SOME ECOLOGICAL NOTES ON THE BLUE COLOR PHASE OF THE CRAYFISH, *ORCONECTES VIRILIS*, IN TWO LAKES[1]

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ABSTRACT

Ecological data on growth, population density and mortality were collected and analyzed for blue color phase variants of the crayfish populations in North Twin and South Twin Lake, Otsego County, Michigan. Crayfish were collected with baited minnow traps, growth was determined by size frequency analysis of the total catch, and mortality analyzed by use of sequential mark and recapture population estimates. The results suggest that growth is density dependent, survival between blue and normally brown color phases is not different and that the percentage of blue color phase variants in these populations does not exceed one percent of the total population. The lack of difference in mortality rates between the olive brown and blue color phases and the lack of blue crayfish in the stomachs of the fish in these lakes does not support the thesis of selective mortality on the conspicuous blue color phase.

INTRODUCTION

The earliest reference to blue color-variants of crayfish is that of Lereboullet (1851). There are several reports of blue-color variants of North American crayfish. These variants have been reported for *Cambarus carolinus dubius* Faxon by Newcombe (1929); for *Procambarus clarkii* (Girard) from Louisiana by Penn (1950); for *Cambarus bartonii bartonii*, *C. longulus longulus*, and several species of *Procambarus* reported by Horton H. Hobbs, Jr., cited by Hand (1954); and for *Pacifasticus* sp. reported by Hand (1954). In addition, *Cambarus monongalensis* Ortmann (Ortmann 1906), *Procambarus hagenianus* (Faxon), and two undescribed species of the genus *Cambarus* are typically blue in color (H. H. Hobbs, Jr., cited by Hand, 1954). Smiley and Miller (1971) describe a blue variant for *Procambarus a. acutus*. Hobbs (cited by Hand, 1954) also indicated that local populations of *Cambarus carolinus* Erickson and *P. advena* (LeConte) may have a blue phase. In the genus *Orconectes*, *O. immunis* (Hagen) (Kent, 1901) and *O. virilis* (Hagen) (Loeb 1967) have blue color-variants. Also Dowell and Winier (1969) report a bilateral color anomaly in *O. immunis*, with the right half azure blue and the left normal.

Kent (1901) suggested that, in *Orconectes immunis*, color might be a function of the environment, i.e. background coloration, and mentions green, red, black, and blue color-phases for this species. We are not certain what Kent meant by black and red colors. During the past several years more than a quarter million living specimens of *O. virilis* with most of the color phases described by Kent have been seen by Momot in the populations of North Twin, South Twin, and West Lost Lakes, Otsego County, Michigan. Very-dark-green specimens could be the black phase described by Kent (1901). Many newly molted crayfish are pinkish-red in color, though some pinkish-red specimens are occasionally seen. The blue color-phases range from a very pale blue to a very vivid azure blue. We observed blue young-of-the-year *O. virilis* in aquaria to be very pale blue in color, with the blue color intensifying as they aged; blue crayfish were kept for a period of one year. Intergrades of pinkish-blue and greenish-blue colors have also been seen. Background coloration might possibly play some role in intensifying some colors, but most of the literature on crayfish explains the color of crayfish as being due to genetic causes, or as a result of diet, or possibly both.

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The pigment responsible for coloration in crustaceans is a carotenoid called astaxanthin (Fox, 1953; Goodwin, 1960). Astaxanthin appears red if unconjugated with a protein, and green, blue, purple and other colors if conjugated with protein. The blue pigment in crayfish is a cartenoid protein complex. Any denaturing of the protein releases the carotenoid, which reverts to a red color. This probably explains some of Kent's (1901) observations that sunlight caused a red color-change in crayfish pigment. Further, Wolfe and Cornwell (1964) showed that the red color in crayfish, due to the carotenoid pigment, is caused by diet rather than by the presence of light. With any breakdown of the masking pigment, the carotenoid pigment becomes evident. D. L. Fox (cited by Dowell and Winier, 1969) believes that color is governed by the kind, amount, or binding character of the protein molecules, which bind the astaxanthin rather than the astaxanthin itself. When normally colored *O. virilis* die, they turn a vivid red color as the protein denatures and the astaxanthin becomes evident. However, when blue *O. virilis* kept in aquaria died, they remained a blue color, indicating that astaxanthin may not be present. The blue color-variant of *O. virilis* may be due to a recessive gene, possibly a form of albinism. At least it seems that astaxanthin is not biochemically deposited. Perhaps it is a gene or a deletion of a gene which then blocks the formation of astaxanthin from dietary carotenoids. The fact that both various shades of blue and intergrades—brownish blue, pinkish-blue—are seen suggests that possibly there is a gene or series of genes of low penetrance. The bilateral color anomaly (blue and normal color) of *O. immunis* certainly further suggests that the blue coloration is a genetic rather than environmental effect. However, it is not a case of gynandromorphism, since the animal was a complete female (Dowell and Winier, 1969). Obviously the solution to the problem of coloration in crayfish will not begin to be solved until the behavioral characteristics of genes controlling the phenotypic variation in pigment formation in crayfish can be followed in the laboratory.

It is rather interesting that, of the three lakes from which we have seen tens of thousands of specimens, the blue phenotype is known only in North and South Twin Lakes. None have ever been observed in West Lost Lake. These lakes were treated with the insecticide Rotenone in the 1930's to remove existing fish prior to their management as trout-only lakes for "put-and-take" fishing with hatchery fish. Since they are typical "pothole" lakes, with no inlets or outlets, the crayfish had to be introduced by anglers, since Rotenone is even more toxic to arthropods than to fish. Dr. Thomas Waters (Univ. of Minn.) was a resident biologist at the Pigeon River Area Trout Research Station, which is near these lakes, and stated that he spoke to a fisherman who claims to have seen crayfish brought by an angler from one of the Twin Lakes and placed in the other. Quite possibly intensive interbreeding of a very small brood stock containing a gene for the blue phenotype is the reason why the blue phenotype is found in some of these lakes with the regularity reported here.

During the springs and summers of 1968 and 1969, catch records were kept on the occurrence of this blue phase in North Twin and South Twin Lakes. After completion of the study and computation of the data involving all of the crayfish, a study of the population dynamics of the blue crayfish was made. This provided interesting data for comparison with the total crayfish population, the other crayfish being predominately olive-brown colored. The blue color-phase was suspected to be more vulnerable to predation than the normal, olive-brown phase, since it could easily be seen as it moved about the lake bottom.

The objective of this study was to decide whether the population dynamics of the blue phase of *Orconectes virilis* as a consumer in the two marl lakes differed in any respect from that of the total crayfish population. This required detailed knowledge of the density, growth, and mortality of the blue-crayfish population.

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LOCATION OF STUDY AREA

Data on blue crayfish were collected from North Twin and South Twin Lakes in Otsego County, Michigan, from late June to early July (considered to be spring) and again from late July to mid-August (summer) of 1968 and 1969. These lakes are in the Pigeon River Trout Research Area, which is under the administration of the Research and Development Division of the Michigan Department of Natural Resources. These small lakes are believed to have originated as limestone sinks. Thick encrustations of marl are present throughout the lakes (Momot, 1967). The limnological features of the two lakes are presented in Table 1 (Tanner, 1960). These lakes are considered to be low in productivity and lack submerged aquatic vegetation.

TABLE 1

Physical and chemical characteristics of the study lakes

Characteristics	South Twin Lake	North Twin Lake
Surface area (acres)	3.9	4.7
Depth (ft.)		
Maximum	34	44
Average	24	28
Bottom soil type		
Shoal	sand	sand
Sublittoral	peat	peat
Profundal	peat	peat
Methyl orange alkalinity	74	32
Secchi disk reading (in ft)	12.7	15.1
Average depth of thermocline (in ft)	12–30	15–36

METHODS

Round commercial wire minnow-traps baited with fish remains effectively collected crayfish larger than 23 mm in cephalothorax length. Traps were set in transects extending lakeward from the shore left for 24 hours, and then were lifted and rebaited. After being marked, measured, and weighed, crayfish were released in the center of the lake (Momot, 1967).

Size frequency graphs of the total catch of blue crayfish were constructed to analyze the age composition of the crayfish population. Because of molting, crayfish growth proceeds in steps. "Size-frequency polygons break up the population into natural size groups with distinct, easily followed modes" (VanDeventer, 1937). These size groups were then analyzed to disclose the number of age classes (a standard method of determining age in these animals, the merits and shortcomings of which are described in Momot, 1967). Although there were enough data taken from both lakes in the summer of 1968, the data from the springs of 1968 and 1969 (females only) and the summer of 1969 were very meager.

The Schumacher-Eschmeyer mark-and-recapture method of population determination (Table 2) was used because it avoids the problem of random mixing. Only data on female crayfish were recorded in the spring. This is because the data were taken from collections of both the olive-brown and blue phases made for another study in which only females were collected and marked in order (Momot and Gowing, In prep.) to obtain female population estimates with which to relate data on egg production in the spring. Mark-and-recapture population estimates of both phases were made later in the year, for both males and females, to give standing crop.

TABLE 2

Population estimates of blue crayfish during the summers of 1968 and 1969

Size interval examined	Sex	Number collected	Number of recaptures	Total sampling period in days	Estimated population	95% Confidence limits
1968	North Twin					
23–33 mm	♂	28	22	14	35	(31–43)
22–32 mm	♀	14	4	16	32	(18–176)
	South Twin					
23–31 mm	♂	40	20	11	61	(55–74)
23–28 mm	♀	12	7	18	18	(13–33)
1969	North Twin					
22–37 mm	♂	6	2	15	11	(6–109)
26–35 mm	♀	3	2	15	4	(3–10)
	South Twin					
29–34 mm	♂	6	4	7	8	(6–20)
22–27 mm	♀	2	0	7	—	———

RESULTS AND OBSERVATIONS

Population Estimation

A decrease in total crayfish population was noted in 1969, compared to that of 1968. In fact, the summer population of 1968 was 5.5 times that of 1969 (Tables 3 and 4). Probably a greater survival of 0—age crayfish in 1967 produced this difference. Age I animals are numerically dominant over older age groups simply because mortality increases with age.

TABLE 3

Population estimates of blue female crayfish during the springs of 1968 and 1969

Size interval	Lake	Collected number	Number of recaptures	Total sampling period in days	Estimated population	95% Confidence limits
1968	North Twin					
———		—	—	10	—	———
	South Twin					
26 mm		1	0	10	—	———
1969	North Twin					
25–33 mm		3	2	10	4	(3–17)
	South Twin					
26–28 mm		3	2	10	4	(3–17)

TABLE 4

Total population density of blue crayfish by age class in 1968 and 1969 as determined from length-frequency curve analysis (summer and spring)

		North Twin	
	Year	1968	1969
Males			
	Age I	22	3
	II	5	2
	III	—	1
		27	6
Females			
	Age I	12	1
	II	4	2
		16	3
		South Twin	
	Year	1968	1969
Males			
	Age I	31	2
	II	2	4
		33	6
Females			
	Age I	15	5
	II	—	—
		15	5

In order to check on the accuracy of the mark-and-recapture estimate of the blue crayfish population, it was compared with an independent estimate of the size of the blue population, derived as follows. (1) An estimate of the total population of both color phases was made by the mark-and-recapture technique (Momot and Gowing, In prep.). (2) Size-frequency graphs of the total population of blue and brown crayfish then provided the total catch of each color phase. (3) The percentage of blue crayfish in the total catch was then determined from the catch record (Table 5, column 3). (4) The total number of blue crayfish was

TABLE 5

Comparison of the percent of total crayfish captured that were blue to the blue crayfish population estimate during the summers of 1968 and 1969

Year	Lake	Sex	Percent blue crayfish in total catch	Percent blue crayfish in total catch multiplied by the total estimated crayfish population	Independent estimate of the blue crayfish population based on recaptures of blue crayfish only
1968	North Twin	♂	0.0063	46.3	35
	North Twin	♀	0.0090	40.3	32
	South Twin	♂	0.0037	63.5	61
	South Twin	♀	0.0056	43.5	18
1969	North Twin	♂	0.0023	11.7	11
	North Twin	♀	0.0029	11.5	4
	South Twin	♂	0.0018	9.1	8
	South Twin	♀	0.0041	12.7	—

then determined by multiplying the percentage of blue crayfish in the total catch (Table 5, column 3) by the mark-and-recapture estimate of the total population of both blue and brown crayfish (Table 5, column 4). This result agrees in magnitude with the Schumacher mark-and-recapture estimates of the blue-crayfish populations during the summers of 1968 and 1969 (Table 5, column 5), except for the data on the females in South Twin Lake in 1968. Thus the mark-and-recapture population estimates of the blue phase are reasonably representative of the blue-crayfish populations in the two lakes.

Mortality

Estimates of mortality rates were made possible by the use of sequential population estimates. The formula used for calculating the instantaneous rate of mortality (Ricker, 1958) was:

$$N_t/N_o = e^{-it},$$

where N_t = population size at t,
N_o = initial population size,
t = the length of the time interval (1 year)
i = the instantaneous rate of natural mortality, and
e = the base of natural logarithms.

Mortality rates were only calculated for the summer periods (Table 6), as

TABLE 6

Annual mortality rate of adult blue crayfish compared to adult brown crayfish

Lakes and Year	Annual mortality rate of brown adult males	Annual mortality rate of blue adult males	Annual mortality rate of brown adult females	Annual mortality rate of blue adult females
North Twin—1968–69	0.75	0.69	0.59	0.75
South Twin—1968–69	0.89	0.87	0.81	0.78

there were insufficient spring data. In comparing the mortality of blue crayfish with the mortality rate of the total crayfish population, no really significant differences were found in South Twin Lake. The mortality rate of female blue crayfish is slightly higher than for brown crayfish in North Twin Lake. No differences were found among the males in this lake. However, there is a lack of sufficient data on blue crayfish from other years with which to compare these data, to see if such a trend occurred in other years.

Growth

Because males molt twice per year and females only once, one would expect a significant difference in mean length between the two sexes at Age 1 (Momot, 1967; Caldwell and Bovbjerg, 1969). This difference should then tend to increase with each succeeding age group. Table 7 records the growth of captured crayfish during the springs and summers of 1968 and 1969. The generally higher growth rate in 1969 is probably a reflection of the lower density in 1969 compared to 1968. So few blue crayfish were captured in the springs of both years and throughout all of 1969 that no other meaningful comparisons can be made.

DISCUSSION

The role played by the blue crayfish in North Twin and South Twin Lakes is certainly one worthy of speculation. However, because of the small population involved, the only conclusive statements to be made are those concerning population size and mortality rates. The close agreement of the independent population estimates of the blue crayfish determined by multiplying the ratio of captured blue crayfish in the catch by the total population of both blue and normal-colored crayfish with the Schumacher-Eschmeyer population estimates is gratifying. If these results could be considered valid, then the percentage of blue crayfish in the populations of the two lakes is very small. The lack of difference in mortality

TABLE 7

Comparison of carapace lengths of brown crayfish to those of blue crayfish during the summers of 1968 and 1969. Data recorded as X±S.E. (no. of specimens)

Year	Lake	Age Group	Mean length of brown male crayfish	Mean length of blue male crayfish	Mean length of brown female crayfish	Mean length of blue female crayfish
1968	North Twin	I	26.1±.05(1,214)	25.7± .35(22)	24.9±.08(647)	25.1±.55(11)
		II	34.2±.10(213)	31.8± .37(5)	30.6±.10(179)	31.0±1.0(2)
	South Twin	I	26.6±.07(2,067)	26.5± .32(31)	26.9±.13(1,205)	25.9± .38(14)
		II	35.0±.17(164)	35.5± .59(2)	30.8±.09(255)	————
1969	North Twin	I	27.2±.09(620)	26.0±2.0(3)	24.6±.06(656)	26.0± .00(1)
		II	35.1±.12(259)	33.5± .59(2)	29.5±.06(381)	33.0±2.0(2)
		III	42.7±.57(8)	37.0± .00(1)		
	South Twin	I	32.5±.03(1,535)	29.5± .59(2)	27.1±.10(292)	24.5±2.51(2)
		II	35.9±.04(779)	32.8± .48(4)	30.5±0.10(212)	

rates between the olive-brown and blue color-phases also does not support the thesis of selective mortality, i.e. selective predation is not occurring, or if it is, it is compensated for by lower rates of mortality from other causes. An examination of several hundred trout stomachs never disclosed a blue crayfish (Momot and Gowing, In prep.) in spite of the fact that blue crayfish formed from 0.2 to 0.8 percent of the population. If the trout were selective for blue crayfish, at least a few of them should have occurred in the fish stomachs. More complete information is necessary to confirm any of these conclusions and especially to denote any significant pattern in survival between the populations in these lakes and year-to-year changes within one lake.

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