EFFECTIVENESS OF ROAD TUNNELS FOR THE SANTA CRUZ LONG-TOED SALAMANDER

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The susceptibility of amphibians and reptiles to injury or death while crossing roads has been well documented (van Gelder 1973, Fahrig et al. 1995, Trombulak and Frissel 2000, Carr and Fahrig 2001). Adult salamanders of the genus *Ambystoma*, which often migrate on rainy nights in large numbers during their breeding season, are at risk if they encounter busy roads. Amphibian tunnels have been installed across roads in many places in Europe and the eastern United States to facilitate safe passage and reduce road mortality of newts, salamanders and anurans, although success has been variable (Brehm 1989, Jackson and Tyning 1989).

In 1998, the U. S. Fish and Wildlife Service approved a Habitat Conservation Plan (HCP) for the endangered Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*) at the Seascape Uplands residential development in southwest Santa Cruz County, California (Thomas Reid Associates 1995). The HCP set aside approximately 61 ha as a preserve for the Santa Cruz long-toed salamander and permitted 103 homes on the remaining 18 ha. A road and several building sites were situated along a ridge between the breeding pond and known upland habitat, which introduced a barrier to natural movements and increased the chance of road-kill. Installation and testing of tunnels to promote safe passage across the roads was a requirement of the HCP. In 1999, 6 tunnels and 300 m of permanent drift fencing were installed along the roads of the development.

In 2000, we attached temporary fencing to the permanent drift fence at the 2 amphibian tunnels nearest the breeding pond, resulting in a 300-m drift fence. The purpose of this study was to determine what percentage of Santa Cruz long-toed salamanders that encounter the drift fence successfully pass through the tunnels and how far they would travel along the drift fence to pass through the tunnels. These data are being used to help determine if the tunnels are an effective means to facilitate safe passage of the Santa Cruz long-toed salamander across the roadways at Seascape Uplands and if the installation of additional permanent fencing is warranted.

STUDY AREA

Our study area was located at the Seascape Uplands residential development in Aptos approximately 18 km southeast of the City of Santa Cruz in southwest Santa Cruz County, California. As of June 2002, 45 of the 103 homes permitted by the HCP were built or under construction. Approximately 60 ha of the 79 ha site is owned and managed by the Center for Natural Lands Management (Fallbrook, CA) as a preserve for the Santa Cruz long-toed salamander. A 0.4-ha seasonal pond is present on the property, which has provided breeding habitat for the Santa Cruz long-toed salamander since at least 1974 (Ruth 1989). Habitats on the site consist primarily of annual grassland, live-oak woodland, and coastal scrub. Elevations range from 55 to 110 m above sea level. The study was conducted along a ridgeline that is a known movement corridor between upland habitat to the east and the breeding pond situated in a seasonal drainage to the west. Using a combination of permanent and temporary drift fences, we linked 2 tunnels situated 183 m and 366 m from the breeding pond along a 0.3-km length of roadway (Figure 1). The area was chosen because it is a known migratory route for the Santa Cruz long-toed salamander: pitfall trapping during inbound migrations along roughly the same length of drift fencing resulted in the capture of 149 adults in 1998-99 (Laabs and Allaback, unpublished data) and 213 adults in 1986-87 (Ruth 1989).

METHODS

In 1999, 6 ACO Polymer Products, Inc. tunnels (5 @ 32 cm high by 47 cm wide, 1 @ 21 cm high by 23 cm wide) were installed across Ventana Way at the Seascape Uplands residential development in Aptos, California. The tunnels were designed specifically for amphibians and were therefore made of a non-abrasive cement polymer with slots along the top to let light and moisture inside. Entrances were screened with wire mesh (5 cm by 10 cm) to reduce predator access. Tunnel 1 was 11.1 m long and Tunnel 2 was 12 m long. Approximately 33 m of drift fence manufactured by ACO Polymer Products, Inc., was permanently installed at the entrance of Tunnel 1 and 31 m at Tunnel 2. The permanent fencing (40 cm high) was made of recycled plastic and curved to be directional: amphibians on the outside cannot climb the overhanging curve while individuals on the inside can drop over the fence (Brehm 1989). The remaining drift fence was installed in 2000 and consisted of silt fencing (Enge 1997) buried 15 cm with 76 cm above ground attached to existing retaining walls within 2 m to 4 m of Ventana Way. The resulting drift fence was 300 m long and connected both tunnels. Due to steep contours and to reduce disturbance to native habitat, the drift fence paralleled the roadway. A structure was built at the entrance to Tunnel 1, similar to the design recommended by the manufacturer, to direct salamanders traveling parallel to the fence towards the mouth of the tunnel. The pond side of each tunnel was enclosed with a drift fence and pitfall traps were used to capture individuals that passed through the tunnel (Figure 1).

Survey methodology was similar to that used by Jackson and Tyning (1989). Surveys were performed on 5 rainy nights in late fall and winter when migratory movements towards the pond were anticipated. Marking sessions were conducted between 2000 and 2400 on 13 December 2000, 10 January, 23 January, 25 January, and 17 February 2001 by slowly walking along the drift fence with a headlamp. Adult Santa Cruz long-toed salamanders were captured along the drift fence and their position recorded. Each individual was sexed and tagged with a 6-mm, numbered paper dot (using waterproof paper and ink) affixed with cyanoacrylate (super-glue) near the tip of the tail and held for approximately 15-20 seconds for the tag to set (Jackson and Tyning 1989). Care was taken to ensure that the edge of the tag did not protrude above the dorsum. To make sure that tags were attached, the tail of each animal was lifted slightly by grasping the edge of the tag with forceps or fingers. Individuals were then released facing perpendicular to the fence, because

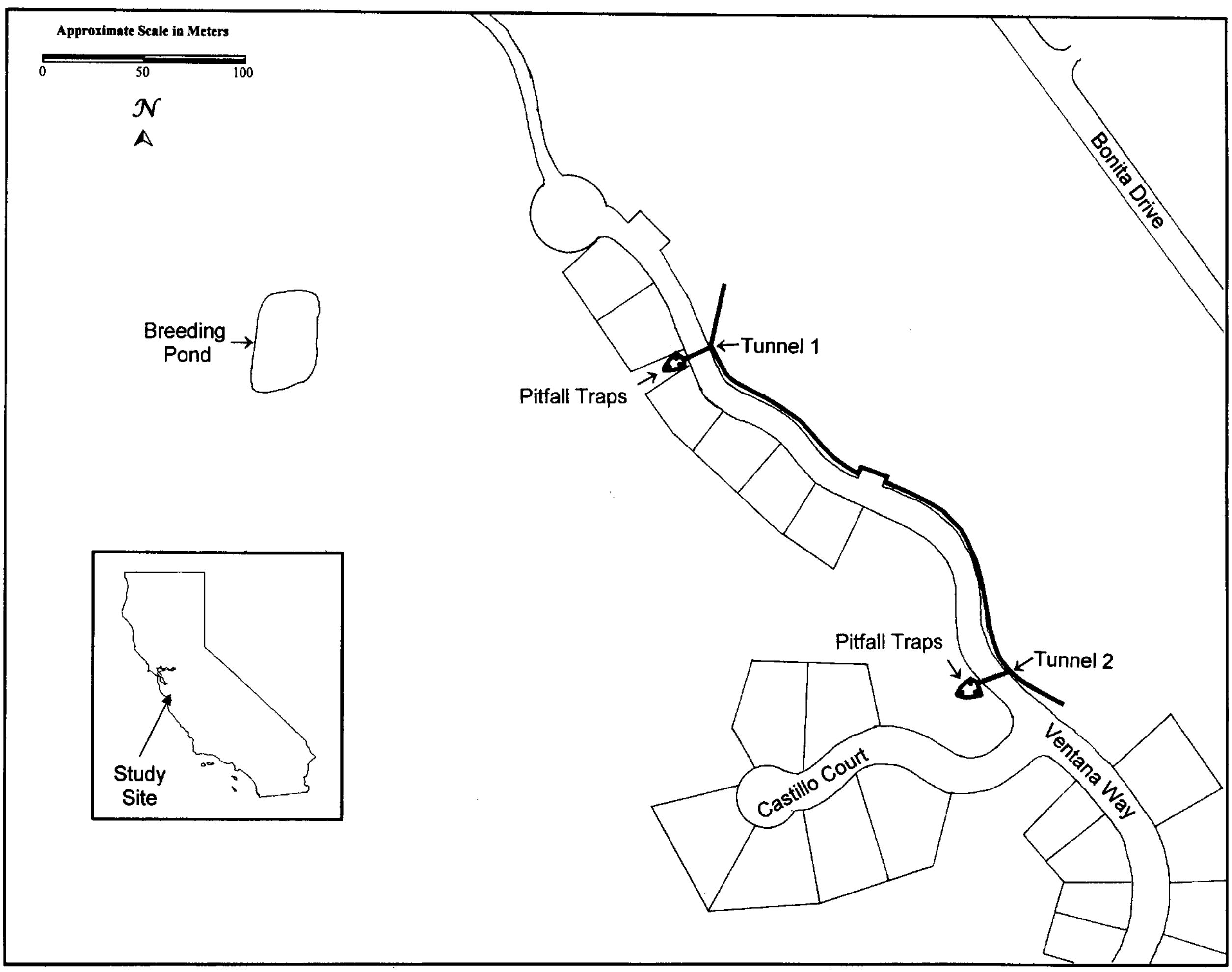

Figure 1. Locations of road tunnels and drift fencing at Seascape Uplands, Santa Cruz County, CA.

it was not always possible to determine the original direction of travel. For 2 days following each marking session, the pitfall traps were checked at dawn and captured individuals were sexed, examined for marks including glue residue indicating tag loss, and released. The effectiveness of the tunnels is expressed as the percentage of those individuals encountered along the fence that were tagged and subsequently captured at the exit of the tunnel. Capture localities along the drift-fence were separated into 10-m segments (Figure 2).

Table 1. Results of drift fence and tunnel testing at Seascape Uplands, Santa Cruz, CA, 2000-01. SCLTS = Santa Cruz long-toed salamander.

Sex	SCLTS marked along drift-fencing	SCLTS recaptured after passing through tunnel	Percentage of marked SCLTS passing through tunnel
Males	26	3	11.5
Females	18	1	5.5
Totals	44	4	9.1

RESULTS

Santa Cruz long-toed salamanders were not distributed randomly along the drift fence. Eight-six percent of all captures were made within 100 m of Tunnel 1 (Figure 2). Pitfall traps were operational during 5 migrations towards the breeding pond. Based on numbers of individuals captured at the pond (Laabs and Allaback, unpublished data), these migrations represent all large-scale movements to the pond. Eighteen adult females and 26 adult males were marked along the drift fence (Table 1). Four of the 44 adults tagged (9%) were subsequently captured in pitfall traps on the pond side of Tunnel 1. All 4 (3 males, 1 female) were initially captured within 16 m of the tunnel entrance. No marked individuals passed through Tunnel 2. Twenty-nine unmarked adult Santa Cruz long-toed salamanders passed through the tunnels. We observed no evidence of tag loss.

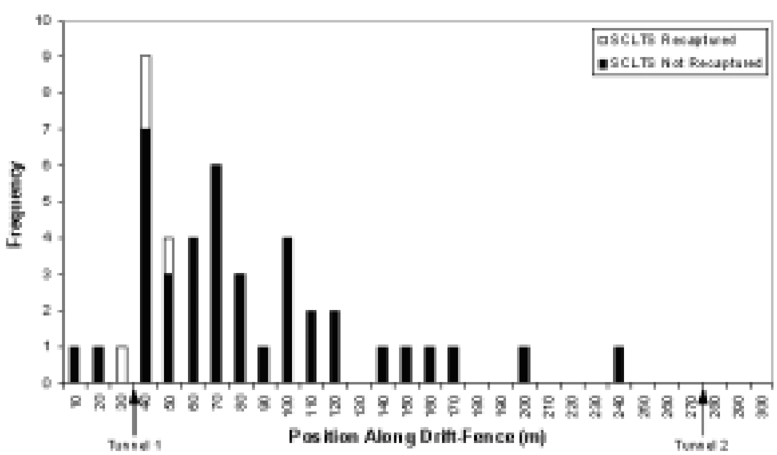

Figure 2. Distribution of Santa Cruz long-toed salamanders marked along a drift fence and recaptured after passing through Tunnel 1 at Seascape Uplands, Santa Cruz, CA, 2000-01. Positions of Tunnels 1 and 2 are noted with arrows.

DISCUSSION

Tunnels have been used to facilitate amphibian movements across roads with various degrees of success (Brehm 1989, Jackson and Tyning 1989). At the Seascape Uplands residential development in 2000-2001, only 9% (4 of 44 adults; 3 captured the same night, 1 captured 2 days after being tagged) of the Santa Cruz long-toed salamanders that encountered the drift fence passed through the 2 tunnels situated closest to the breeding pond. Tunnel effectiveness was therefore considerably lower than the 68% (65 of 95 adults observed exiting the tunnel the same night they were tagged) reported for spotted salamanders (*Ambystoma maculatum*) by Jackson and Tyning (1989), but was similar to the 12% (156 of 1278 individuals captured in pitfall traps) reported for smooth newts (*Triturus vulgaris*) in Germany (Brehm 1989). It is possible that handling and tagging individuals affected their subsequent behavior, although our methods were considerably less invasive than studies that used pitfall traps along the drift fence to test tunnel effectiveness (e.g., Brehm 1989). It is also possible that individuals passed through the tunnels more than 2 days after being marked, outside the period when traps were monitored. Tag loss did not appear to be a factor in this or a previous study using the same method (Jackson and Tyning 1989). Twenty-nine unmarked individuals passed through the tunnels either before or after our night surveys along the drift fence. However, without knowing the total number of individuals that migrated, it was not possible to determine tunnel effectiveness based on captures of unmarked individuals.

The distribution of Santa Cruz long-toed salamanders along the drift fence was consistent with data collected during previous seasons and confirms that the area sampled is an established movement corridor for the species. Based on the orientation of the drift fencing in relation to the breeding pond, it was anticipated that most individuals would be funneled towards Tunnel 1 (Figure 1). However, many individuals appeared disoriented and were first observed moving away from the tunnel entrance. Tunnel effectiveness may have been low due to the length of the drift fence or distance between tunnels. The extensive barrier may have caused individuals to attempt to bypass the fencing, seek breeding locations elsewhere, or forego breeding entirely. Several individuals found near the entrance did not pass through the tunnels and none found greater than 16 m from the entrance passed through the tunnels. We therefore concur with Jackson and Tyning (1989) and Brehm (1989) that the amount and orientation of the drift fence is critical.

Tunnel design must consider both inward and outward migrations of adults and outward dispersal of young. For example, the configuration of the drift fence on the pond side of Tunnel 1 is so restricted that few individuals are expected to encounter the tunnel when they return from breeding or disperse from the pond (Figure 1). If tunnels are not able to facilitate movements of salamanders in both directions, then they are not expected to benefit the population over time (Dodd 1990, Jackson 1996). The success of tunnel systems may be improved by spacing several closely together (ca 30 m) with short lengths (ca 20 m) of funnel-shaped drift fences leading towards all entrances.

Jackson and Tyning (1989) observed several individual *A. maculatum* hesitate at the tunnel entrance before passing through or turning back. To reduce human disturbance, we did not make behavioral observations after each animal was marked and released. Individuals may hesitate or refuse to pass through tunnels due to changes in temperature, moisture, light, airflow or human disturbance (Jackson and Tyning 1989). Given the results of this study, road tunnels should not be the only method employed to facilitate movements of Santa Cruz long-toed salamanders across roads. Although other designs warrant investigation, tunnels and drift fences may not be an effective strategy for mitigating the effects of roads on this listed species.

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