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37

5

Effects of Introduced Bullfrogs, *Rana catesbeiana*, on the Native Frogs of the San Joaquin Valley, California

Peter B. Moyle

Rana catesbeiana was introduced into California between 1914 and 1920 and has since spread throughout the state. In the San Joaquin Valley it has become the dominant frog on the valley floor and has spread into the Sierra Nevada foothills. It is most abundant in the warm low elevation pools of the foothill streams, in areas heavily altered by man, although at least two populations are established above 1600 m elevation. Of the two frog species native to this region, *R. aurora* is either absent or very rare at the present time, while *R. boylii* is found mostly in small permanent foothill streams higher than 200 m elevation, in areas not occupied by *R. catesbeiana*. The disappearance of *R. aurora* from the region, and the continuing reduction in range of *R. boylii*, is attributed to habitat alteration coupled with predation and competition from *R. catesbeiana*.

The bullfrog (*Rana catesbeiana* Shaw), native to the United States east of the Great Plains, was introduced into California several times between 1914 and 1920 (Storer, 1922). After the initial introduction, it was spread rapidly throughout the state by well-meaning naturalists and farmers (Storer, 1925).

Unfortunately, in the San Joaquin Valley and the Sierra Nevada foothills, one of the main by-products of the introduction of the bullfrog seems to have been the elimination of the red-legged frog (*Rana aurora* Baird and Girard) from the valley floor and foothill ponds and the reduction of populations of the foothill yellow-legged frog (*R. boylii* Baird) in the foothill streams. This paper shows how the distributions of *R. catesbeiana* and *R. boylii* have become nearly mutually exclusive in the Sierra Nevada foothills and attempts to document the disappearance of *R. aurora* from the San Joaquin Valley, concomitant with the spread of the *R. catesbeiana*.

Methods

Between 27 July and 4 September 1970, the distribution and ecology of the fishes occurring in the streams of the Sierra Nevada foothills below elevations of 1100 m were studied (Moyle and Nichols, in preparation). At each locality where fish were collected, a rough estimate was also made of abundance of each frog species present, on a 0–3 scale. On this scale, '0' indicated no frogs present, *1*, only one or two individuals observed in sample area, *2*, frogs present in low numbers, (usually, less than 12 observed), and *3*, frogs abundant. The frog abundance was thus rated for most of the streams accessible by road in Tulare, Fresno, Madera, Mariposa, and Tuolumne counties, California. Frogs were found at 95 of the 130 stream localities. During the study period the streams were at their minimum flow. Over half of them were not flowing at all, and water was present only in isolated pools.

At each sampling site estimates and measurements were made of environmental factors that were likely to affect the distribution of the fishes, as discussed in detail in Moyle and Nichols (in preparation). The following were measured: 1) Elevation, in meters. 2) Air and water temperature. Since air temperatures fluctuate 11–17 C. during the day and water temperatures fluctuated with air temperatures, the data analysis was based on the differences between the air and water temperatures. The data differences were coded: *1*, a difference of 0–2.4 C.; *2*, 2.4–4.7 C.; *3*, 4.7–7.1 C.; *4*, 7.1–9.4 C.; *5*, 9.4–11.8 C. 3) Mean depth of water, in meters. 4) Average width of water surface in meters. 5) Water flow in cubic meters per second. 6) Water turbidity rated on a 0–5 scale, where *0* is extremely clear and *5* is extremely turbid. 7) Percentage of the bottom covered with rooted aquatic plants. 8) Percentage of the water surface covered with floating mats of algae, water fern (*Azolla* spp.), or duckweed (*Lemna* spp.). 9) Percentage of sampling area made up of pools. 10) The percentage of the sampling area made of riffles. 11) Percentage of stream bottom composed of silt. 12) Percentage of bottom composed of sand (defined as rock particles less than 2 mm in diameter). 13) Percentage of the bottom composed of gravel (defined as pieces of rock mostly 2–75 mm in diameter). 14) Percentage of bottom covered with cobbles, mostly 75–300 mm in diameter. 15) Percentage of bottom covered with bedrock or boulders larger than 300 mm in diameter. 16) Percentage of the water surface that was apparently shaded most of the day. 17) The extent to which human activities had visibly altered the stream channel and water quality as rated on a 0–5 scale, where *0* indicates no apparent alterations and *5* indicates that both the channel and water had been markedly altered. 18) Stream type, rated as follows: *1*, small, with intermittent flow; *2*, medium sized, with intermittent flow; *3*, large, with intermittent flow; *4*, small (0.1–1.5 cms) with permanent flow; *5*, medium (1.5–3.0 cms); and *6*, large (3.0 + cms) with permanent flow. Each stream was classified by observing the flow at the time of sampling and by information from hydrological maps.

note: Mar 4 1994 - Moyle says that much in this paper is wrong
was corrected in papers by some of his students

373

check Jennings & Hayes 1985 Hayes & Jennings 1986

For each of the 95 localities, the following information was placed on punch cards: 1) Data from the foregoing 18 environmental variables. 2) The abundance rating for each frog species. 3) The abundance rating, on a 1–5 scale, of all fish present.

All 95 cards were then run through a computer programmed to obtain a Pearson correlation matrix for the 21 variables, as well as the means and standard deviations of the variables. The matrix is not reproduced in this paper but copies are available from the author.

Results

Rana catesbeiana.—In the Sierra Nevada foothills, bullfrogs were the most frequently encountered frog species, occurring at 72 percent of the 95 sampling sites where frogs were found. They were found most often (81 percent of samples) along intermittent streams. Only 60 percent of the 95 localities were along such streams. *R. catesbeiana* were most abundant at the lower elevation localities, in shallow, unshaded pools, where water temperatures approached that of the air, 30–35 C. (Table 1). The pools tended to have sand or gravel bottoms and heavy growths of rooted and floating aquatic vegetation (Table 1). The areas in which bullfrogs were most abundant were usually heavily altered by human-related activity, such as cattle-trampled banks, sediment deposition from erosion of roads and construction sites, and small impoundments. The water in these areas tended to be dominated by introduced fish species that thrive in a man-altered environment, such as the green sunfish (*Lepomis cyanellus*) and the mosquitofish (*Gambusia affinis*).

Although no formal surveys were made of other habitats, the bullfrog is the only frog I have encountered in numerous visits to foothill farm ponds and to the sloughs and irrigation ditches of the valley floor.

The exact date when *R. catesbeiana* was introduced into the San Joaquin Valley has not been recorded but it apparently was well established by 1930. A local rancher (W. Ball, personal communication) has told me that bullfrogs were collected from the Kings River, Fresno County, and carried about 60 km to be planted in the San Joaquin River at his ranch near Friant, Fresno County, about 1929. Bullfrogs were introduced into ponds at the San Joaquin Experimental Range in the foothills of Madera County in 1934 (Cohen and Howard, 1958).

R. catesbeiana has adapted to a wide variety of environmental conditions in the region. At the San Joaquin Experimental Range, bullfrogs can go from eggs to metamorphosis in six or seven months enabling them to survive the drying up of the ponds (Cohen and Howard, 1958). Metamorphosis usually takes about two years (Wright and Wright, 1949). Bullfrogs have also adapted to cold conditions at higher altitudes. Populations have become established on the floor of Yosemite Valley, Yosemite National Park, at 1240 m (Karlstrom, 1962; G. Kottcamp, personal communication) at Shaver Lake, Fresno County, 1600 m (J. Canaday, personal communication), and at Hume Lake, Fresno County, 1925 m (H. Basey, personal communication).

Rana boylii.—This species was encountered most frequently (62 percent of samples) along small permanent streams even though only 40 percent of the 95 localities were on such streams. It occurred along intermittent streams only in the absence of the bullfrog.

LE 1. MEANS OF ENVIRONMENTAL VARIABLES ASSOCIATED WITH THE OCCURRENCE OF *Rana boylii* AND *Rana catesbeiana* IN STREAMS OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA.

ble	*Rana boylii* (N = 30)		*Rana catesbeiana* (N = 68)		All localities (N = 95)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
frog abundance	1.7	1.7	0.7	> 0.1	0.6	0.8
lfrog abundance	0.2*	> 0.1	2.0	0.2	1.4	1.1
vation (M)	556	102	342	42	399	243
np. (1–5)	3.6**	0.7	3.0*	0.4	3.1	1.0
depth (M)	0.4	0.1	0.4	0.1	0.4	0.2
dth (M)	1.9	0.3	3.3**	0.4	2.9	0.3
w (cms)	0.7	0.1	0.6	0.1	0.6	0.2
rbidity	1.5*	0.3	2.3**	0.3	2.1	1.0
oted veg. (%)	15*	3	33**	0.4	28	0.3
ating veg. (%)	10	2	24**	3	20	0.2
ols (%)	39*	7	63**	8	56	33
fles (%)	49**	9	26*	3	32	30
ttom						
Silt (%)	10	2	12	2	11	19
Sand (%)	30	6	40	5	37	30
Gravel (%)	6	1	12**	1	10	17
Cobbles (%)	22	4	22	3	21	26
Boulders (%)	32**	6	15*	2	21	22
ade (%)	55**	10	36*	4	40	26
an mod. (1–5)	2.1*	0.4	2.8**	0.3	2.6	1.1
ream type (1–6)	3.1	0.6	2.3*	0.3	2.5	1.8
sh abund. (1–5)	2.3*	0.4	2.8**	0.3	2.7	1.0

* Negative correlation ($P > .05$) between abundance of the frog species and the variable, in the all locality correlation matrix ($N = 95$).

** Positive correlation, as above.

he areas where the foothill yellow-legged og was found tended to be well-shaded, with ear, relatively cool (20–25 C.) water, at igher elevations (Table 1). The stream bot-oms tended to be rocky, with little aquatic egetation (Table 1). Frogs were most bundant where the native fish associations Moyle and Nichols, in preparation) were till intact. Although *R. boylii* lives pri-narily along foothill streams (Zweifel, 1955), t occasionally occurs on the valley floor Livezey, 1962) and may once have been ommon there in some areas (A. Hawbecker, personal communication). I have never col-ected it below 200 m elevation. Wright and Wright (1949) recorded capturing *R. boylii* n 1942 along Sycamore Creek, Fresno County, an intermittent stream of the lower foothills, in an area now submerged by Pine Flat Reservoir. The stream above the reservoir now contains only *R. catesbeiana* although a few *R. boylii* were found far up a small tributary to the main stream.

Rana aurora.—No red-legged frogs were encountered during this study. Since they are apparently adapted for pond and stream pool life (Wright and Wright, 1949; Stebbins, 1954) there seems to be plenty of suitable habitat for them, both in the foothills and on the valley floor. These areas all contain large populations of *R. catesbeiana*. Records of *R. aurora* in the San Joaquin Valley and surrounding foothills are scanty. Storer (1925) found a few on the valley floor in Merced and Fresno counties. Wright and Wright (1949) record them as being present on the valley floor near Fresno in 1942. There are a few records from Yosemite National Park but none are less than twenty years old (W. R. Jones, personal communication). The only recent record is that of H. E. Basey (personal communication) who collected *R. aurora* in the foothills along Piney Creek, Mariposa, Tuolumne, and Stanislaus counties in March, 1972. This area, however, is now undergoing rapid development, associated

with the new Don Pedro Reservoir. It thus appears that *R. aurora* has disappeared entirely from the floor of the San Joaquin Valley, an observation first made by Stebbins (1966). It has also largely disappeared from the foothills, although a few isolated populations may still exist at higher altitudes.

CONCLUSIONS

The disappearance of the *R. aurora* from the valley and foothills, and the reduction in range of the *R. boylii*, seems to be the result of man-caused alterations of their habitats, coupled with the introduction of *R. catesbeiana*. Bullfrog introductions were probably the single most important factor in the elimination of the *R. aurora*, since Wright and Wright (1949) record *R. aurora* populations in irrigation ditches and in farm ponds. *R. catesbeiana* has ecological requirements similar to those of *R. aurora* but grows much larger and is known to prey on other frogs and tadpoles (Cohen and Howard, 1958; Frost, 1935). Although Zweifel (1955) records the two species cohabiting waters elsewhere, *R. aurora* was probably eliminated from the valley and foothills by *R. catesbeiana* through a combination of predation and competition. *R. catesbeiana* has similarly been held partially responsible for the elimination of the Vegas Valley frog, *R. pipiens fisheri* (Committee on Rare and Endangered Wildlife Species, 1966).

The situation with *R. boylii* is more complicated, since it is not usually found in the same type of habitat as *R. catesbeiana*. However, the fact that two species were found together in only three of the 95 foothill stream localities, coupled with evidence that *R. catesbeiana* now occupies areas that once contained *R. boylii*, indicates that some sort of interaction between the two species has and is taking place. The alteration of the foothill streams by man has undoubtedly increased the amount of suitable bullfrog habitat, since they seem to be most abundant in pools behind small dams and in warm stream pools that have been largely denuded of their surrounding protective cover of trees and bushes. In the three small permanent streams where the two species were found together *R. catesbeiana* dominated the pool areas, while *R. boylii* dominated the riffle areas. A few *R. catesbeiana*, including large ones (over 13 cm long), could also be found along the riffle areas. A 1971 study of the feeding habits of the two species in two of the streams where they were found together, Watts Creek and Big Creek, Fresno County, by S. Hayden (unpublished) indicated that both species are omnivorous, although *R. boylii* feeds more on flying insects and the bullfrog more on submerged organisms. No *R. boylii* were found in *R. catesbeiana* stomachs, but small pond turtles, *Clemmys marmorata*, were found in the stomach of one large bullfrog. Large captive bullfrogs, kept in an outdoor swimming pool, ate small *R. boylii* soon after the *R. boylii* were introduced. Thus, *R. catesbeiana* seems capable of both preying on and competing with *R. boylii* to the detriment of *R. boylii* populations. Predation and competition would be particularly important during very dry years, when even usually permanent streams cease to flow, forcing the two species together in the remaining pools.

If the present rapid rate of alteration of the foothill streams continues, *R. catesbeiana* will probably replace *R. boylii* throughout the Sierra Nevada foothills. If streams are preserved in their natural condition, it is possible that the two species will eventually segregate ecologically, as *R. aurora* and *R. boylii* presumably once did (Zwiefel, 1955). Efforts should be made, however, to eliminate *R. catesbeiana* from isolated areas where it is now in contact with *R. boylii*. Native frog populations would probably also benefit from less restrictive regulations governing the commercial and sport taking of *R. catesbeiana*. Management practices in California at the present time are increasingly limiting the take of *R. catesbeiana*, especially by commercial froggers (Treanor and Nicols, 1972). In addition, further introductions into the Sierra Nevada foothills of other frog species, particularly the leopard frog, *Rana pipiens*, should be prevented, in order to leave some vestiges of the original ecological situation for future scientists to study. Already, *R. pipiens* has become established on the floor of the San Joaquin Valley, in Tulare County (Stebbins, 1966).

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LITERATURE CITED

COHEN, N. W., AND W. E. HOWARD. 1958. Bullfrog food and growth at San Joaquin Experimental Range, California. Copeia 1958:223–225.

COMMITTEE ON RARE AND ENDANGERED WILDLIFE SPECIES. 1966. Rare and Endangered Wildlife of the United States. Bureau of Sport Fish., Wildl. Res. Pub. 34:RA-9.

FROST, S. W. 1935. The food of *Rana catesbeiana* Shaw. Copeia 1935:15–18.

KARLSTROM, E. L. 1962. The toad genus *Bufo* in the Sierra Nevada of California. Univ. Calif. Publ. Zool. 62:1–104.

LIVEZEY, R. L. 1962. Distribution of some California amphibians and reptiles. Herpetologica 18:279–281.

STEBBINS, R. C. 1954. Amphibians and Reptiles of Western North America. McGraw-Hill Book Co., N. Y.

———. 1966. A Field Guide to Western Reptiles and Amphibians. Houghton Mifflin Co., Boston.

STORER, T. I. 1922. The eastern bullfrog in California. Calif. Fish Game 8:219–224.

———. 1925. A Synopsis of the Amphibia of California. Univ. Calif. Press, Berkeley.

TREANOR, R. R., AND S. J. NICOLS. 1972. A preliminary study of the commercial and sporting utilization of the bullfrog, *R. catesbeiana* Shaw, in California. Calif. Dept. Fish Game. Inland Fish. Admin. Rpt. 72-4.

WRIGHT, A. H., AND A. A. WRIGHT. 1949. Handbook of frogs and toads of the United States and Canada. Comstock Publ. Ithaca, New York.

ZWEIFEL, R. C. 1955. Ecology, distribution, and systematics of frogs of the *Rana boylii* group. Univ. Calif. Publ. Zool. 54:207–292.

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Frequencies of Anomalies in a Bothid, *Paralichthys californicus*, and a Pleuronectid, *Hypsopsetta guttulata*, Flatfish

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Occurrence of abnormal coloration, hooking or cranial depression, optic decussation and liver side reversal are reported for *Paralichthys californicus* (Bothidae) and *Hypsopsetta guttulata* (Pleuronectidae). California halibut possessed anomaly frequencies of 1.6 to 20.8 per thousand while diamond turbot had approximately half this frequency (1.2 to 9.5 per thousand).

ANOMALIES in pigmentation and anatomy were found during studies on the California halibut, *Paralichthys californicus*, (Bothidae), and diamond turbot, *Hypsopsetta guttulata*, (Pleuronectidae), in Anaheim Bay, California. Only three anomalous California halibut have hitherto been described (Phillips, 1932; McKeever, 1958), and no anomalous diamond turbot have been reported. Between January 1970 and February 1971, 1256 *P. californicus* and 2504 *H. guttulata* were examined for external anomalies. Most were released, but those kept for further examination are deposited in the Los Angeles County Museum of Natural History.

A typical anomaly of flatfishes, ambicoloration, has been ranked by Norman (1934) as being total, almost total, or partial. Albinism as reported by Veen (1969) was never noted in either species involved here.

Parker (1903) found a monomorphic optic chiasma in both Bothidae and Pleuronectidae although most other fishes had dimorphic chiasma. Bothids have a decussation with the left optic nerve (to the right eye) crossing over the right optic nerve, while pleuronectids have the opposite condition, with the right optic nerve crossing over the left. We found exceptions to this in *P. californicus* and *H. guttulata*.

Cunningham and MacMunn (1894), Cunningham (1907), Norman (1934), and Hubbs and Hubbs (1944) found that the liver is characteristically on the left side of the intestine in all teleosts. In *P. californicus* we found exceptions to this condition.

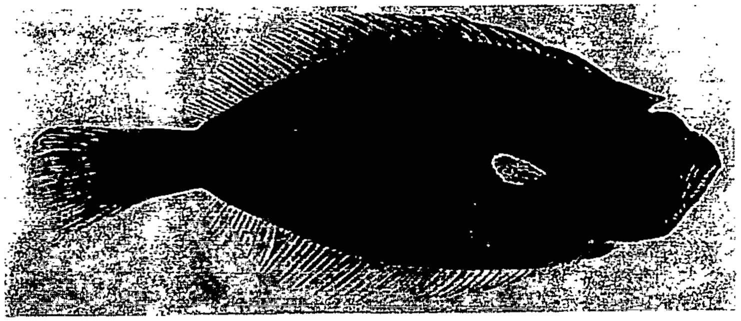

Fig. 1. Totally ambicolored *Paralichthys californicus*. LACM #9371-6. Note dorsal hook and position of eye. Eyed side normally pigmented.

PARALICHTHYS CALIFORNICUS

In the California halibut, total ambicoloration (Fig. 1) and almost total ambicoloration was found (Table 1).

Extreme ambicoloration was always associated with head anomalies, namely, abnormal position of the migrating eye and the formation of the anterior dorsal fin into a fleshy hook (Fig. 1). Migration of the eye in totally ambicolored individuals ended on the dorsal crest, under the fleshy hook, and in almost totally ambicolored individuals the eye migrated over the dorsal crest, but did not reach the normal position.

Partial ambicoloration of California halibut occurred in various patterns, some of which were repetitious. Partially ambicolored individuals did not have head anomalies.

In *P. californicus* ctenoid scales were invariably associated with pigmented areas and cycloid scales with non-pigmented areas, this held true on anomalous fish, thus they had ctenoid scales on the pigmented portions of the blind side.

Two normally pigmented individuals had the anterior dorsal fin formed into a fleshy hook. The migrating eye was positioned similarly to that of the almost totally ambicolored individuals.

Reversals of the normal condition existed in the optic decussation and in the liver (Table 1).

HYPSOPSETTA GUTTULATA

Ambicoloration in diamond turbot was total, almost total, and partial (Fig. 2 and 3, Table 1). Extreme ambicoloration was associated with dorsal head anomalies. Rather than a fleshy hook, as in the California halibut, a depression was formed in the frontal region (Fig. 2).

Partial ambicoloration occurred in various patterns, some of which were repetitious. Blotching and irregular pigmentation of the blind side was noted, but usually this was associated with scar tissue or puncture injuries of tagging.

TABLE 1. FREQUENCY OF OCCURRENCE OF ANOMALIES (EXPRESSED AS ANOMALITIES PER 1000 FISH) AND SINISTRAL:DEXTRAL RATIOS IN *P. californicus* AND *H. guttulata*. Numbers in parentheses indicate sample size.

Anomaly	*P. californicus*	*H. guttulata*
Total ambicoloration	3.2 (1256)	1.2 (2504)
Almost total ambicoloration	1.6 (1256)	1.2 (2504)
Partial ambicoloration	10.8 (1256)	5.6 (2504)
Dorsal head anomalies	6.4 (1256)	3.2 (2504)
Optic reversal	20.8 (144)	9.5 (105)
Liver reversal	19.2 (417)	0.0 (550)
Ratio sinistral:dextral	1.85:1 (1256)	All dextral (2504)