Amphibia-Reptilia 28 (2007): 531-536

A PIT tag based analysis of annual movement patterns of adult fire salamanders (*Salamandra salamandra*) in a Middle European habitat

Ulrich Schulte[1], Daniel Küsters[2], Sebastian Steinfartz[1,2,*]

Abstract. We studied patterns of annual movement of individual adult fire salamanders (*Salamandra salamandra*) during the years 2001 and 2002 in Western Germany in a typical middle European habitat for this species. We tested whether salamanders inhabit small home ranges and move little during the activity period as predicted for a species that shows strong site fidelity to a limited area. Initially, 98 individuals were collected in their natural habitat and marked with passive integrated transponder (PIT) tags. Of those individuals 88 were released at the collection site for recapture during the activity periods of the years 2001 and 2002. Ten marked individuals were kept in captivity to test for the tolerance of PIT tags. We did not find any negative impact of PIT tags on marked individuals of *S. salamandra*, neither under captive nor natural conditions. Forty-seven of the marked individuals (corresponding to 53% of the 88 released ones) were recaptured at least once and 28 individuals (corresponding to 32%) were recaptured multiple times. The return rate of males (78%) was higher than for females (43%). Mean home range size (and standard deviation) was estimated to 494 ± 282 m^2 for 4 individuals as the minimum convex polygon based on 5 to 6 recapture events for each individual per year and to 1295 ± 853 m^2 for 3 individuals with 8 records over two years. Minimum distances moved inferred from individual recaptures increased during the activity period of both years with time, indicating that individuals have more of a tendency to disperse than to stay within a limited area. Our data suggest therefore that *S. salamandra* adults display site fidelity, but use a much larger area than hitherto documented for this and other terrestrial salamander species.

Keywords: amphibians, home range size, movement pattern, PIT tags, recapture, *Salamandra salamandra*, site fidelity.

Introduction

Strong site fidelity to a limited area and small home ranges seem to be a characteristic trait of terrestrial salamanders. It appears to be especially pronounced in species without an aquatic stage in the life cycle (Mathis et al., 1995) and is therefore reported for plethondontid salamanders (e.g., *Plethodon kentucki* inhabited home ranges of a few square meters over several years; Marvin, 2001) and European terrestrial salamanders of the family Salamandridae. Strong site fidelity in combination with small home range size has been shown for Alpine salamanders, *Salamandra atra* (Klewen, 1991; Bonato and Fracasso, 2003) and *S. lanzai* (Riberon and Miaud, 2000). It was also shown for the fire salamander (*Salamandra salamandra*), which also often serves as a text book example of strong site fidelity of European urodeles (e.g., Pough et al., 2001). First evidence of strong site fidelity in *S. salamandra* to a limited spatial area dates back to over 40 years ago (Joly, 1963), showing that adult *S. salamandra* remained within an area of only 68 m^2 for 7 years. Recently, site fidelity has been confirmed for a population of *S. s. gallaica* in an anthropogenically structured environment in Portugal (Rebelo and Leclair, 2003).

In this study we investigate the annual movement behaviour of adult fire salamanders in a typical middle European habitat for this species during subsequent activity periods of the years 2001 and 2002. First, we tested whether previously reported strong site fidelity of *S. salamandra* to a limited area is reflected by movement patterns observed for individuals during two annual activity periods. If fire salamanders display as strong a site fidelity as was shown for Alpine salamanders, then the distance moved should

1 - Present address: Sebastian Steinfartz, University of Bielefeld, Department of Animal Behavior, Morgenbreede 45, 33615 Bielefeld, Germany
2 - University of Cologne, Institute of Genetics, Weyertal 121, D-50931 Cologne, Germany
*Corresponding author; e-mail: sebastian.steinfartz@uni-bielefeld.de

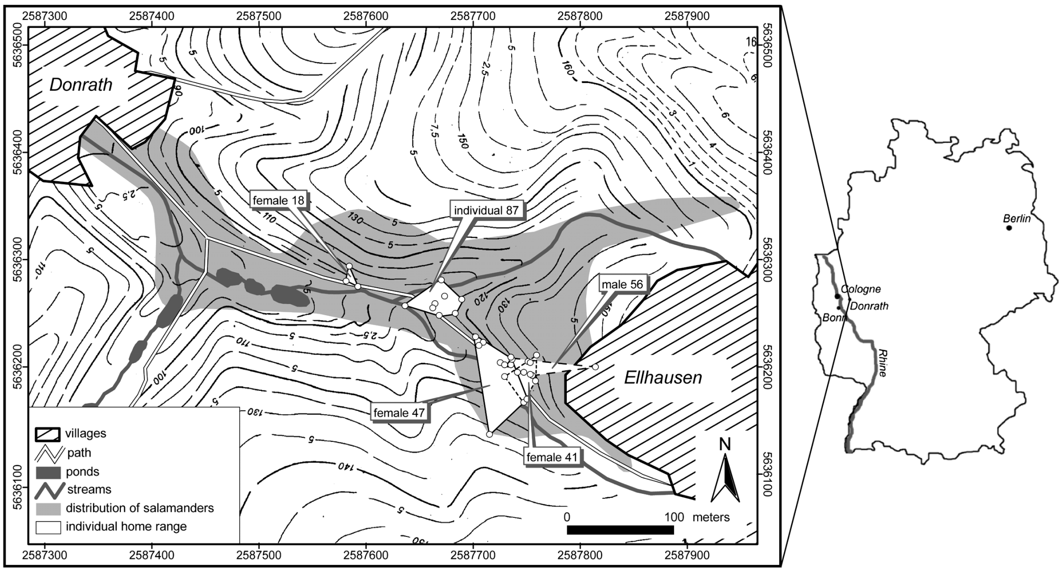

Figure 1. Location (Gauss-Krueger coordinates; Potsdam) of the study site near Donrath in which movement patterns of fire salamanders (*Salamandra salamandra*) were studied during the years 2001 and 2002. The area in which fire salamanders were recorded is sketched in grey. Home ranges of individuals that have been recaptured at least 5 times (see table 1) are presented.

quickly reach an asymptote over time. Furthermore, we tested whether fire salamanders do indeed inhabit the small home range sizes as indicated by the studies of Joly (1963, 1968) by estimating home range during a one- and two-year period for individuals that have been recaptured several times. Our data add important new information on movement characteristics of adult fire salamanders and suggest that basic spatial characteristics of this species may be site-specific.

Material and methods

Study site

Our study site is part of the Ellhauser Forest located in Western Germany 25 km south-east of Cologne near Donrath within the Bergisches Land (fig. 1). It is easily accessible at night from major streets and has already served as a study site for a paternity analysis in *S. salamandra* (Steinfartz et al., 2006). According to Thiesmeier (2004) it represents a typical habitat of *S. salamandra* in Germany, with small permanent streams used for the deposition of larvae and a forest that is mainly composed of beech (*Fagus sylvatica*) and oak (*Quercus robur*). Its average altitude is around 200 m a.s.l. and the annual precipitation is around 1100 mm/m^2. Other amphibian species found in the Ellhauser forest include *Triturus alpestris*, *T. vulgaris*, *T. helveticus*, *Bufo bufo* and *Rana temporaria.* Salamanders can be found in adjacent forest patches and we expect that our study population represents an open population as salamanders are able to move freely between these areas.

Marking and recapture of adult S. salamandra

Adult salamanders larger than 12 cm in total length were collected during 10 rainy nights in spring of the year 2001 (5 nights in March, 2 nights in April and 3 nights in May) and during another 3 nights in 2002 (one night each in March, April and May). Coordinates (Gauss-Krueger, Potsdam-Datum) were recorded using a differential Global Positioning System (GPS) with an accuracy of three meters. Ninety-eight individuals were taken to the laboratory where they were fitted with a Euro-I. D. bio-glass transponder (weight 0.09 g, length 12 mm, diameter 2.2 mm). Each transponder had a unique code according to ISO 11784 that was verified with a LID-500 hand scanner. Before transplantation, the transponder and forceps were disinfected in 70% alcohol. A tiny incision was made in the skin (dorso lateral trunk above the costal grooves) with a sterile scalpel and curved forceps were used to carefully lift up the skin from the underlying muscle. The transponder was then inserted subcutaneously into the incision. In order to prevent it from slipping out of the incision the transponder was pushed further under the skin from the insertion site. Healing had already begun by the following day, and individuals were released in the study area at the site of initial capture. As we used some of the individuals from this study site to also investigate patterns of multiple paternity (Steinfartz et al., 2006) we had a bias of females among marked individuals. Eighty-eight individuals (61 females, 23 males and 4 individuals of unknown sex) fitted with PIT tags were released at the site of initial capture and 10 individuals (5 males and 5 females) with PIT tags were kept in captivity from 2001-2003 as a control group to test for the tolerance of applied PIT tags.

As fire salamanders are mainly active at night and only if humidity is high, we conducted field visits during rainy nights to locate marked individuals. Field visits consisted of repeated intensive searches using torches by 2-3 persons for 5-6 hours in a fixed sub-area of the Ellhauser forest (corresponding to 0.290 km^2, see fig. 1) during 34 rainy nights (initial capture events included) in the salamanders' activity period from March until October in 2001 (21 nights: 5 × March, 2 × April, 3 × May, 6 × June, 1 × July, 3 × September, 1 × October) and 2002 (13 nights: 1 × January, 1 × February, 2 × March, 1 × April, 2 × May, 2 × June, 1 × July, 2 × September, 1 × October). Each salamander located was scanned with a LID-500 hand scanner and if a transponder was detected both the corresponding transponder code and the coordinates (Gauss-Krueger, Potsdam-Datum) of the recapture site were recorded using a differential Global Positioning System (GPS).

Estimating annual movement

We estimated the annual movement of an individual as the sum of the minimum distances between recapture localities (in a chronological order) for the activity periods of years 2001 and 2002 separately. Distances moved were calculated as the Euclidian distance $d(x, y) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$ (coordinate site $A(x_1/y_1)$, coordinate site $B(x_2/y_2)$) on the basis of the Gauss-Krueger coordinates of the two locations and then summed for a specific individual. Some individuals were analysed for both activity periods, if this individual had been found at least two times in each annual activity period. In order to test whether distances moved are time-dependent (i.e., distances moved increase over time) or remained unchanged, correlations among variables (time between first and last capture vs. the corresponding distance) were tested with a Spearman rank test using the program Statistica 7.0. We tested whether the individual distances moved differed between sexes by using a two-tailed Mann-Whitney U-test.

Home range size

A rough estimate of the annual home range was calculated for 1 male and 3 females (individuals 18, 41, 47 and 56) that were recaptured between 5 to 6 times within one activity period. The first capture locality was assumed to be within the individual's home range and was used as the home reference position. Home range size was estimated as a minimum convex polygon using the software CALHOME (Calhome, 1994). We tested a 90% utilization distribution to make use of all datapoints. Additionally, we estimated the home range size over both years for 3 individuals (individuals 41, 47 and 87) that were recaptured 8 times during 2001 and 2002. Note, that individuals 41 and 47 were also analysed for the one-year period in 2001.

Results

Recapture data and tolerance of PIT tags

Forty-seven (corresponding to 53%) of the initially 88 marked and released individuals were recaptured once and 28 (corresponding to 32%) of them multiple times. The ratio of recaptured males compared to recaptured females was high, as 78% of marked males were recaptured, whereas only 43% of marked females could be relocated. Multiple recaptures varied between 2 to 8 per individual for both years. The proportion of non-recaptured individuals was 47% (corresponding to 41 individuals).

All 10 individuals that had been fitted with a transponder and kept in captivity between 2001-2003 survived and did not show any behavioural differences with regard to the 10 unmarked individuals that were kept under identical conditions. Also, several females that were marked with PIT tags produced normal larvae under natural conditions, as reported in Steinfartz et al. (2006).

Annual movement characteristics of S. salamandra

The annual movement distances of 34 adult *S. salamandra* monitored during the activity period of 2001 increased significantly as time between captures increased (Spearman rank correlation $r_s = 0.401$, $P < 0.05$, $n = 34$; fig. 2). A similar result was obtained for the activity period of the year 2002, in which the distance moved of 17 individuals increased with time ($r_s = 0.697$, $P < 0.01$, $n = 17$; fig. 2). We could not detect sex-specific differences in movement, neither for selected time windows in the year 2001 (0-20 days, Mann-Whitney U-test, $z = -0.25$, $P = 0.905$, $n = 4$ and 5; 120-140 days, U-test, $z = -0.98$, $P = 0.413$, $n = 4$ and 5), nor over the whole activity period (2001: U-test, $z = -0.37$, $P = 0.728$, $n = 14$ and 16; 2002: U-test, $z = -0.29$, $P = 0.833$, $n = 8$ and 5). Mean distance moved (and standard deviation) for both sexes in 2001 was 52 ± 49 m and 117 ± 173 m in 2002. We found that

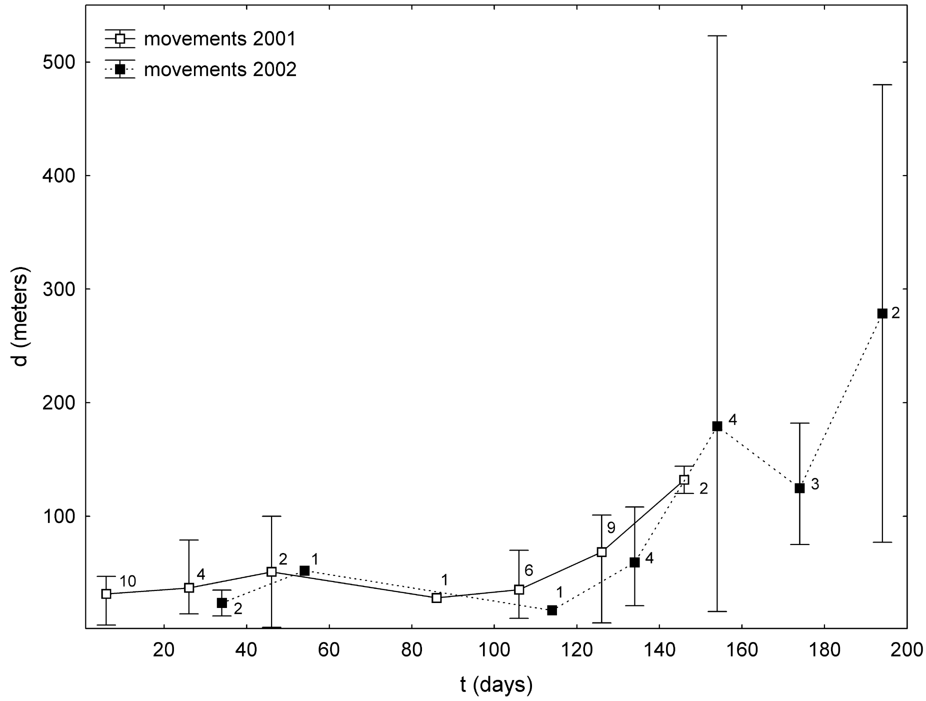

Figure 2. Dispersal of individual adult fire salamanders in the study area during the activity period of the years 2001 ($n = 34$) and 2002 ($n = 17$). For each individual that was recaptured at least twice during the respective activity period the distance moved was plotted against the time in which the movement occurred (see Material and Methods for details). Individuals were grouped into time intervals of 20 days and the mean distance moved plus the 0.95^* non-outlier range is shown. Note that some of the individuals were monitored in both years.

individuals remained in more or less the same locality for 3 months and moved a maximum of 503 m within 2 months.

Home range size

A rough home range estimate for one activity period was calculated for individuals that were recaptured at least five times. Considering a 90% utilization contour of the minimum convex polygon we found that individuals used a minimum area of 78 m^2 and a maximum area of 678 m^2 (mean ± SD = q 494 ± 282 m^2). The home range size for three individuals that were recaptured 8 times during 2001 and 2002 increased to a minimum area of 659 m^2 and a maximum area of 2265 m^2 (mean ± SD = 1295 ± 853 m^2; table 1 and fig. 1).

Table 1. Estimated home range sizes (HR) of the program CALHOME as minimum convex polygons for 4 adult *S. salamandra* for a one year activity period and for 3 adults for a two year activity period. Please note that some of the individuals were used for both estimations.

Animal	Sex	HR	Sightings	Year
18	female	78 m^2	6	2001
41	female	659 m^2	6	2002
41	female	659 m^2	8	2001/2002
47	female	563 m^2	5	2002
47	female	2266 m^2	8	2001/2002
56	male	678 m^2	5	2001
87	unknown	963 m^2	8	2001/2002

Discussion

As with most other terrestrial salamanders, fire salamanders are assumed to display a strong site fidelity within a limited area. This assumption dates back to the studies of Joly (1963, 1968) who showed that *S. salamandra* remained on average in a relatively small area of 68 m^2 over several years. Although the study of Klewen (1985) in a geographically close and similarly structured habitat as our study site generally supported this view, it also showed that one individual moved nearly one kilometre between years. The most recent study investigating site fidelity of *Salamandra salamandra* is the one of Rebelo and Leclair (2003) in an anthropogenically structured habitat in Portugal. Within an area of approximately one hectare in an abandoned orchard the return rate of 582 initially marked individuals was around 60% over a six-year time period, indicating considerable site fidelity of recaptured individuals over the years.

In our study we were interested in the annual movement patterns of adult *S. salamandra* and whether these movement patterns are in line with the assumed strong site fidelity of *S. salamandra* to a limited area. Therefore, we used the same approach Bonato and Fracasso (2003) applied to a population of Alpine salamanders (*Salamandra atra aurorae*) in which an increase in distances moved over time was taken as evidence for a tendency to disperse, whereas strong site fidelity to a limited spatial area would be indicated by stagnating movement distances over time. According to this approach Bonato and Fracasso (2003) found that adults of *S. a. aurorae* were attached to a restricted spatial area, whereas juveniles had a tendency to disperse. According to this classification the adult fire salamanders in our study area showed a clear tendency to disperse within an activity period (years 2001 and 2002; fig. 2). Still, most of these animals were found during the two-year period in the study area. Our data therefore suggest that fire salamanders display site fidelity but can use larger home ranges than was found in other populations. This view is in line with our estimated home range size (mean $\pm$ SD $=$ 494 ± 282 m^2) for a single activity period and the home range size (mean $\pm$ SD $= 1295 \pm 853$ m^2; fig. 1) calculated for two years that are much larger than previously estimated home ranges sizes for other *S. salamandra* populations by Denoël (1996; mean $=$ 55 m^2) and Joly (1968; mean $=$ 68 m^2). Also, in comparison to other closely related terrestrial salamandrid species such as *S. lanzai* that inhabit home ranges between 16-98 m^2 (Riberon and Miaud, 2000) our values are much larger. Although our estimate of home range size is very rough due to the low number of datapoints, it can be seen as an underestimation of the real home range size since home range size generally increases with number of records and over time (Rose, 1982). Furthermore, compared to some North-American *Plethodon* species that inhabit home ranges of only a few square meters (Kramer et al., 1993; Marvin, 2001) the relatively large estimated home ranges of *S. salamandra* indicate within- and between-species differences among terrestrial salamanders.

We found that the return rate of males (78%) was nearly twice as high as for females (43%). This could be interpreted as a sign that site fidelity is more strongly expressed in males than in females. However, we did not find that the moved distances of males during an activity period were different for those moved by females. Rather, we think that the higher return rate of males correlate with general differences in activity patterns between sexes. Klewen (1985) found that 60% of observed animals between March-May were females, whereas 75% of the animals observed during the rest of the activity period (May-November) were males. Evaluating sex-specific activity patterns of salamanders in our study area during the activity period of 2002 (n $=$ 143 males and 124 females) we obtained a similar picture. Fifty-six percent of all observed animals between March and May were females, whereas 60% of all animals found from May until November were males. Thus, we conclude that the higher percentage return rate in males compared with females is caused by a higher activity of males than females.

Although amphibians are generally portrayed as poor dispersers with terrestrial salamanders being extreme examples of this strong site fidelity to small areas with more or less no observable movement over time, Smith and Green

(2005) suggest that amphibians are much better dispersers than hitherto thought. Our results support this new view, as they show that fire salamanders, cited as text book examples of strong site fidelity with small home ranges, use much larger home ranges than expected for a terrestrial salamander. We think that the dispersal ability of adult fire salamanders remains underestimated and that future studies should focus on larger study areas that will also take into account possible long distance dispersal of individuals. We also would like to point out that many of the movement characteristics of *S. salamandra* rest mainly on the proportion of individuals that have been recaptured in rather small study areas. Although return rates were relatively high in our and other studies (e.g., Rebelo and Leclair, 2003), more than 40% of the marked fire salamanders were not recaptured at all. Therefore it is possible that additional movement characteristics of this species have not yet been explored.

Acknowledgements. The authors thank Sebastian Neubert and Mario Rembold who assisted during the field surveys and Diethard Tautz for logistic support. Benedikt Schmidt, Mathieu Denoël and two anonymous reviewers gave valuable comments that substantially improved this manuscript. The language of this paper has been improved by Renata Platenberg. Permissions to collect and mark salamanders were granted by the department of Natural Protection of the Rhein-Sieg Kreis. This study was supported by a grant of the Deutsche Forschungsgemeinschaft (DFG) to Diethard Tautz and Sebastian Steinfartz (Ta99/16-1) to study speciation processes in terrestrial salamanders.

References

Bonato, L., Fracasso, G. (2003): Movements, distribution pattern and density in a population of *Salamandra atra aurorae* (Caudata: Salamandridae). Amphibia-Reptilia **24**: 251-260.

Calhome (1994): A Home Range Analysis Program, MS-DOS Version 1.0, 25 July 1994.

Denoël, M. (1996): Phénologie et domaine vital de la salamandre terrestre *Salamandra salamandra terrestris* (Amphibia, Caudata) dans un bois du Pays de Herve (Belgique). Cah. Ethol. **16**: 291-306.

Joly, J. (1963): La sédentarité et le retour au gite chez la Salamandra tâchetée. C. R. Acad. Sci. **256**: 3510-3521.

Joly, J. (1968): Données écologiques sur la salamandre tachetée, *Salamandra salamandra*. Ann. Sci. Nat. Zool. **12**: 301-366.

Klewen, R. (1985): Untersuchungen zur Ökologie und Populationsbiologie des Feuersalamanders (*Salamandra salamandra terrestris*) an einer isolierten Population im Kreis Paderborn. Abh. Landesmus. Naturk. Münster **47**: 1-51.

Klewen, R. (1991): Die Landsalamander Europas, Teil 1. Wittenberg Lutherstadt, Die Neue Brehm Bücherei.

Kramer, P., Reichenbach, N., Hayslett, M., Sattler, P. (1993): Population dynamics and conservation of Otter salamanders, *Plethodon hubrichti*. J. Herpetol. **27**: 431-435.

Marvin, G.A. (2001): Age, growth, and long-term site fidelity in the terrestrial plethodontid salamander, *Plethodon kentucki*. Copeia **2001**: 108-117.

Mathis, A., Jaeger, R.G., Keen, W.H., Ducey, P.K., Walls, S.C., Buchanan, B.W. (1995): Aggression and territoriality by salamanders and a comparison with the territorial behaviour of frogs. In: Amphibian Biology-Social Behaviour, p. 633-676. Heatwole, H., Sullivan, B.K., Eds, New South Wales, Surrey Beatty and Sons.

Pough, F.H., Andrews, R.M., Cadle, J.E., Crump, M.L., Savitzky, A.H., Wells, K.D. (2001): Herpetology. 2nd Edition. New Jersey, Prentice-Hall.

Rebelo, R., Leclair, M.H. (2003): Site tenacity in the terrestrial salamandrid, *Salamandra salamandra*. J. Herpetol. **37**: 440-445.

Riberon, A., Miaud, C. (2000): Home range and shelter use in *Salamandra lanzai* (Caudata: Salamandridae). Amphibia-Reptilia **21**: 255-260.

Rose, B. (1982): Lizard home ranges: methodology and functions. J. Herpetol. **16**: 253-269.

Smith, M.A., Green, D.M. (2005): Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations? Ecography **28**: 110-128.

Steinfartz, S., Stemshorn, K., Küsters, D., Tautz, D. (2006): Patterns of multiple paternity within and between annual reproduction cycles of the fire salamander (*S. salamandra*) under natural conditions. J. Zool. **268**: 1-8.

Thiesmeier, B. (2004): Der Feuersalamander. Laurenti Verlag, Bielefeld, Germany.

Received: November 6, 2006. Accepted: May 14, 2007.