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# LONG-TERM MONITORING OF TIGER SALAMANDERS, *AMBYSTOMA TIGRINUM*, IN THE BOULDER FOOTHILLS

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## ABSTRACT

During 16 days over a three year period (1995-1997), we seined four ponds on Shanahan Hill (ridge) in the Boulder, Colorado, foothills to monitor populations of the Tiger Salamander, *Ambystoma tigrinum*. Recaptures were sufficiently frequent for population abundances to be quantified by mark-recapture for Pollywog and Shanahan Hill ponds. A variety of changes have occurred to the salamander populations in these ponds since they were previously sampled (1974-1975). The most conspicuous change was the loss of most salamanders from Abbey Pond, possibly due to colonization of the pond by introduced crayfish, *Orconectes virilis*. In addition, neotenic salamanders populated Shanahan Hill Pond and, during 1995-1997, became more numerous at Pollywog Pond.

## OBJECTIVE AND HYPOTHESES

The overall objective of the work was to assess the long term health of populations of the Tiger Salamander, *Ambystoma tigrinum*, in the Boulder foothills, specifically the ponds on Shanahan Hill in the Boulder Open Space. The work will provide insight into the long-term health of the habitat, by providing baseline data for future comparisons and by comparing the current situation to population data from 1974-1975 (Rodda, 1975a; 1975b; 1986). Although there are no immediate plans to use the data for tests of large scale habitat alterations (e.g., introduction of exotic species such as bluegills, *Lepomis macrochirus*; discontinuation of grazing; deposition of air pollutants in vulnerable surface waters), these data will provide long-term assessments that might contribute to such tests. Larson and Fivizanni (1994) proposed that Tiger Salamanders be used as indicators of environmental stress. Population data collected by this study could contribute to evaluation of stress responses.

The primary null hypothesis tested was that there had been no change in the abundances of the salamanders since 1974-1975. Secondary null hypotheses were that there had been no inter-pond movements of marked individuals among the ponds. The secondary null hypothesis was not rigorously tested, as it is probable that most of the previously marked individuals have died in the intervening 20-21 years. However, it is possible that some of the marked individuals survive, as the tags are permanent, some have been recovered by other researchers in the last decade (David Norris, pers. comm.), and the proven longevity of neotenic tiger salamanders is in excess of 25 years (Nigrelli, 1954. Terrestrial morphs are known to survive for more than 20 years (Slavens and Slavens, 1992), and an adult of a closely related species, *A. maculatum*, has lived to 29 years (Koch, 1952).

Scientific progress will be aided by making available basic demography facts on a species that has attracted some attention in environmental health studies (e.g., Harte and Hoffman, 1989; Pechmann and Wilbur, 1994). This work will contribute to the herpetological inventory requested for Boulder Open Space. To the extent that basic inventory data informs scientists with regard to large scale environmental changes such as species introductions, or the effects of livestock grazing (Heyer et al., 1994), this study will contribute to the identification of appropriate management policies for the Open Space.

## METHODOLOGY

The ponds (see Table 1), located in section 18 of the South Mesa Trail area, were sampled with a hand held seine on 16 days over three years (1995-1997). Captives were temporarily held in plastic buckets while we collected basic morphological measurements (snout-vent length, total length, head width, sex, and mass). Unmarked individuals were permanently marked with tiny monel metal jaw tags (National Band and Tag, Co.), and all individuals were released at their point of original capture after completion of measuring and tagging at each pond. Additional field methods followed those of Rodda (1975a). Frogs seen at the ponds were noted, but no attempt was made to systematically detect species other than Tiger Salamanders.

The mark-recapture abundance program CAPTURE was used to estimate fall and spring population abundance where numbers of marked individuals were sufficient. The best model was selected on the basis of measured heterogeneity in capture rates.

Table 1. Site characteristics of the sampled ponds.

| Site | Elevation (m) | Latitude | Longitude |
|---|---|---|---|
| Pollywog | 1749 | 39°57'35" | 105°15'40" |
| Abbey | 1766 | 39°57'55" | 105°15'45" |
| Salamander | 1798 | 39°57'50" | 105°16'00" |
| Shanahan Hill | 1846 | 39°57'58" | 105°16'15" |

## RESULTS AND CONCLUSIONS

The results are best understood with a little background on the complex life history of the Tiger Salamander (Sexton and Bizer 1978). All Tiger Salamanders begin life as an egg. In the Shanahan Hill area, eggs are generally laid in late spring (April-May). The eggs hatch a few weeks later into unpatterned brown aquatic larvae with feathery gills protruding from the sides of their neck. The larvae feed on plankton, other invertebrates, and occasionally each other (Collins and Holomuzki 1984, Collins et al. 1993) and grow rapidly throughout the summer. In late summer (typically early Aug. in our area) they may metamorphose into terrestrial morphs, which lack gills and are boldly marked with yellow on a black background. Those that do metamorphose generally leave the pond at a size (snout-vent length or SVL) of 60-70 mm (means range 65-68 mm). The metamorphs (newly metamorphosed terrestrial morphs) will migrate a short distance away from the pond, usually to live in rodent burrows for the majority of the year (Gordon 1968, Semlitsch 1981, Loredo et al. 1996). After they mature, they return to the pond (now as "terrestrial adults" rather than "metamorphs") for a few weeks to breed, usually in late spring. We do not know whether this occurs in the spring following metamorphosis (unlikely, as no tagged metamorphs have been recaptured as terrestrial adults in our sample) or years later. Based on studies elsewhere (and incomplete but particularly relevant data from 1974-1975), it is likely that maturation occurs after a year or more of terrestrial living. Male terrestrial morphs spend much more time at the breeding pond than do females (Semlitsch 1981); thus male-biased sex ratios are expected among breeding terrestrial morphs.

The Tiger Salamanders that remain in the pond and do not metamorphose in their first fall are subsequently termed "neotenes," denoting that they are retaining larval characteristics into a later life stage. Our use of the term "neotenes" applies to any gilled salamanders larger than the size at which they would normally metamorphose (i.e., 65 mm), but we cannot be sure of their reproductive status without examining their gonads internally (which we did only for one very small sample late in 1997). Thus, we classified every captured salamander into one of four classes: larva, metamorph, terrestrial adult, or neotene. Those classified as larva or metamorph are immature or juvenile; "neotenes" may be either immature or mature. We are developing criteria for dividing the neotene class into pre-reproductive and reproductive neotenes, but this work is not finished. The smallest "neotene" that was clearly reproductive was about 80 mm SVL, whereas the largest newly maturing neotene was about 100 mm SVL (in 1974-1975 the average size of neotenes at breeding time in Abbey Pond was 91 mm). The threshold size seems to vary from pond to pond. Neotenes probably do not breed in their second summer; in Pollywog they seem to breed first in their third summer, but we do not know if this is typical of the ponds on Shanahan Hill.

Neotenes retain the developmental capability to metamorphose into terrestrial morphs at any time or at any size (Sprules 1974a); however, in our experience only a very small percentage of the population that is older than 6 months will metamorphose at any one time unless the pond begins to dry (which may stimulate mass metamorphosis). Unlike a neotene, which can metamorphose into a terrestrial morph at any time, a terrestrial morph can never change back into a neotene. A few individuals begin the transformation from gilled to terrestrial morph but do not complete it. For example, they may develop some yellow spots, but retain gills. Until the gills are resorbed, these individuals are classified as neotenes. While the propensity to follow a given life history track may have a genetic component, it is not fixed (Whiteman 1994, Whiteman et al. 1996). The progeny of a terrestrial morph may become a neotene or a terrestrial morph, as may those descended from neotenes. In the laboratory, terrestrial morphs will mate with neotenes, but it is not clear how often this occurs in nature, as peak mating season for neotenes may occur slightly earlier in the year than that for terrestrial morphs (see Krenz and Sever 1995).

To summarize, a salamander that survives to adulthood will follow one of three life histories (Sexton and Bizer 1978): egg-larva-metamorph-terrestrial adult (= standard track), egg-larva-neotene (= neotenic or paedomorphic track), or (rarely in our area) egg-larva-neotene-metamorph-terrestrial adult (= delayed metamorphosis). Note that the metamorphic or "standard" track is not necessarily standard in our part of the country; it is only "standard" for the species as a whole.

The four ponds in our study area had different frequencies of the life history possibilities. In the early 1970s, all individuals in Salamander and Shanahan Hill ponds metamorphosed (standard track) and most in Abbey and Pollywog ponds reproduced as neotenes (neotenic track). In the late 1990s, most individuals in Salamander Pond metamorphosed (as before), most in Shanahan Hill Pond were neotenes (neotenic forms appeared and became modal), few salamanders survived in Abbey and all of those that did metamorphosed (loss of neotenic life histories) , and both tracks were well represented in Pollywog Pond (no discernible change).

The seine we used in our study had holes about 8 mm in diameter. Thus any larva smaller than this size were not sampled by us. If the small larvae of salamanders or frogs are eaten by predators before they reach a size large enough to be seined, we might not know they were present. Therefore, our counts of larvae should be treated only as counts of large larvae. Salamander larvae became large enough to appear in samples by mid-summer.

We did not tag any salamanders of less than 65 mm SVL, and we sometimes left untagged neotenes up to 75 mm SVL. Thus population estimates are for the stratum of the population larger than 75 mm, and late summer increases in the population size reflect normal growth of larvae from an untagged to a tagable size class. Salamanders that are larger than about 75 mm are rarely eaten by their conspecifics; thus they have in some sense "made it" into the adult population. In this sense, the normal late summer/early fall influx of tagable animals represents recruitment, or additions to the potentially reproducing population.

Pollywog Pond

In the spring, Pollywog Pond was characterized by detectable turbidity and little or no emergent vegetation. At full pool in 1995 and 1997 the circumference of the pond measured approximately 90 m, and in 1996 the pond measured 73 m. Turbidity decreased to little or none in the fall and approximately 25% of the pond was covered with emergent *Typha*. The circumference of the pond was reduced to 69 m, 49 m, and 57 m in fall of the three years. Other amphibians were often found at this pond. *Pseudacris triseriata* called in the spring and up to 88 tadpoles were captured in the seine. Both adult *Rana pipiens* and *Bufo woodhousi* were found in or around the pond. Large numbers of dytiscid beetles were also found and may provide a large food supply for the larval and neotenic salamanders.

In 1995, no larvae or neotenes were caught at Pollywog during the three capture occasions in the spring (Table 2). A total of 7 individual terrestrials (11 captures) were captured during this time (18 May and 27 June). They likely bred and produced the 18 larvae caught (SVL $\bar{x}$=63) in late summer (3 Aug). The last capture occasion of the 1995 season (13 Sept.) resulted in no terrestrial or neotene captures. Based on the size of larvae captured early in 1996, and the estimated size of metamorphosis (SVL=66, n=7), it is likely that the larvae caught in summer 1995 had metamorphosed and left the pond before our fall sample on 13 Sept.

On 7 and 26 June 1996, we captured 124 larvae on each occasion (Table 2). These larvae were undoubtedly the result of eggs laid earlier in the season. The large size of larvae for this time of year indicated that breeding had occurred unusually early in 1996 at Pollywog Pond (the other ponds showed a more typical phenology). On 5 July we captured 183 larvae, 7 of which were metamorphosing at an average SVL of 66 mm. We didn't visit the ponds again until Oct by which time captures had declined significantly. Assuming average capture rates ("p-hat") were constant among capture occasions, between 70 and 90% of the population metamorphosed and left the pond (a few undoubtedly died). The neotenes remaining in the population in October were large enough to mark; the population estimate of individuals (70mm SVL and larger) over three occasions (Oct 3, 4, and 9) was 157 (p-hat = 0.16, Fig. 1). Variances were high and the number of captures was low, producing wide confidence intervals. One terrestrial was caught on 3 Oct., apparently an adult that returned to the pond to overwinter.

In 1997, a minimum SVL of 70 was used once again to define the stratum of animals to be sampled in the spring and fall. None of the captures from April to September were smaller than ~60 mm SVL so it is likely that there was no recruitment in 1997, with all neotenes having been born in 1995 (possible, though none detected in fall 1995) or 1996 (more likely). The best population estimate for spring was 89 (p-hat = 0.63) and the best estimate for fall was 58 (p-hat = 0.35; Fig. 1). Both estimates have fairly tight confidence limits (Fig. 1). The difference in estimated population size represents a population reduction of about 35%, indicating appreciable attrition, perhaps including some second summer metamorphosis (common at high elevation, but we have not seen in this area).

It wasn't until the two capture occasions in September 1997 that we were able to identify any neotenic males in this population. This was surprising to us because we had observed neotenes large enough (based on the males in Shanahan Hill Pond) to be mature for at least the preceding 12 months, however, it appears that we underestimated the size at maturity for males in this population (SVL $\bar{x}$=109, range 98-120, n=20). We have not attempted to determine why sexual maturation occurred at a larger size in Pollywog Pond, but our records indicate that growth of neotenes in Pollywog Pond is two orders of magnitude faster than it is for neotenes in Shanahan Hill Pond, and the body condition of neotenes in Pollywog is consistently better. If maturation is at least partially a function of a salamander's age, one would expect maturation to occur at a larger size in the pond where growth is faster. This has been observed in Tiger Salamanders from

Michigan (Wilbur and Collins 1973). We suspect that primary productivity in Pollywog Pond is enhanced by greater light penetration through the clear water. Productivity of plankton and invertebrates may reflect higher primary productivity.

Those individuals metamorphosing did so in the normal size range: 65-70 mm SVL. Average growth rates were obtained from 67 individuals which were recaptured at least once over the course of the three year study. These individuals averaged 0.10 mm/day.

Although this pond produced rapid and fairly consistent growth, it stands out as unusual in that neotenes were absent from the pond in 1995, and there appears to have been a total failure of recruitment in 1997. Total recruitment failure was observed in Abbey Pond in 1974. When turbidity is low (as it was most of the time during 1995-1997 in Pollywog Pond), it may not be possible for larvae to escape cannibalistic neotenes (although there was plenty of vegetative cover). Thus, two scenarios could account for the lack of recruitment in 1997: all larvae fell prey to conspecifics because they had no place to hide in the clear water, or few eggs were laid because there were no adult neotenes in the pond in spring 1997 (though there were gravid terrestrial adults and these presumably bred). The absence of adult neotenes in 1997 is due to the absence of both juvenile and adult neotenes in 1995. Pond drying in 1994 or earlier could have eliminated the neotene population from Pollywog Pond (although not quantified through mark-recapture, a typical population of neotenes was present in 1974). The pond was at maximal depth in spring 1995 and its level was fairly stable 1995-1997. We are unaware of any definitive records of the depth of this pond before 1995, and would appreciate being informed of records. Another possibility is that some chemical, biochemical, or thermal stress eliminated neotenes from this pond in one or more of the preceding years. Again, we would be interested in additional information along these lines. One possibility is that herbicides being used to control weeds in the area (a target population of Canada Thistle plants is present in and around the pond) could have inadvertently produced a problem for the salamanders: Australians have recently discovered that the surfactants used in many herbicide preparations are lethal to amphibians in very low concentrations (ca. 1-3 ppm; Mann and Alexander 1997). These compounds are not usually persistant for more than a few days (although they may last for months under dry conditions), however, and therefore any chemical stressors that were present before 1995 would no longer be detectable.

We detected no major long-term change in the status of this pond from 1974 to 1997. The absence of a neotenic population at the start of 1995 may represent a one-time event.

Table 2. Number of captures made at Pollywog Pond with mean SVL (mm) of sample in parenthesis.

| | Spring | | | Fall | | |
|---|---|---|---|---|---|---|
| Occasion | 1 | 2 | 3 | 4 | 5 | 6 |
| 1995 | 0 | 0 | 0 | 18 (63) | 0 | n/a |
| 1996 | 124(37) | 124(48) | 183(52) | 53(80) | 19(81) | 27(80) |
| 1997 | 34(83) | 45(84) | 59(92) | 18(107) | 34(107) | n/a |

Table 3. Capture history of marked larval/neotenic salamanders with SVL>69mm at Pollywog Pond.

| 1996 | 7-Jun | 26-Jun | 5-Jul | 4-Oct | 9-Oct | 16-Oct |
|---|---|---|---|---|---|---|
| Animals captured | 0 | 1 | 1 | 23 | 18 | 35 |
| New captures | 0 | 1 | 1 | 23 | 17 | 25 |

| 1997 | 28-Apr | 15-May | 18-Jun | 11-Sep | 12-Sep |
|---|---|---|---|---|---|
| Animals captured | 33 | 44 | 35 | 18 | 27 |
| New captures | 33 | 39 | 14 | 3 | 5 |

Shanahan Hill Pond

Throughout spring and fall, Shanahan Hill Pond was characterized by high turbidity and no emergent vegetation. Dogs, usually several, entered the pond during each of our visits. Primary productivity seemed to be lower at Shanahan Hill Pond than in any of the other ponds we sampled. A few other amphibians were noted in or around the pond, primarily *Bufo woodhousei*. On occasion *Pseudacris* were heard calling from a short distance away from the pond. There appeared to be a dearth of insects except for one occasion in the spring of 1997 when dying cicadas were falling into the pond in substantial numbers.

To estimate population abundance in Shanahan, we assumed those individuals above 74 mm SVL were resident. This probably somewhat underestimates the true abundance of the population because it appears as though only a small proportion of the population metamorphoses. We do not have sufficient data on the size at metamorphosis for this population. We recorded only 10 individuals as 'metamorphosing', however, 4 of these were caught later (in the fall) as neotenes. The remaining 6 had an average SVL of 86 mm.

In 1995 the spring population estimate was 154 (p-hat = 0.24), and the fall estimate was 110 (p-hat = 0.39, Fig. 2). Based on the relative number of juveniles in the population, the recruitment rate was 17-23%. The fall abundance represents a 29% population reduction, a reflection of individuals metamorphosing and mortality. A total of 6 terrestrials were captured on 18 May and 01 June.

The spring 1996 estimate of 105 (p-hat $\bar{x}$= 0.50) was about equivalent to the fall 95 estimate, which suggests there was little or no winter mortality (Fig. 2). From spring to fall 1996 there was a 30% increase in the population estimate (to 136, p-hat = 0.54), and based on the relative number of juveniles present in the population, recruitment was as high as 22%. Like Pollywog Pond, only one terrestrial was caught in 1996, on 5 July.

The spring 1997 population estimate of 256 (p-hat = 0.25) was higher than the fall 96 estimate (Fig. 2). It suggests that there was substantial winter growth (larvae becoming large enough overwinter to surpass the size threshold in the spring) and little winter mortality. Of the 12 marked individuals that were captured during fall 1996 while smaller than the size threshold, one recaptured in the spring had grown to exceed the size threshold. Only two captures were made with individuals shorter than 75 mm SVL in the spring. Thus, there is some evidence to support rapid winter growth. We heard from a number of local residents that had seen winterkilled salamanders at the pond during the 1996-1997 winter, but based on our population counts, overwinter mortality does not appear to have occurred on a large scale.

The fall 1997 estimate was 196 (p-hat 0.31), indicating about 23% of the population leaving the pond or dying during summer 1997. The relative change in the population of juveniles was an increase of roughly 20% in the fall. A total of 48 terrestrials were caught on 28 April and 15 May, 9 of which were males that were caught on both occasions. An additional terrestrial was captured on 11 September.

Average size of mature males was slightly lower in Shanahan Hill Pond than in Pollywog (SVL $\bar{x}$=101, range=80-132, n=444). Average growth rates were obtained from 243 individuals which were recaptured at least once over the course of the three year study. These individuals averaged 0.001 mm/day. Compared to the population in Pollywog pond, this population has little or no individual growth.

Table 4. Capture history of marked larval/neotenic salamanders with SVL>74mm at Shanahan Hill Pond.

| 1995 | 18-May | 1-Jun | 27-Jun | 3-Aug | 13-Sep | |
|---|---|---|---|---|---|---|
| Animals captured | 35 | 40 | 35 | 34 | 51 | |
| New captures | 35 | 32 | 22 | 18 | 31 | |

| 1996 | 7-Jun | 26-Jun | 5-Jul | 4-Oct | 9-Oct | 16-Oct |
|---|---|---|---|---|---|---|
| Animals captured | 41 | 49 | 46 | 47 | 101 | 64 |
| New captures | 41 | 34 | 18 | 20 | 14 | 4 |

| 1997 | 28-Apr | 15-May | 18-Jun | 11-Sep | 12-Sep | |
|---|---|---|---|---|---|---|
| Animals captured | 47 | 85 | 61 | 77 | 44 | |
| New captures | 47 | 74 | 29 | 42 | 10 | |

Table 5. Capture history of larval/neotenic salamanders with SVL<75 at Shanahan Hill Pond

| Occasion | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1995 | 19 | 10 | 22 | 25 | 19 |
| 1996 | 12 | 15 | 6 | 16 | 30 |
| 1997 | 1 | 1 | 0 | 42 | 41 |

The most notable feature of the salamander population in Shanahan Hill Pond was the negligible growth of marked individuals. Yet in the winter of 1996-1997 the jump in population size suggested rapid juvenile growth during winter, a time when salamander growth is normally negligible or negative (Rodda 1975a). One possibility is that the high summer turbidity of this pond impeded the feeding of large neotenes (which prey (visually?) on large invertebrates or vertebrates).

We have not visited this pond in winter, but the primary cause for high turbidity in this pond is probably the large number of dogs entering it, and this factor may be reduced in winter. Sprules (1974b) found that low growth rate was associated with higer rates of neoteny in *Ambystoma gracile* populations. Thus it is possible that high turbidity has led to low foraging success which has led to low growth rate, which increases the probability of the neotenic life history track. Additional information is needed to understand the unusual lack of growth in this population.

The most conspicuous change in this pond's salamander population from 1974 to 1997 was the presence in 1995-1997 of a large population of neotenes (none was observed in 20 samples in 1974). The absence of a neotenic population in 1974 is less expected than the presence of one in 1995-1997. Thus, one would like to know if the pond had dried prior to 1974 or experienced some other stressor. This will be extremely difficult to determine at this time, although the spring that feeds this pond has exhibited notable stability over the years we have visited this pond. Another possibility is that high turbidity subsequent to heavy recreational use of the area after about 1970 has reduced summertime salamander foraging success so that the neotenic life history track has been stimulated (see above).

Abbey Pond

Abbey Pond was characterized by moderately extensive emergent vegetative cover. It was greatest in the low water year of 1996, with vegetative cover exceeding 50% in the spring and 75% in the fall. Water turbidity was high each time we visited the pond. Nearly every seine pull we made at this pond produced numerous introduced crayfish, *Orconectes virilis.* As crayfish are bottom-dwelling or fossorial, as well as nocturnal or crepuscular in habits, one would not have expected many to appear in our midday seines through the water column. The large numbers we observed suggest a very dense population. *Pseudacris* tadpoles and adults, *Bufo woodhousei* adults, and *Rana pipiens* adults were found at this pond.

During spring 1995, two individual male terrestrials (four captures) were made, and during late summer four individual metamorphosing larvae were captured. These were unusually large ($\bar{x}$= 97 mm SVL), perhaps due to a good ratio of food supply to competition. Only one male terrestrial was captured in 1996, on 7 June. In 1997, five terrestrials were captured on 28 April (1 female, 4 males) and five terrestrials were captured on 15 May (1 female, 4 males), of which two males were recaptures.

Although the pond contained about 300 neotenes and dozens of terrestrials entered to breed in 1974 and 1975, this pond probably no longer contains a resident population of neotenes. Based on the low number of captures, only a few metamorphs emerge from the pond. A possible cause for the low populations numbers may be the establishment of the crayfish population. Crayfish are omnivorous predators which are known to feed on the eggs, larvae, and adults of salamanders and frogs (Axelsson et al. 1997, Gamradt and Kats 1996, Gamradt et al. 1997). The species of crayfish found in the pond is from the eastern US, indicating that the population was either initiated in the pond since 1975 by someone (perhaps discarding fish bait) or the pond was colonized by overland movement of crayfish from a nearby non-native source pond (crayfish occasionally move overland during damp weather and they could travel upstream along the pond's overflow channel when it is flowing, as it did in 1995). For natural dispersal to have played a role in bringing the crayfish to Abbey Pond, a nearby introduced population must exist. We have not attempted to determine if this is the case.

The absence of neotenic salamanders at Abbey Pond made it very unlikely that animals tagged in 1974 would be recovered, as most (62%; 113 of 183) of the tags put out in the area in 1974 were attached to salamanders in Abbey. We have not yet found any individuals that have moved among the ponds nor have survived from the 1974 marking to the present.

Salamander Pond

In 1995, the pond was characterized by little emergent vegetation in the spring to complete coverage of vegetation in the fall. Little seining was possible in 1996, due to the complete coverage of vegetation and low water levels, and once again, in 1997, there was complete coverage of vegetation by the fall. *Pseudacris* were often found calling, and metamorphosing tadpoles were found in substantial numbers in the pond.

Larval salamanders were captured on two of the five capture occasions in 1995. On 27 June, the third capture occasion for spring, 19 larval salamanders were captured (SVL $\bar{x}$=43), 13 of which were noticeably full of food and many of which regurgitated tadpoles when handled. In addition to the salamanders, we seined 360 *Pseudacris* tadpoles and 181 metamorphosing froglets. On 3 Aug, 16 larval salamanders were captured (SVL $\bar{x}$=54). We visited Salamander Pond four times in 1996; however, the water level was high enough only in the first spring occasion, 07 June, to warrant seining. No salamanders were captured. During the rest of the spring through the fall, the water level was too low and the emergent *Typha* too extensive to permit seining.

We seined Salamander Pond on two spring occasions in 1997. On 28 April four male terrestrials were captured, and on 15 May, two additional male terrestrials were captured. We visited the pond two additional times, and according to a visual survey, we estimated the pond to have at least two terrestrials and 100 larvae on 18 June. Again, the water level was too low and the emergent *Typha* too pervasive to permit seining. We did not see any salamanders on our last visit on 11 September. None of 6 terrestrials marked in the spring of 1997 nor the single larva marked in 1995 was recaptured.

This pond was not adequately sampled due to the extensive stands of cattails; however, we have no evidence to suggest that it has changed appreciably in the last 25 years. The pond appeared to produce a substantial number of frogs and salamanders each year in 1974 as well as in 1995-1997.

## SUMMARY

The amphibian faunas of the ponds on Shanahan Hill have not been constant over the last 24 years. Large populations of neotenes in particular have formed where there were none before, and in other cases, neotene populations have died out. Due to the lengthy lifespans of these salamanders, these changes occur over a matter of years and are therefore relatively easy to monitor. Furthermore, the sensitivity of amphibians to both terrestrial and aquatic stressors makes them relatively useful as bioindicators. The populations of Northern Leopard Frogs, *Rana pipiens*, in this area are small and probably vulnerable to local extinction. Tiger Salamanders are not of concern from an endangered species point of view, but they are useful for measuring the health of the ponds because they are so numerous, long-lived, and easily sampled.

Our results suggest that biotic pollution of waters through unauthorized introductions (e.g., crayfish) may be a problem for the long-term survival of native amphibians. More data are needed to determine if crayfish have been responsible for the decline of the salamander population in Abbey Pond and such data should be obtained as quickly as possible to forestall future extirpations if the crayfish are responsible. It is our understanding that crayfish eradication is practical under the conditions present in these small isolated bodies of water.

In addition, it would seem worthwhile to more carefully assess the impacts that might occur due to accidental contamination of waters by surfactants or other chemicals in herbicide preparations. Newer formulations of herbicides are

available without the problematic surfactants, under such names as Roundup Bioactive, etc. (Bidwell and Tyler 1997). Unfortunately, the US EPA does not require testing of such compounds on amphibians. Australian researchers are leading in this area, so persons familiar with their findings should be consulted for current information. A good contact is Christine Bishop, a leading Canadian toxicologist specializing in amphibian issues (cab.bishop@cciw.ca).

A final concern suggested by our findings is that salamander growth was negligible in Shanahan Hill Pond, perhaps as a result of artificially high turbidity of that pond. Additional data from matched ponds that differed only in turbidity would be needed to determine if high turbidity was responsible for the low growth. Although declining at present, the salamander population in Shanahan Hill Pond is relatively dense in spite of the negligible growth, but a longer period of monitoring would be necessary to assess whether the population is stable over more than one salamander generation.

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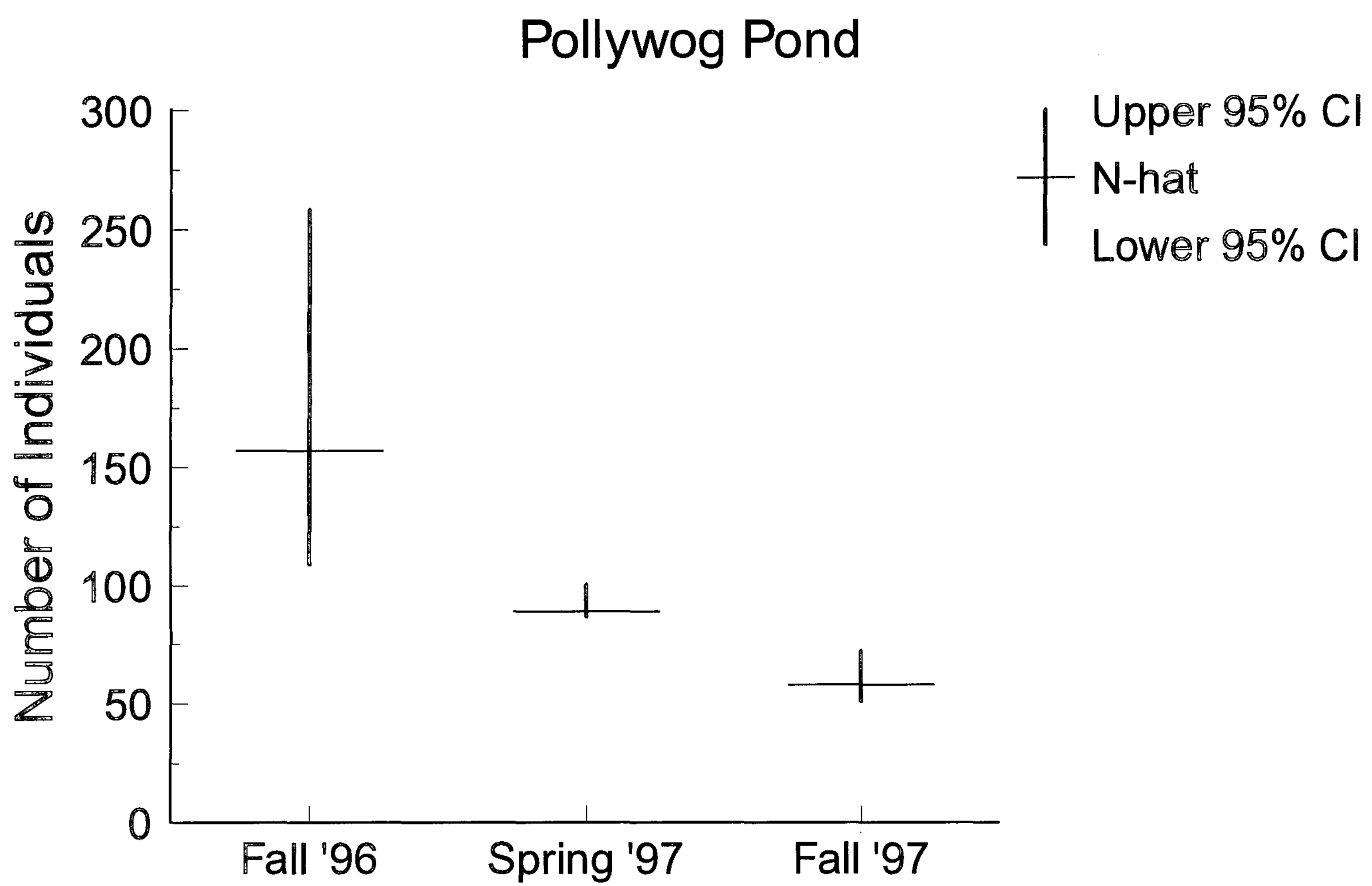
Captions to figures

Fig. 1. Population estimates for Pollywog Pond 1995-1995.

Fig. 2. Population estimates for Shanahan Hill Pond 1995-1997.


Pollywog Pond
Number of Individuals
300
250
200
150
100
50
0
Fall '96
Spring '97
Fall '97
Upper 95% CI
N-hat
Lower 95% CI

Shanahan Hill Pond