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Migration and Speciation in Newts

An embryologist turns naturalist and conducts field experiments on homing behavior and speciation in newts.

Victor C. Twitty

I have chosen to deal in this article with the subject that is of most interest to me personally—namely, the working relationship I have enjoyed for over twenty-five years with my favorite animals, the newts of California. When I first went to Stanford University in the early thirties and began what I thought was the hopeless task of finding an adequate substitute in the West for the classical *Amblystoma punctatum* that was the mainstay of experimental morphologists in the eastern United States, I stumbled across three or four new species and subspecies of the California newt in the course of collecting material for embryological studies from various parts of the state. And the work that I have done since then has been largely shaped by the amphibian friendships I formed at that time. Having discovered these new species, and given them names (it was someone else, however, who named one subspecies *twittyi*—later declared invalid!), I have developed a proprietary interest, and maybe a feeling of obligation to them, that has influenced my choice of experiments ever since, including some that are quite far afield from my original interest and training.

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As a student of Ross G. Harrison, I was of course at the time looking for things that I could get my iridectomy scissors into, and the first thing that struck me was the markedly different pigment patterns that distinguished the larvae of the species of California newts.

The neural-crest origin of the pigment cells was just in the process of being established at that time by DuShane, and as a confirmed heteroplastic grafter it was inevitable that I would soon begin switching neural crest and related tissues back and forth between the embryos of the species; by this method, and also through the use of tissue culture, I was able eventually to analyze in considerable detail the developmental basis of the hereditary differences in pigment patterns. This led in turn to studies on the problem of cell migration per se, and if I were writing this article five or six years ago it would undoubtedly deal with cell patterns or cell movements, or some other related embryological topic.

But in the meantime my interest has been diverted to other aspects of the biology of California newts, and instead of dealing with the movements of salamander cells, this account will deal mostly with the migrations of the adult newts themselves. This may seem to be a surprising transfer of emphasis, but from the time I first came to know these animals and began to experiment with their embryos, certain collateral questions arose that have continued to intrigue me. For example, I had learned shortly after discovery of the species that artificially produced hybrids were completely viable, but at the time methods had not been developed for rearing California newts, whether normal or hybrid, to maturity in the laboratory, and so I did not know whether the hybrids were fertile. Also, in working out the life histories of the different species I became aware of some interesting differences in their behavior. For example, one species would lay its eggs singly, another in flat clusters, another in round clusters; one would choose quiet water for spawning, another rapid mountain streams; and so on. To make a long story short, I had always wanted to undertake some experiments—merely as a sideline, I thought at the time—to learn whether artificially produced hybrids would grow to maturity if released in nature, and if so, whether they would be fertile—would perhaps even interbreed with the native parental populations, with all of the interesting possibilities that that would present—and also to learn how hybridization might affect some of the behavioral differences I have mentioned.

An opportunity to test these somewhat visionary questions came in 1953 when I obtained permission from the owners to establish a field station on a large ranch in the coastal mountains of Sonoma County about 100 miles north of San Francisco (*1*). Western newts require four or five years to reach sexual maturity, and needless to say the answers to the questions will be slow in coming. The last couple of years we have begun to get some very encouraging results, however, and later I shall indicate briefly where we stand.

But it is principally some of the unexpected by-products of the project with which I should like to deal at present.

Migration Studies

When we began planting young hybrids in a selected experimental stream on the ranch, the alarming thought struck us that even if the hybrids did survive to maturity they might scatter over the whole countryside and eventually select for breeding an entirely different stream—maybe in the next county.

And so we were immediately faced with the question: Do newts have a fixed home range throughout their lives, or are their yearly movements to and from the water of a random nature, perhaps carrying them to new breeding sites each year? I had never anticipated that I would become involved in such unfamiliar issues as this, but I can say that the study of the problem has been just as fascinating—and just as involved and difficult—as the study of the migrations of salamander cells.

And so, as briefly as possible, let me outline what we have learned and what remains to be learned.

Taricha rivularis (*2*) is the species that is most abundant at the ranch, and is the one that we have used for the migration studies. *Taricha granulosa* is also present there, but in much smaller populations. The other two forms, *T. torosa* and *T. t. sierrae,* are native to other regions of the state. In one part or another of California, *T. granulosa* is sympatric with the other three forms, but the latter are not known to be sympatric with one another.

There are several streams on the ranch, but we have selected for our work one that is called Pepperwood Creek, a tributary of the Wheatfield Fork of the Gualala River. Pepperwood Creek is a small stream, but it is literally crawling with newts during the breeding season. To give you some idea of the size of the population we are working with, I might mention that since the project began we have, by systematic collecting, removed from a 1½-mile stretch of this stream—the portion we have set aside for our studies—a total of over 24,000 females, partly for use in the hybridization experiments. That is a lot of "waterdogs," as they are called in California. The effects of this inroad on the size and on the sex ratio of the *rivularis* population is an incidental problem of considerable interest in itself, and one that we are following in some detail.

Figure 1, a contour map prepared from a U.S. Forest Service aerial photograph, shows the course of the experimental stream and the topography of the adjoining terrain. For recording our results, the portion of the stream selected for the study was marked off into a series of 58 "stations" or intervals, each 50 yards in length and identified by numerals painted on trees or boulders along the stream.

The great majority of the population inhabits the mountainous and heavily wooded slope to the south, and from here each spring the newts descend to the stream for breeding. At the end of the mating season they leave the water abruptly and redistribute themselves over the mountainside, where they spend the dry summer months underground.

When the rains begin in the autumn or winter the animals emerge again and forage on the forest floor, often high upon the mountainside. Since the ter-

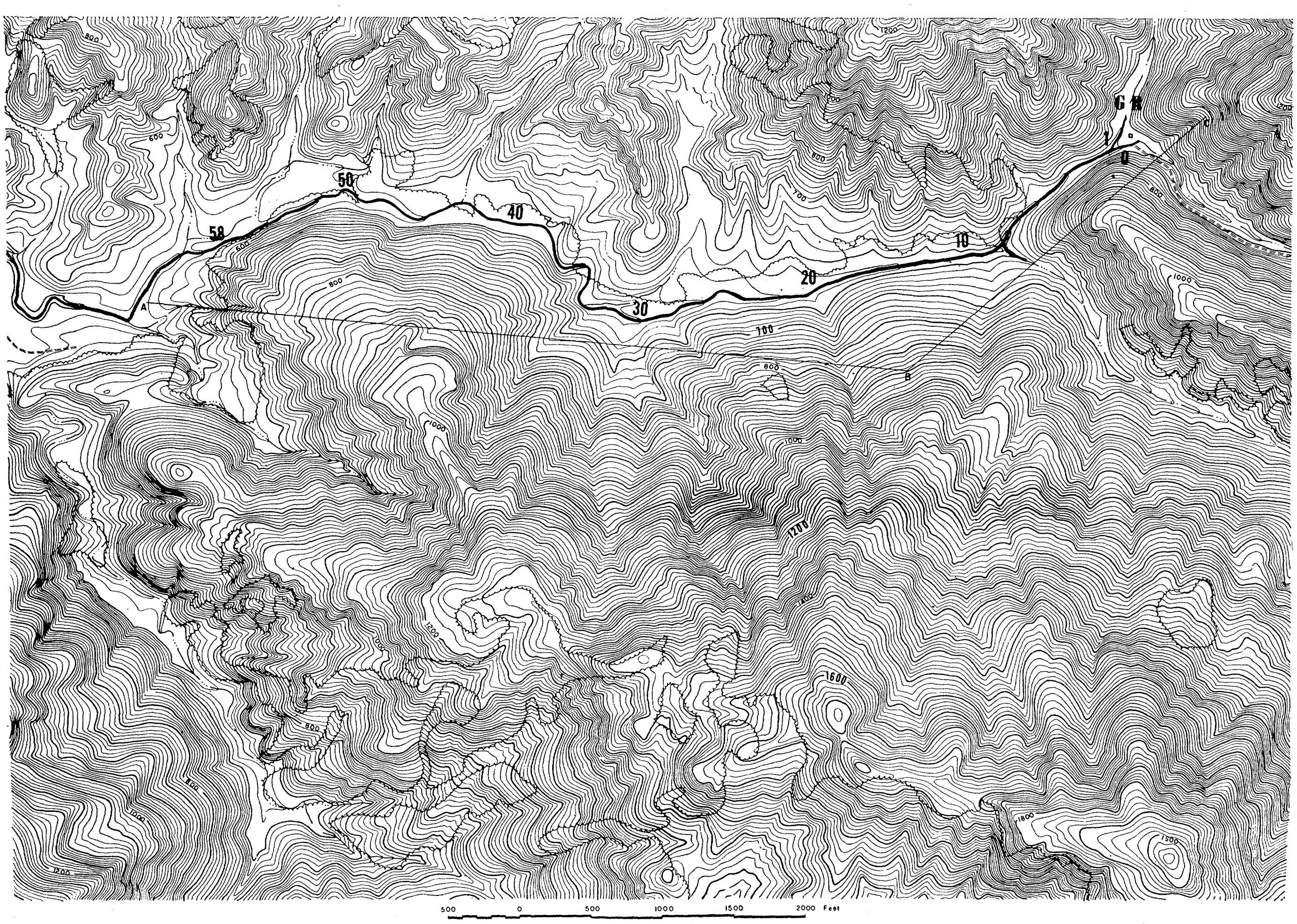
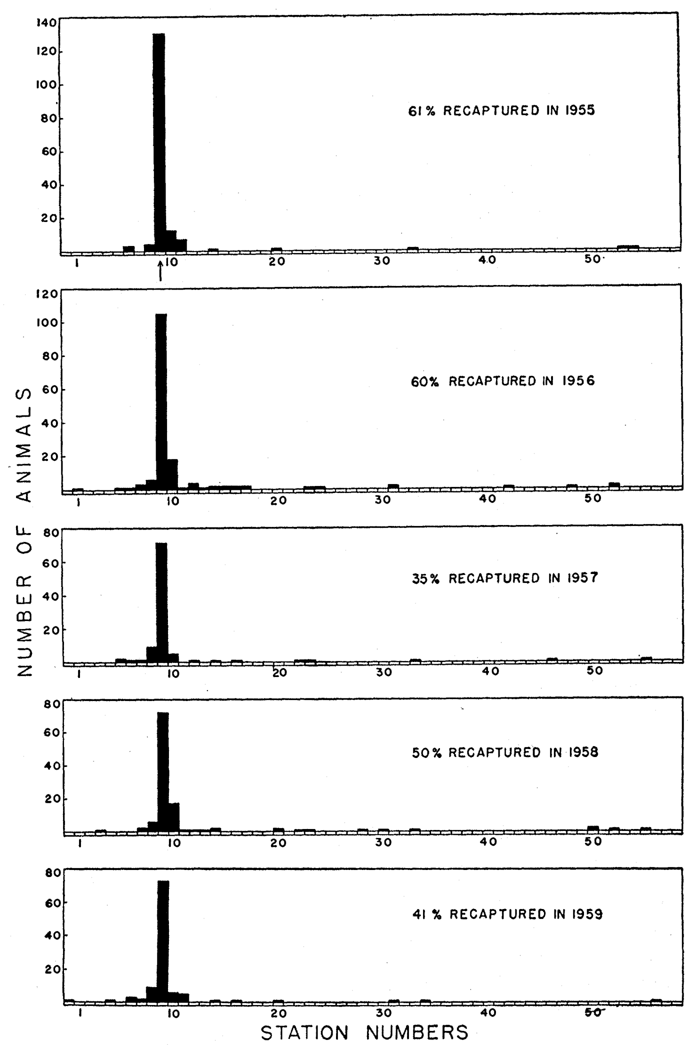


Fig. 1. Contour map prepared from a U.S. Forest Service aerial photograph, showing the experimental stream and the topography of the adjoining terrain. Each spring newts descend to the stream for breeding, primarily from the mountainous slope to the south.

rain they traverse in returning to the stream as the breeding season approaches is very rugged and irregular, cut by many gullies and ravines, one wonders whether a given animal returns to the same segment of stream where it had bred the year before, or whether it is perhaps diverted to a new point of entry. In other words, are we dealing in this study with a single, shifting population within which there is relatively free mixing and interbreeding of individuals throughout the experimental area, or is it perhaps instead a more or less stable mosaic of relatively isolated subpopulations, each with its own "home area" and restricted segment of the experimental stretch, to which the same group of individuals returns year after year for mating and reproduction?

To find the answer we have marked literally thousands of animals for subsequent recognition, and I shall cite the results of only a few representative series.

In 1953 we collected 262 males from a single pool at station 9, marked them, and returned them to the same pool. The first observations on this series were made two years later, and observations have been made each year subsequently (Fig. 2). As you will note, year after year virtually all of the animals recaptured were taken at or very near the pool where they were originally collected and marked. This was as true this past season, after six years, as it was in the beginning. The percentage of recaptures has also been high, over 60 percent the first year and still about 40 percent this last year. (In fact, a total of 85 percent has been recaptured over the years, but never that many during any single season.) Incidentally, this speaks for the longevity of the species



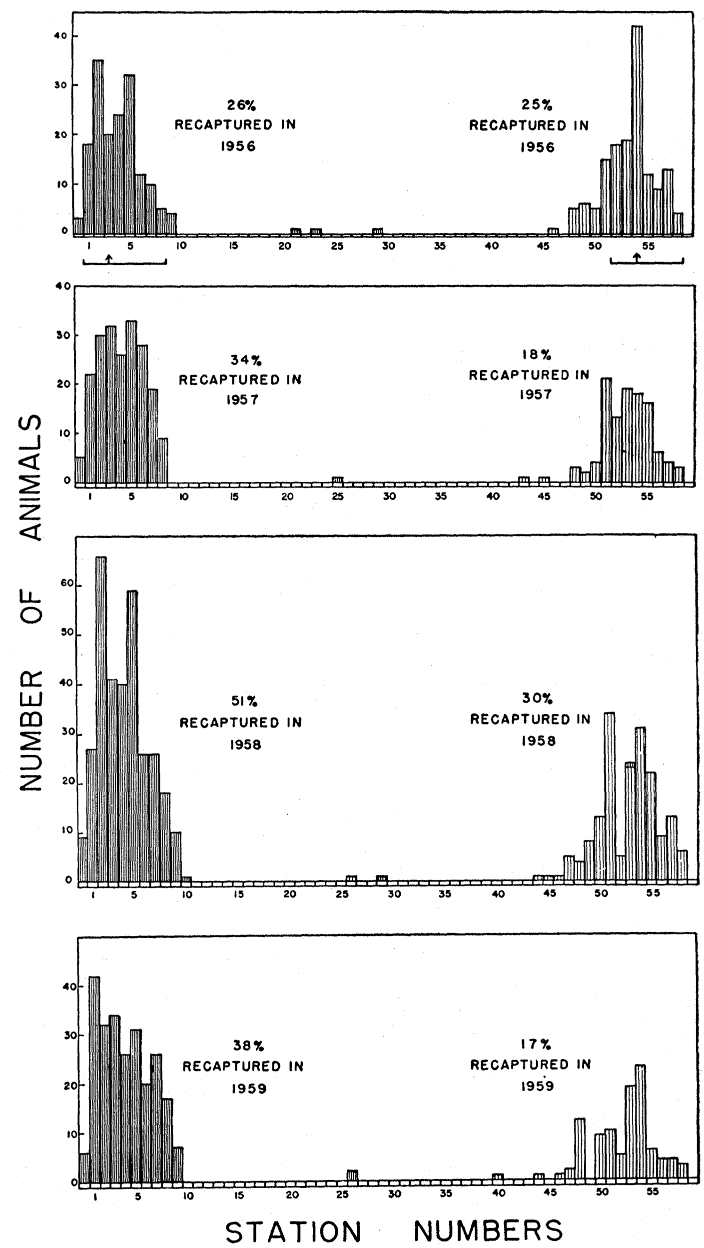
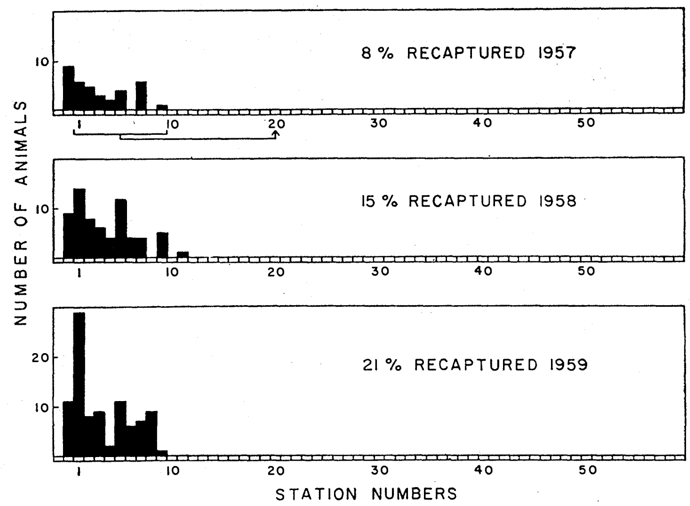


Fig. 2 (left). In 1953 adult newts were collected from a pool at station 9, marked to permit their subsequent recognition, and released in the same pool. The graphs show the locations where they were recaptured in later years, beginning in 1955. For recording the recaptures the stream was marked off into 50-yard segments or "stations." Fig. 3 (right). Graphs showing the locations of recaptures over a four-year period for two series of marked newts. The brackets and arrows indicate where each series was collected and released, respectively, in 1955.



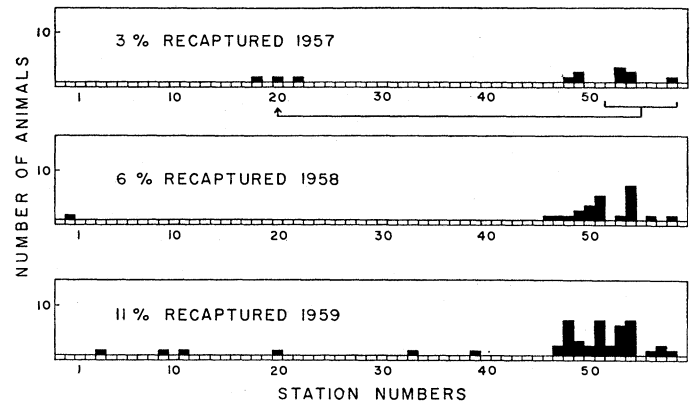


Fig. 4 (left). Graphs showing the return to the home segment of the stream of newts that had been displaced in 1956 to a point about half a mile downstream. Fig. 5 (right). Graphs showing the return, with a few scattered exceptions, of newts to the home segment of stream after displacement in 1956 to a point about one mile upstream.

and also for the low rate of mortality in the adult population.

To appreciate these results one must bear in mind that these are animals that in many cases have moved relatively great distances up and down the mountainside between successive breeding seasons.

Figure 3 shows the results, over a period of four years, of two additional series of marking experiments. These animals were collected from longer segments of stream, one series from the upper part of the experimental stretch and the other from the lower end of it. In each case they were all released in a single pool, near the middle of the segment in which they had been collected. The graphs showing their recapture in subsequent years are self-explanatory, and it is as evident as it was in the preceding series that the animals find their way back to the home segment of stream year after year with almost monotonous regularity and fidelity. In our daily patrol of the entire experimental stretch throughout the breeding season the location where these animals will be recaptured is so predictable that we are almost grateful when we encounter an exception—as we very seldom do.

The next experiments show that this behavior is based on a very positive affinity or sense of identification that the animals develop for their home segment of stream, and an ability to relocate it and recognize it after they have been displaced to foreign segments.

In the series represented in Fig. 4, adults were collected from the upper segment of the experimental stream, marked, and released downstream at station 20, about half a mile away. The graphs show the recaptures during the three succeeding years. Without exception, all of the animals recaptured had successfully relocated the home segment of stream.

It is true that the percentage of recaptures is lower than before, only 8 percent the first year. But you will note that the percentage has increased each year subsequently. This must mean that some of these animals had retained a memory of the home area, and the ability to recognize it, for at least three years. During that period, while still searching for their home base, they were unwilling to settle for any other segment of the stream. In a sense, then, the very ability to reproduce is dependent upon association with the home area. Why they should be so fussy and selective is difficult to see. One part of the stream is inherently as suitable for reproduction as another, as shown by the fact that the population breeds throughout the entire stretch.

Figure 5 shows the results with a similar series in which the animals were displaced for approximately a mile, from the lower end of the experimental stretch to station 20. The results are the same as before, except that the percentage of successful returns is lower, and there are a few animals that have apparently tossed in the sponge and settled for other than the home segment of stream. It is as if they have finally decided that the home stretch is simply out of reach and have resigned themselves eventually to acceptance of the breeding ground that is nearest at hand.

Incidentally, I should stress that these homing returns are made, not by way of the stream channel itself, but overland between breeding seasons; this, in view of the rugged nature of the terrain, makes the journey even longer and tougher.

One wonders how much further these animals could be displaced and still find their way home. Have we, in this last series, almost approached the "point of no return"? Until this year I would have been inclined to say so, but it appears that this is not the case.

In 1956 about a thousand females collected during the season from the experimental stretch were marked and released in a stream in a deep canyon on the other side of the mountain ridge that rises to the south of Pepperwood Creek (Fig. 1). The release point is perhaps three miles from the experimental stretch and is so inaccessible that we have not revisited it since the animals were transferred there. The ridge separating the two streams rises a good thousand feet above them, and frankly, I never expected to hear from these displaced animals again. However, near the end of this past spawning season they began to show up, and we recorded 18 individuals that were clearly members of the series. Next year I am sure we shall find more. There is not time to discuss the implication of this, or of other related experiments we have made, except to point out that whether it reflects a true homing search or not, as I am confident it does, it is a remarkable achievement by animals as relatively sluggish and slow-paced as newts. Considering the size of newts and their rate of locomotion, the distances involved are really very great.

Navigation or Random Search?

The next question is whether the animals we have displaced from one part of the experimental stretch to another find their way back home by random search or by oriented migration involving some form of true navigation.

Thus far, we have tested this in the following manner.

Figure 6 shows a star-shaped enclosure that we constructed of wire mesh near the streamside, about midway along the experimental stretch. The black line and arrow parallel the axis of the nearby stream and indicate the direction of flow of the stream. At the tip of each arm of the enclosure there is an opening into an escape-proof trap. In the center is a release box from which animals can escape by a spiral ramp through an opening in the lid of the box. Animals are placed in this box, usually in late afternoon, and the traps are checked for captured animals the following morning. Animals are collected from the water, either upstream or downstream from the enclosure, and placed in the release box, and the traps are examined the next morning to see whether the newts have started back in the right or in the wrong direction.

To summarize the results as briefly as possible, we found that if the animals are taken from distances not exceeding about 700 yards, then a very great majority, consistently 80 to 95 percent, orient their movements in the right direction. When they are taken from greater distances, their initial movements appear to be in random directions. We have tested this repeatedly and with large numbers of animals.

To evaluate the homing series described above in terms of these results with the "star-trap," the implication is that animals displaced more than about half a mile from their home area are stimulated by the displacement to initiate a searching behavior that is at first lacking in orientation. However, once they are carried by these random movements within striking distance of the home territory, they pick up signals or landmarks that enable them to navigate the remainder of the distance with remarkable directness.

Nature of the Signals

The next question, of course, is: What is the nature of the signals or landmarks, and what are the senses employed in their recognition?

One thinks first of all, perhaps, of the visual recognition of familiar landmarks or topographical features, since vision is so important in the homing behavior of certain other animals.

For reasons I shall not go into it is not simple to test this critically by the star-trap method, but we have tested it in another, perhaps even more direct and convincing, way.

We again collected a series of animals from the extreme upper end of the experimental stretch and displaced them to station 20. In this case, however, before they were displaced they were completely and permanently blinded by the

Fig. 6. A star-shaped enclosure, with an escape-proof trap at the tip of each arm, designed to test the ability of newts to orient their movements after transfer to the enclosure from other locations. The enclosure is situated near the breeding stream (the black line is parallel to the stream, and the arrow indicates the direction of stream flow), and animals to be tested are collected from upstream or downstream locations and placed in the release box in the center of the enclosure.

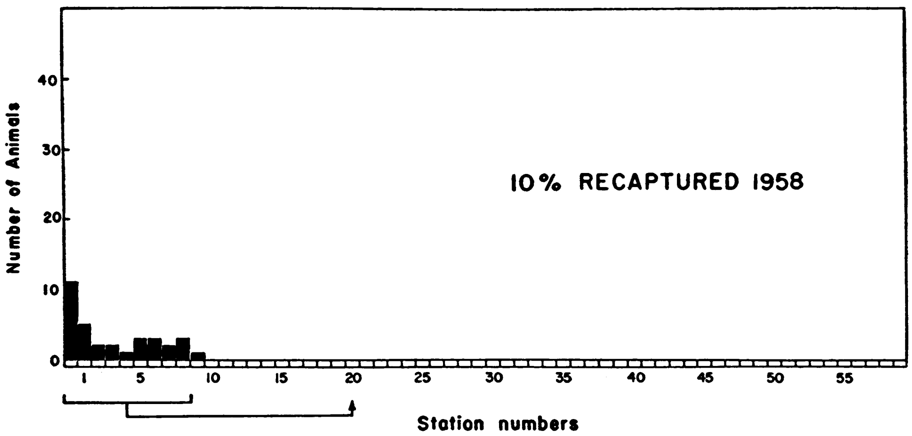


Fig. 7. Graph showing the return of newts to the home segment of the stream a year after they had been blinded by the removal of both eyes and displaced to a point about half a mile downstream.

surgical removal of both eyes. Figure 7 shows the recaptures a year later. Without exception all were back in the segment of the stream from which they had been taken. We were not too confident that these blinded animals would even survive, and when we found that their homing behavior was unimpaired we were admittedly surprised and impressed. Only 10 percent of the animals were recaptured, but this is as high—in fact a bit higher—than the first-year recaptures with the comparable series of normal or sighted animals described above. At the very least, this series shows that recognition of the home territory, once the animals relocate it, is certainly not accomplished through any visual associations that they have developed.

Another possibility that we have considered is that the animals orient their movements and identify the home segment of stream, or its bordering terrain, through kinesthetic memory—if there is such an expression. Any one of *us*, very conceivably, if we tramped repeatedly over an area of irregular terrain, might come to memorize its topographical features or pattern so completely that we could subsequently recognize any given spot within the area and orient our route accordingly in any chosen direction—even if we were blinded. Likewise the newts: During the rainy months preceding the breeding season they forage actively on the forest floor, and over the years they very possibly encompass and come to memorize the topographical pattern of a fairly large area of terrain extending upstream and downstream from the more restricted point where they eventually enter the water to breed.

We have tested this possibility, or have tried to test it, in the way described below, and the results indicate that, just as vision is not the means by which migration is oriented, neither is kinesthetic sense.

First of all, we simply covered the

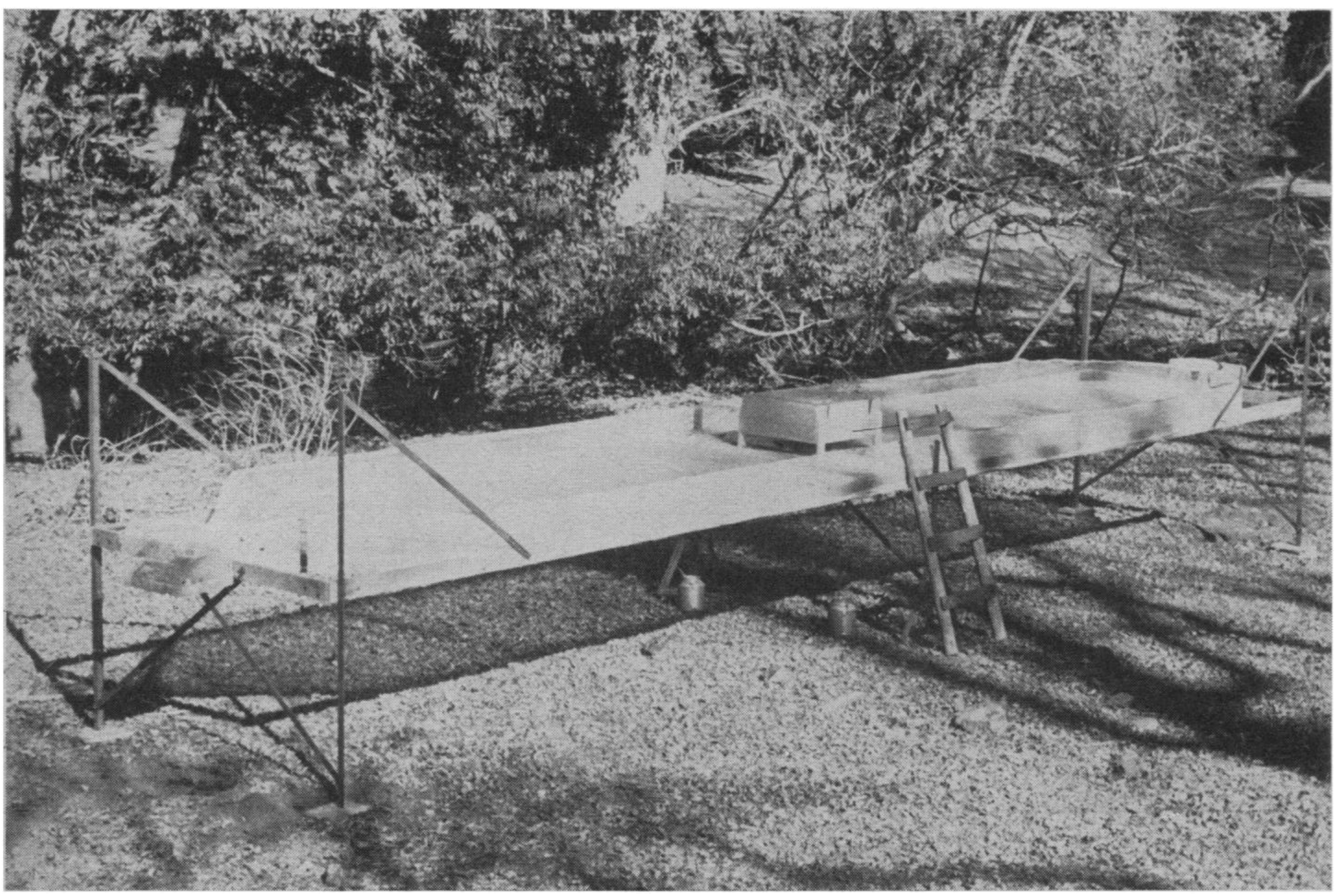


Fig. 8. A platform that may be adjusted to different heights and degrees of inclination, designed to test the ability of newts to orient their movements when crawling on an unfamiliar and artificial terrain.

floor of the star-trap with a carpeting that would erase or conceal any of the natural irregularities of the terrain within the test enclosure. For this we used a plastic sheeting, known commercially as "Visqueen." However, animals tested under these conditions oriented their movements just as well, or seemingly as well, as when the floor of the enclosure was left in its natural state.

A somewhat fancier test and one that permits more refined analysis was performed by construction of a large platform (30 by 6 feet) that could be adjusted at different heights above the ground and could be tilted at different angles. A release box was placed at its center and a trap at each end (Fig. 8). The platform was installed near the creek, with its long axis parallel to the stream. Near the end of the past breeding season it was placed in operation in a sharply tilted position, with the downstream end elevated about five feet above the opposite or upstream end. Mixed groups of animals, half of them collected from downstream locations and half from upstream, were placed in the release box. In spite of the tilt, which presents an entirely new and foreign "topography" to the animals, the two groups sorted themselves out with very few errors, each moving in the direction of the home segment of stream. It seems clear from these tests that the animals do not "feel their way home" through recognition of familiar features of the immediate terrain in areas to which they have been displaced.

What are the possibilities that remain? I think that hearing can be discounted, and this leaves principally olfaction or related chemical senses. Do these animals smell their way home, and when they get there, does home—to them—mean a familiar and distinctive set of odors peculiar to the soil and vegetation along the streamside at that particular point? In animals as earth-bound as salamanders, living throughout their terrestrial phase in such intimate association with humid soil and all its products, I suppose it is not unlikely that the chemistry of their environment looms larger in their experience than do impressions of sight and sound. We do know that these newts have a remarkable sense of smell, or of chemical detection. It is by means of scent that the males detect the presence and location of females when the females enter the stream for breeding. A female, or even a sponge soaked in water in which females have been stored, dipped briefly in the water will excite and attract males situated many yards down-current.

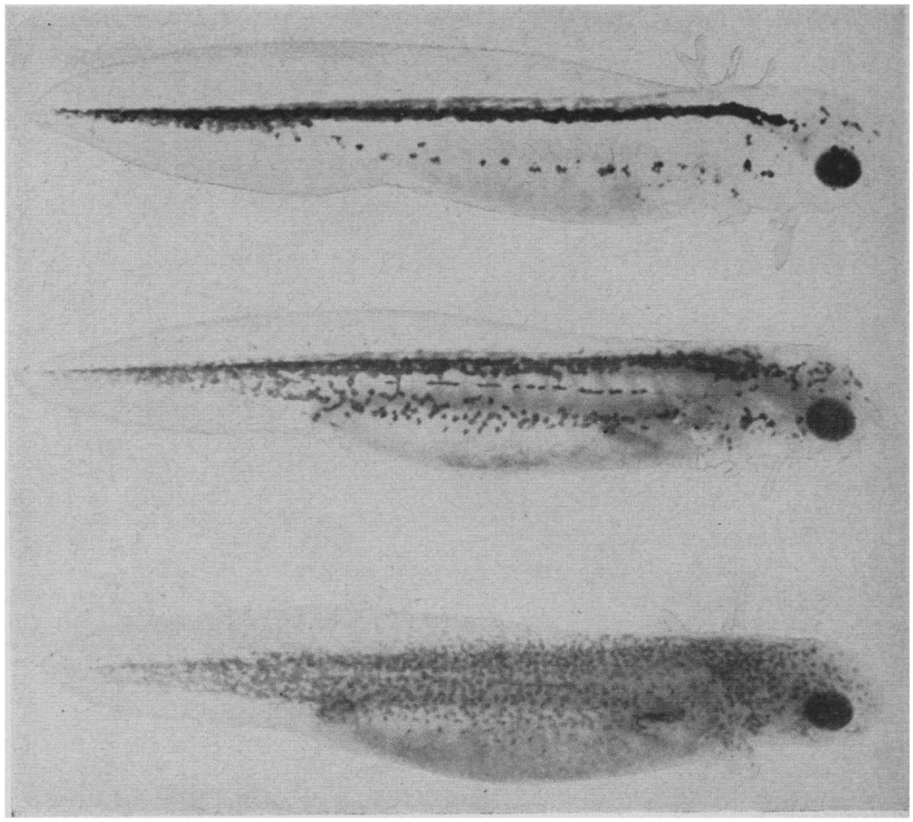


Fig. 9. Hybridization of *Taricha torosa* and *T. rivularis*. Young larva of (top) *torosa*; (bottom) *rivularis*; (middle) *rivularis* ♀ × *torosa* ♂ hybrid.

When we plug the nasal passages with Vaseline, as can be very effectively done by injecting barely melted Vaseline into the nares, and test the animals in the star-trap, orientation does seem to disappear or at least be greatly reduced. In fact, most of the animals fail to migrate at all and remain in the release box. However, the effects of a badly stuffed-up nose may prove to be merely traumatic or disturbing in nature and not due to the loss of the sense of smell as such.

So next year we plan to concentrate on a rather elaborate study of the possible role of odor, and I hope we shall be able to settle the matter. As I have told the chaplain at Stanford, if it proves not to be a question of odor, then the whole problem really lies more in his realm than in mine, and I will gladly assign it to one of his theology majors.

The Home Area

But whatever the sensory mechanism (or mechanisms) proves to be, I think the most interesting thing about the whole business is the simple biological fact that identification with the home area seems to mean so much to the salamanders. To them there is clearly "no place like home."

There are, of course, certain well-recognized advantages or consequences of spatial localization within animal populations. It tends to stabilize and equalize distribution of the members of a population, and accordingly to reduce competition. It assures the selection of suitable—that is, already tested—spawning sites and hence minimizes gametic wastage such as would occur if eggs were laid in portions of streams that go underground during the summer before the tadpoles could metamorphose. Since it reduces the effective size of breeding populations, it also minimizes the swamping of mutant genes that may arise, and thereby facilitates genetic differentiation or speciation.

It must also carry its penalties, however, since, as we have seen, animals are reluctant to enter an unfamiliar segment of stream—even though it may be completely suitable for breeding. This means, in effect, that accidental displacement can be tantamount to reproductive death, if the animals are unable to relocate—or are in any way prevented from relocating—the home area.

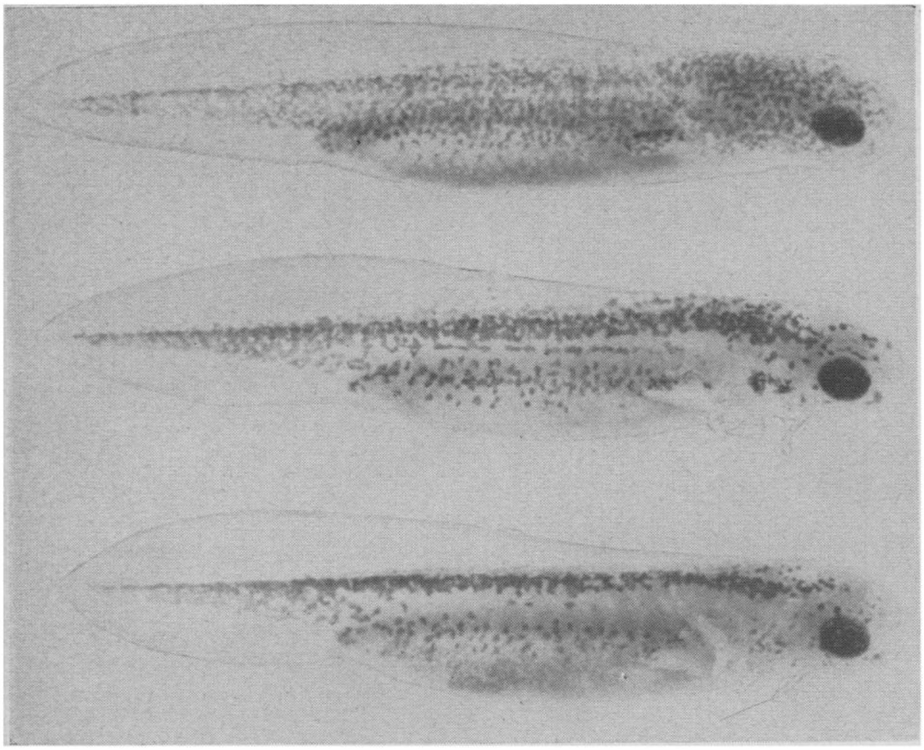


Fig. 10. Members of a backcross series (eggs of *rivularis* fertilized by sperm of a male *rivularis* ♀ × *torosa* ♂ hybrid) selected to show the F_2 segregation of pigmentary characteristics. (Top) *Rivularis*-type pigment pattern; (bottom) hybrid-type pattern; (middle) pattern intermediate to the other two.

But in any case, good or bad, it is a refinement of behavior that somehow I never expected to find so highly developed in animals that, until now, I must confess, I had always considered to be among the least discerning of vertebrates. In any event, I shall never again think of salamanders as mere egg-laying machines, created for the special benefit of the experimental embryologist.

Genetic Testing Ground

And now to turn briefly to another phase of the program. As I indicated above, in its inception the project at the ranch was designed to throw some light on the genetics and speciation of California newts, not on their ethology.

When one becomes involved in the systematics of a genus there are certain important questions that inevitably arise. Do or can the species form viable and fertile hybrids? If so, why do sympatric pairs of species preserve their separate identities—that is, what are the isolating mechanisms that prevent interbreeding? In the case of species that are *not* sympatric, would they, if it were not for their geographical isolation, prove capable of interbreeding successfully—and if so, what would the ultimate consequences be?

To test these and related questions we have attempted to convert the experimental stream at the ranch into a sort of genetic testing ground, or genetic melting pot. Since 1953 we have produced by artificial hybridization, and introduced into the experimental stretch as young tadpoles, some 200,000 hybrids of three different interspecific combinations. In addition, we have introduced tadpoles of the species that are not native to that part of the state. In other words, as I am sure some systematists will feel, we are really messing up nature rather badly in poor little Pepperwood Creek.

As I said earlier, it is too soon to know what the ultimate genetic consequences may be, if any. In order to have completed the program myself, I should have initiated it many years earlier. But we are beginning to learn a few things, and I shall run through some of them very briefly.

We have recaptured only a few mature hybrids as yet, but enough to know that they *can* survive and return to the breeding stream as adults.

Moreover, we have shown that the hybrids of the California species of newts are fertile—in both sexes. With the hybrids recaptured in nature, and others reared to maturity simultaneously in the laboratory, we have tested fertility by backcrossing the hybrids to the parental species by artificial fertilization. We have tested several interspecific combinations, and all have proved fertile, although we shall need to accumulate more data before it can be determined whether there is possibly some reduction in fertility.

This shows that hybrid inviability or infertility are not the reproductive barriers that isolate pairs of newt species that occur together in California. In the case of such species, that breed in the same bodies of water at the same season of the year, we believe that the barriers to interbreeding have instead a behavioral or psychological basis, and through a detailed study of courtship patterns (see cover picture) in the different species we are attempting to determine the nature of these ethological blocks to successful interspecific mating.

Thus far we have been unable to induce either sympatric or allopatric pairs of species to interbreed voluntarily, either in the laboratory or when confined together in escape-proof enclosures constructed in the stream itself. There is some indication, however, that these behavioral barriers to interbreeding disappear with hybridization. In the one case tested, when an adult hybrid male was placed in a mating enclosure with a female of the maternal species, successful mating and ovulation ensued. This suggests the possibility that if we can establish sizable populations of hybrids in the experimental area, introgression and consequent modification of the native population may occur.

The species of California newts have striking differences in larval pigment pattern, as I mentioned above, and when the hybrids of these species are backcrossed to the parental species, the offspring show a clear genetic segregation in their pigmentary characteristics.

Figure 9 (top) shows a young larva of *torosa* with its sharp pigment band, and (bottom) a larva of *rivularis* with its uniformly dispersed pigmentation. Between the two is a hybrid of the two species, and as one can see, it is roughly intermediate in its pigment pattern.

If we backcross an adult of the hybrid to one of the parent species the offspring show a spectrum of pigment patterns ranging between those characteristic of the hybrid and those characteristic of the backcross parent. Figure 10 shows three such backcross offspring, one with a hybrid-type pattern, one with a *rivularis*-type pattern, and a third with an intermediate pattern. Other characters, such as the presence and size of the balancer and the size of the dorsal fin, also segregate in the backcrosses, and they segregate independently of one another and of pigment pattern. The ratios of segregation indicate that the numbers of genes that differentiate the species with respect to these characters are not very large.

There is not space to deal with the corresponding results of backcrosses involving other species combinations.

These are elementary genetic experiments, but since they involve my California newts, and since I have been for years uncertain of the feasibility of making any type of genetic analysis at all with these animals, the results are of special interest to me personally.

Conclusion

In presenting this account I am well aware that developmental biologists will possibly react with the feeling, "there goes another embryologist down the drain," and animal behaviorists will point with gratification, on the other hand, to the evidence that here is an embryologist who has finally seen the true light—even though he sees it dimly and is still an amateur. In any case, the reader in whose mind problems of speciation are uppermost, especially during this much celebrated Darwin Centennial year, can consider himself fortunate that he is not using experimental animals that yield genetic information as slowly as do California newts.

Notes

1. I wish to thank Mr. and Mrs. T. L. Hedgpeth and more recent owners of the ranch, particularly Mr. and Mrs. Stanley Richardson, Jr., for the facilities and courtesies they have generously extended to me. The project has been supported in part by grants from the National Science Foundation.
2. The genus was formerly designated *Triturus*.

Analysis of References in Critical Tables

National origin of physicochemical data is determined from literature citations in two research projects.

Bruno J. Zwolinski and Frederick D. Rossini

In recent years, particularly in the past decade, the advances and activities in the political, economic, and scientific areas of human endeavor have been examined from several points of view, in an attempt to delineate progress, major trends and their causes and interactions, and interrelationships with respect to future prospects and predictions in these areas, on both a national and an international level. In every analysis we are confronted with perennial questions as to the authenticity of the information or facts analyzed and their interpretation. Recently a thought-provoking article by Crane and Heumann was published entitled "*Chemical Abstracts* measures a nation's research" (*1*). Their thesis is that, since *Chemical Abstracts* has been working for over 50 years to cover the world's chemical literature as completely as possible, and since chemistry is a fundamental science closely integrated with a number of areas in the general field of physical, engineering, and biological sciences, the number of articles published in a particular country and abstracted in *Chemical Abstracts* should be a relative measure of national scientific activity.

As was to have been expected, the timely article by Crane and Heumann and the statistics which they gave elicited responses from readers which were both laudatory and critical in nature, particularly with respect to the total scientific activity—past, present, and future—of the United States and the U.S.S.R. In his brief comments on the letters received regarding the implications of the scientific information given in his article, Crane (*2*) pointed out specifically that the *Chemical Abstracts* statistics do not measure quality. He also doubted the availability of an effective measure of quality that would have general applicability.

A few months prior to the appearance of the article by Crane and Heumann, an independent study was undertaken in the Chemical and Petroleum Research Laboratory of the Carnegie Institute of Technology on the problem of national scientific activity and contributions. In this study the references by country of origin in the "General list of references" in the critical tables of the American Petroleum Institute Research Project 44 on "Data on Hydrocarbons and Related Compounds" and in the critical tables of the Manufacturing Chemists Association Research Project on "Properties of Chemical Compounds" were subjected to analysis.

Continuing Critical Tables

A few brief comments on the history of these two projects and on the nature of the selected values of physicochemical data with which they are concerned may be in order. Both of these projects on the compilation of continuing critical tables of basic scientific data are research projects of the chemical and petroleum research laboratory of the department of chemistry at the Carnegie Institute of Technology. The American Petroleum Institute Research Project 44 began work in September 1942, at the National Bureau of Standards, under the direction of Frederick D. Rossini. In June 1950 this project was moved to the Carnegie Institute of Technology. The purpose of the project is to compile and keep up to date a complete and self-consistent set of tables of critically se-

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