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Authors: Pedro Sarmento, Carlos Carrapato

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# The use of Spatially Explicit Capture-Recapture models for estimating Iberian lynx abundance in a newly reintroduced population

Pedro Sarmento. Instituto da Conservação da Natureza e das Florestas. Centro Polivalente de Divulgação da Casa do Lanternim. Rua D. Sancho II, nº 15 | 7750–350 Mértola, Portugal. sarmentop@gmail.com. 0035 +1 915557075 (corresponding author).

Universidade de Aveiro Centro de Estudos do Ambiente e do Mar, Biology, Campus de Santiago, Avenida João Jacinto de Magalhães, Aveiro, PT 3810-193

Carlos Carrapato. Instituto da Conservação da Natureza e das Florestas. Centro Polivalente de Divulgação da Casa do Lanternim. Rua D. Sancho II, nº 15 | 7750–350 Mértola, Portugal. carlos.carrapato@icnf.pt

Heading: Iberian lynx abundance

## Abstract

From 2015 till 2018, 33 lynxes were released in southeast Portugal (Guadiana valley) as a result of an Iberian reintroduction project. Since then, at least 45 lynxes were born in the wild during 3 breeding seasons. In 2018, a combination of sign search and camera trapping was applied to estimate lynx abundance in the Guadiana reintroduction area, using spatially explicit capture-recapture (SECR) models with the incorporation of sex-specific parameters. A total effort of 7210 trap-days led to 218 independent lynx captures (except for yearlings), which corresponded to 22 adults or sub-adults in 50 stations (28%). The estimated population size was 22-29 individuals (adults and sub-adults) in the 723 km$^2$ study area, leading to a density of 3.4 lynxes (>1-year-old)/100 km$^2$. Individuals were heterogeneously distributed, since most lynxes occurred in clusters with a few lynxes scattered among them. Use of space was sex-dependent and, as expected, males moved more distances than females. Apart from the estimated 22-29 over 1 year-old lynxes, the study detected the presence of 27 yearlings. The reintroduction project is still at an early stage, since the goal for a baseline population has not yet been reached (15 reproductive females) and it is therefore essential to improve organizational issues to implement a viable long-term system covering all critical areas, namely long-term replicable census for population monitoring.

Key words: camera-traps; capture-recapture; reintroduction; spatial models

## Introduction

By the end of the 20th century the Iberian lynx (*Lynx pardinus*) had become nearly extinct, comprising roughly 120 individuals in only two breeding populations located in Andalusia (Spain) (Guzmán et al., 2005; Simón et al., 2009). A captive breeding program was started in 2003 with the purpose of obtaining suitable animals for reintroduction and to guarantee a genetic backup as insurance for a potential extinction in the wild (Vargas et al., 2009). A Spanish-Portuguese EU Life project was started in 2012 to detect, prepare and establish 5 reintroduction areas with suitable capacity to support self-sustaining Iberian lynx populations (www.iberlince.eu). Using captivity-bred animals, lynx releases were initiated in Spain (firstly in Andalusia in 2011, then in Extremadura and Castilla La Mancha in 2014) and in Portugal (2015). In 2016, the species conservation status was changed by the IUCN from “Critically Endangered” to “Endangered” (IUCN, 2016) and by 2016, the species numbers in Spain and Portugal had increased to 540 adults (JAA, 2018).

In Portugal, 33 lynxes (16 M: 17 F) were released in southeast Portugal (Guadiana valley) between 2015 and 2018. Since then, at least 45 lynxes have been born in the wild during 3 breeding seasons (from 2016 till 2018). Most lynxes have established stable home ranges and social relations (Sarmento et al., 2017) and the population has grown significantly, especially in 2017 and 2018, when the number of breeding females increased from 2 to 11 (Sarmento P. unpub. data).

With more than 50 animals covering an area larger than 200 km$^2$, it has become vital to develop reliable large-scale methods to estimate abundance and population density, since these key population parameters are crucial to conservation planning. Radio-tracking is time demanding and expensive, and it is not feasible to radio-mark all individuals in the population and non-invasive genetic tracking based on the genetic analysis of scats can be rather expensive. As lynx have individually identifiable coat patterns, camera-trapping therefore appears to be the best method for surveying the population, while allowing researchers to detect reproduction and identify new individuals (Gil-Sánchez et al. 2011; Foster and Harmsen, 2012).

In recent years, camera-trapping has been responsible for important progresses in the study of elusive animals, by being non-intrusive and applicable over large studies areas (Repucci et al., 2011; Sollmann et al., 2011).

In the last 15 years, spatially explicit capture-recapture (SECR) models have been widely used (Efford, 2011; Royle et al., 2013; Wilton et al., 2014). These models use the captures' spatial locations to estimate an individual's activity center activity, with the objective to estimate density while accounting for variation in detectability among individuals due to different exposure to sampling effort (Gardner et al., 2010). SECR models are flexible and they can incorporate individual covariates, such as sex (Efford, 2011). The incorporation of sex as a covariate is important since differences in use of space according to sex have been observed for lynx populations (Gil-Sánchez et al., 2011).Differences in movement between sexes can lead to differences in encounter probabilities, which should be taken into account when assessing population density and abundance (Sollmann et al., 2011).

In this study, SECR models incorporating sex-specific parameters were used to estimate the Iberian lynx abundance in the Guadiana reintroduction area. The core objective of this study was testing whether camera-trapping can be used to survey the population and estimate population size with enough precision to inform future management, thus contributing to an improved management of the new population. At the same time, we aimed to verify if the goal of establish 10 breeding females by 2020 could be achieved.

## Material and methods

### Study area

The study area is located in the southeast of Portugal and it includes about 85,000 ha consisting of the Vale do Guadiana Natural Park (GVNP), the Guadiana Site of Community Importance (Natura 2000 Network, SIC Guadiana PTCON0036) and their surroundings (Fig. 1). The area is covered by scrublands, typical of the dry thermo-Mediterranean environment. The *Myrto communis-Querceto rotundifoliae* S. series is dominant, although the landscape is occasionally dominated by sub-serial stages of *Genisto hirsutae-Cistetum ladaniferi, Cistetosum monspeliensis* and *Rhamnetum oleoidis*. Scrublands are fragmented by cereal, pasturelands and plantations by *Pinus pinea* and *Quercus rotundifolia*. These vegetation patches occur mainly in the Guadiana riverbanks and neighboring valleys, and in the main elevations. This area is bordered to the west by steppe habitat composed by cultivated grassland.

### Field methods

This study was conducted from August till October 2018 and it was designed in accordance with data obtained from lynx monitoring activities ongoing in the study area since 2015. Since then, lynx monitoring has been organized in 3 levels: radio-tracking of released animals, camera trapping, and sign survey for collecting evidence of presence (tracks, scats). These methods provided accurate data on the area occupied by the population, the body condition of lynxes, their abundance and occurrence of reproduction, but in 2018, the population surpassed 50 individuals and it became necessary to standardize a population survey method, based on camera trapping, which could be replicated in future years.

In the present study, to select the placement of the camera-trapping grid it was firstly necessary to outline the geographic range of the reintroduced population. According to preceding data obtained by radio-tracking of released lynxes and ad-hoc camera trapping for detecting the presence of unmarked animals born in the wild, the potential lynx range was divided in 257 1x1 km UTM squares, which were then surveyed for detecting lynx presence by searching for potential scats.

Considering the lynx presence survey results, 178 camera trap stations were distributed in a grid arrangement with a distance of 1 km between stations over 2 areas (Fig.1). We also incorporated marginal areas in the grid (without confirmation of lynx presence), which could, in theory, support individuals due to their habitat suitability and high prey density (Fig. 1).

Each station consisted of only one camera, considering that images from both flanks of each adult and subadult (1-2 years old) were available. These images were obtained either during the handling procedures before release for captive born lynxes or using paired-opposed cameras (two cameras placed in front of each other) in the preceding year, for wild born animals. If an unidentified lynx was detected, a second opposed camera was placed in the station, in order to distinguish this lynx from another unknown lynx.

Cameras were placed 20-30 cm above the ground in places where the likelihood of detecting a lynx was higher (dirty roads near latrines) and programmed to take a sequence of 3 pictures for each detection with a 10 seconds interval. Two types of cameras were used: Bushnell Trophy Cam® with black leds and Browning trail Cameras®. Each camera remained in the field for 45 days.

## Analytical methods

Spatially explicit capture-recapture models result from a combination of a state model and an observation model (Borchers and Efford 2008). The state model describes the geographic distribution of individual activity centers, while the observation or spatial detection model describes the probability of detecting an individual at a specified detector (*e.g*. camera trap) as a function of the distance of this detector from a central point in the animal's home range, the animal's activity center (Borchers and Efford, 2008).

The basic assumption of SECR models is the existence of activity centers $s_i = (s_{1i}, s_{2i})$ for each animal, which will remain constant during the survey (Gardner et al., 2010) and which are randomly dispersed across an area *S*. To incorporate movement, the encounter rate of an individual with a camera station is defined as a monotonically decreasing function of the distance from $s_i$ to that station. The number of times animal *i* is detected by trap *j* during a sampling occasion ($y_{ij}$) is a random variable following a Poisson distribution and with mean $\lambda_{ij}$ (Gardner et al., 2010):

$$y_{ij} \sim Poisson(\lambda_{ij})$$

For a lynx *i* captured in a station *j*, the model assumes a log-linear form (Royle and Gardner, 2011):

$$\log(\lambda_{ij}) = \log(g_0) - (\frac{1}{2\sigma^2}){d_{ij}}^2$$

Here, $g_0$ is the basal encounter rate defined as the predictable number of detections in a camera station during an occasion $j$, when the activity center of the individual coincides precisely with the trapping station. The function $d_{ij} = \|s_i - x_j\|$ is the distance between the activity center and trapping station $j$. The detection function, defined as a half-normal model, has a scaling parameter σ, that controls the function, and assuming a bivariate normal model of space use, sigma can be used to calculate a 95% home range radius. More generally, sigma is related to the size of the home range. Considering that the activity centers ($s_i$) are not observed $d_{ij}$ is classified as a latent variable (Sollmann et al., 2011).

Density (*D*), is calculated by dividing *N* (the number of activity centers in the state-space) by the area of the state space (*S*), which is user–defined, includes the trapping grid (Borchers and Efford, 2008), and needs to be large enough to contain all individuals potentially exposed to the grid. A 10 km buffer was defined around the camera trapping grid, in order to be big enough to include activity centers of all animals that could have been exposed to the camera-trap grid, which corresponds to 2-3 time the estimate for sigma (Royle et al. 2013). We characterized our state-space using a binary habitat mask of "suitable" vs "unsuitable" habitat. This constrains activity centers to be located only in suitable habitat, which included all forest and shrub (habitat types that could be used by lynxes as cover. A 723 $km^2$-area of interest was therefore defined using this procedure.

The secr package was used, which is based on the maximum likelihood methodology (ML SECR) (Efford, 2011). Defining the detector type is a key step when using this package. Considering that camera traps do not capture animals but merely confirm their passage we use a detector type named “count”. Two separate data files were compiled: 1) one file containing data on each detector’s (cameras) identification and geographic coordinates;

2) another file containing the capture histories, which include animal identification, the occasion (day), and the detector.

Four a priori models were compared, including a null model with no covariates (g0[.] σ[.]), as well as 3 models with the effect of sex on the detection parameters (g0[.] σ[sex], g0[sex] σ[.] and g0[sex] σ[sex]). Population size was estimated using the expected population size (E[N]), obtained from the best supported model (Efford and Fewster 2012).

Contender models were ranked using the Akaike Information Criterion adjusted for small samples sizes (AICc) by estimating their Akaike weights (Burnham and Anderson, 2002). Models with ΔAICc values ≤ 2 from the most parsimonious model were considered powerfully supported. ΔAICc values were used to compute $\omega i$, which is the weight of indication in favor of a model being the best approximating model, given the model set (Burnham and Anderson, 2002). Unless a single model had a $\omega i > 0.9$, other models were considered when inferring from the data, by calculating the averaged parameters using $\omega$ values (Burnham and Anderson, 2002).

Population closure was estimated using the statistical test of Stanley and Burnham (1999). Lastly, the probable locations of home range centers of the detected lynxes were estimated for the best-ranked model by using the function 'fxi' of the package secr (Borchers and Efford, 2008), which displays contours of the probability density function for the estimated location of range centers

## Results

Lynx presence was detected in 76 1x1 UTM squares (30%) (Figure 1). An effort of 7,210 trap-days produced 218 independent lynx captures, as defined as a capture of the same animal in the same camera with more than 24 hours of interval, (excluding yearlings, which were not included in the analysis), detecting a total of 22 adults or sub-adults (11

M: 11 F) in 50 stations (28%). A total of 18 lynxes were detected in more than one station and an individual was detected on average at 3.7 cameras. The total number of captured animals included 10 captive born lynxes and 12 lynxes born in the wild. Trapping success was 3.0 independent captures/100 trap-days. Reproduction was confirmed for 11 females with the detection of 27 yearlings and the mean litter size was 2.45 cubs per female (min =1; max = 4). The mean number of independent detections per station was 1.2 (SE =1.5; min =0; max =22). Only 2 individuals were not recaptured and the mean number of captures per lynx was 9.9 (SE = 4.7; min = 1; max = 22). The closure test showed population closure (z = 0.54; p = 0.71), indicating that the population was closed to gains and losses during the trapping period.

The g0[.] σ[sex]model was the most supported with an AICc weight of 1 (Table 1). The estimated activity centers were mostly located in the southern part of the lynx range around the area where reintroduction began, and most animals established their home ranges (Fig. 2). Considering the best ranking model, baseline encounter rate (g0) was identical for males and females, but the scaling parameter (σ) was 1.3 higher for males (Table 2). This parameter reached the asymptotic zero at approximately 7 000 meters, indicating that a lynx whose activity center was located at this distance from a given trap had a theoretical capture probability of zero in that specific trap. Considering the contours of the net probability of detection, animals with an activity center within a buffer of 250 m around the trapping polygon had a 0.99 probability of being caught in any trap.

Taking into account the most parsimonious model, the expected population size (E[N]) was 24 individuals (adults and sub-adults) (SE = 3.3; 95% CI =22 – 29) in the 723 km$^2$ study area, leading to a density of 3.4 lynxes (>1-year-old)/100 km$^2$ (SE = 0.46; 95% CI = 3.1-4.1) (Table 2).

## Discussion

As in other studies (Gil-Sánchez et al., 2011), using standardized transects for identifying the lynx population´s geographic range was important to design a precise field survey with a high detection probability. Considering adult and sub-adult individuals known to live in the sampling area, only 3 individuals were not detected and previously unidentified lynxes were discovered. In accordance with this high probability of detecting individuals in the target population, we obtained accurate abundance estimates.

The use of a discrete habitat mask has a clear effect on the estimate of the effective sampled area (Royle et al., 2013). However, it is an important approach towards biological reality (Magoun et al., 2011), by eliminating open grasslands habitats which tend to be avoid by lynxes (Palomares et al., 2001). In fact, most camera-trapping studies are not based on randomly arranged sampling stations. Instead, they are based on a selection of preferred habitats and trails that are used by the targeted species (Gil-Sánchez et al., 2011; Silver et al., 2004; Foster and Harmsen, 2012; Royle et al., 2011; Repucci et al., 2011).

Considering the distance between cameras, the sampling design used in the present study can be considered an intensive survey (Wilton et al., 2014), since 5-6 cameras were placed in each potential average home-range (Sarmento et al., 2017). This was a clear contribution to increase capture probability and to decrease the coefficient of variation (CV) of parameters estimates (Table 2). Pollock et al. (1990) suggested a CV <20% accurate estimates which are fundamental for a suitable population management. In the present study, this value was accomplished for all parameters within the best-ranked model, by detecting a large percentage of individuals and with detections at multiple stations.

The logistical limitations of applying such a large survey are relatively small and this sampling design has proved effective, particularly in combination with a previous sign survey, which produced a more accurate scenario of the population distribution, which, in turn, allowed for a better coverage of traps. A prior evaluation of the area occupied by the population was necessary to reduce the photo-trapping effort, since without this process it would be necessary to sample a much larger area and move more cameras to other locations (between 40-80 new stations). Taking into account the expansion of the population it will be necessary to widen the area sampled over the next few years. However, it should not be necessary to apply the process of searching for lynx signs in the whole area, but rather in peripheral or inter-nucleus locations in order to understand the geographic boundaries of the population.

In this study, lynxes presented a heterogeneous distribution, where most lynxes occurred in clusters and only a few lynxes were scattered among them. Heterogeneous densities are common in large carnivore populations occupying diverse landscapes (Gil-Sánchez et al., 2011; Silver et al., 2004; Janecka et al., 2016), particularly among recent recolonizing populations (Diefenbach et al., 2006).

Use of space was found to be sex-specific, since distinct movement parameters were found for males and females. As expected, males tend to move more than females, having larger home ranges (Ferreras et al., 1997; Gil-Sánchez et al., 2011; Sarmento et al., 2017).

Considering the absence of published data, the presented density estimates cannot be compared with other reintroduction areas. However, density estimates for the species are available from Doñana in 2002-2003 (Garrote et al., 2010) and for Sierra Morena between 1999 and 2008 (4.04 lynxes >1-year-old/100 km$^2$ and 39.04/100 km$^2$ respectively), which used a traditional capture-recapture framework. However, both populations were affected by the rabbit hemorrhagic disease (RHD) outbreak in the early 1990s (Villafuerte et al.,

1994) and subsequently, both were submitted to conservation actions, such as supplementary feeding. Therefore, density values estimated for these populations should not be compared with the density values obtained in the present study.

## Conclusions and conservation implications

With the increase of reintroduced populations, accompanied by an increasing number of lynxes, it is necessary to use more robust models that can also provide information about the spatial distribution of individuals (Royle et al., 2013). In fact, most conservation decisions for Iberian lynx (e.g. the number of animals to release each year and release locations) are based on the spatial variation of abundance. Basically, new releases target areas without lynx occurrence, which contributes to a less fragmented distribution. At the same time, spatial information can be extremely useful when designing trapping campaigns for lynx captures. In fact, camera traps can be aimed at selected animals by placing them in the 0.90 capture probability area obtained using SECR models. The results of this study were applied in October and November 2018 when a lynx capture campaign was carried out to place radio-collars and collect biological samples. The high capture success rate (4.6 captures/100 trap-days) was a direct result of a trapping methodology based on rigorous information on the individuals’ use of space.

Considering all age classes, the number of lynxes in 2018 was higher than the number of released lynxes. In 2019, an even higher number of adults in the wild is foreseeable. The project’s expected objectives were surpassed, since the goal of establishing10 breeding females by 2020 was accomplished 2 years in advance. Our survey protocol will be use continuously for monitoring the population in a yearly basis and to verify if the goals are being achieved.The population growth rate and the high number of births are good indicators that it will be possible to reach the final objective of 30 breeding females by 2022 (ICNF 2014). Once this objective is reached, the reintroduction approach will no longer be supported by annual releases. Instead, genetic management will be applied, consisting on occasional selected releases aimed at maintaining genetic diversity (Lucena-Perez et al., 2017) in order to obtaining a self-sustaining population.

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Figure 1. Camera traps geographic locations and 1x1 UTM squares used to monitor Iberian lynx abundance in the Guadiana valley (Portugal) in 2018.

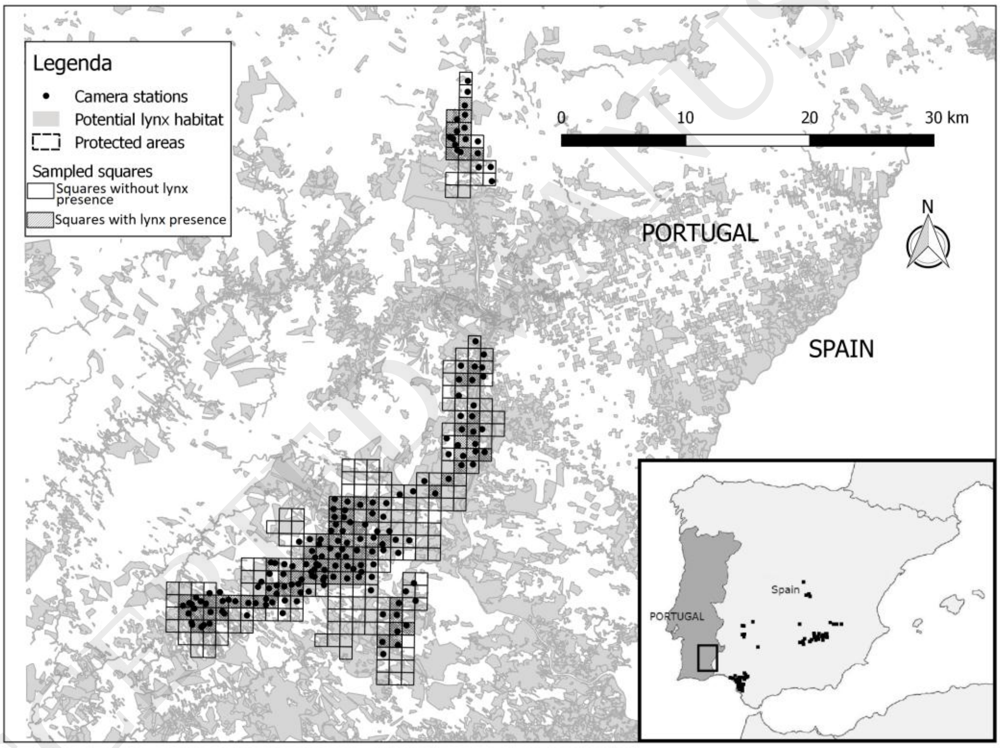

Figure 2. Estimated location of home range centers of lynxes detected in the Guadiana valley (Portugal), considering the best-ranked model.

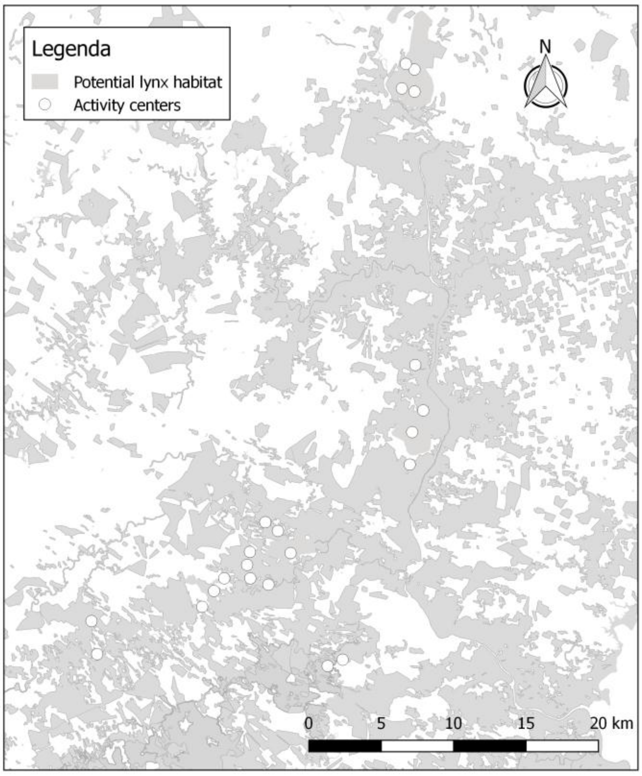

Table 1 - Model selection results for fitted SCR models ranked by AICc to estimate Iberian lynx density in Guadiana Valley (Portugal), in 2018, using camera trapping. K – Number of parameters; LL – Log likelihood; wi – AICc weight

| | K | LL | AIC | AICc | ΔAICc | wi |
|---|---|---|---|---|---|---|
| g0(.)sigma(sex) | 4 | -1106.4 | 222.85 | 226.03 | 0 | 1 |
| g0(sex)sigma(.) | 4 | -1202.9 | 2415.8 | 2119.55 | 192.95 | 0 |
| g0(sex)sigma(sex) | 5 | -1205.9 | 2423.83 | 2429.44 | 202.83 | 0 |
| g0(.)sigma(.) | 4 | -1209.8 | 2427.65 | 2430 | 203.4 | 0 |

Table 2. Real parameter estimates and their precision (CV) for the SCR models to estimate Iberian lynx density ($\widehat{D}$; lynxes per 100 km$^2$) in the Guadiana Valley (Portugal) base on camera trapping. g0 - basal encounter rate; σ - scaling parameter

| | Density | | | | g0 | | | | | σ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| model | | SE | 95% CI | CV | | | SE | 95% CI | CV | | SE | 95% CI | CV |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| g0(.)sigma(sex) | 3.4 | 0.7 | 3.2-4.1 | 17 | M | 0.02 | 0.001 | 0.01-0.02 | 9 | 5.1 | 1.3 | 5.2-5.3 | 19 |
| | | | | | F | 0.02 | 0.001 | 0.01-0.02 | 9 | 3.8 | 0.04 | 3.1-4.2 | 15 |
| g0(sex)sigma(.) | 1.6 | 3.5 | 1.2-2.6 | | M | 0.01 | 0.0006 | 0.01-0.01 | 2 | 3.8 | 1.5 | 3.3-4.7 | 29 |
| | | | | | F | 0.01 | 0.002 | 0.01-0.02 | 28 | 3.8 | 1.5 | 3.3-4.8 | 29 |
| g0(sex)sigma(sex) | 2.2 | 0.4 | 1.4-3.0 | 24 | M | 0.03 | 0.008 | 0.02-0.05 | 37 | 4.1 | 1.8 | 3.2-5.0 | 31 |
| | | | | | F | 0.03 | 0.008 | 0.02-0.05 | 37 | 3.8 | 1.5 | 3.3-4.8 | 27 |
| g0(.)sigma(.) | 2.3 | 0.4 | 1.6-3.2 | 23 | | 0.02 | 0.002 | 0.01-0.02 | 14 | 4.1 | 1.5 | 3.2-5.0 | 28 |