Thematic Paper #4

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Landscape-scale, ecology-based management of wild tiger populations

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LANDSCAPE-SCALE, ECOLOGY-BASED MANAGEMENT OF WILD TIGER POPULATIONS

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ABSTRACT

This paper specifically addresses critical issues facing recovery and management of wild tiger populations through conservation interventions that are typically made at the scale of 'Tiger Conservation Landscapes'. Our proposed science-based approach is centered on meeting the ecological needs of tigers. We define demographically viable source populations of tigers, estimate core areas required to sustain these in different eco-regions and biomes. Examples of tiger conservation landscape matrices defined as above, and their social and conservation contexts, are provided from across tiger range. We then enumerate commonly applied landscape level conservation interventions.

As a platform for further discussions at the workshop, we evaluate relative effectiveness of various interventions in some specific Tiger Conservation Landscapes that we are familiar with. Thereafter, we suggest different rigorous metrics that can be potentially applied in the future for reliably measuring successes or failures of tiger conservation interventions at the landscape scale. This analysis sets the stage for identifying a few critical interventions that can link landscape level management of tigers to other thematic topics covered in the workshop.

1. INTRODUCTION

This workshop aims at evolving a global strategy to ‘save the tiger’ in partnership with range states, and, national and international NGO partners. The possible list of conservation interventions include: tiger-trade/demand suppression; sustained financing of conservation efforts; improving field protection of tigers; reducing biomass extraction and fragmentation of tiger habitats; resolving human-tiger conflicts and building up necessary technical and social capacity/capital in range countries to execute these varied interventions. However, such an array of interventions, evolved at a global level, must ultimately be implemented at a manageable local scale. Our premise here is that for a species like tigers (not necessarily for all forms of biodiversity) the appropriate spatial scale to implement conservation efforts and evaluate them is ‘the landscape’ scale.

Our analyses of problems and interventions at landscape scale will mesh with thematic papers covering other strategic themes being discussed at this workshop. It is our firm belief that it is essential to keep the *tiger's own ecological needs at the landscape scale absolutely central* to tiger conservation efforts. To be effective, global tiger conservation must build outwards from this ecological kernel, rather than go top down fitting the tiger's needs into our own societal priorities, as often has been the case.

We define our typical 'tiger conservation landscape' as harboring one or more 'source populations' of wild tigers embedded within it. The size, shape and geographic or meta-population attributes of this source-landscape configuration should ideally be defined using scientific data on tiger ecology. However, we note that these attributes are unavoidably also constrained and shaped by local human ecology and socio-economic considerations. The Tiger Conservation Landscape (TCL) as defined here comprises of connected 'cores zones' (CZ) holding tiger source populations that are reproducing above replacement levels, either partially or fully embedded within 'buffers' comprising of 'tiger-permeable habitats' under multiple land-uses, which are often 'sinks' for tigers. Thus, ensuring demographic viability of 'source populations' and/or of the meta-populations in a landscape should be seen as the central objective of management. We note that TCLs defined as above may not necessarily correspond with TCLs identified in the earlier global priority setting efforts.

Because Protected Area definitions such as 'National Park', 'Wildlife Sanctuary' and 'Tiger Reserve' have varied connotations in different range states and regional contexts, we have adhered to this simple metrics of *source populations and meta-populations* functioning at *landscape level*. Typical conservation interventions at this scale will dove-tail into topics such as "smart infrastructure", "poverty trap", "demand management", "law enforcement", "capacity building", "resource needs", "sustainable finance" etc., being covered by authors of other thematic papers. Our paper is primarily directed at range country managers and conservationists, *not* at academic tiger biologists or social scientists. Therefore, we use a popular writing format with a 'sample' bibliography, which is short only because of constraints of space.

A major goal of this paper is to try to persuade key actors to *identify effective tiger recovery actions at the landscape scale required in specific contexts*, and to abstain from some current standard forms of investments, which are either directly inimical to tigers or distract tiger managers away from most urgent, effective actions. We also focus on the need for rigorous evaluations of interventions in real time, an objective 'tiger score card' approach, that moves away from the prevailing one based on 'expert opinions' and 'short term site- visits'. The tiger is in dire trouble: success in this context must be clearly measured by *recovery of tiger numbers*, regardless of whatever else our interventions may or may not achieve *in any given landscape*.

With these broad goals in view, we address following specific objectives:

1. Defining tiger conservation landscapes in different biomes/eco-regions, based on ecological needs of recovering and sustaining demographically viable tiger source populations and meta-populations.

2. Identifying key practices of tiger recovery and management at the landscape level that appear to have 'worked' or 'not worked' in the past 35 years.

3. Suggesting mechanisms to reliably and objectively assess future successes (and failures) of tiger conservation interventions using ecological monitoring data.

We base this assessment on studies sampled in the bibliography as well as our collective experience in designing and implementing tiger research, conservation and management projects in India, Bangladesh, Bhutan, Nepal, Russia, China, Indonesia, Myanmar, Thailand and Cambodia. However, given the varied nature of conservation contexts and problems encountered in tiger range countries, there are bound to be gaps and lacunae in our prescriptions. We hope these gaps can be addressed through consultations at the workshop.

2. ECOLOGICAL NEEDS AND VIABILITY OF TIGER POPULATIONS

2.1. Tiger's are adapted to a wide range of habitats: temperatures ranging from -35 degree C to +48 degree C; precipitation regimes from 800 mm to 8000 mm; altitudes between sea level to 5000 m; diversity of forest types ranging from semi-desert scrub, tropical dry and moist deciduous, evergreen, sub-tropical, temperate taiga, mangrove and alluvial grasslands. However, year-round availability of drinking water and shade for thermo-regulation are essential. This environmental adaptability permitted tigers to historically occupy a vast range extending from the Russian Far East to Iraq, from Armenia to the Indonesian Island of Bali. However, across this entire range of environments, tigers cannot survive without one critical element: an assemblage of *large-bodied (>30 kg) ungulate prey occurring at sufficient densities*.

The tiger is a large, obligate carnivore that typically consumes about 50 deer -sized prey animals per year (60-70 prey animals in the case of females raising 2-4 cubs to dispersal age of 18-24 months). Assuming a 8-10% cropping rate on standing prey numbers annually, this intake translates to a ratio of 500 ungulate prey (of >30 kg body mass) for every tiger. So the *potential* carrying capacity for tigers is primarily determined by *available* prey density **(Figure-1):** this is virtually the iron-law of tiger conservation.

However, the real determinant of present carrying capacity for tigers in a landscape is the *actual available prey density*, after accounting for human impacts on potential prey density determined by habitat types. Therefore, mere presence (or expected presence) of large ungulate prey species in a landscape does not mean much: there is a prey-density threshold below which tigers can not reproduce at or above replacement levels. The fact that tigers were extirpated over 93% of their range in the last 100 years is attributable largely to this fact. Therefore, biome type, eco-region, forest type or any other descriptor that can be quickly assessed using remotely sensed landscape ecological tools, cannot fully inform us about the current or future carrying capacity for tigers, although in combination with ground level data on tiger and/or prey densities these tools can be useful.

A related consideration is whether the prey-base supporting a tiger population now comprises of wild or domestic ungulates. In India and Nepal, most tiger source populations appear to survive primarily on wild prey in protected reserves. However, the relative importance of domestic ungulates appears to be greater in subtropical habitats in Bhutan, China and in tropical evergreen forests of Laos, parts of Malaysia and Indonesia due to over-hunting of wild prey and close interspersion of human settlements within extensive forested tracts. From reports of conflict and livestock predation from some of these regions, it is likely that tigers are surviving in many areas primarily on livestock, as was the case of tigers in southern Asia in early parts of the twentieth century.

Tigers are territorial animals and the size of the breeding female territory is the central mechanism by which tiger's space themselves in a landscape. Female territory size is inversely related to prey densities: More prey there are, more breeding females can be packed into a given habitat **(Figure 1, Table-1)**.

Typically breeding males have territories that cover those of several females (usually ≥3), maintaining exclusive breeding access to these females and protecting cubs from infanticide from other males. Female home range sizes range from <15 km^2 on the Indian subcontinent to over 500 km^2 in the Russian Far East. Tigers may move tens of kilometers per day and sub-adults may disperse over hundreds of kilometers in search of vacant territories provided there is suitable cover. In addition to breeding (or resident) tigers, the population consists of cubs<1 year age, juveniles of 1-2 year age, which are dependent on their mother.

Tigers are particularly sensitive to human-caused mortality of breeding adults (as opposed to adult, non-resident 'floaters') and the loss of a breeder has consequences beyond the loss of that individual. When an adult male is killed, infanticide by immigrating males may cause declines in reproduction. Cubs often die when their mothers are poached, and adult females may be particularly susceptible to poaching in areas where people have guns because, instead of fleeing, they may attack people to protect their cubs. Further, in recovering populations, females may divide territories with their daughters, allowing their daughters to settle in their natal home ranges, thereby avoiding the dangers of dispersal, resulting in higher survival and younger ages of first reproduction. If mortality is high among adult females, they may not live long enough to divide territories with daughters.

2.2. The definition of a 'viable tiger population' is the ecological basis on which we can define 'tiger conservation landscapes'. For the purpose of this paper, we focus only on demographic viability and avoid debating different views on genetic viability of tiger population. Based on a series of tiger biology-based studies and historical evidence, we recommend that 25 breeding females should be considered as the minimum for a demographically viable population. Although an area may not support such numbers initially, eventually after recovery this should be the minimum number that should be attainable. With current knowledge of potentially attainable prey densities in different habitat types, such assessments can be made rapidly. This suggested *minimum number* of 25 breeding females should be used as a baseline for identifying Tiger Conservation Landscapes as areas that have the potential to achieve and sustain them over a 10-30 year recovery time frame. Tiger conservation landscapes should be chosen and prioritized on such an ecological basis, rather than only using maps or remotely sensed data. Thus, science tells us what sort of minimum landscape and core breeding area (population source) size may be *attainable*. Based on potential carrying capacity and other practical considerations such as administrative or political feasibilities, conservation choices must be made. In this context we note that a hypothesized projection matrix population model, which was parameterized using demographic data from the Russian Far East but without incorporating immigration rates, suggests that the number of required females for a demographically viable source population may be as high as 83 females. However, the number of 25 females we use here is based on an alternative modeling approach and is supported by actual population dynamic data from Nagarahole, India.

In **Table-1**, we present a summary of required size of a source population area appropriate for different biomes/habitat types. We emphasize that these ‘core areas’ are protected, conflict-free zones, where tigresses can raise cubs to dispersal stage naturally.

2.3. Once protected, these tiger source populations are visualized to increase to attain the potential carrying capacity set by the prey-base, with substantial numbers of new tigers being recruited through reproduction, and, possibly immigration from other connected sources. In productive habitats females first breed at the age of 2-3 years, produce litters of 3-4 cubs who survive to dispersal age. Breeding once in 3 years a single female can produce 15 cubs during her reproductive lifespan of 7-10 years, at an average rate of 1-1.5 cubs/breeding female/year. There are several anecdotal records for such reproduction as well as one rigorous population dynamic study of 10 year duration that documents these high recruitment rates from Nagarahole, India. A natural corollary to such high reproduction is that, once saturation densities are attained, there is bound to be high rates of mortalities (natural or human induced) and some permanent emigration to other populations or into the surrounding landscape sinks. Sub-adults disperse away from the natal areas at about 2 years of age, and become ‘floaters’ searching for territories to take over and settle. Higher reproduction rates results in an annual surplus consisting of post-dispersal sub-adults or evicted breeders. On the other hand, human-induced mortalities that primarily affect ‘floaters’ may not have much of an effect on tiger numbers, given that a substantial surplus of such floaters are produced annually in high density source populations **(Table-2)**.

Consequently, managers must recognize that a high number of tiger mortality records alone do not indicate that tiger a population is threatened. The key questions are: (1) is the tiger source population at the potential density it can attain? (2) are reproductive rates normal and (3) are tigers that are being killed, dispersers or evicted breeders past their prime reproductive age? If the answers to above three questions are “yes”, reports of tiger deaths alone may not be sufficient cause for alarm and may distract attention from the key task of maintaining high tiger densities. Annual tiger mortalities in reasonable numbers may be the price we pay for achieving localized success in tiger conservation. We summarize typical figures for recruitment and mortality rates expected in tiger populations of various sizes (**Table-2**).

Thus the tiger is a “fragile species” in the sense that it comes into conflict with humans easily, ranges over large areas, requires a large prey base, and, is targeted by organized wildlife crime for body parts. However, it is also a “resilient species” because of its high reproduction rates, ability to attain high densities in some types of habitats, great dispersal and ranging abilities, wide geographic range, and, is tremendously popular with a global cultural appeal.

2.4. Based on the foregoing analysis, we have tried to provide wildlife managers with an ecology-based, but pragmatic framework with some illustrative examples of key characteristics of tiger source populations and landscapes **(Table-3 and Table-4)** we are familiar with. We submit that useful interventions in any tiger conservation landscapes must aim to be based on prey and tiger density data, or at the very least educated guesses based on current knowledge of tiger ecology as well as assessments of what has worked or not worked in the past. It should also be based pragmatically on what can be achieved in the continually changing social and management context.

3. ASSESSMENT OF 'BEST PRACTICES' IN TIGER MANAGEMENT AT LANDSCAPE LEVELS

Critical, effective conservation interventions *can only be implemented at the landscape level* by state and/or non-governmental agencies. Our approach here is not to make a shopping list of all such possible interventions, but to isolate a few critical actions likely to yield results in a 5-10 year time frame, to stem local declines of wild tigers and recover populations. *Our own assessment of the potential effectiveness of these interventions is provided in* **Table-5**, *but a deeper assessment in each specific context is essential as a part of discussions at the workshop*.

These interventions can also be visualized as those with more immediate impact on tiger and prey populations as opposed to those interventions with longer-term impacts. All these *landscape level* conservation interventions must necessarily dovetail into other cross cutting 'themes' listed for discussion at this workshop. We briefly describe some possible interventions here below:

3.1. Anti-hunting operations on ground

Although hunting of tigers is illegal across their range, hunting of prey is legal or quasi legal in several landscapes outside of southern Asia. There are anti-hunting law enforcement actions in the field such as armed foot patrols, vehicle patrols, forest camps, guard posts, etc primarily to deter/apprehend/regulate hunting of tigers and less frequently hunting of large ungulate prey. These patrols primarily target stopping illegal hunters who may employ guns, snares, traps or poisons. Such patrols are typically implemented by local forest/wildlife authorities or military or special forest police forces or other land-management agencies.

3.2. Regulation of biomass removal and land encroachments

Field patrols (armed or un-armed), road closures, fencing or trenching of forest boundaries, in order to prevent logging and other biomass removal and to prevent minor land encroachments. These actions are mainly carried out by local land-managers or forestry departments with the primary purpose of protecting land and forest products. Suppression of forest fires also is one such activity entrusted to them. Such 'regulators' of habitat use/damage may not necessarily be inclined to prevent illegal hunting of prey species or tigers, and might occasionally even indulge in poaching themselves or collude with poachers.

3.3. Local level wildlife crime detection

Usually organized wildlife traders who operate centralized international or national crime networks are monitored and controlled by separate centralized authorities set up for the purpose. However, additionally, sometimes local police or wildlife/forestry authorities may also monitor or gather intelligence on poaching pressure emanating from villages or urban centers as a result of activities of local people who may not always be a part of wider wildlife crime networks. These local enforcement agencies do not typically focus solely on wildlife crime but work incidentally and sporadically.

3.4. Resolving Human-Tiger conflicts: "Reactive Measures"

Conflicts occur due to tiger predation on livestock or more rarely on humans. Presence of abundant free-ranging livestock or even wild prey attracted to crops in human settlements can invite tiger depredations, particularly in tiger habitats where wild ungulate densities are depressed. Methods for reducing such conflict and its impacts on tigers and people include: improved livestock management; improved wild prey management; zoning to reduce overlap with humans and livestock and tigers; local education; livestock compensation or insurance and emergency response to specific conflict situations by appropriate authorities. In such contexts killing or capture and removal of the problem tiger (either into captivity or for translocation into a new habitat) are practiced. We must note that conflict will never be eliminated around source populations at carrying capacity, because there will always be sub-adults, evicted residents as well as sick or injured individual tigers, which take livestock as easy prey. In a few rare cases emergency response teams specially trained to deal with such conflict have been deployed.

3.5. Preventing Human-Tiger conflicts: "Proactive Measures"

In India, Thailand and Nepal relocation of village settlements out of core tiger habitats has been adopted as a strategy with three intertwined goals: prevention of human-tiger conflicts, elimination of hunting and other human impacts on tigers/prey, and, over the longer term consolidation of tiger habitats through "avoided development" in the form of future intrusion of roads, power lines and such other public service utilities that are increasingly fragmenting tiger habitats.

3.6. Long-term consolidation and "De-fragmentation" of tiger habitats

Preventing externally imposed fragmentation and loss of connectivity by keeping out intrusions in the form of infrastructure/development projects is becoming an important activity in the face of rising prosperity and economic development in Asia. Traditionally such drivers of habitat fragmentation have been river-valley dams, highways, mines, power plants and other industrial activity. However, we note that in recent time tremendous negative impacts are being unleashed by forms of 'green energy generation', which is being heavily promoted in the context of global warming. Windmill farms, run of the river and micro/mini hydro-electric projects etc. belong to this category of impacts. The required responses involve closing down or phasing out even existing projects of such kind usually as a result of local, national or international pressure or litigation sponsored by non-governmental players.

3.7. "Community-based Conservation" and biomass harvest schemes

To enlist public support for tiger conservation, attempts are made to implement various kinds of community-based conservation projects (ICDPs) and such other schemes for promoting exploitation of timber or a variety of non-timber forest products (NTFP), removal of weeds and other forms biomass for consumptive uses by local people. Such interventions may be implemented by National, regional or local governments, or even NGOs in some cases.

3.8. Tiger "Habitat Enrichment" Practices

Management authorities of tiger conservation areas expend large sums of money and invest a lot of manpower on activities such as: laying new roads or improving older ones, creating new water resources such as check dams or manipulating vegetation, with the explicit goal of 'increasing food and water availability to wildlife' or to promote tourist viewing of animals. In India, in recent years these types of investments are forming a major part of tiger reserve management budgets.

3.9. Supplementing tiger or prey populations through translocations or release of captive-bred animals

Sometimes, attempts are made to increase tiger densities through release of individual animals from other wild populations (translocations) including 'problem' animals caught in conflict situations or using tigers raised in captivity. In a few cases attempts have also been made to release captive bred prey species into tiger habitats in attempts to get rid of surplus animals in captivity or to increase prey population densities. These interventions are usually undertaken by reserve authorities often with support and involvement of commercial tiger farms, or non profit agencies.

3.10. Tiger-centric tourism

Tiger related tourism activities (primarily in India and Nepal) come in two flavors: those that cater to budget local tourists, and those that cater to high-end tourists (both local and foreign). Activities include driving up to and approaching habituated tigers on elephant back, adventure tourism activities such as rafting or trekking, camping in the forest, driving vehicles cross country and increasingly construction of buildings and luxury resorts that externalize their energy consumption, sewage and other disturbances on to surrounding tiger habitats.

In **Table-5**, we illustrate some of these types of interventions, indicating wherever possible, examples of both positive and negative results we have observed.

4. A TIGER SCORE CARD: OBJECTIVE MEASURES OF SUCCESS

4.1. The goal of *tiger recovery projects at landscape scales* now should be able to deal with a crisis situation and recover tiger numbers. Broader forms of biodiversity conservation or integrated community conservation projects *can afford* to have diverse goals, longer time frames, and a wider set of 'soft' metrics, such as, amount of money spent, quantum of human employment generated, biomass produced or consumed, degree of human welfare gains made, etc, to measure successes (or failures). These surrogate metrics are not very relevant in the crisis that confronts wild tigers now. In fact there are many biodiversity and community conservation projects, which aimed at tiger conservation as a key goal, but because of the use of surrogate metrics failed to assess if they headed towards their stated goal of tiger conservation or in an opposite direction (e.g. World Bank-GEF Eco-development projects in India of the late 1990s).

We believe that the most favored form of evaluation of tiger conservation projects being applied currently, which consists of brief site visits by "experts", often applying "IUCN guidelines" and such other subjective yardsticks, are wholly inadequate to the challenge on hand. The reason wildlife managers or institutions often apply such poor surrogates to measure tiger conservation successes are many and complex, and, fall within the ambit of other thematic papers presented in this workshop. We submit that even broader overall assessment of tiger conservation projects must use some objective measures of threat levels and of actions taken to address key threats.

Tiger population recovery (or lack thereof) can most reliably be monitored by directly measuring *absolute tiger densities* (number of tigers/100 km^2), particularly in core source areas, because tigers may sometimes be eliminated by direct poaching, fairly quickly, regardless of prey density and habitat conditions. Similarly, directly measuring changes in *relative tiger densities* or changes in their spatial distributions (habitat occupancy) across larger landscapes can help direct conservation interventions at wider scales beyond core areas.

Measuring the *potential tiger carrying capacities of core areas through assessments of prey base (ungulate densities)*, and quantitatively monitoring *levels of various threats to tigers, prey and habitats* on a systematic, scientific basis will provide valuable feedback about effectiveness of conservation actions. Detailed publications, manuals, software, and video-guides covering these monitoring concepts and methods are now available. Therefore, lack of practical, rigorous tools for measuring tiger conservation successes at landscape scales cannot continue to be an excuse anymore to defer honest evaluations.

We broadly propose the following approaches to conservation monitoring at Tiger Conservation Landscape/source population scales:

4. 2. *Direct ecological measurements:* counting tigers and prey; assessing habitat conditions; human impacts on tigers, prey and habitats. These must employ ecology-based, statistically sound monitoring/evaluation approaches, tools and resources. The 'state variables' (e.g. density) or the vital rates (e.g. survival) that are measured will differ depending on geographic scale of the study and even drivers of temporal changes (survival, movement) can be measured reliably now.

Furthermore, in addition to *field measurements* of tigers and prey densities, an array of landscape-ecological and *remotely-sensed* data can be used to monitor habitat related variables (extent of forest fires, potential impact of infrastructure projects) at landscape scales. There is also a substantial literature on *directly* measuring human impacts and threat levels such as hunting intensity, fragmentation, forest product exploitation etc.

In **Table-6**, we list various types of monitoring required at source population and overall landscape levels. Where possible we have mentioned specific techniques or tools. We have also provided relevant source materials and where possible given examples of such monitoring work being carried on. While there are many potential indicators of success, *we stress that the ultimate reliable measure of successful species recovery is* increase in tiger densities and range expansions.

5. DISCUSSION

We submit that prioritization of conservation interventions in Tiger Conservation Landscapes at national/regional levels should be based on ecological criteria described above. However, pragmatic criteria such as existence of political will (a particular country, state, government or NGO may have greater ability or commitment to deliver tiger conservation), protection of the Tiger Conservation Landscape in question (say presence of armed insurgents or civil strife) do inevitably play a role in landscape-level tiger conservation interventions and priority-setting. Our submission here is that Tiger Conservation Landscapes should not be selected for investments or interventions based purely on emotional or political considerations, as is often the case. As an example, we cite the disproportionate investments made in attempted tiger recovery at Sarikska Tiger Reserve in India, considering the relatively poor potential of the site for tigers.

Another problem is that, so far, most attempts at defining and setting tiger conservation priorities have been almost entirely based on landscape ecology tools depending primarily on remotely-sensed data, with some *ad hoc* incorporation of expert opinions on tiger status (**Figure 2 & 3**). Such maps can only set priorities based on the physical area of habitat and incorporating some remotely-sensed covariates. However, we submit that, because: 1) it is not the extent of habitat, but prey densities that determine tiger presence and density; and 2) even when prey densities are adequate, direct poaching may rapidly eliminate tigers. Consequently, purely map-based approaches have limited use for managing wild tigers at the landscape scale, which is under consideration here.

Even a recent field survey of distribution of major Indian tiger sub-populations shows that there is very little correspondence between the landscapes currently holding the largest Indian tiger sub-populations (e.g. Western Ghats, Corbett, Kanha-Pench) and the much larger Tiger Conservation Landscapes identified in the states of Andhra, Chattisgarh, Orissa or Arunachal Pradesh (e.g. Sanderson et al. 2006). The same problem is reflected globally, with the importance the Indian subcontinent that possibly holds more than 50% of the entire wild tiger population being underplayed in preference to larger landscapes in SE Asia (e.g. in Myanmar, Cambodia) that are now virtually devoid of tigers (**Figure 3**).

In Figure **3a** we categorize proportion of currently available potential tiger habitat in major bio-regions. Assuming prey densities are optimized in each biome type Figure **3b** shows potential maximum tiger numbers that can be supported in each region. In contrast, Figure **3c** shows how the best available “guesstimates” of current tiger numbers stack up among these regions. These kinds of analyses at finer geographical scales are bound to be very useful for making conservation decisions and investments.

Lack of reliable data on tiger dispersal capabilities in various land cover types poses a serious problem in clearly identifying genuinely insular Tiger Conservation Landscapes (TCL). The current distance metrics used to separate landscapes, which are based on earlier data from Chitwan and appear to be too conservative. These need to be based on more recent tiger movement data.

6. Conclusions

We believe the following key recommendations emerge from our analysis as a basis for further discussions at the workshop:

1. Identify, based on existing ecological-data, the current status of the world's wild tigers, what are their realistic prospects and where should future tiger conservation investments be targeted, and in what proportions at regional, country and landscape levels.

2. The need to re-emphasize the earlier "circling the wagons" approach to tiger conservation focused on enforcement-oriented protection of source populations, over the more widely promoted but loosely formulated approach of creating larger "tiger friendly landscapes" - or what we would call "drawing circles on maps without any wagons on the ground". Clearly there has been a steep slide in protection of core areas during the last decade or so as the management priorities have shifted. This mission-drift towards new activities such as rural development, community forestry has largely driven the decline of protection. As a result key tiger source populations have collapsed one after the other even in productive habitats of southern Asia. This mission-drift away from core area protection towards "eco-development", "habitat enrichment", "captive-breeding" and "translocation of tigers or prey" etc., needs to be arrested urgently to restore the priority for protection that did exist a quarter century ago in all key tiger landscapes particularly in southern Asia.

3. Given the urgency of providing increased protection to tigers, prey and habitats, the next key issue is to identify the appropriate national/regional/local authority who can actually implement effective protection/enforcement on ground, required in each specific Tiger Conservation Landscape, state, country or region. *It must be noted that such effective ground protection did indeed exist in several tiger habitats in India and Nepal during the 1974-1984 period, under forest department or paramilitary management, before institutional mission-drift and wider socio-political changes undermined such efforts in the subsequent years.*

4. Accomplishing, over the long term at least, de-fragmentation and consolidation of key Tiger Conservation Landscapes across tiger range, using *a judicious, fair, and generous voluntary relocation of human settlements from critical tiger source population areas, as a direct method for promoting human welfare and reduction of biomass extraction, rather than shunning this sound approach as has been the case with some GTI partner institutions in the past*. Even in the face of Asia's rapid economic growth, reducing fragmentation pressures through combination of 'smart infrastructure development' and voluntary relocation is recommended as opposed to current practices.

5. Instituting and implementing objective, reliable scientific monitoring of tigers, prey, habitats, and anthropogenic impacts and threats on these, using proven, rigorous methods. *Towards this end, making tiger monitoring activities genuinely independent of local tiger management authority, by ensuring scientific and civil-society participation, and, thereby ensuring data integrity and transparency*. Move away from current practices of evaluating tiger conservation projects using official reviews, short term site visits, expert appraisals of various sorts and such other forms of subjective (and sometimes self-serving) processes. Eventually, aim at integrating the scientific monitoring of wild tigers

into a formal adaptive management framework, at least in some key Tiger Conservation Landscapes of the world.

We hope that the workshop will provide a useful forum for moving forward on ideas leading to a world that will forever have wild tigers roaming free.

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Table 1. Relationship between biome type, potential tiger densities/1000 km^2 and size of area (km^2) required to support source populations with different numbers of breeding females

Biome type	Potential overall tiger density	Potential breeding female density	Typical female range size	Area required to sustain different numbers of breeding females in source populations				
				5	**10**	**25**	**50**	**100**
Temperate forests	10	3	330	1650	3300	8250	16500	33000
Tropical evergreen/mangrove forests	30	10	100	500	1000	2500	5000	10000
Tropical deciduous forests	100	33	30	150	300	750	1500	3000
Alluvial grasslands	150	50	20	100	200	500	1000	2000

Table 2. Typical numbers of tigers from expected annual reproduction and expected annual losses (morality or dispersal), from source populations assumed to be at saturation densities with different numbers of breeding females. The age categories used are: cubs< 1 year age; juveniles 1-2 years; dispersers >2 years. These numbers are only indicative and based primarily on published work on tiger population dynamics at Nagarahole, India. They are only meant suggest that normal, healthy tiger populations have naturally high rates of annual losses and do not incorporate annual stochastic variations of various kinds.

Number of breeding females	Number of cubs born per year	Number of cubs reaching juvenile stage	Juveniles reaching dispersal age=expected losses of tigers per year
5	5	3	3
10	10	6	5
25	25	15	14
50	50	30	27
100	100	60	54

Table 3. Examples of expected demographic characteristics of tiger populations in some typical landscape matrices in tiger range. Buffers are wider areas adjacent to the cores. Their quality is categorized as: F=Source is fully buffered by tiger permeable landscape; P=Partially buffered, with rest being hard edge; and H=source is almost surrounded by Hard Edge not permeable to tiger movement. Buffer Area Size is categorized as: L= buffer > source area; and S=buffer<source area. Level of connectivity is categorized as Yes or No, depending on if the landscape is connected to other nearby landscapes to form a meta-population of tigers.

Name of Site/Landscape/Region	Tiger density /100 km^2			No of Breeding Females in Source Population			Buffer Type & Quality		
	D>10	D=3-8	D<1	N>25	N=10-25	N<10	Buffer type	Buffer size	Connectivity
Nagarahole-Bandipur	X			X			P	S	YES
Bhadra		X				X	P	S	YES
Anshi-Dandeli			X			X	F	L	YES
Kudremukh			X			X	P	S	YES
BRT		X			X		P	L	YES
Kanha	X			X			F	L	YES
Pench (MP+MH)		X			X		P	L	YES
Tadoba		X				X	P	S	YES
Melghat		X			X		P	L	YES
Ranthambore	X				X		H	S	NO
Kaziranga	X			X			P	S	YES
Sundarbans (India+Bangladesh)			X	X			F	L	NO
Huai Kha Khaeng+Thung Yai		X		X			F	L	YES
Endau-Rompin+logging concession			X			X	P	L	YES
Gunung Leuser Landscape			X	X			F	L	YES
Hukaung Valley			X			X	F	L	YES
Seima-Mondulkiri			X			X	P	S	NO
Nam Et Phou Louey			X			X	P	L	YES
Russian Far East			X	X			F	L	YES

Table 4. Examples of conservation contexts and management characteristics of some typical landscape matrices in tiger range.

Name of Site/Landscape/Region	Social tolerance level for tiger reserves			Enforcement Authority
	High	Low	None	
Nagarahole-Bandipur	X			State Forest-Wildlife department
Bhadra	X			State Forest-Wildlife department
Anshi-Dandeli		X		State Forest-Wildlife department
Kudremukh		X		State Forest-Wildlife department
BRT	X			State Forest-Wildlife department
Kanha	X			State Forest-Wildlife department
Pench (MP+MH)	X			State Forest-Wildlife department
Tadoba		X		State Forest-Wildlife department
Melghat		X		State Forest-Wildlife department
Ranthambore	X			State Forest-Wildlife department
Kaziranga	X			State Forest-Wildlife department
Sundarbans (India+Bangladesh)		X		State Forest-Wildlife department
Huai Kha Khaeng + Thung Yai		X		Federal-Wildlife department
Endau Rompin + Logging concession			X	State Wildlife department+Private
Gunung Leuser landscape			X	State+Federal Wildlife department+Police
Hukaung Valley			X	Federal Wildlife department, insurgents
Seima-Mondulkiri			X	Provincial Forest+Police+NGOs
Nam Et Phou Louey			X	Federal Forest-Wildlife department
Russian Far East		X		Provincial-Wildlife department

Table 5. Examples of relative effectiveness of various conservation/management interventions observed by the authors in some Tiger Conservation Landscapes, regions or countries. These are meant serve as a discussion platform for generating more systematic, rigorous assessments in future.

Type of intervention	Assessed effectiveness/impact			
	Reasonably Effective	Partial	Ineffective	Negative
Anti-hunting operations on ground	Kaziranga, Nagarahole	Huai Kha Khaeng	Hukaung Valley	?
Restrictions: biomass, encroachments	Kaziranga, Kanha	Tadoba, Chitwan	Sundarbans	?
Local level detection of wildlife trade	Nagarahole, G. Leuser	Kanha	Namdapha	?
Conflict resolution (Reactive)	Russian Far East	Sundarbans	Gunung Leuser	?
Conflict resolution (Proactive) through voluntary relocations	Bhadra, Nagarahole	Huai Kha Kaeng	Panna, Tadoba?	?
Habitat consolidation through land purchases and voluntary relocations	Bhadra, Kudremukh	Nagarahole	?	
ICDP, Eco-development biomass harvest schemes	?	Sundarbans, BRT	Periyar	Nagarahole, Buxa
Habitat manipulation,‘enrichment’	?	Kaziranga		Nagarahole, Pench
Tiger or prey translocation/releases	?	?	Sariska, Panna	?
“Tiger-centric” tourism	Chitwan	Kanha	Panna, Sariska	Ranthambore
Nature Education by NGOs or other	Nagarahole	Nam Et Phou Louey	?	-

Table 6. Objectives, Approaches and Methods for Monitoring Successes or Failures of Tiger Conservation Projects.

Measurement Objective	Suggested method	Expected Result	Advantages or disadvantages
Keeping track of individual tigers and their movements	Radio-telemetry –VHF, GPS	Real time tracking of individuals	Real time data and immediate detection after poaching if any
Estimating tiger numbers/densities in key source populations	Annual 45-60 day photographic capture recapture sampling or scat-DNA sampling	Annual data on tiger numbers and changes in them	Enables reliable assessment of population status and lag-time tracking the fate of some individuals
Estimating tiger numbers, survival, recruitment rates etc in key tiger populations	Annual 45-60 day photographic capture recapture sampling or scat-DNA sampling extended over multiple years	Tiger numbers, changes and estimates of survival and recruitment rates	Enables reliable assessment of whether the population is holding steady and if mortalities are really causing declines.
Estimating relative densities of tigers over large landscapes and changes in tiger distribution patterns	Large cell occupancy surveys of tiger signs in a capture recapture framework, accounting directly for detectability	Tiger density index showing spatial variation, estimate of proportion of habitat occupied	Enables reliable monitoring of habitat occupancy changes and spatial distribution of tigers due to population extinctions or recolonizations
Estimating numbers for tigers over large landscapes and changes in tiger distribution patterns	Sign surveys and integrated modeling of sign based occupancy data with abundance measures derived from camera trapping	Tiger number estimates for large regions based on occupancy modeling	Enables generation of tiger numbers over large region explicitly accounting for detectability.
Estimating carrying capacities for tigers in source areas	Estimation of prey densities from line transect surveys	Absolute density estimates for principal prey species	Enables reliable estimation of tiger numbers that could potentially be supported in a given habitat
Estimating relative prey densities accounting for detectability, in habitats where line transect surveys	Small cell occupancy surveys of prey animal signs in a capture recapture framework	Relative density estimates for prey species as well as their	Where absolute densities cannot be estimated at least reliable estimates of prey densities can be measured to

Measurement Objective	Suggested method	Expected Result	Advantages or disadvantages
are not feasible	to assess habitat occupancy and relative densities of principal prey species	habitat occupancy patterns	assess status of an area to support tigers.
Direct measurement of human impacts like hunting, biomass removal and other disturbances	Surveys in the field counting impact signs or using quantitatively structured questionnaires	Quantitative measures of levels of various negative human impacts	Early warning of poaching of tiger, prey and other impacts, most useful in combination with tiger monitoring data
Direct measurement of patrolling and other on ground protective efforts	MIST patrol monitoring system, and other local systems in use	Quantitative measures of levels of effort put into direct protection	Useful to keep track of management performance objectively
Remotely-sensed data on habitats, forest fires, local encroachments, intrusions of infrastructure projects and other impacts	Remote-sensing, GIS tools	Objective and quantitative measures of large scale habitat impacts	Useful to keep track of threats in real time
Surveys of local peoples and visitor attitudes towards tigers, reserves, management etc	Questionnaire surveys	Measures of public perception of tiger reserves, their value and management quality	Useful to formulate interventions that aim at changing perceptions in favor of tiger conservation

Figure 1. Relationship between prey density, home range sizes of breeding tigresses, and, overall tiger density.

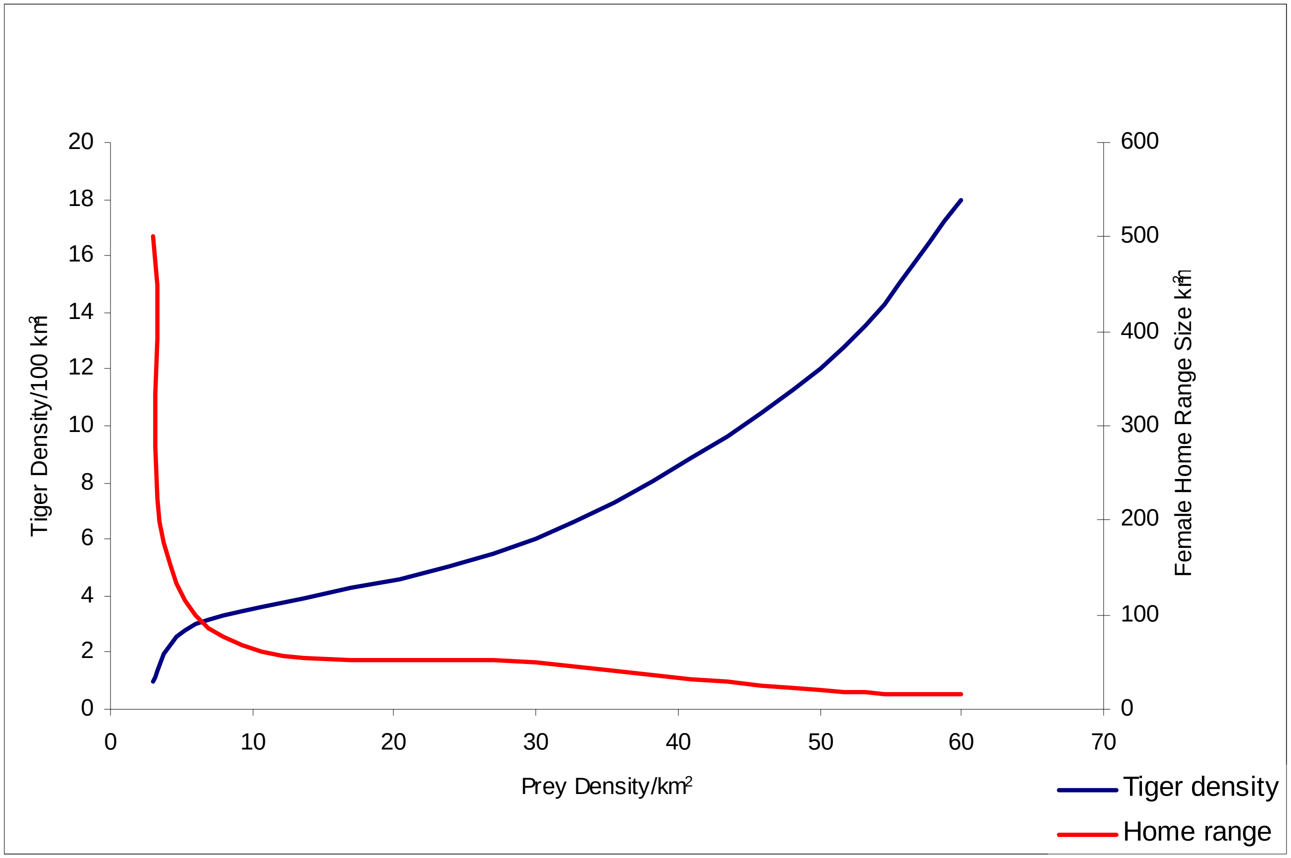

Figure 2. Map of Tiger Conservation Landscapes (TCLs) with total areas (km^2) and proportion of protected areas in each region.

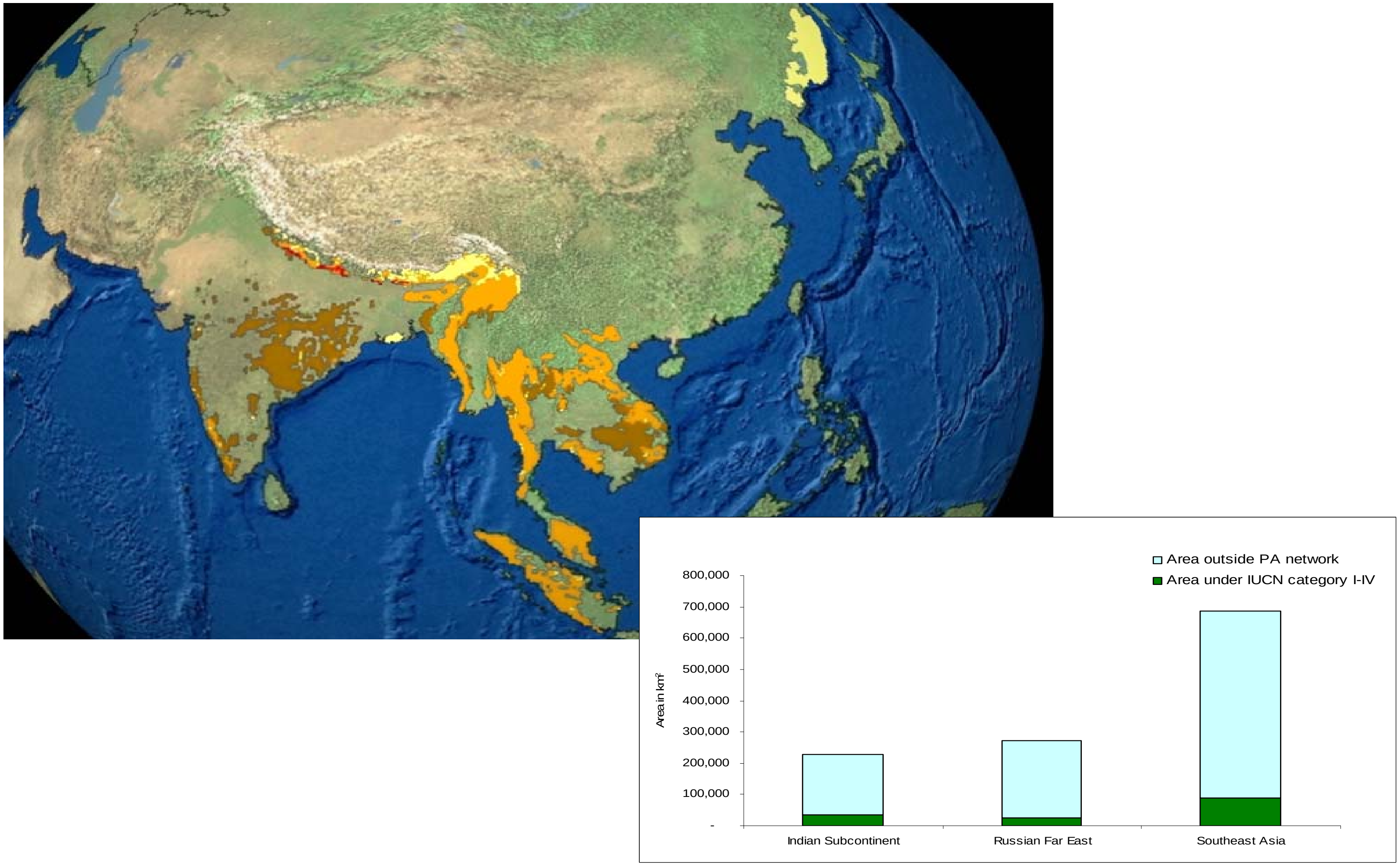

Figure 3. (a) Proportion of potential tiger habitat in different regions (of the total area of 1.1 million km^2), (b) Maximum tiger numbers attainable within potential habitat in different regions given that optimal densities can be attained, and, (c) "Guesstimated" present tiger numbers in different regions.