Chapter II. Home Range and Movement Pattern

“We invoke the Earth upon which foliage and trees are firmly held, unthreatened, the Earth which is equipped with all good things in a stable environment of harmony.”

-Atharvaveda

Objectives

Patterns of space use and distribution reveal key information on species biology and behaviour, which are basis of conservation management. These patterns relate closely to demographic parameters (Smith and McDougal 1991, Wielgus et al. 2001) that affect population viability (Chapron et al. 2008, Packer et al. 2009), sex ratio (Emlen and Oring 1977), degree of polygyny (Yudakov and Nikolaev 1987, Smith and McDougal 1991) and effective population size of a species (Smith and McDougal 1991, Chepko-Sade et al. 1987, Clutton-Brock and Harvey 1978). Spatial occupancy pattern or home range sizes have inverse relationship with population density (Majumder et al. 2012) due to resource limitations. Accordingly, individual animal space use defines the area negotiated for foraging, shelter and reproduction (Powell 2012). Studies of animal space use patterns and ecological processes underlying those patterns potentially enable improved management inputs for conservation of threatened wild species (Wilson 2010). This important knowledge is possible only by advanced telemetry methods which allow close observations, collection of sufficient spatial location data and subsequent analyses with required precision and accuracy (Kaczensky et al. 2008). Tiger (Panthera tigris) is the top order predator in the Indian subcontinent, with high flagship and conservation value (Seidensticker 2010, Rastogi et al. 2012, Karanth et al. 2012). Given that the tiger populations have undergone drastic declines in number to as low as 3200 individuals (which is ~ 3% of its historical population) surviving in < 7% of their historical range (Seidensticker et al. 2010, Tilson and Nyhus 2010), recovery efforts including reintroduction are being promoted across the range countries. Nevertheless, such recovery efforts are limited by inadequate understanding of the behaviour of reintroduced animals (Fischer and Lindenmayer 2000, Breitenmoser et al. 2001). The characteristics of home range, movement patterns and interspecific interaction of released animals are indicative of the post-release response of each animal and the overall success of the release efforts (Berger-Tal and Saltz 2014).
Tigers were translocated to Panna from three different source populations within central India between 2009 and 2011 and were closely monitored including some of the offspring based on telemetry tools. In this chapter (1) initial exploration pattern of reintroduced tigers were analysed, (2) investigated the effects of release site on final home range selection by individual tiger, (3) estimated movement characteristics and spatio-temporal home range sizes along with spatial overlaps, and (4) compared the home range size of the reintroduced/re-established tigers in Panna with the home ranges of tigers in other natural populations.

This chapter provides long-term information on the behavioural response of reintroduced tiger population and present a synoptic view of the reintroduced tiger behaviour in dry-deciduous ecosystem. Information on the behavioural response of reintroduced tigers in new environment are value addition to the science of tiger reintroduction biology which explore a wealth of conservation knowledge and quantitative information on species response in such recovery efforts will ultimately determine the management consideration required for achieving targeted conservation goals in India and elsewhere in the tiger range countries.

Materials and Methods

Study animals

As stated in chapter III, six tigers were reintroduced in Panna from 2009 and 2014 as a part of the recovery efforts. Three tigers (two females, named T1 and T2 and one male, named T3) were translocated in 2009 from Bandhavgarh Tiger Reserve, Kanha Tiger Reserves and Pench Tiger Reserve (Figure 6.1). These animals were housed in one hectare enclosure within the reserve for veterinary observation and facilitating local acclimatization to the environment for few days, before released in the wild. T3, however, dispersed out of the reserve traversing 350 km along the forest patches and complex terrain for one and half month, but was recaptured and hard-released in Panna. In 2011, two more females (T4 and T5), both were raised in captivity and semi-wild conditions, were translocated as experimental addition to the founder individuals. In 2015, one female (T6) was translocated from Pench Tiger Reserve. One more male (T7) that was a problem animal in the city of Bhopal was rescued and released in Panna in October 2015 as problem solving strategy and has not been included for the analyses. Individual identity was assigned based on the chronology of translocation event, while the cubs were coded indicating respective mother,
litter number and individual cub number (e.g. P111 denotes tigress T1’s first litter and cub number one) wherever identified with certainty.

Figure 6.1: Map showing geographical locations of Panna Tiger Reserve, Madhya Pradesh, India, along with other source tiger reserves (in dark black border).

Capture and radio collaring

Nine tigers (six founder adults and three offspring sub-adults) were captured by chemical immobilization using “Hellabrunn mixture” (125 mg xylazine + 100 mg ketamine/ml) (Hafner et al. 1989) administrated through Tele-inject projector (Model 4V.31). Initial dose was determined based on visual estimation of target animal’s body weight, age and sex of the tiger and were usually of 2.75 ml for adult females (ca. 140 – 150 kg) and 3 ml for adult males (ca. 200 – 220 kg). Adult male, however, required supplementation of 1.2 ml. Drug induction time ranged between 26 and 36 minutes and effective handling time was between 25 and 29 minutes. After taking necessary body measurements and veterinary investigations including age estimation, yohimbine hydrochloride was administered intramuscularly at a
dose of 5 mg for every 50 mg of xylaxine (Hafner et al. 1989) that enabled effective reversal of the sedated animal and resulted in complete recovery within 10 – 28 minutes (Figure 6.2).

We fitted VHF/GPS/UHF collar (African Wildlife Tracking® Inc and Vetronic Aerospace®) to three animals (T1, T2 and T6), VHF/GPS/Satellite collar (Telonics® Inc) two animals (T3 and T4) and VHF radio collar (Telonics® Inc) to four animals (T5, P111, P212 and P213). All collars consisted of lithium battery as power source with a life expectancy of about > 36 months. Radio-collars weighed ≤ 1.2 kg; equivalent to < 1% of body weight of radio-collared tiger for both sexes.

![Figure 6.2](image)

**Figure 6.2:** (A) Radio collaring of tiger (B) Release of tiger at Panna Tiger Reserve.

**Telemetry data**

All the collared animals were monitored intensively involving UHF and satellite tools and where VHF only involved, dedicated teams of trained field staff (with a mobile vehicle) supported by professional researchers tracked the animals on 24x7 basis. All GPS collection schedules used for this analyses varied between 4 and 6 hours. The mean horizontal spatial accuracy for the Telonics® Inc and Vectronic Aerospace® GPS radio-collars were 2-10 m (Telonics GEN4 GPS Systems Manual 2009). While, it was 1-15 m for the African Wildlife Tracking® Inc collars (Alfred et al. 2012).

A total of 64176 locations were recorded for all collared animals during the study period. Of these, 29% locations were obtained by following ‘home in’ method, recorded within range of 300 m (exact locations were obtained by projection function executed in excel 2010 spreadsheet). In addition, each tiger was frequently observed through elephant back from close distance, as near as 20m. All such locations were obtained with accuracy of < 20 m.
radius taking into consideration GPS as well as position error. Other details related to telemetry data are provided in Supporting Information (S1-6.1).

**Data analyses**

1. **Explorative movement**

   We plotted the home range size against time in days, until the maximum home range size was reached, which represented the exploratory time. 15 days GPS location sets were additively used for calculating 100% Minimum Convex Polygon (MCP) for all reintroduced tigers since their release in the wild.

2. **Site fidelity**

   Site fidelity was tested for the entire datasets, excluding the exploratory period, using *rhr* package of R (Signer and Balkenhol. 2014). We calculated two metrics for each tiger’s movement trajectory: a linearity index (LI) and the mean square distance (MSD) as suggested by Schoener (1981) and Spencer et al. (1990). We set the number of simulated trajectories at 500, calculated LI and MSD for each of the simulated trajectory and compared the simulated trajectories with the real trajectories. Significantly lower values of MSD and LI for the real trajectory reflected the existence of site fidelity among the radio collared tigers. This analysis also supported reliability of home range estimation for each sample data sets (Schoener 1981, Spencer et al. 1990).

3. **Home ranges**

   We created asymptotic curves for all the tigers to determine the required sample size for home range analysis involving Minimum Convex Polygon method (Steiniger and Hunter 2013) in HoRAE Toolbox of Open JUMP Version 1.6.1 (Steiniger and Hunter 2012). In this method, the home range estimated from first three points were progressively re-estimated by adding sequential points until the home range size saturated. Home ranges of each tiger were estimated based on conventional 100% MCP and 95% fixed kernel (FK) methods, and core area of activity was estimated on 50% utilization distribution contour, computed from 50% FK. The home range estimates were (1) Initial exploration area; (2) Initial home ranges of reintroduced individuals; (3) Winter home range; (4) Summer home range; (5) Monsoon home range and (6) Annual home Range. A subjective visual choice for smoothing factor for all animals across year and seasons was set at 1000 m after conducting several trials between 600 and 1200 m (Silverman 1986, Wand and Jones 1995). We used bivariate normal fixed
kernel density estimator to estimate utilization distribution for individual tiger across all seasons and year. All these analyses were performed using Hawth’s Analysis tool in ArcGIS 9.3 (Beyer 2004).

4. Home range overlaps

We calculated probability home range (PHR) indices to measure overlap between utilization distribution (UD) of each paired animals (Fieberg and Kochanny 2005). Probability home range computes the volume under the UD of the tiger ‘j’ that is inside the home range of tiger ‘i’ (e.g., the probability to find tiger ‘j’ in the home range of tiger ‘i’), given as:

$$\text{PHR}_{ij} = \int \int \text{UD}_j (x, y) \, dx \, dy$$

where $\text{UD}_j (x, y)$ is the value of utilization distribution of the tiger ‘j’ at the point $x, y$. Probability value of each animal were multiplied pair wise with each other to find union probability between each paired animals. This analysis was performed using kernel overlap function in adehabitat package of R (Calenge 2006).

5. Home range comparison with other studies

We have analysed 23 studies on tiger involving telemetry, field observations and camera trap techniques from relevant literature. These included one telemetry (Goodrich et al.2010) and four snow tracking studies (Matyushkin 1978, Poddubnaya and Kovalen 1993, Salkina 1993, Yudakov and Nikolaev 1987) on Amur tigers; 12 telemetry based studies (Seidensticker 1976, Sunquist 1981, Sunquist 2010, Chundawat et al. 1997, Chundawat et al. 2016, Karanth and Sunquist 2000, Smith 1984, Sankar et al. 2010, Barlow et al. 2011, Athreya et al. 2014, Sharma et al. 2011, Chakravarty 2009, Majumder et al. 2012), 1 camera trap based study (Sharma et al. 2010) and 1 field observation based home range study (Schaller 1967) on Indian tiger; 3 radio telemetry based (Report ZSL 2003, Priatna et al. 2012, Maddox et al. 2007) and 1 camera trap based projects (Franklin et al. 1999) on Sumatran tigers. Majority of these studies (18 studies) estimated home ranges based on 100% MCP, while only few studies were adopted other methods for home range estimations (3 studies with 95% MCP and 2 studies with 95% FK methods). We estimated 95% FK area for explaining spatio-temporal patterns of home ranges and MCP was computed for comparison with other studies which used only MCP based estimation.
6. Movement characteristics

Directionality of movement from release site was evaluated for all translocated tigers during the exploratory period. We measured the distances and bearing of each GPS locations from the release site for each tiger. We used Rayleigh (Z) Test in Oriana V.4 (Kovach 2011) to confirm uniformity or directionality for all angular distributions (keeping release site as mid-point). This Test signifies whether release site has any influence on home range choice by the translocated tigers. Further, linear distance travelled by each animal on every day was calculated in both exploratory and settlement periods annually and seasonally to quantify rate of movement by all tigers during each time scale.

Statistical analyses

Statistical evaluations for home ranges and movement patterns were carried out using SPSS software (version 20.0) (SPSS Inc. Chicago USA) and Oriana V.4 (Kovach 2011). All statistical means were presented with the standard deviation (± SD). Normality of variables was tested using Shapiro-Wilk tests, and in cases where there was significant deviation from normality; non-parametric tests were used. Levene’s F – test was performed to determine homogeneity of variance, and all statistical tests were two-tailed unless otherwise mentioned. Two independent sample comparisons were carried out using standard student t-test or non-parametric equivalent Mann–Whitney U test. For multiple sample comparison, one way ANOVA or its non-parametric equivalent Kruskal–Wallis test was performed. All graphical figures were prepared using Microsoft Excel 2013, Oriana V.4 and ggplot2 package of R (Wickham 2009)

Results

Exploratory area

All founder tigers (N = 6) explored larger areas during initial stage. T3 moved out of the Panna for about six weeks and had the largest exploration area of 598 km² including agriculture-village matrix. It traversed linear distance of 250 km away from the release site and had total movement of 440 km in these six weeks. Subsequently, it was recaptured, released back and soon settled in the reserve. All reintroduced females explored between 50 and 250 km² area within a period of 60 to 165 days, although T4 and T5 (the captive/semi wild raised females) had relatively less exploratory area (Range: 55-109, N = 2) in
comparison to other wild founder females (Range: 246-195, N = 3) as shown in Figure 6.3 and Table 6.1.
Figure 6.3: (a) Graph showing maximum area explored by each translocated tiger during exploratory period. (b) 100% MCP home ranges (± Standard Deviation) of individual tiger obtained by cumulative sequential samples plotted against number of cumulative locations, showing adequacy of sampling effort.
<table>
<thead>
<tr>
<th>Tiger ID</th>
<th>Sex</th>
<th>Initial Exploration Range (Km²)</th>
<th>Initial Home Range (Km²)</th>
<th>Winter (Km²)</th>
<th>Summer (Km²)</th>
<th>Monsoon (Km²)</th>
<th>Annual (Km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>95% FK</td>
<td>100% MCP</td>
<td>95% FK</td>
<td>50% FK</td>
<td>100% MCP</td>
<td>95% FK</td>
</tr>
<tr>
<td>T1</td>
<td>F</td>
<td>156</td>
<td>98</td>
<td>99</td>
<td>25</td>
<td>45</td>
<td>53</td>
</tr>
<tr>
<td>T2</td>
<td>F</td>
<td>246</td>
<td>96</td>
<td>102</td>
<td>28</td>
<td>40</td>
<td>54</td>
</tr>
<tr>
<td>T4</td>
<td>F</td>
<td>55</td>
<td>32</td>
<td>45</td>
<td>11</td>
<td>77</td>
<td>67</td>
</tr>
<tr>
<td>T5</td>
<td>F</td>
<td>109</td>
<td>60</td>
<td>56</td>
<td>14</td>
<td>73</td>
<td>62</td>
</tr>
<tr>
<td>T6</td>
<td>F</td>
<td>195</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P213</td>
<td>F</td>
<td>-</td>
<td>37</td>
<td>42</td>
<td>12</td>
<td>65</td>
<td>63</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>152.2</td>
<td>64.6</td>
<td>68.8</td>
<td>18.0</td>
<td>60.0</td>
<td>59.8</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>74.0</td>
<td>31.4</td>
<td>29.4</td>
<td>7.9</td>
<td>16.6</td>
<td>6.0</td>
</tr>
<tr>
<td>T3</td>
<td>M</td>
<td>598</td>
<td>450</td>
<td>301</td>
<td>68</td>
<td>147</td>
<td>128</td>
</tr>
<tr>
<td>P111</td>
<td>M</td>
<td>-</td>
<td>115</td>
<td>84</td>
<td>13</td>
<td>137</td>
<td>91</td>
</tr>
<tr>
<td>P212</td>
<td>M</td>
<td>-</td>
<td>173</td>
<td>118</td>
<td>20</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>598</td>
<td>246.0</td>
<td>167.6</td>
<td>33.6</td>
<td>122.6</td>
<td>101.0</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>-</td>
<td>179.0</td>
<td>116.7</td>
<td>29.9</td>
<td>33.8</td>
<td>23.6</td>
</tr>
</tbody>
</table>

Table 6.1: Home range estimates for reintroduced tigers and their offspring in Panna Tiger Reserve, Madhya Pradesh, India
**Site fidelity**

The MSD and LI for all the cases were below the 95% confidence interval from the random simulated trajectories and thus, site fidelity can be assumed for all reintroduced tigers and 3 of their offspring (Figure 6.4).

**Effective sample size**

Home range estimation based on 100% MCP against series of sample sizes reached asymptotic for all tigers, but at different sample sizes for males and females (Figure 6.3b). Sample size adequacy was not tested for initial exploration and initial home range time frame by assuming their instability.

**Home range estimates**

Home range estimates for all the collared animals are given in Table 1. As expected, exploratory areas were significantly larger than initial home range areas for all translocated tigers (Wilcoxon Signed Ranks Test, z = -2.20, P = .03, one-tailed). Males had larger home ranges than females in their annual ($U = 0.0, N_1 = 5, N_2 = 3, P = 0.02$), initial ($U = 2.0, N_1 = 5, N_2 = 4, P = 0.05$), winter ($U = 0.0, N_1 = 5, N_2 = 3, P = 0.02$), summer ($U = 0.0, N_1 = 5, N_2 = 3, P = 0.02$) and monsoon ($U = 1.0, N_1 = 5, N_2 = 3, P = 0.05$) estimates. However, home ranges did not vary between seasons for males (Kruskal Wallis Test, $X^2_2 = 0.26, P = 0.87$) and females (Kruskal Wallis Test, $X^2_2 = 0.98, P = 0.61$) (Table 6.1, Figure 6.5).

Home range overlaps were larger between sexes than within sexes (Table 6.2). P111 (F1 male) home range was overlapped with T2 (founder female) and P213 (F1 female) home ranges. T3 (founder male) home range was mostly overlapped with T1 (founder female). P212 (F1 male) home range was overlapped with T5 (founder female). Home range overlap estimates for all the target individuals are given in the Table 6.2.

**Home range comparison with other studies**

It was evident that the home ranges of tigers from Panna reintroduced population were strikingly the largest amongst the known home range estimates for Indian tiger. Adult male annual home ranges were significantly larger in this study than reported from elsewhere ($t_{10} = -2.709, P < 0.05$). Mean home range of reintroduced male tigers (n=1) and adult offspring (n = 2) was 2.3 times larger than the other populations, but female home ranges did vary significantly ($t_{14} = -0.58, P = 0.87$) as shown in Figure 5. However, the annual home range of males in the re-established population (founder and offspring) (n = 3) was comparable with
that of historic males (n = 2) in Panna Tiger Reserve (Mann-Whitney U = 0, P = 0.08), while it was significantly larger for females (n = 6) as compared to the historic population (n=4) (Mann-Whitney U = 0, P = 0.01, one tailed) (Figure 6.6).

Movement characteristics

Regardless of sexes (male or female), origin (wild or captive) and release process (hard release or soft release), release site had no influence on home range establishment by all the tigers (Figure: 6.7, Table: 6.3). Rate of movement per day was significantly higher during exploratory period than established period (Mann-Whitney U = 4, P < 0.05), with mean movement rate for females was 6.2 km/day (n = 5), while in case of male (n = 1) was 9.2 km/day (n = 1) during exploratory period and it was 3.2 km/day (n = 5) for females and 4.9 km/day (n = 3) for male during established period. Subsequently, the rate of movement did not vary significantly across seasons (Kruskal Wallis = 1.5, P = 0.47); which was also substantiated by pair wise comparison of all seasons (Dunn’s multiple comparison test, P > 0.05).
Figure 6.4: The results for assessing site fidelity consists of two box plots for each radio collared individual. 1st one is the Mean Squared Distance (MSD) and the second one is Linearity Index (LI) for the simulated trajectories. The values for MSD and LI from the observed data are indicated with a solid horizontal line and also represented next to each box plot.
Figure 6.5: (a) Map showing initial exploration of translocated tigers. (b) Initial home range after their exploratory period. (c) Winter home ranges during 2013. (d) Summer home ranges during 2013. (e) Monsoon home ranges during 2013 (f) Annual home ranges during 2013

Table 6.2: Probability of home ranges overlaps between tigers in Panna Tiger Reserve, Madhya Pradesh, India

<table>
<thead>
<tr>
<th></th>
<th>P111</th>
<th>P212</th>
<th>P213</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>P111</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P212</td>
<td>0.00</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P213</td>
<td>0.51</td>
<td>0.00</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>0.41</td>
<td>0.00</td>
<td>0.02</td>
<td>0.02</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>0.10</td>
<td>0.06</td>
<td>0.03</td>
<td>0.63</td>
<td>0.17</td>
<td>0.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>T5</td>
<td>0.00</td>
<td>0.65</td>
<td>0.00</td>
<td>0.04</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Figure 6.6: (a) Comparative study of home ranges reported for Amur, Sumatran and Indian Tigers. (b) Comparative home range estimates of Panna reintroduced tigers and other Indian tigers.
Table 6.3: Rayleigh Test of uniformity shows that release site did not have influence the choice of home range

<table>
<thead>
<tr>
<th>Tiger</th>
<th>$\mu$</th>
<th>$r$</th>
<th>Circular-SD</th>
<th>Rayleigh Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°</td>
<td></td>
<td>°</td>
<td>$Z$</td>
</tr>
<tr>
<td>T1</td>
<td>49.31</td>
<td>0.70</td>
<td>47.64°</td>
<td>698.71</td>
</tr>
<tr>
<td>T2</td>
<td>166.04</td>
<td>0.61</td>
<td>56.63°</td>
<td>519.42</td>
</tr>
<tr>
<td>T3</td>
<td>144.82</td>
<td>0.34</td>
<td>84.12°</td>
<td>64.52</td>
</tr>
<tr>
<td>T4</td>
<td>234.76</td>
<td>0.22</td>
<td>99.60°</td>
<td>92.29</td>
</tr>
<tr>
<td>T5</td>
<td>274.74</td>
<td>0.81</td>
<td>36.91°</td>
<td>556.59</td>
</tr>
<tr>
<td>T6</td>
<td>242.91</td>
<td>0.81</td>
<td>37.19°</td>
<td>420.57</td>
</tr>
</tbody>
</table>
Figure 6.7: T1, T2, T3, T4, T5 and T6 movement direction after release in Panna Tiger Reserve
Discussion

Movement and home range characteristics are key determinants of survival, fitness and consequent ecological impacts of large carnivores such as tiger which is ought to make careful choices in daily life and in overall behavioural responses (Goodrich et al. 2010, Sunquist 1981). Given that tiger is a secretive and elusive species, understanding such behavioural responses is highly challenging, unless equipped with suitable monitoring tools, such as radio or GPS telemetry. There has not been many previous studies which could utilize such technological inputs and where it was attempted, except for the long-term study carried out in Chitwan National Park during 1980s (Sunquist 1981, Smith 1993), sample sizes had always been low, constraining data quality and interpretations (Smith 1984, Karanth and Sunquist 2000, Chakravarty 2009, Sankar et al. 2010, Barlow et al. 2011, Majumder et al. 2012, Athreya et al. 2014, Chundawat et al. 2016). Dispersal events to new environment reflect the ability of the animals to implement decision process linked to fitness (Smith 1993). However, almost all the information on such dispersal, although scanty, and related home range establishment in tiger relates to sub-adults and responses of adults to newer environment was not known. Local extinction of tiger and subsequent successful reintroduction efforts (Ramesh et al. 2015) presented a pioneering opportunity where substantial number of adults and sub adults could be monitored for several years, thus bridging some of knowledge gap in tiger biology. Radio telemetry played a key role in tiger recovery as it enabled close monitoring and protection of every reintroduced tiger. This is the first-ever home range study on tiger in India where sample size is large, monitored for prolonged period and subjected to comprehensive statistical analyses on site fidelity, movement characteristics and home range estimation.

Prior to this study, there were only a handful of tiger translocation efforts but these were rather sporadic events and rescue cases (Seidensticker et al. 1976, Miquelle et al. 2001, Goodrich et al. 2005). Post release monitoring in these cases was not done adequately due to various reasons including non-deployment of telemetry devices and long term monitoring strategy. A similar reintroduction effort in Sariska Tiger Reserve in the state of Rajasthan in India met with low breeding success (Sankar et al. 2010) due to anthropogenic causes (Bhattacharjee et al. 2015, Ramesh et al. 2015), primarily offering home range knowledge on founder individuals. In other studies in Russia involving captive Siberian tigers, where one adult Siberian male and two young female tigers were released from the Otis rehabilitation Centre into the wild, the ultimate fate of the male remain unclear, while the two other female
died during the monitoring period (Miquelle et al. 2001, Goodrich and Miquelle 2005), although recent efforts are being made. The high rate of reintroduction/ translocation failure in the past indicates that the science behind tiger reintroduction biology is still in its infancy and warrants greater attention (Reddy et al. 2016).

Our study has demonstrated that release site of animal has no influence on territory selection rather the tigers explored maximum area where they could probably find adequate resources and suitable habitat for foraging and reproduction. Also, both soft and hard releases produced similar results. These are key information for managers for planning release strategies including resource requirement. Such behavioural response partly demonstrates dispersal success regardless of spatial position of natal areas and the overall survival ability of tiger. Tests for site fidelity have provided valuable insights into the spatial ecology and sociality of a population (Spencer et al. 1990, Swihart and Slade 1997). Reintroduced and offspring males home ranges were significantly larger than other male tiger home ranges reported for Indian tigers, except the historic tiger population in Panna which also had large home range than other tiger populations (Chundawat et al. 2016). However, female home ranges were only marginally larger than other reported female home ranges, but was significantly larger than the historic female population in Panna. Such large home range of males in this system is likely due to lack of suitable core areas in close vicinity for resting, presence of low density of prey and sparse water distribution during summer at this tropical dry deciduous forest (Chundawat 1997). Other reason for the comparatively larger home range of males in our study area (both reintroduced and historic population) could be the minimum intra-sex competition (Majumder et al. 2012) due to low male tiger density or other unexplained factors. In such situations or when there is a large overlap of male home ranges including of floater males (Chundawat et al. 2016), the population dynamics gets affected and positively, the females perhaps gain enhanced opportunity to genetic choices for progeny (Reddy et al. 2016), which is otherwise limited in large carnivores (Larivière and Ferguson 2003). Male home ranges were larger than those of females, as would be expected in any tiger populations and also in other major solitary carnivores (Sandell 1989a & b). Tiger and other felid species are polygynous in nature. Hence, the difference is likely because male always tend to maximize their home range than female to increase their reproductive fitness by bringing more reproducing females within their home ranges (Lott 1991, Sandell1989a). In this population, female home ranges were slightly larger in comparison with other female home ranges reported elsewhere for this species. Theoretically, their home range size should be
large enough to fulfil prey availability, meeting the energy requirements of their survival and rearing cubs.

In the reintroduction program, establishment of home ranges marks beginning of reintroduction success and indicates habitat suitability of the release site. Although feasibility study demonstrated the resource availability in the area (Ramesh et al. 2009), the spatial patterns of the home ranges demonstrate resource distribution and sense of security felt by the animals. Such knowledge was critical to provide management inputs and for close monitoring to detect other life history events. It was for the first time that the response of adult tigers in new environment has been documented and it appears that tigers apply specific cues to choose the suitable areas. The comparative analysis of home range with the past study in the same area (Chundawat et al. 2016) demonstrate that reintroduced population behaves almost exactly the same way as native population. This is a significant result and provide support for reintroduction strategies as effective option to restore ecological integrity of the area where local extinction has taken place. Specific to the site, the recovering tiger population is not competing for the resources, thus providing indication that the area is still capable of holding more tigers or provide optimal habitats for long-term viability of the tiger population. Although the home ranges extend beyond the typical administrative boundary of the protected area (Chundawat et al. 2016), it reflects true nature of tiger populations wherein the home ranges are only likely to expand with increasing population density and the long-term survival can only be facilitated by taking into account the meta-population structure and the dispersal ability of the individuals.
Supporting Information

Table S1 – 6.1: Information on reintroduction events and telemetry data used for home range estimation (F: female, M: male, W: wild, C: captive, a: GPS fixes, b: location collected through VHF telemetry)

<table>
<thead>
<tr>
<th>Tiger (Sex)</th>
<th>Aerial distance from source site (Km)</th>
<th>Age at 1st collaring (Months)</th>
<th>Weight (Kg)</th>
<th>Initial exploration (Founder individuals)</th>
<th>Initial home range (Founder and offspring)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Duration</td>
<td>N (Location)</td>
</tr>
<tr>
<td>T1 (F)</td>
<td>155</td>
<td>42</td>
<td>140</td>
<td>3rd Mar 2009-15th Aug 2009</td>
<td>1395 a</td>
</tr>
<tr>
<td>T2 (F)</td>
<td>270</td>
<td>42</td>
<td>150</td>
<td>9th Mar 2009-31st Aug 2009</td>
<td>1380 a</td>
</tr>
<tr>
<td>T3 (M)</td>
<td>283</td>
<td>60</td>
<td>200</td>
<td>6th Nov 2009 -31st Jan 2010</td>
<td>557 a</td>
</tr>
<tr>
<td>T4 (F)</td>
<td>270</td>
<td>72</td>
<td>106</td>
<td>26th Mar 2011-31st Aug 2011</td>
<td>1895 a</td>
</tr>
<tr>
<td>T5 (F)</td>
<td>270</td>
<td>80</td>
<td>95</td>
<td>13th Nov 2011-31st Jan 2012</td>
<td>635 b</td>
</tr>
<tr>
<td>T6 (F)</td>
<td>283</td>
<td>42</td>
<td>105</td>
<td>23rd January 2014-31st March 2014</td>
<td>641 a</td>
</tr>
<tr>
<td>P111 (M)</td>
<td>-</td>
<td>21</td>
<td>130</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P212 (M)</td>
<td>-</td>
<td>19</td>
<td>110</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P213 (F)</td>
<td>-</td>
<td>19</td>
<td>87</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
### Seasonality in established home range (Founder and offspring)

<table>
<thead>
<tr>
<th>Tiger (Origin)</th>
<th>Winter (Founder and offspring)</th>
<th>Summer (Founder and offspring)</th>
<th>Monsoon (Founder and offspring)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration</td>
<td>N (Location)</td>
<td>X (Location/day) ± SD</td>
</tr>
<tr>
<td>T1 (W)</td>
<td>1st December 2012- 28th February 2013</td>
<td>232&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.58 ± 4.24</td>
</tr>
<tr>
<td>T2 (W)</td>
<td>0.6 ± 0.4</td>
<td>055&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>T3 (W)</td>
<td>7.0 ± 5.6</td>
<td>617&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>T4 (C)</td>
<td>6.3 ± 5.6</td>
<td>549&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>T5 (C)</td>
<td>4.3 ± 5.0</td>
<td>380&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>P111 (W)</td>
<td>11.6 ± 6.2</td>
<td>1034&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>P212 (W)</td>
<td>5.5 ± 5.3</td>
<td>474&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>P213 (W)</td>
<td>7.8 ± 5.7</td>
<td>696&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>