair and remunerative price for sugarcane. The CACP considers factors such as cultivation costs, supply and demand situations, market price trends (both domestic and global), impact on consumers, and the environment. The final decision on MSP levels is made by the Cabinet Committee on Economic Affairs (CCEA) of the Union government. MSP benefits farmers by ensuring income security, price stability, encouraging production, and promoting food security. However, challenges exist, including ineffective implementation and dominance of MSP for certain crops like wheat and rice. There is a demand to legalize MSP to provide stronger support to farmers

**District as a unit, all crops having MSP or other standard source of market value are included as follows;**

## Minimum Support Prices

(According to crop year) (Rs per quintal)

| Sl. No. | Commodity | Variety | 2018-19 | 2019-20 | 2020-21 | 2021-22 | 2022-23 | 2023-24 | (#) increase in MSP 2023-24 over 2022-23 |
|---|---|---|---|---|---|---|---|---|---|
| | **KHARIF CROPS** | | | | | | | | |
| 1 | PADDY | Common | 1750 | 1815 | 1868 | 1940 | 2040 | 2183 | 143(7.0) |
| | | Grade 'A' | 1770 | 1835 | 1888 | 1960 | 2060 | 2203 | 143(6.9) |
| 2 | JOWAR | Hybrid | 2430 | 2550 | 2620 | 2738 | 2970 | 3180 | 210(7.1) |
| | | Maldandi | 2450 | 2570 | 2640 | 2758 | 2990 | 3225 | 235(7.9) |
| 3 | BAJRA | | 1950 | 2000 | 2150 | 2250 | 2350 | 2500 | 150(6.4) |
| 4 | RAGI | | 2897 | 3150 | 3295 | 3377 | 3578 | 3846 | 268(7.5) |
| 5 | MAIZE | | 1700 | 1760 | 1850 | 1870 | 1962 | 2090 | 128(6.5) |
| 6 | TUR (ARHAR) | | 5675 | 5800 | 6000 | 6300 | 6600 | 7000 | 400(6.1) |
| 7 | MOONG | | 6975 | 7050 | 7196 | 7275 | 7755 | 8558 | 803(10.4) |
| 8 | URAD | | 5600 | 5700 | 6000 | 6300 | 6600 | 6950 | 350(5.3) |
| 9 | GROUNDNUT | | 4890 | 5090 | 5275 | 5550 | 5850 | 6377 | 527(9.0) |
| 10 | SUNFLOWER SEED | | 5388 | 5650 | 5885 | 6015 | 6400 | 6760 | 360(5.6) |
| 11 | SOYABEEN (yellow) | | 3399 | 3710 | 3880 | 3950 | 4300 | 4600 | 300(7.0) |
| 12 | SESAMUM | | 6249 | 6485 | 6855 | 7307 | 7830 | 8635 | 805(10.3) |
| 13 | NIGERSEED | | 5877 | 5940 | 6695 | 6930 | 7287 | 7734 | 447(6.1) |
| 14 | COTTON | Medium Staple | 5150 | 5255 | 5515 | 5726 | 6080 | 6620 | 540(8.9) |
| | | Long Staple | 5450 | 5550 | 5825 | 6025 | 6380 | 7020 | 640(10.0) |
| | **RABI CROPS** | | | | | | | | |
| 15 | WHEAT | | 1840 | 1925 | 1975 | 2015 | 2125 | | |
| 16 | BARLEY | | 1440 | 1525 | 1600 | 1635 | 1735 | | |
| 17 | GRAM | | 4620 | 4875 | 5100 | 5230 | 5335 | | |
| 18 | MASUR (LENTIL) | | 4475 | 4800 | 5100 | 5500 | 6000 | | |
| 19 | RAPESEED & MUSTARD | | 4200 | 4425 | 4650 | 5050 | 5450 | | |
| 20 | SAFFLOWER | | 4945 | 5215 | 5327 | 5441 | 5650 | | |
| 21 | TORIA | | 4190 | 4425 | 4650 | 5050 | 5450 | | |
| | **OTHER CROPS** | | | | | | | | |
| 22 | COPRA (Calender Year) | Milling | 7511 | 9521 | 9960 | 10335 | 10590 | 10860 | 270(2.5) |
| | | Ball | 7750 | 9920 | 10300 | 10600 | 11000 | 11750 | 750(6.8) |
| 23 | DE-HUSKED COCONUT (Calender Year) | | 2030 | 2571 | 2700 | 2800 | 2860 | 2930 | 70(2.4) |
| 24 | JUTE | | 3700 | 3950 | 4225 | 4500 | 4750 | 5050 | 300(6.3) |

# Figures in brackets indicate percentage increase

To find out total production values for all crops we used the following formula:

**Total Production = Σ Production of crop * MSP**

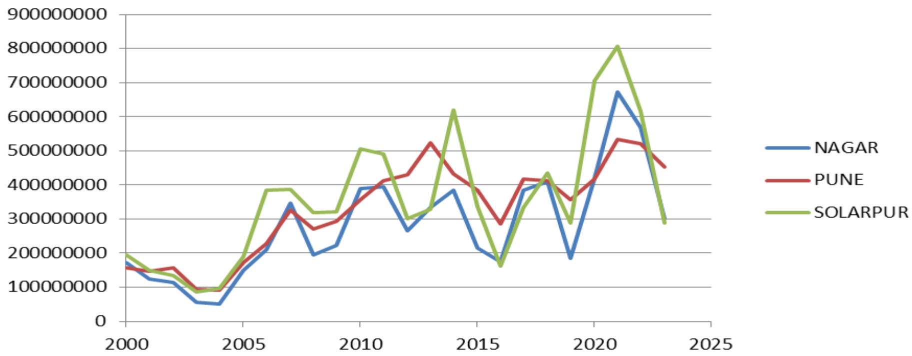
(MSP: minimal support prices)

**After further analysis we have used this total production for the following results.**

The below table shows slopes of each district after using msp for total production, for calculating slopes we have used regression analysis and find out trends**.**

**TRENDS DISCOVER USING MSP**

**Fig A**

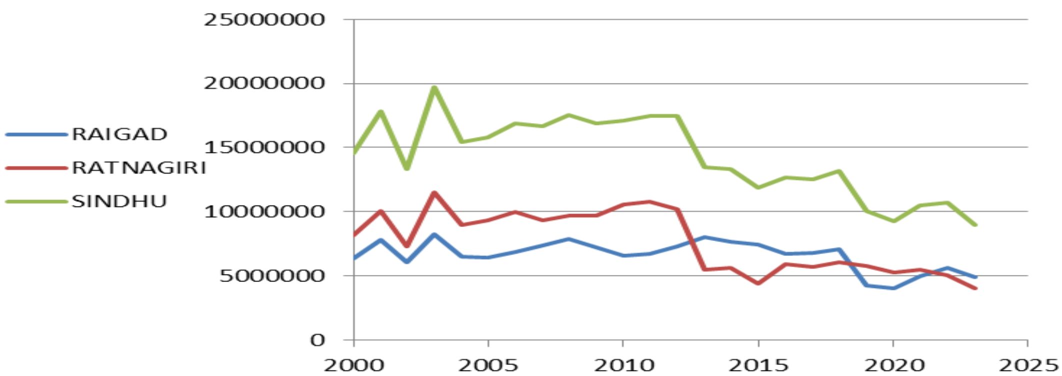



| Regression trend | Slope | slope*100/avg(data) |
|---|---|---|
| Nagar | 15438681.93 | 14.92691255 |
| Pune | 16599998.18 | 12.88651129 |
| Solapur | 17276491.09 | 13.05693028 |

After analysing each district, we identified positive increasing trends in total crop production, as well as negative decreasing trends. We found that non-forest areas showed growth in crop production, while crop production decreased in forest areas.

In Figure A, we have observed positive increasing trends in the years 2000-2023 for districts such as Nagpur, Pune, and Solapur, which are located in non-forest areas.

**Fig B**




| Regression trend | Slope | slope*100/avg(data) |
|---|---|---|
| Raigad | -86067.2807 | -1.248453066 |
| Ratnagiri | -252868.634 | -2.751052425 |

| | | |
|---|---|---|
| **Sindhudurg** | **-338934.915** | **-2.094979717** |

In districts like Raigad, Ratnagiri, and Sindhudurga in the Kokan Vibhag area of Maharashtra, there is a negative trend, as seen in Fig B. This leads us to hypothesize that agriculture in forest areas are experiencing a loss in agriculture.

Our main objective for this project is to investigate the impact of forest areas on agriculture. It is possible that the presence of mammalian herbivorous species in these areas, which feed on plants, is one of the reasons for agricultural loss.

Farmers interviewed online have complained about mammals eating their plants. Despite the forest areas having a conducive environment for crop production, such as high rainfall, suitable soil, and favorable atmosphere, agricultural loss still occurs. This is an important point to consider.

**HOW IS FOREST COVER AND WILD MAMMALIAN herbivore density related to agricultural productivity trends?**

We used forest department data for this analysis from to further process analysis.

**Correlation analysis:**

**Fig. A**

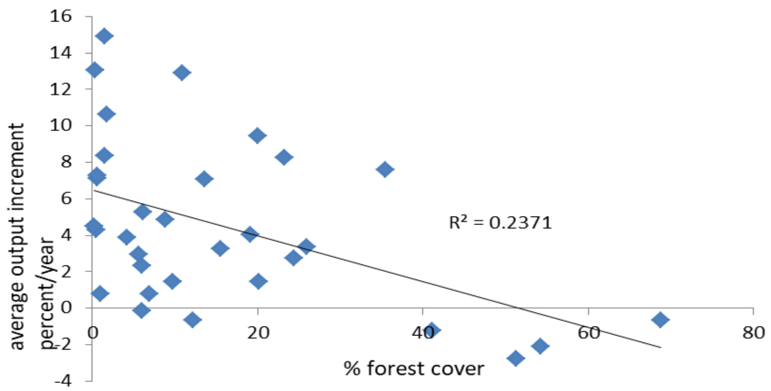
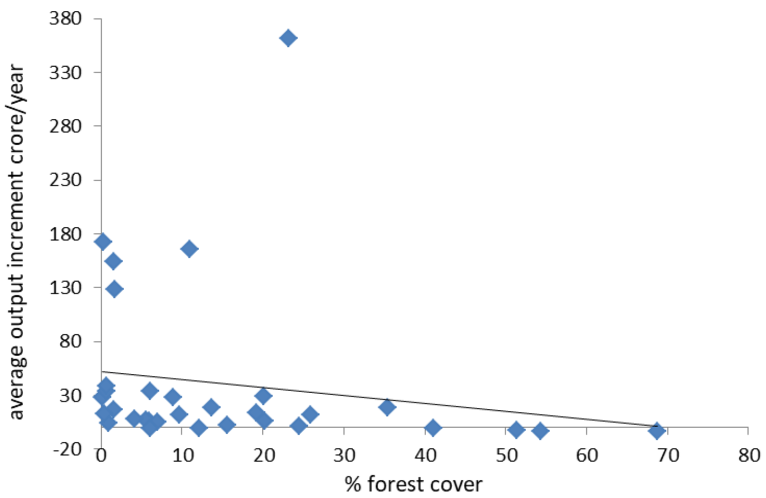



**Fig. B**

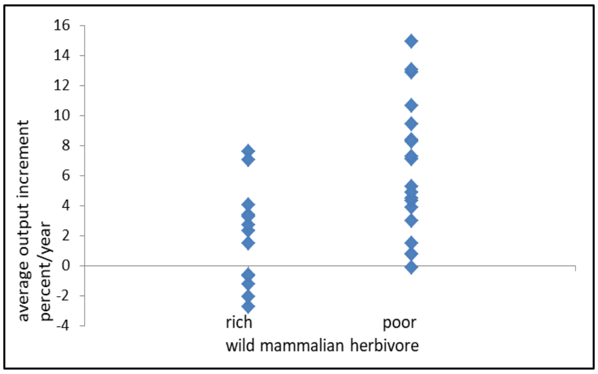


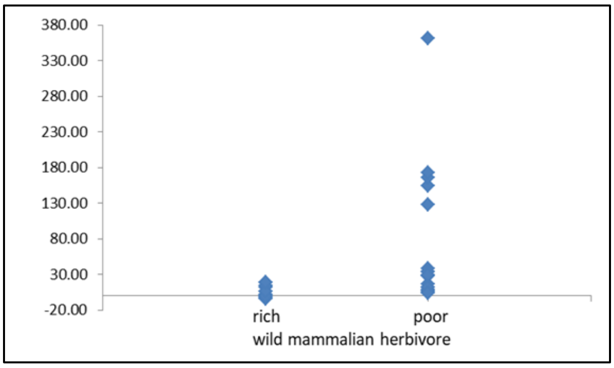

We have used scatter plots to display the relationship between the forest area coverage percentage and the total crop production percentage per year. We found a negative correlation between the average yearly percentage increase and the forest cover percentage, which could be linked to the presence of wild mammalian herbivores.

For a clearer picture, we also plotted a scatter plot for total production in crore/year. We observed that when 30% of the area is covered by forest, there is a low increase in production.

**Presence of mammalian herbivore diversity impact oncrop production.**

We can see relationship between average increment plant growth in percent and wild mammalian herbivore presence




**Interpretation:**The richness of wild mammalian herbivores (animals that eat plants) is negatively correlated with the average increase in crop production per year. This means that areas with high abundence of herbivores experience lower agricultural growh.

**Open questions to be addressed.**

- How to infer causality?
- Assuming causal relationship, can we estimate
- the cost of wildlife conservation policy paid by farmers
- 3. Who pays the cost? Whether the cost can be distributed better over the society.
- 4. Can we reduce the adverse impact on agriculture while simultaneously maintaining a sensible conservation policy?
- 5. The Area with Highest Forest Cover Having Presence of Mammalian Herbivores.
- 6. Area With Having High Diversity of Herbivores Causing Lower Increment of Growth of Plants.

**Checking Trends in Land under Cultivation: -**

**Objective:**

This study aims to investigate trends in the area under cultivation to determine if challenges like crop destruction by animals (e.g., monkeys) and farmer migration to cities (e.g., Mumbai, Pune) are reflected in the data. Farmers in forested regions have reported such issues, and we want to examine whether these trends are evident in the data.

  - **Absolute Difference**:

Absolute Difference = | Area in 2020−Area in 2000|

This measures the total change in cultivated land over time.

- **Percent Difference**:

Percent Difference= ( $\frac{\text{Area in 2020}-\text{Area in 2000}}{\text{Area in 2000}}$ )×100

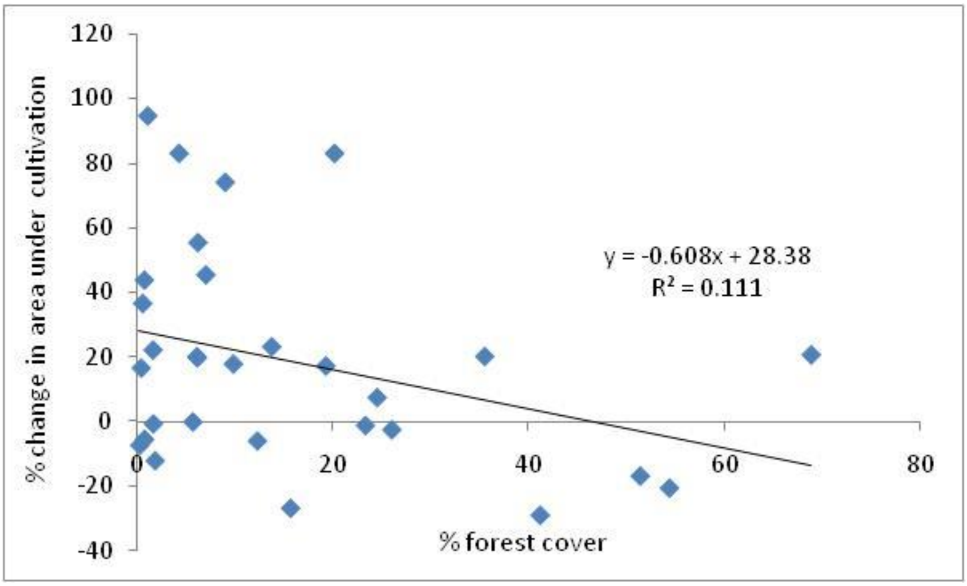
This calculates the relative change in cultivated land as a percentage of the 2000 value.We compared forest cover data with these differences to check if regions with higher forest cover show significant declines in cultivation.

| District | forest cover | wild herbivore | hange in are | % change |
|---|---|---|---|---|
| Akola | 6 | 1 | 995 | 19.89204 |
| Amaravati | 25.94 | 1 | -225.38 | -2.68982 |
| Aurangabac | 5.61 | 2 | -26.16 | -0.26781 |
| Beed | 1.53 | 2 | 1881.08 | 21.98551 |
| Bhandara | 24.44 | 1 | 163.54 | 7.278149 |
| Buldhana | 6.12 | 2 | 3900.23 | 55.22841 |
| Chandrapui | 35.43 | 1 | 877.57 | 19.99932 |
| Dhule | 4.19 | 2 | 3240.71 | 82.86142 |
| Gadchiroli | 68.81 | 1 | 341.41 | 20.4928 |
| Gondia | 15.59 | 1 | -655.56 | -26.9667 |
| Hingoli | 0.99 | 2 | 3898.45 | 94.4392 |
| Jalgaon | 9.75 | 2 | 1530.07 | 17.65601 |
| Jalna | 0.47 | 2 | 2286.19 | 36.39271 |
| Kolhapur | 23.24 | 2 | -50.36 | -1.37296 |
| Latur | 0.18 | 2 | -370.77 | -7.49788 |
| nagar | 1.57 | 2 | -108.02 | -0.84655 |
| Nagpur | 20.22 | 1 | | |
| Nanded | 8.9 | 2 | 6000.71 | 73.88217 |
| Nandurbar | 20.08 | 2 | 3240.71 | 82.86142 |
| Nasik | 6.93 | 2 | 1791.11 | 45.25291 |
| Osmanabac | 0.66 | 2 | -392.84 | -5.6736 |
| Parbhani | 0.65 | 2 | 3226.95 | 43.61922 |
| Pune | 10.94 | 2 | | |
| raigad | 41.1 | 1 | -824.24 | -29.1663 |
| ratnagiri | 51.33 | 1 | -354.58 | -17.0062 |
| Sangali | 1.75 | 2 | -717.54 | -12.2384 |
| Satara | 12.2 | 1 | -320.69 | -6.17186 |
| sindhudurg | 54.31 | 1 | -366.67 | -20.7158 |
| Solapur | 0.33 | 2 | 1568.6 | 16.42685 |
| thane | 31.37 | 1 | | |
| Vardha | 13.66 | 1 | 902.78 | 22.98905 |
| Washim | 6.06 | 2 | 860.13 | 19.61528 |
| Yawatmal | 19.2 | 1 | 1265.18 | 17.06935 |

**Scatter plots:**

We visualized trends in the area under cultivation using scatterplots of **absolute difference** and **percent difference** with respect **to forest cover.**

A) **percent difference in (area x seasons) under cultivation:** (Areas around Mumbai, Thane, Pune and Nagpur where urban and industrial expansion is known to have replaced land under cultivation is excluded from the analysis)

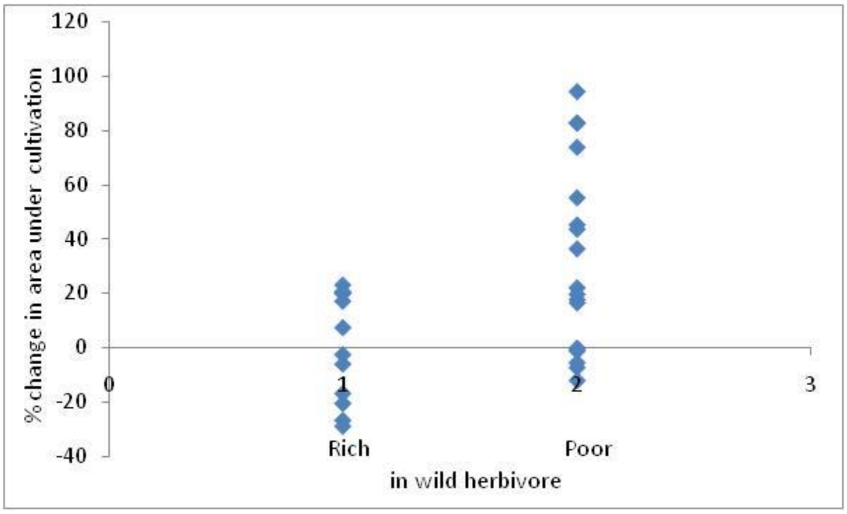



**Interpretation: -**

Above plots shows that there is negative relationship in difference in areas and forest cover areas. Means that cultivated areas decreases as forest cover increases.

Also, in 2000, farming was more prevalent in areas near forests. By 2020, many of these areas appear to have been abandoned for cultivation, possibly due to challenges like crop destruction by animals or migration to urban areas.

**Percent difference in area under cultivation in wildlife rich versus poorer districts**




- The graph categorizes regions into rich wildlife presence and poorer presence
- **Y-Axis ( % Difference in Cultivated Area)**:
- The y-axis represents the (absolute/percent) difference in the cultivated area between 2000 and 2020, indicating how much the area has changed over the two decades.

**Interpretation:** The area under cultivation is greater in non-forest areas compared to forest areas and indicates a shift in farming from forested to non-forest areas, with non-forest regions seeing greater increases in cultivation. This is likely due to challenges in forest areas, such as crop destruction by wild animals and restrictive government policies.

**Reason for Decline in Agricultural Productivity in Forest Area**

**1. Environmental Factors:**

- **Human-Wildlife Conflict:**
  - Forest regions are prone to wildlife encroachments (e.g., wild boars, monkeys, deer), damaging standing crops and reducing yields.
- **Limited Arable Land:**
  - Expansion of protected forest zones restricts the availability of cultivable land, leading to lower agricultural output.

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**2. Economic and Policy Factors:**

- **Lack of Investment in Agriculture:**
  - Forest regions often have underdeveloped infrastructure (e.g., irrigation facilities, markets), affecting productivity.
- **Forest Conservation Policies:**

- Stringent forest conservation laws restrict the use of forest resources, such as timber, grazing lands, and water sources, impacting agriculture.

- **Low Adoption of Modern Techniques:**
  - Farmers in these areas may lack access to technology like precision farming, leading to traditional practices that are less productive.

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**3. Social and Demographic Factors:**

- **Aging Farming Population:**
  - Younger generations often migrate, leaving agriculture to older farmers who may not adopt modern methods.
- **Labor Shortages:**
  - Migration to suburban or urban areas reduces the labor pool available for farming, leading to declines in productivity.
  -

**CONCLUSION:**

- In 2000, farming was more prevalent in areas near forests. By 2020, many of these areas appear to have been abandoned for cultivation, possibly due to challenges like crop destruction by animals or migration to urban areas.
- The limited variance explained by forest cover suggests that while forest cover may play a role in changes to cultivated area, other factors (e.g., urban migration, socio-economic changes, or agricultural policies) likely have a significant impact as well.

Over the last one year, the **Center for Sustainable Development** has been studying the problem of human-wildlife conflicts that afflicts India’s farmers.

In this report we present the findings from our study. We make estimates of net annual agricultural loss in the State of Maharashtra based on **six different approaches**. This reflects the occurrence, extent, and enormity of the problem, demonstrating that it is not limited to protected areas. We set out the steps for further action. Our study focuses specifically on the economic losses suffered by farmers due to wild herbivores. We include **visible and invisible damages and the direct and indirect costs** incurred by the farmers. While human attacks by carnivores, particularly tigers, receive significant media attention, the widespread damage caused by herbivores such as wild boar, nilgai, and macaque remains unappreciated. Our study shows that this conflict is costing the state tens of thousands of crores every year and therefore is a serious concern for the state's economy.

Centre for Sustainable Development

Education : An Ennobling Influence

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