



A morphometric study of a hybrid newt population (*Triturus cristatus*/*T. carnifex*): Beam Brook Nurseries, Surrey, U.K.

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The crested or great crested newt (*Triturus cristatus* spp) is declining and now considered threatened in many of the countries where it is present. This has resulted in the four members of the superspecies being afforded protection under local, national and international law. This study looks at a possible threat to *T. cristatus* in southern England through hybridization, by the introduction of a related alien species (*T. carnifex*). The study used multivariate morphometrics to discriminate closely related species, and their hybrids. The character set involved both continuous and meristic data, collected through body measurements and colour pattern. The identification of the species and/or hybrids at the introduction site and surrounding areas was mapped. From the results it can be inferred that hybridization has taken place at the introduction site, but there is no morphological evidence for the spread of hybrids/aliens in to the surrounding areas.

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ADDITIONAL KEY WORDS:—hybridization – introduction – alien – newt – competition – multivariate – morphometrics.

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INTRODUCTION

Introduced organisms are often detrimental to the host community. The effects of these 'alien' species can be seen in a direct way, usually through an alteration of the trophic or spatial structure of the community, or indirectly through an alteration of the species composition within it (Peterken, 1992; Simberloff & Stirling, 1996; Muoneke, Maughan, & Douglas, 1991; Woodroffe, Lawton & Davidson, 1990; Guan & Wiles, 1996). These introductions can be purposeful, as in the case of the giant toad (*Bufo marinus*, Schneid.) in Australia to control the sugar cane beetle (Eastal, 1981), or accidental, as in the case of the bull frog (*Rana catesbeiana*, Shaw) where pets have escaped or have been released (reviewed in Stumpel, 1992).

Where an introduction is taxonomically closer to members of a community into which it is being released it is more likely to have an effect than if it was taxonomically distant (Griffiths, Davidson & Birks, 1996, Echelle & Echelle, 1997). The major impact will be seen through either competition, with one species being excluded, or hybridization of the two species resulting in reduced species diversity.

The introduction/hybridization of non-native *Triturus* species within the U.K. are represented by at least two species (Cunningham & Langton, 1997). Breeding colonies of Alpine newts (*Triturus alpestris*, Laurenti) have been documented in Sussex (Banks, 1989), Tyne & Wear (Banks & Laverick, 1986) and Surrey (Lever, 1980; Gillett, 1988). The Italian crested newt (*Triturus carnifex*, Laurenti) has only been documented as breeding at one site, the Beam Brook nurseries site in Surrey (Lever, 1980). The site has been associated with the importation/breeding of alien species since being established in 1903 by T. B. Rothwell. As the majority of the amphibians were kept outside (in concrete pits), individuals were able to occasionally escape into the surrounding areas, colonizing local ponds via waterways. Original price lists from the 1930s and 1940s list a range of exotic species, including the Italian crested newt (*T. carnifex*) although the origin of these remains obscure and could include specimens from adjoining countries. There is now concern surrounding its movement away from this site and the possible hybridization with the native species (*T. cristatus*, Laurenti).

In general, *T. cristatus* has a medium build. Its coloration shows distinctive white stippling along their sides/legs, an orange belly with a variable pattern of black spots. By contrast, *T. carnifex* has a medium to heavy build. Its coloration shows little or no white stippling, and a yellow belly with large, round, ill-defined dark greyish/black spots. The females often have a yellow vertebral stripe (Arnold, Burton & Ovenden, 1992). A visual comparison of the two species body forms will usually show *T. cristatus* to have shorter legs for the same interlimb distance (Wolterstorff, 1923). Where the two species live in sympatry, occasional hybridization may occur, producing F1 hybrids (Schmidtler, 1976; Freytag, 1978; Arntzen & Thorpe, 1999).

F1 hybrids are often intermediate in their phenotypic characters (Lantz, 1947; Vallee, 1959; Thorpe & Leamy, 1983; Griffiths, Roberts & Sims, 1987; Scriven & Bauchau, 1992; Arntzen & Wallis, 1994), allowing individuals to be identified by multivariate analysis of these features (Thorpe & Leamy, 1983; Scriven & Bauchau, 1992; Giannasi, Thorpe & Malhotra, 1997). This technique has practical advantages, including relatively low expense and low skill levels, whilst enabling large amounts of data to be obtained and processed in a short time. Unlike molecular methods, it can be readily carried out in the field allowing one to decide sampling strategies in an interactive manner.

TABLE 1. Breakdown of species from sites 1–9.

Species	Location	Sample size
Italian sites (Pure <i>T. carnifex</i>)	Site 1. Naples	50 Female 50 Male
	Site 2. Trieste	5 Female 5 Male
U.K. sites (Pure <i>T. cristatus</i>)	Site 3. Peterborough	74 Female 26 Male
	Site 4. Newborough	22 Female 29 Male
Potential hybrid sites (<i>T. cris/T. cam.</i>)	Site 5. Beambrook	60 Female 35 Male
	Site 6. Tooloogawa 12 acre	5 Female 5 Male
	Site 7. Tooloogawa 9 acre	11 Female 6 Male
	Site 8. Holmwood Pk Fm	15 Female 2 Male
	Site 9. Capel Post House	4 Female 1 Male

Licence details: Site 3 (E.N 19980838/39), Site 4 (C.C.W SA 3098), Sites 5–9 (E.N 19971195), (Release licence – WCA/97/13)

METHODS AND MATERIAL

Collection/measurement of samples

The study is based on an analysis of 405 newts collected at a number of locations within Italy and the U.K. (see Table 1 for breakdown). The U.K. samples were all wild populations, caught under licence with a net over a period of night/day sessions during June 1998. These samples, from two locations were used to characterize the multivariate morphology of the U.K. great crested newt (*T. cristatus*).

The Italian samples were also from two differing locations. A southern population originating 30 km SE of Naples, and now housed at the University of Torino. The second, a northern population, was part of a captive collection, and included several freshly caught samples, all originating from pools within the limestone massif surrounding Trieste. These were used to characterize the multivariate morphology of the Italian crested newt (*T. carnifex*). For the location of the Surrey sites see Figure 1.

The second stage of the fieldwork involved collecting samples at varying distances from Beam Brook, to show how far the *T. carnifex* phenotype had travelled from the site of origin within 60 years. Sites where previous sightings of great crested newts had been observed were used. The data collected at each site was statistically analysed as before, at the end of every day. This enabled a decision to be made based upon each day's results, moving further away from the source if hybrids/*carnifex* were found, or moving further in if none were found.

All samples smaller than 100 mm total length were rejected to ensure that only mature adults were measured, this was also confirmed by inspection of the cloacal area. The use of adult specimens counteracts any problems of allometric growth, with a rapid slowing down in growth being linked to sexual maturity (Francillon-Vieillot, Arntzen & Geraudie, 1990).

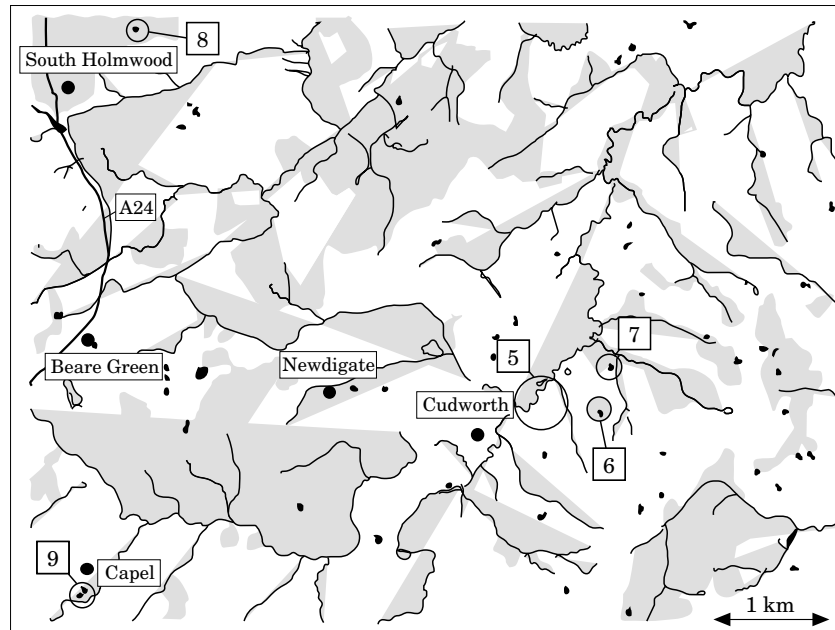


Figure 1. Potential hybrid sites, Surrey. Hydrology (Solid lines) and forested areas (Hatched). Beam Brook (5), Tooologawa 12 Acre Field (6), Tooologawa 9 Acre Field (7), Holmwood Park Farm (8), Capel Post House (9).

All samples were live specimens, to avoid problems involved in measuring preserved specimens (Lee, 1982; Verrell, 1985). The samples when measured were placed on a moistened white towel to avoid the melanistic colour changes that occur in newts when placed on coloured surfaces (Lantz & Callan, 1954). Their morphometric characters were then taken with a digital vernier gauge to within 0.1 mm, with specimens returned to the field within 24 hours. The morphometric characters measured can be seen in Table 2 and Figure 2.

Data analysis

All statistical tests were conducted using a PC running BMDP statistical software (BMDP Statistical Software, Los Angeles CA 90025). Initially the data were checked and characters CF2 and CH2 rejected, as they were missing for some samples. Colour pattern characters were tested for a significant difference in the within/between group variation using an ANOVA while equivalent tests were carried out on the body measurements by ANCOVA with snout–vent length as the independent variable.

A canonical variate analysis (CVA) was performed on all data from sites 1–4, (separately for the sexes), to test if one could discriminate between the two taxa (95% of individuals should be within approximately 2SD of the group means). In addition, it also provided a list of discriminate factors indicating the weighting of each character, and its contribution to species separation. This analysis was then re-run with the putative hybrid individuals added. Any F1 hybrids, being of an

TABLE 2. Morphological character measurements (Body/Colour)

Character/abbreviation	Explanation of character measurement
BA. Eye width	Distance between corners of the eye.
BB. Inter-orbital distance	Distance from cornea to cornea across head.
BC. Eye-nose distance	Distance from snout tip to rear eye corner.
BD1. Head width	Distance across head in line with eyes.
BD2. Head length	Distance from snout tip to corner of mouth.
BE. Head depth	Distance vertically from front of eye to lower jaw.
BF1. Proximal forelimb length	Distance from body side to elbow when at right angle.
BF2. Distal forelimb length	Distance from elbow to beginning of thumb.
BF3. Longest toe forelimb	Distance from tip to metatarsal.
BGI. Interlimb	Distance between limb sockets, taken from underneath.
BGL. Tail length—cloaca	Distance from tail tip to outer edge of cloaca.
BGS. SVL	Distance from snout tip to outer edge of cloaca.
BGT. Tail length	Distance from tail tip to inner edge of cloaca.
BH1. Proximal hindlimb length	Distance from body side to elbow when at right angle.
BH2. Distal hindlimb length	Distance from elbow to pseudo-toe spot.
BH3. Longest toe hindlimb	Distance from tip to metacarpal.
BTL. Total length	Distance from snout tip to tail tip.
CA1. Black/brown top of head	Measured as a % of the total area.
CA2. Green on top of head	Measured as a % of the total area.
CB. Black spots on tail	Number of black spots on tail area.
CD1. Black spots (dorsal)	Number of black spots on one dorsal side.
CD2. White spots (dorsal)	No. of spots, one side, measured on interlimb median.
CD3. Depth of white spots	Depth as a % of white spots on one dorsal side.
Underside colour—CE1. Head	Yellow/orange in this area.
CE2. Trunk	Yellow/orange in this area.
CE3. Tail	Yellow/orange in this area.
CF1. Light spots forelimb underside	Light spots on underside of forelimb as a %.
CF2. Black spots on forelimb palm	Number of black spots on fore-palm.
CF3. Light/dark bands on forelimb toe	Number of light/dark bands on longest forelimb toe.
CG. Post-cloacal mark	Yellow/orange in this area.
CH1. Light spots hindlimb underside	Light spots on underside of hindlimb as a %.
CH2. Black spots on hindlimb palm	Number of black spots on hindlimb palm.
CH3. Light/dark bands on hindlimb toe	Number of light/dark bands on longest hindlimb toe.

intermediate nature, would then appear between the boundaries of the species groups.

RESULTS

ANOVA/ANCOVA

Some of the characters showed a significant difference among the sexes when working at the 95% significance level. This indicated sexual dimorphism, and a need for the sexes to be analysed separately. Those characters that showed no significant differences at the 95% significance level between localities were excluded from the analysis, localities being of most relevance to this study. This result indicated that as there was much greater between-group variance than within-group variance, discrimination between *T. cristatus* and *T. carnifex* was possible.

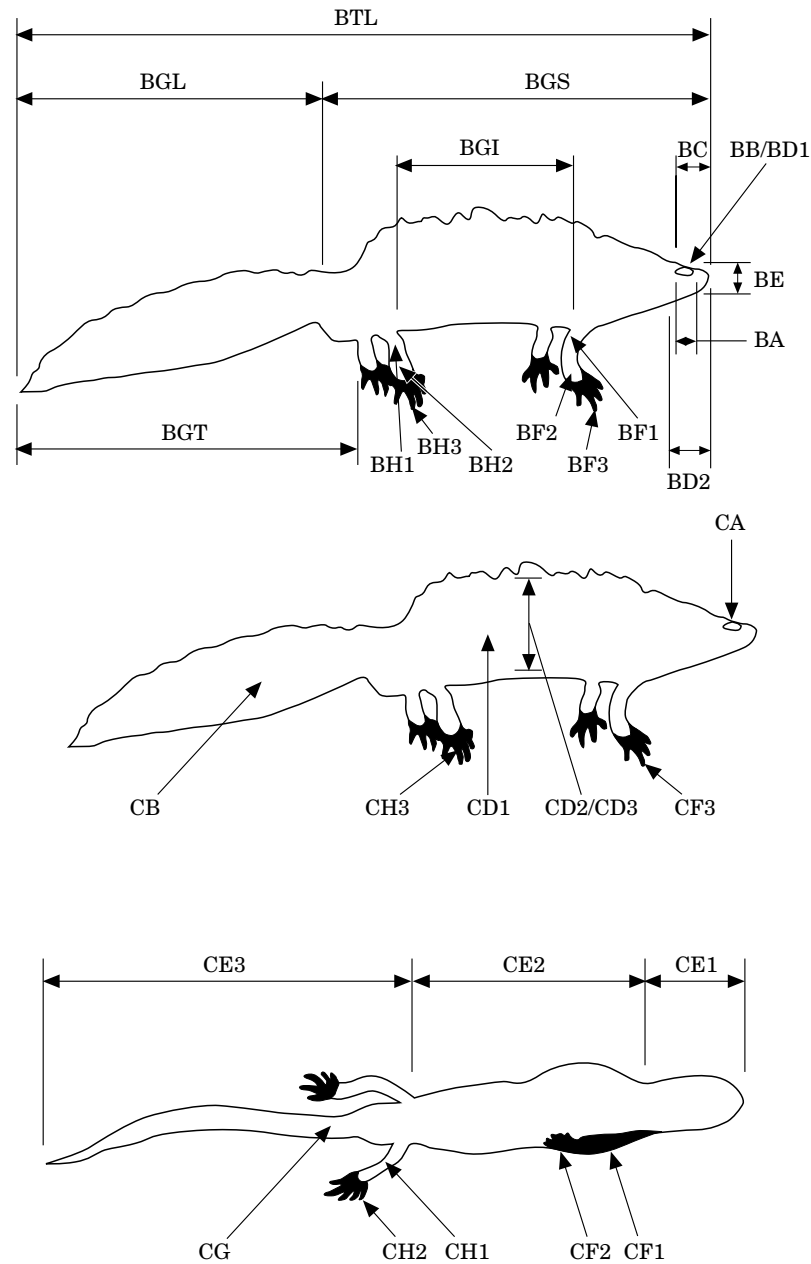


Figure 2. Body/colour measurements on crested newts (*Triturus cristatus*, *T. carnifex* and hybrids). See Table 2 for key.

Pure sample sites: canonical variate analyses

CVA sites 1–4

Although the data sets were analysed separately for both sexes, similar results were achieved. This study will concentrate on the results of the female data sets, due to their larger sample sizes.

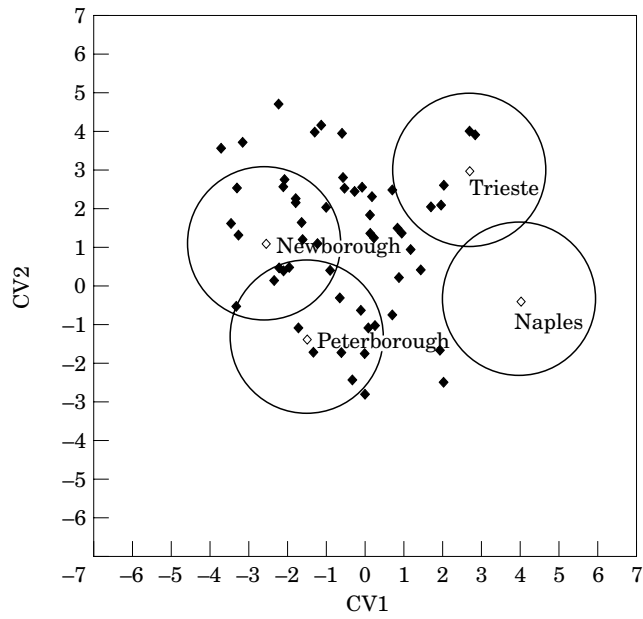


Figure 3. Pure sample means (Sites 1–4) with circles indicating 2 SD, and individuals from Beam Brook Nurseries (Site 5). Females. Axis measurements in standard deviations.

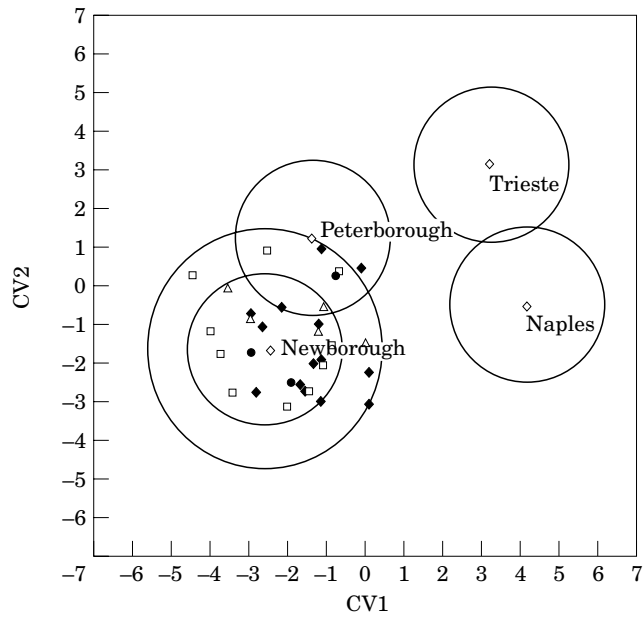


Figure 4. Pure sample means (Sites 1–4) with circles indicating 2/3 SD, and individuals from Tooloogawa 12 Acre Field, Tooloogawa 9 Acre Field, Holmwood Park Farm, Capel Post House (Sites 6–9). Females. Axis measurements in standard deviations. Legend: (\diamond) sites 1–4 (site means), (Δ) site 6 (Tooloogawa 12 Acre Field) (\square) site 7 (Tooloogawa 9 Acre Field), (\blacklozenge) site 8 (Holmwood Park Farm), (\bullet) site 9 (Capel Post House).

The correct classifications for the pure female samples (sites 1–4) were high (98% overall), with misclassified samples still being placed into the same taxon group. Those characters that appeared to be having the greatest impact were BA, BB, BD1, BE, BF2, BH1, CE1. From these results it appears that the Italian populations have a tendency for wider eyes, larger inter-orbital distances, smaller head widths, deeper heads, longer distal fore-limbs, shorter proximal hind-limbs, and no yellow markings under the head. The British populations tend to have the opposite character states.

CVA sites 1–5, with potential hybrid individuals

The potential hybrid individuals from site 5 (Fig. 3) were added to the pure sample CVA. The majority were intermediate between the Italian and British groups, with the remainder falling within 2 or 3 SD of each pure group mean. It is worth noting the bias towards *T. cristatus* in the Beam Brook samples. The results from this CVA infer that there are both *T. carnifex* and hybrids at the Beam Brook site.

CVA sites 6–9, with individuals from sites surrounding the nurseries

The individuals from sites 6–9 were added to the pure sample CVA (Fig. 4). Although the sample sizes vary greatly (see Table 1), one theme becomes apparent from studying the plots. The majority of individuals fall within 2 SD of the Peterborough or Newborough means, and all within 3 SD. There are no individuals that have either *T. carnifex* or hybrid morphology.

To summarize, the study results infer that some hybrids (intermediate in morphology between *T. cristatus* and *T. carnifex*), and pure *T. carnifex* are present at Beam Brook nurseries, with the majority of samples being morphologically more similar to *T. cristatus*. Additionally, there is no morphometric evidence to suggest that intermediate hybrids, or pure *T. carnifex*, are present in the surrounding countryside at the sampling sites.

DISCUSSION

The multivariate method used in this study has enabled separation of the two species and their F1 Hybrids with a set of 12 characters for each sex (see Table 3).

The results from sites 5–9 confirm that both *T. cristatus*/*T. carnifex* exist at Beam Brook, that hybridization has taken place, but may not have spread from the site. The failure of hybridization to spread could be dependent upon several types of barrier being present.

Several studies of courtship behaviour in *T. cristatus* and *T. marmoratus* Latreille, (Arntzen & Sparreboom, 1989; Zuidervijk, 1990) show the existence of both qualitative and quantitative differences. As *T. cristatus*/*T. marmoratus* hybridize naturally, it is unlikely that this would act as a barrier within the evolutionarily closer members of the *T. cristatus* superspecies.

Genetically, *T. cristatus*/*T. carnifex* allozymes show a genetic distance differentiation of 0.38 (Nei's D) from each other, whereas *T. cristatus*/*T. marmoratus* is much greater at 0.84 (Nei's D) (Macgregor, Sessions & Arntzen, 1990). As *T. marmoratus* hybridizes

TABLE 3. Morphometric characters showing values higher than 0.2 for pure *T. cristatus*/*T. carnifex* (sites 1–4) (L=Large/Long, S=Small/Short, N/A=Not Applicable).

Character	<i>T. cristatus</i>		<i>T. carnifex</i>	
	Male	Female	Male	Female
BA. Eye width.	S	S	L	L
BB. Inter-orbital distance	S	S	L	L
BC. Eye–nose distance	L	S	S	L
BD1. Head width	L	L	S	S
BD2. Head length	S	N/A	L	N/A
BE. Head depth	S	S	L	L
BF1. Proximal forelimb length	S	N/A	L	N/A
BF2. Distal forelimb length	S	S	L	L
BF3. Longest toe forelimb	N/A	S	N/A	L
BGL. Tail length minus cloaca	S	S	L	L
BGT. Tail length	L	L	S	S
BH1. Proximal hindlimb length	N/A	L	N/A	S
BH2. Distal hindlimb length	S	N/A	L	N/A
BH3. Longest toe hindlimb	N/A	S	N/A	L
Underside colour – CE1. Head	S	L	L	S

with *T. cristatus* with limited success (Arntzen & Wallis, 1991), the possibility of genetic incompatibility being a barrier between *T. cristatus*/*T. carnifex* seems unlikely.

The ability for a species to introgress and hybridize successfully can be dependent on a number of factors including the suitability of habitat to which it has been introduced. *T. cristatus* prefers flat areas, with pools containing an abundance of aquatic vegetation, whereas *T. carnifex* thrives in disturbed areas, with little or no cover, and pools with or without vegetation (Arntzen & Thorpe, 1999). This habitat preference can act as a barrier, separating *Triturus* species when living sympatrically (Schoorl & Zuiderwijk, 1981; Arntzen & Wallis, 1991). At present, through reviewing the data, it appears that *T. cristatus* is still the dominant species at all of the sites. This could be due to environmental factors over the possible 60 year introduction period favouring the *T. cristatus* preference for undisturbed habitat. As Beam Brook and the surrounding areas have seen much development in the past 60 years, this appears to be in conflict with what would be expected. Results obtained in a similar study of *Triturus* sites around Lake Geneva (Arntzen & Thorpe, 1999) show that since its introduction in the 1940s *T. carnifex* has become the dominant species (especially in disturbed areas), swamping *T. cristatus* sites within its generation radius (1–3 km). Where sites are further apart (i.e. 7 km), they have remained pure *T. cristatus*. The difference in the extent/manner of disturbance between the two study areas may explain the different results.

There could be other negative effects acting against *T. carnifex*. As the population is smaller it will naturally have mated more often with *T. cristatus*, this being a disadvantage if there is hybrid inferiority (Callan & Spurway, 1951; Arntzen & Hedlund, 1990).

From the analyses we can offer several explanations for the patterns that we see.

- (1) That hybridization has only occurred at the Beam Brook site, and that *T. carnifex* has not spread.

- (2) That *T. carnifex* hybrids have spread from the site, possibly hybridized, but then regressed back.
- (3) That *T. carnifex* hybrids have spread from the site, possibly hybridized, but have been missed by our choice of sites.

Option 3 seems unlikely, as the nearest two sites were both easily accessible for colonization, and reflected similar habitats in all directions away from the site. To reject either of the other options is much more difficult. If *T. carnifex* hybrids had spread from the site and regressed back, a 'genetic footprint' may still be evident. However, morphometrics is unable to detect this. Here the use of molecular techniques would need to be used, allowing a finer investigation of hybridization, the extent of its introgression, and its direction to be mapped.

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