

## Appendix 2. Silver Carp

These pictures are images of live and preserved specimens of silver carp (*Hypophthalmichthys molitrix*). Text descriptions and line drawings from Chapman and Wang (2006), and Yi and others (1988) are also presented, when available, for comparison purposes.

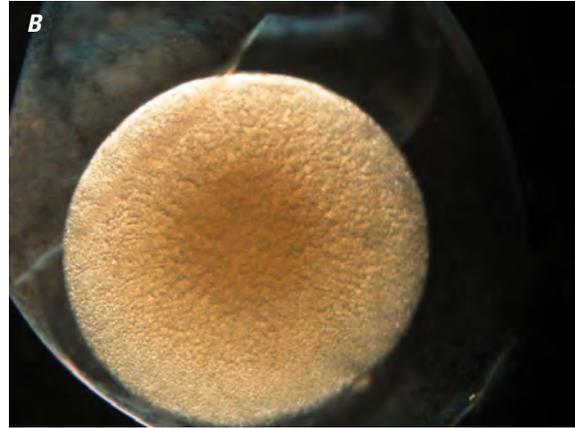
Preliminary data on timing and required cumulative thermal units (CTUs) are also presented, though this data is based on a single experiment, and is likely to be revised with further experiments. The magnification listed is the total magnification (ocular x objective) for each picture.

## 2 Developmental Rate and Behavior of Early Life Stages of Bighead Carp and Silver Carp

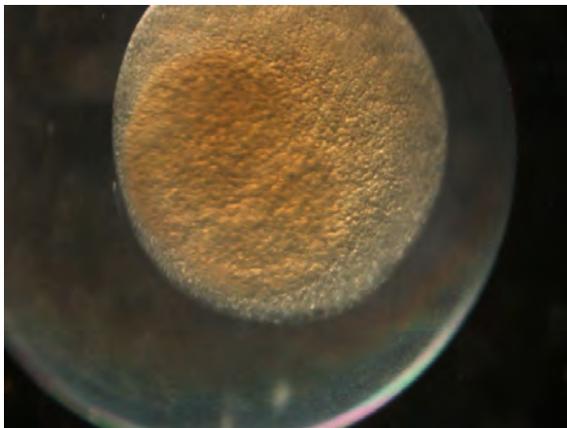
**Table 2-1.** Timing and required CTUs for achieving developmental stages of silver carp.

[This data is based on a single experiment, and is likely to be revised with further experiments. CTU, cumulative thermal unit; °C, degrees Celsius;  $T_{min}$ , thermal minimum; --, not available]

Stage	Time			CTU (Calculated using 11.1°C as $T_{min}$ )			
	Yi	High	Low	Yi (21°C)	High (22.5°C)	Low (19.6°C)	
1	1-cell	--	0	0	--	0	0
2	2-cell	--	0:58	1:30	--	11.02	12.75
3	4-cell	--	1:21	1:48	--	15.39	15.30
4	8-cell	1:20	1:46	2:18	13.33	20.14	19.55
5	16-cell	1:45	2:14	2:49	17.50	25.46	23.94
6	32-cell	1:57	2:29	3:33	19.50	28.31	30.18
7	64-cell	2:30	3:03	4:02	25.00	34.77	34.28
8	128-cell	3:35	3:45	4:31	35.83	42.75	38.39
9	Morula	4:20	4:30	5:03	43.33	51.30	42.93
10	Early blastula	4:55	5:00	6:03	49.17	57.00	51.43
11	Mid-blastula	5:20	6:29	8:37	53.33	73.91	73.24
12	Late blastula	6:40	7:29	9:08	66.67	85.31	77.63
13	Early gastrula	8:40	8:31	11:39	86.67	97.09	99.03
14	Mid-gastrula	10:15	9:31	13:07	102.50	108.49	111.49
15	Late gastrula	12:50	10:01	14:12	128.33	114.19	120.70
16	Neurula	14:10	11:34	15:36	141.67	131.86	132.60
17	Blastopore closure	14:45	12:00	17:49	115.00	136.80	151.44
18	Somite appearance	15:20	13:39	18:24	153.33	153.71	156.40
19	Optic primordium	16:15	14:36	19:52	162.50	166.44	168.87
20	Optic vesicle	17:00	16:35	21:32	170.00	189.05	183.03
21	Olfactory placode	18:25	17:39	22:37	184.17	201.21	192.24
22	Tail bud	19:30	18:13	24:10	195.00	207.67	205.42
23	Otic capsule	20:45	--	25:33	207.50	--	217.18
24	Tail vesicle	22:00	--	26:30	220.00	--	225.25
25	Caudal fin	22:35	20:07	27:11	225.83	229.33	231.06
26	Lens formation	23:00	20:55	27:38	230.00	238.45	234.88
27	Muscular effect	24:25	22:10	28:59	244.17	252.70	246.36
28	Heart rudiment	28:20	23:02	29:31	283.33	262.58	250.89
29	Otolith appearance	30:00	23:29	31:29	300.00	267.71	267.61
30	Heart pulsation	34:15	--	34:31	342.50	280.82	293.39
31	Hatching	38:00	26:41	45:26	380.00	306.86	390.73
32	Pectoral fin bud	48:00	33:12	60:22	480.00	381.80	519.15
33	Gill arch	53:00	45:06	77:34	530.00	518.65	667.07
34	Xanthic eye	63:00	53:53	--	630.00	619.66	--
35	Gill filament	74:00	60:39	94:33	740.00	697.48	813.13
36	Melanoid eye	92:00	77:36	119:20	920.00	892.40	1,026.27
37	Gas bladder emergence	106:00	109:00	159:50	1,060.00	1,253.50	1,374.57
38	One chamber gas bladder	146:00	137:00	183:30	1,460.00	1,575.50	1,578.10
39	Yolk absorption	168:00	168:17	--	1,680.00	1,935.26	--
40	Dorsal fin differentiation	212:00	--	--	2,120.00	--	--

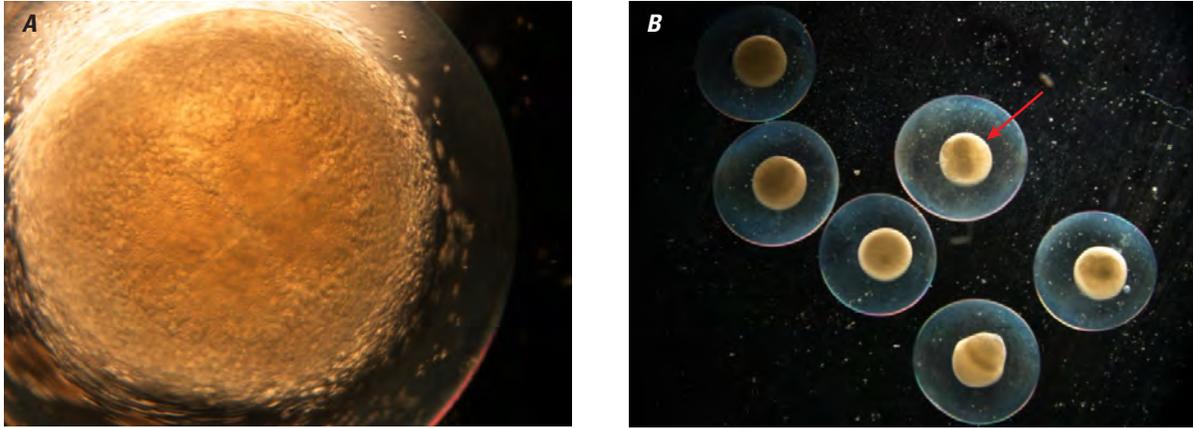


**Figure 2-1.** Stage 1: 1-cell stage of silver carp development. *A*, Preserved specimen, high temperature treatment, 0:48 post fertilization, picture taken with 40x magnification. *B*, Preserved specimen, low temperature treatment, 1:19 post fertilization, picture taken with 50x magnification. *C*, Live specimen, low temperature treatment, 0:45 post fertilization, picture taken with 10x magnification.

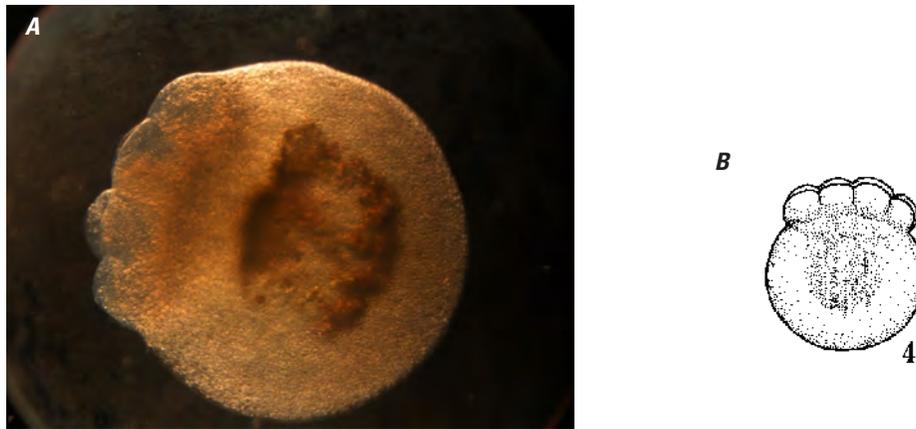


**Figure 2-2.** Stage 2: 2-cell stage of silver carp development. Preserved specimen, high temperature treatment, 0:58 post fertilization, picture taken with 60x magnification.

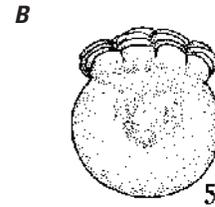
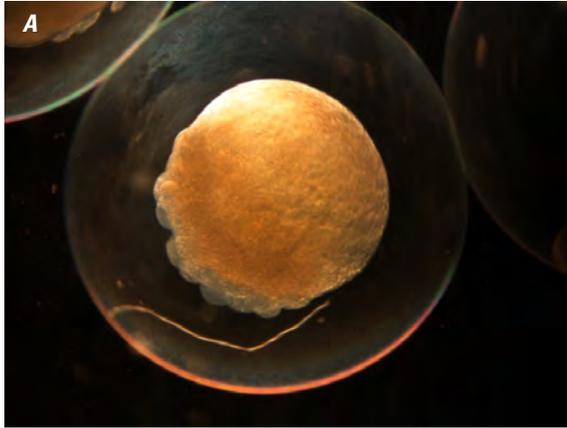
4 Developmental Rate and Behavior of Early Life Stages of Bighead Carp and Silver Carp



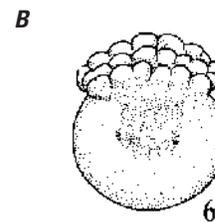
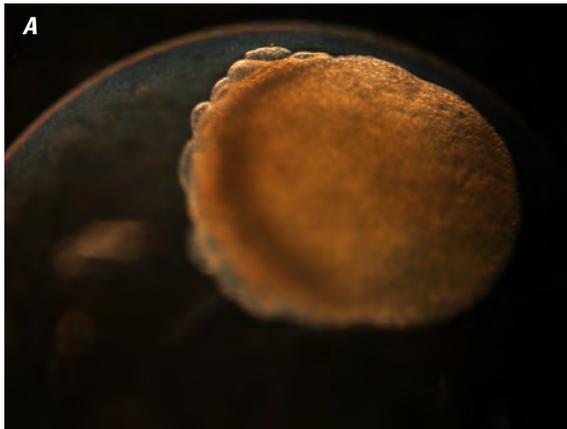
**Figure 2–3.** Stage 3: 4-cell stage of silver carp development. *A*, Preserved specimen, low temperature treatment, 1:48 post fertilization, picture taken with 50x magnification. *B*, Live specimen, low temperature treatment, 2:04 post fertilization, picture taken with 10x magnification. Arrow indicates the 4-cell stage egg.



**Figure 2–4.** Stage 4: 8-cell stage of silver carp development. Cytoplasm widely distributed in yolk (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 2:33 post fertilization, picture taken with 50x magnification. The dark pigment on this embryo is abnormal and indicates the cell will probably not develop much further. *B*, Line drawing of 8-cell stage from Yi and others (1988).

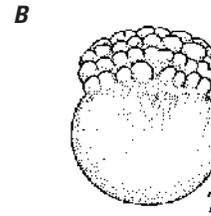
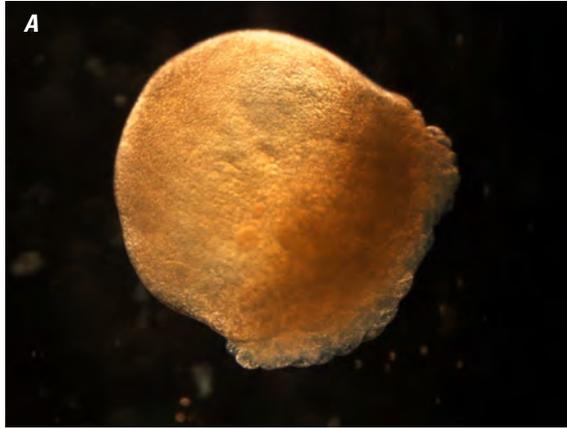


**Figure 2-5.** Stage 5: 16-cell stage of silver carp development. Cytoplasm diminishing (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 3:20 post fertilization, picture taken with 30x magnification. *B*, Line drawing of 16-cell stage from Yi and others (1988).

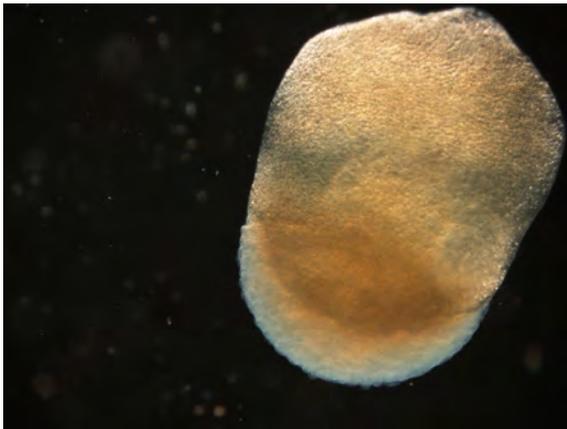


**Figure 2-6.** Stage 6: 32-cell stage of silver carp development. Cytoplasm diminishing (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 3:33 post fertilization, picture taken with 50x magnification. *B*, Line drawing of 32-cell stage from Yi and others (1988).

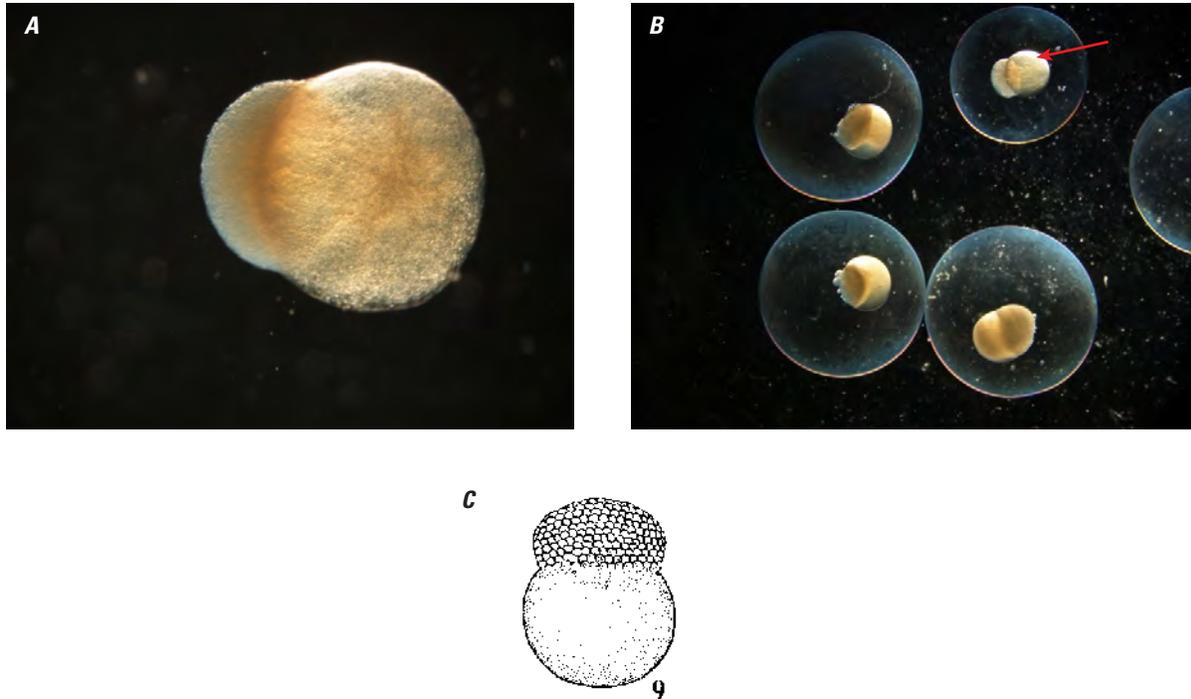
6 Developmental Rate and Behavior of Early Life Stages of Bighead Carp and Silver Carp



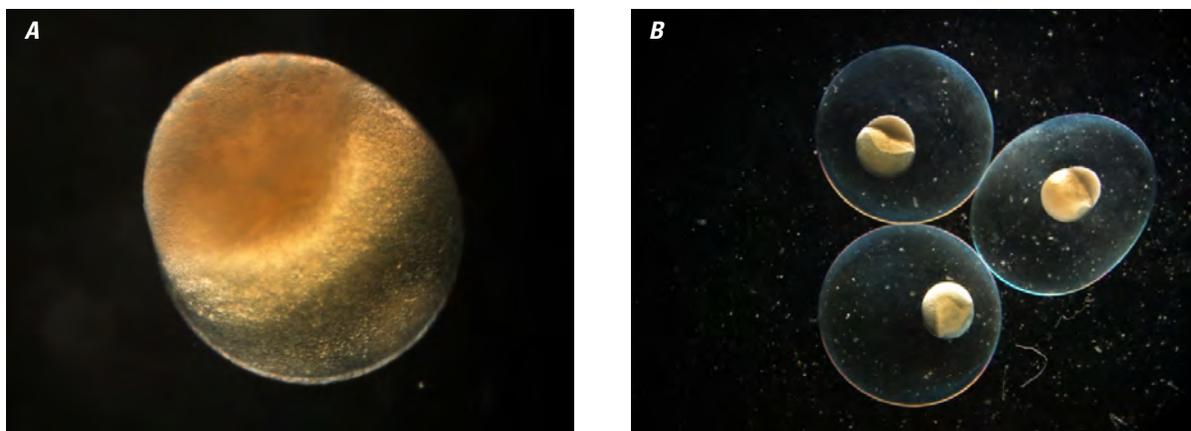
**Figure 2-7.** Stage 7: 64-cell stage of silver carp development. Cytoplasm diminishing (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 4:02 post fertilization, picture taken with 50x magnification. *B*, Line drawing of 64-cell stage from Yi and others (1988).



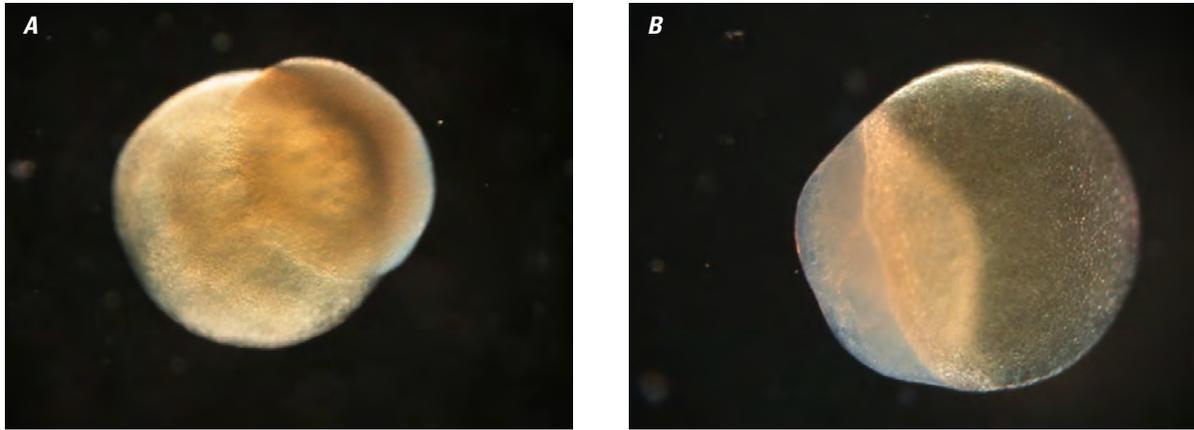
**Figure 2-8.** Stage 8: 128-cell stage of silver carp development. Cytoplasm almost gone. Blastodisc mound-like, several oil droplets on yolk cell (Yi and others, 1988). Preserved specimen, high temperature treatment, 3:45 post fertilization, picture taken with 50x magnification.



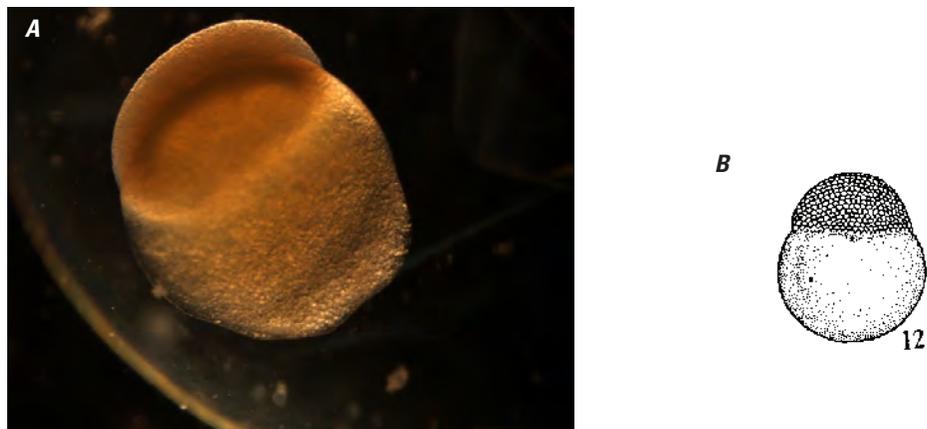
**Figure 2-9.** Stage 9: Morula stage of silver carp development. Cells become smaller, blastodisc highly raised above yolk, cytoplasm disappears (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 4:30 post fertilization, picture taken with 40x magnification. *B*, Live specimen, low temperature treatment, 5:31 post fertilization, picture taken with 10x magnification. Arrow indicates the morula stage egg. *C*, Line drawing of morula stage from Yi and others (1988).



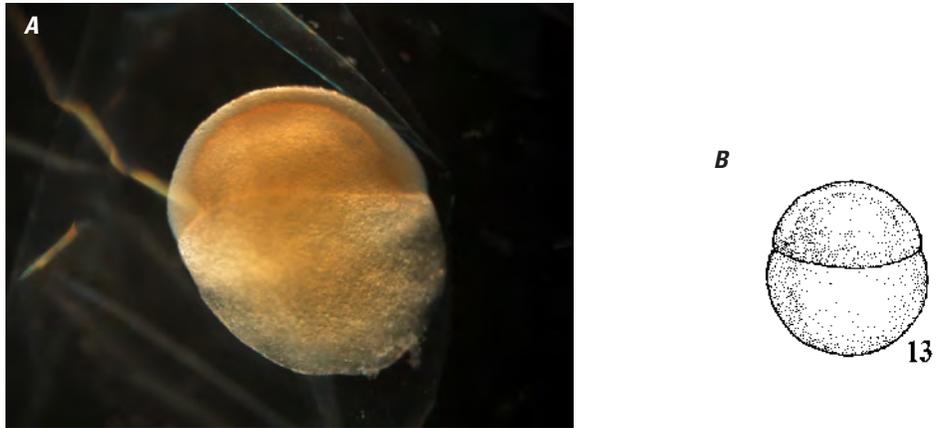
**Figure 2-10.** Stage 10: Early blastula stage of silver carp development. Blastodisc forms half-sphere (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 7:06 post fertilization, picture taken with 60x magnification. *B*, Live specimen, high temperature treatment, 5:33 post fertilization, picture taken with 10x magnification.



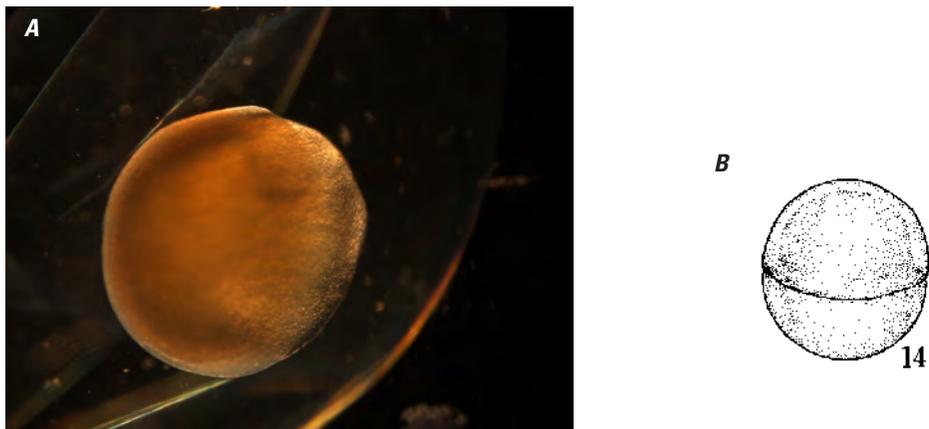
**Figure 2-11.** Stage 11: Mid-blastula stage of silver carp development. Blastodisc begins flattening (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 7:02 post fertilization, picture taken with 50x magnification. *B*, Preserved specimen, high temperature treatment, 6:29 post fertilization, picture taken with 50x magnification.



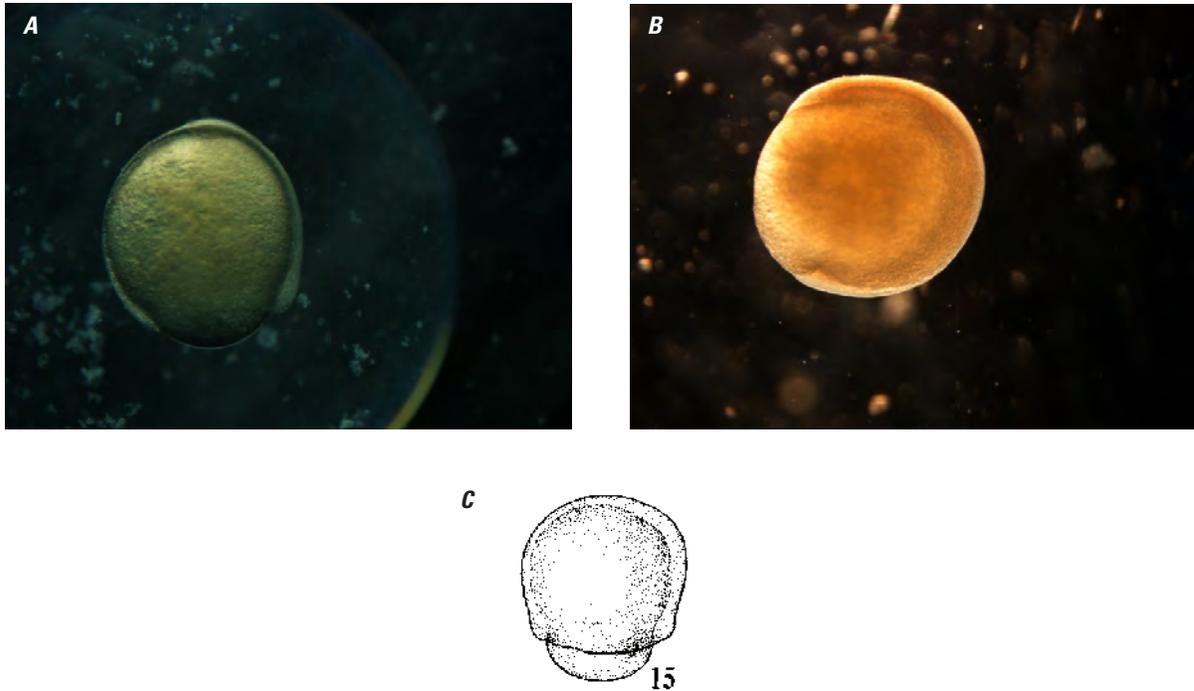
**Figure 2-12.** Stage 12: Late blastula stage of silver carp development. Blastodisc flattens and gradually moves over yolk (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 10:08 post fertilization, picture taken with 50x magnification. *B*, Line drawing of late blastula stage from Yi and others (1988).



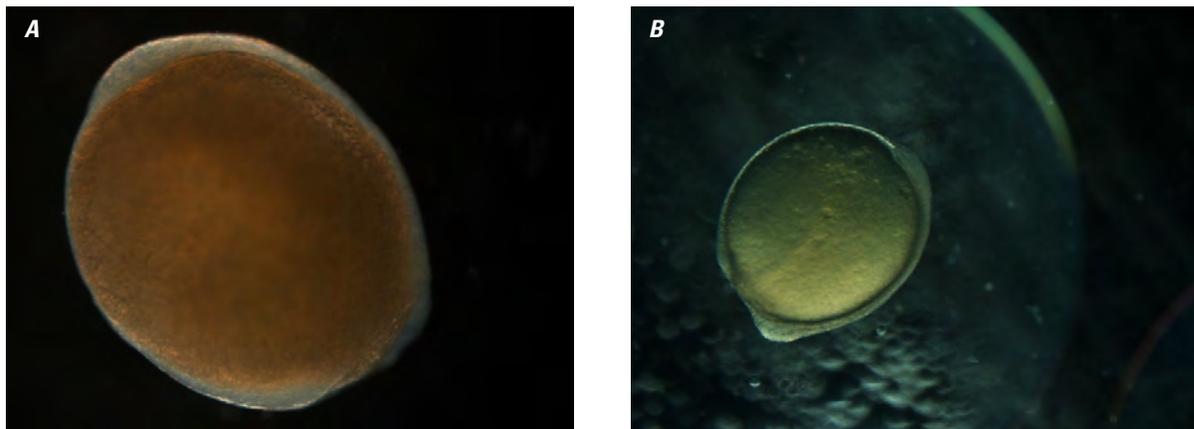
**Figure 2-13.** Stage 13: Early gastrula stage of silver carp development. Germ ring visible, blastoderm covers 1/3 of yolk cell. Egg appears round. (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 11:39 post fertilization, picture taken with 50x magnification. *B*, Line drawing of early gastrula stage from Yi and others (1988).



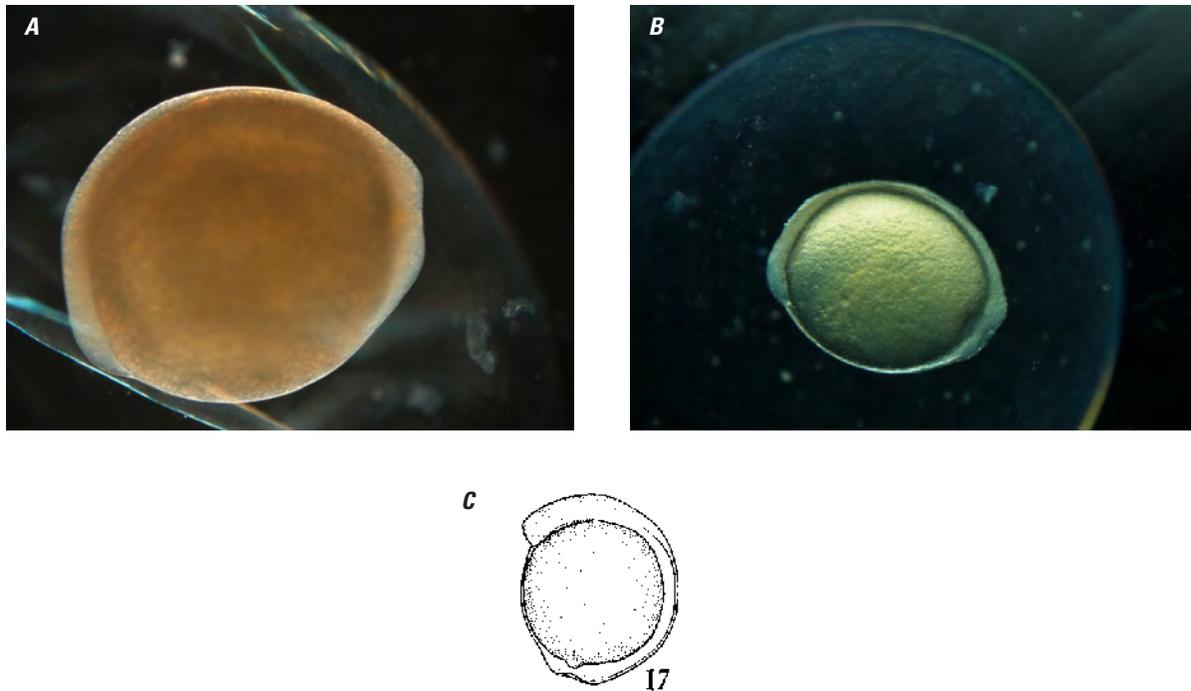
**Figure 2-14.** Stage 14: Mid-gastrula stage of silver carp development. Blastoderm covers 1/2 of yolk cell (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 13:07 post fertilization, picture taken with 50x magnification. *B*, Line drawing of mid-gastrula stage from Yi and others (1988).



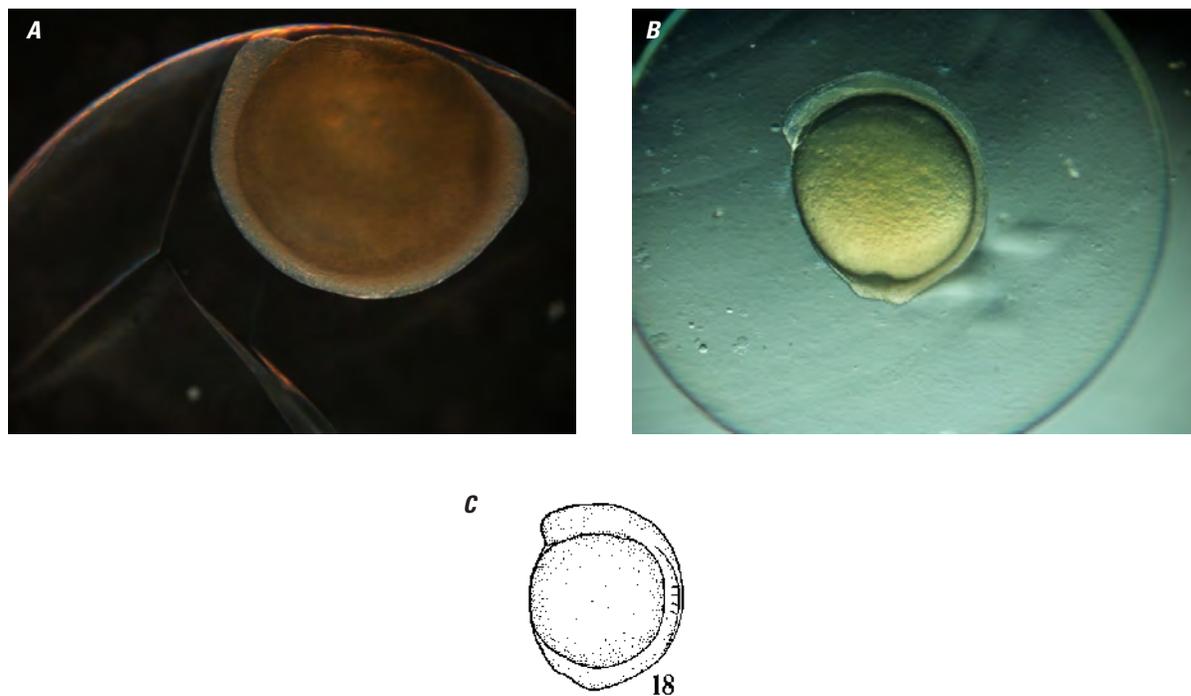
**Figure 2-15.** Stage 15: Late gastrula stage of silver carp development. Embryo head enlarged, blastoderm covers 3/4 of yolk cell (Yi and others, 1988). *A*, Live specimen, low temperature treatment, 17:17 post fertilization, picture taken with 40x magnification. *B*, Preserved specimen, low temperature treatment, 14:30 post fertilization, picture taken with 40x magnification. *C*, Line drawing of late gastrula stage from Yi and others (1988).



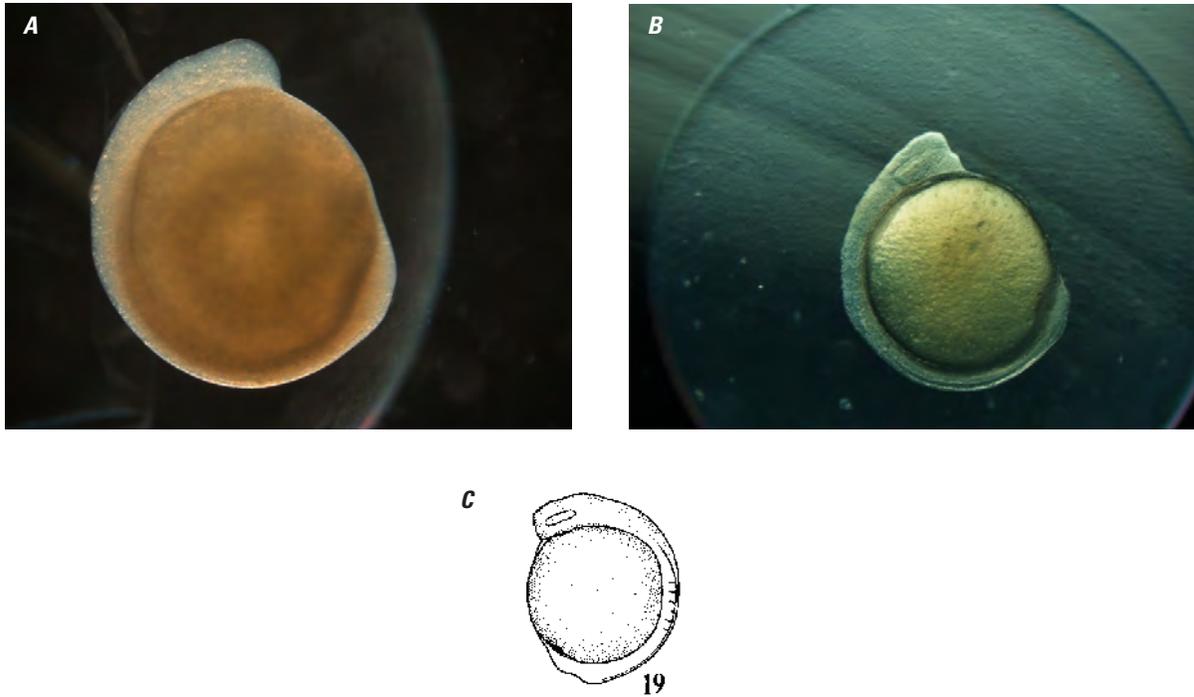
**Figure 2-16.** Stage 16: Neurula stage of silver carp development. Head clearly visible, blastoderm covers almost whole yolk, except for yolk plug (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 17:25 post fertilization, picture taken with 70x magnification. *B*, Live specimen, low temperature treatment, 17:17 post fertilization, picture taken with 40x magnification.



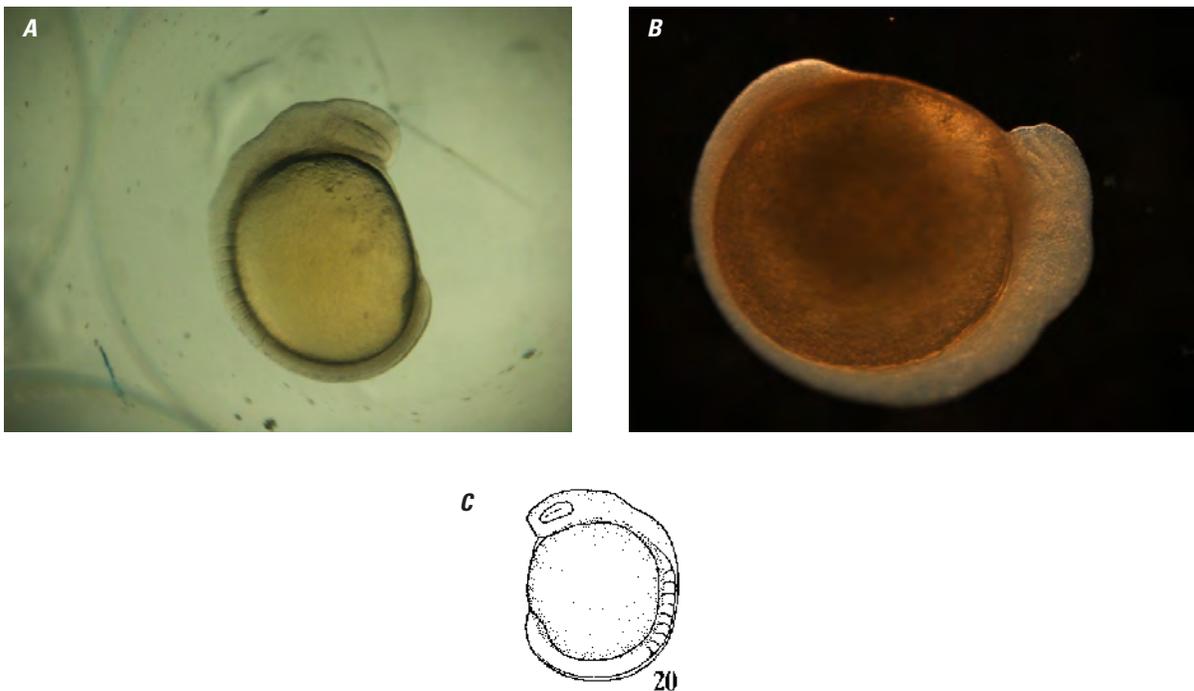
**Figure 2-17.** Stage 17: Blastopore closure stage of silver carp development. Front of head square, yolk round (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 12:30 post fertilization, picture taken with 60x magnification. *B*, Live specimen, low temperature treatment, 17:44 post fertilization, picture taken with 40x magnification. *C*, Line drawing of blastopore closure stage from Yi and others (1988).



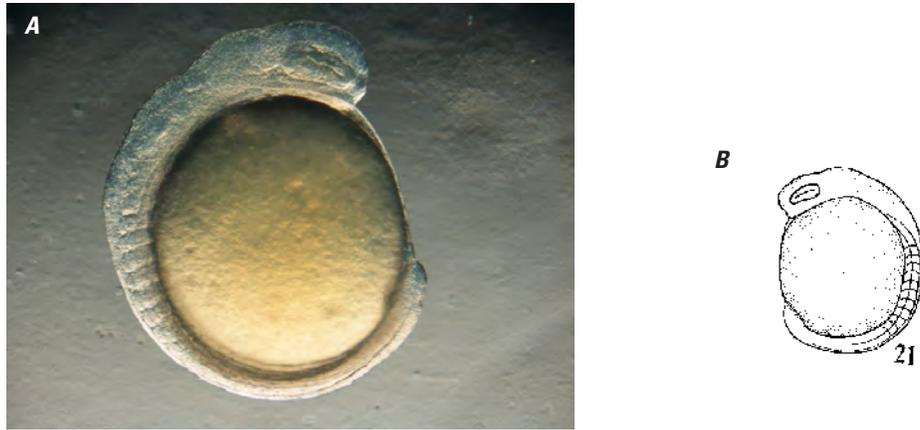
**Figure 2-18.** Stage 18: Somite appearance stage of silver carp development. Somites number 1-3 pairs and optic primordium dimly visible (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 13:29 post fertilization, picture taken with 50x magnification. *B*, Live specimen, low temperature treatment, 18:20 post fertilization, picture taken with 40x magnification. *C*, Line drawing of somite appearance stage from Yi and others (1988).



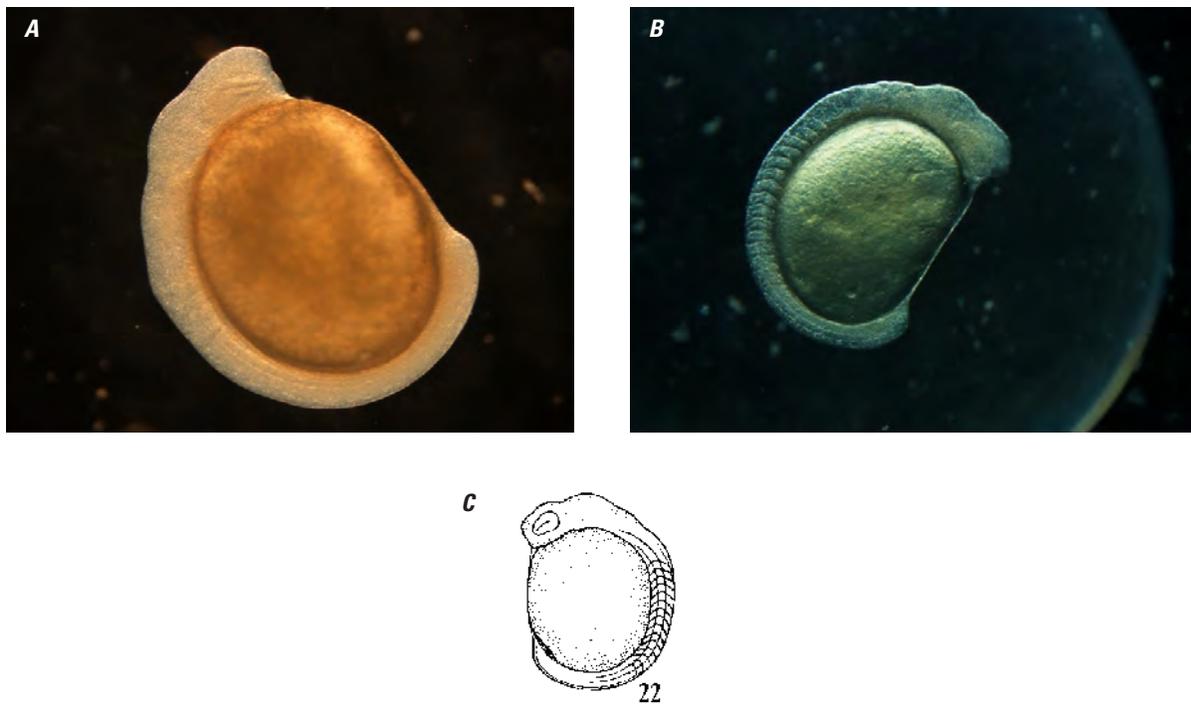
**Figure 2-19.** Stage 19: Optic primordium stage of silver carp development. Optic primordium clearly visible, long and oval shaped. Embryo covers 3/4 of yolk, unencircled yolk margin is convex, 4-6 pairs of somites present. (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 14:35 post fertilization, picture taken with 50x magnification. *B*, Live specimen, low temperature treatment, 21:27 post fertilization, picture taken with 40x magnification. *C*, Line drawing of optic primordium stage from Yi and others (1988).



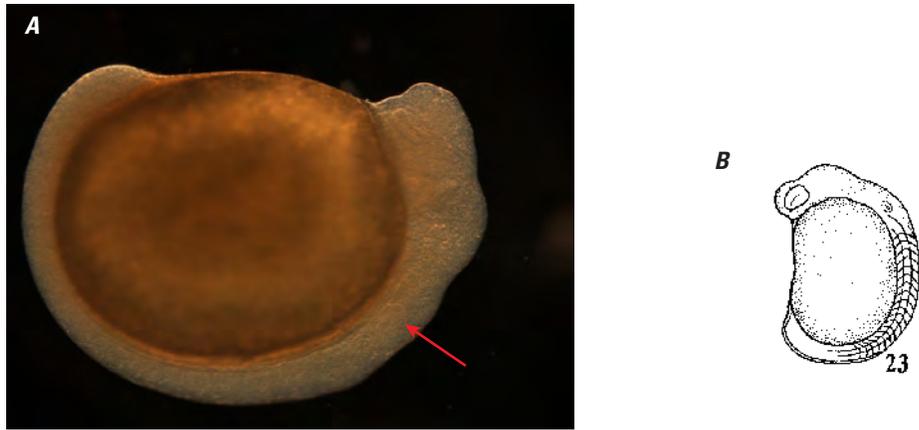
**Figure 2-20.** Stage 20: Optic vesicle stage of silver carp development. Eyes enlarge, 7-9 pairs of somites present (Yi and others, 1988). *A*, Live specimen, high temperature treatment, 16:06 post fertilization, picture taken with 40x magnification. *B*, Preserved specimen, low temperature treatment, 23:32 post fertilization, picture taken with 60x magnification. *C*, Line drawing of optic vesicle stage from Yi and others (1988).



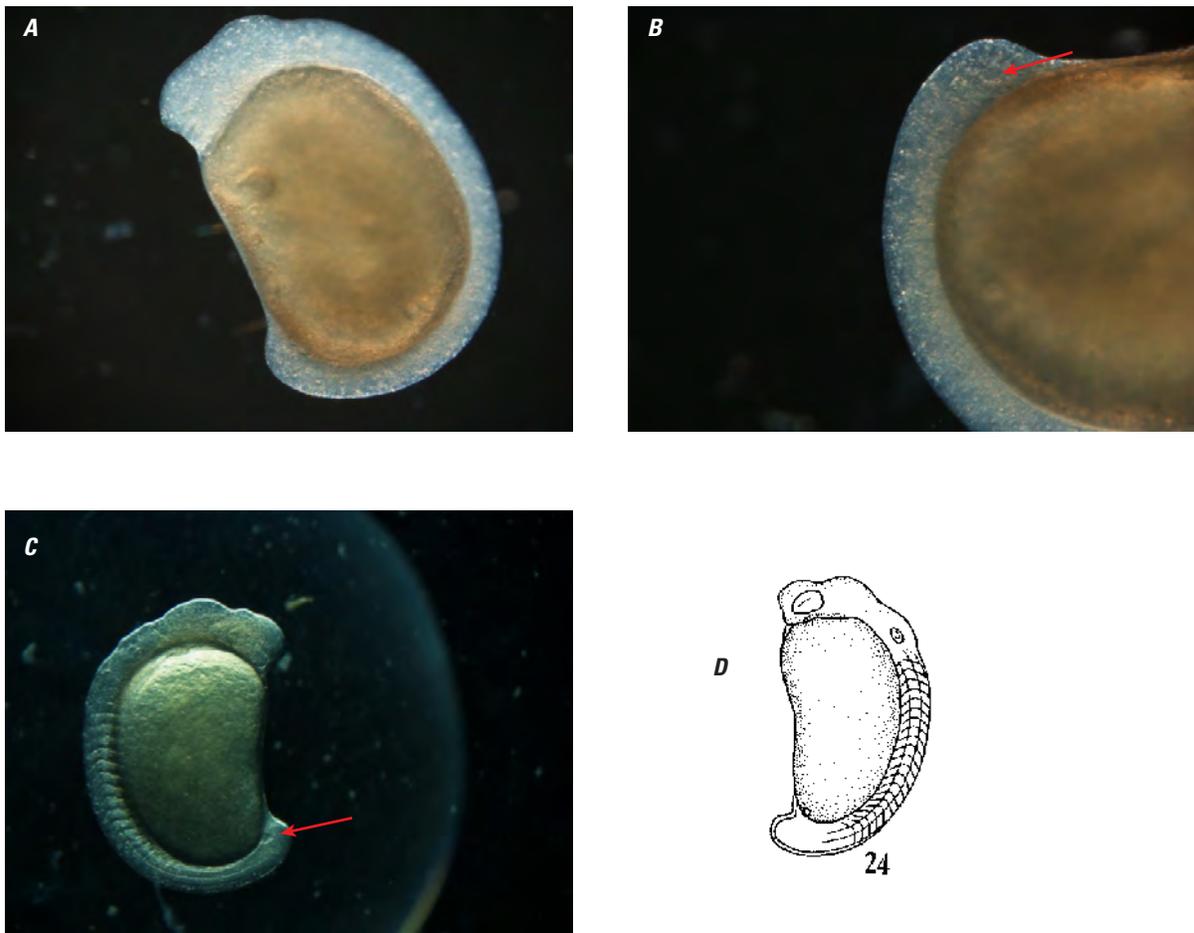
**Figure 2–21.** Stage 21: Olfactory placode stage of silver carp development. Olfactory placode barely visible above optic vesicle, 10–13 pairs of somites present (Yi and others, 1988). *A*, Live specimen, low temperature treatment, 22:37 post fertilization, picture taken with 60x magnification. *B*, Line drawing of olfactory placode stage from Yi and others (1988).



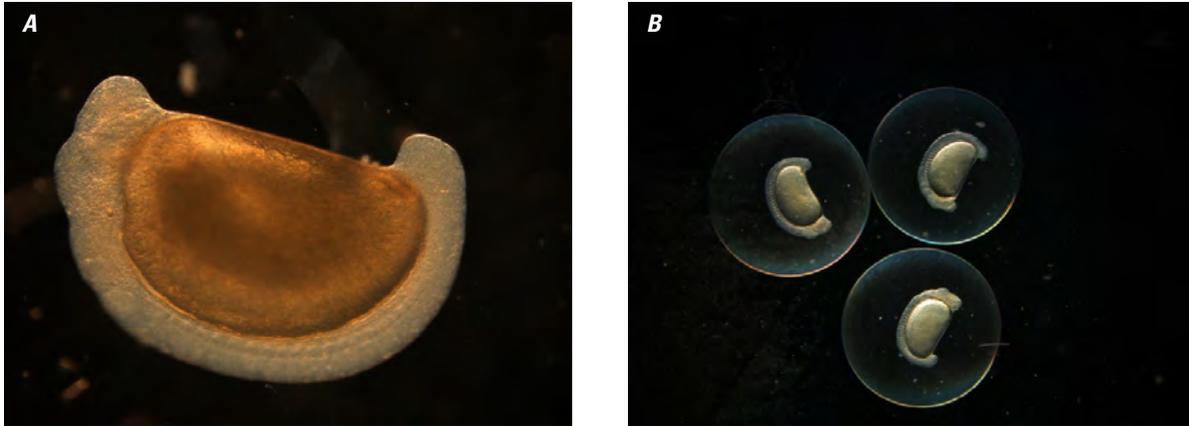
**Figure 2–22.** Stage 22: Tail bud stage of silver carp development. Eyes enlarge, shaped like watermelon seed. Slightly differentiated brain rudiment. Tail bud appears, 14–16 pairs of somites present (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 24:33 post fertilization, picture taken with 50x magnification. *B*, Live specimen, high temperature treatment, 18:05 post fertilization, picture taken with 40x magnification.



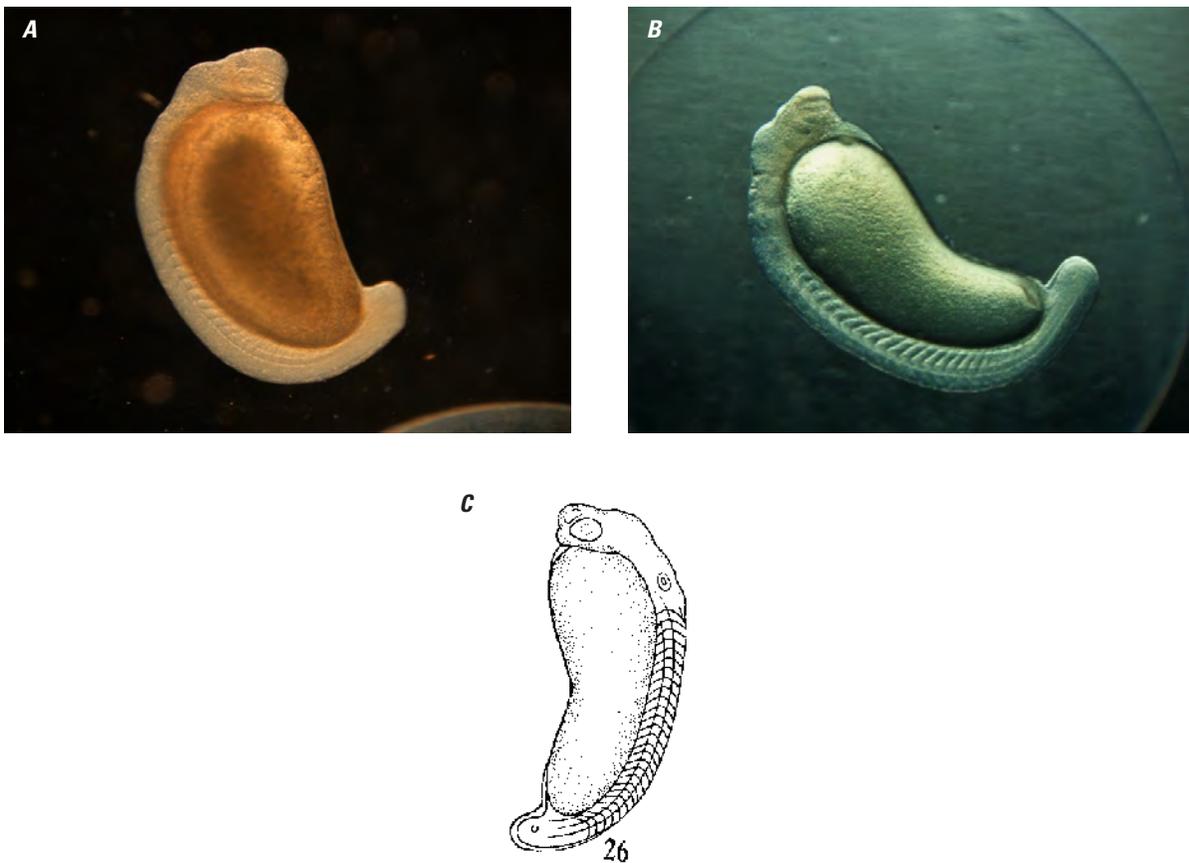
**Figure 2-23.** Stage 23: Otic capsule stage of silver carp development. Tail bud clearly visible, otic capsule appears, yolk elongates and the part of the yolk between the head and the tail begins to invaginate, 17–19 pairs of somites present (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 26:30, picture taken with 60x magnification. Arrow points to the otic capsule. *B*, Line drawing of otic capsule stage from Yi and others (1988).



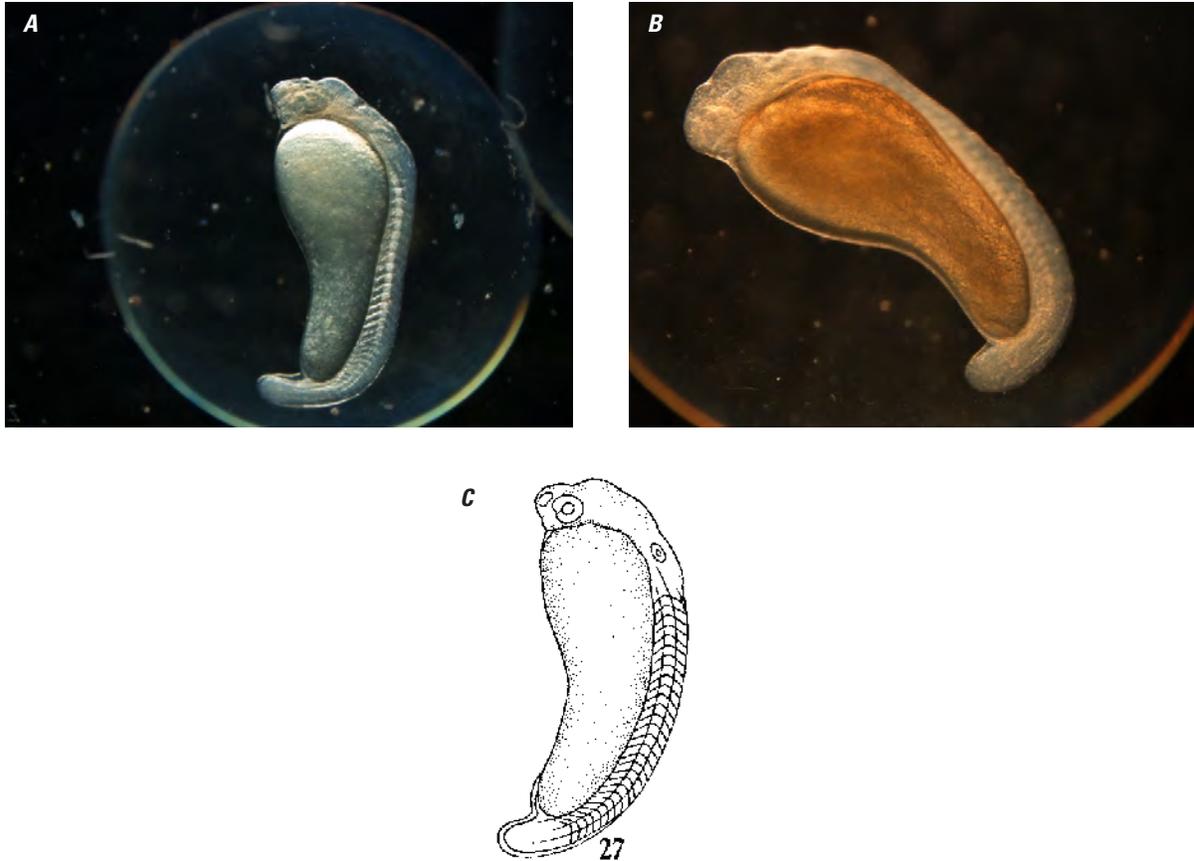
**Figure 2-24.** Tail vesicle stage of silver carp development. Tail bud expands outward, tail vesicle appears, bump on brain area enlarges, yolk is elongated and kidney shaped, 20–21 pairs of somites present (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 19:13 post fertilization, picture taken with 50x magnification. *B*, Preserved specimen, high temperature treatment, 19:13 post fertilization, picture taken with 90x magnification. Arrow points to the tail vesicle. *C*, Live specimen, high temperature treatment, 18:05 post fertilization, picture taken with 40x magnification. Arrow points to the tail vesicle. *D*, Line drawing of tail vesicle stage from Yi and others (1988).



**Figure 2-25.** Stage 25: Caudal fin stage of silver carp development. Caudal fin expands outward, embryo and yolk elongates, 22–23 pairs of somites present (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 28:10 post fertilization, picture taken with 50x magnification. *B*, Live specimen, low temperature treatment, 28:10 post fertilization, picture taken with 10x magnification.



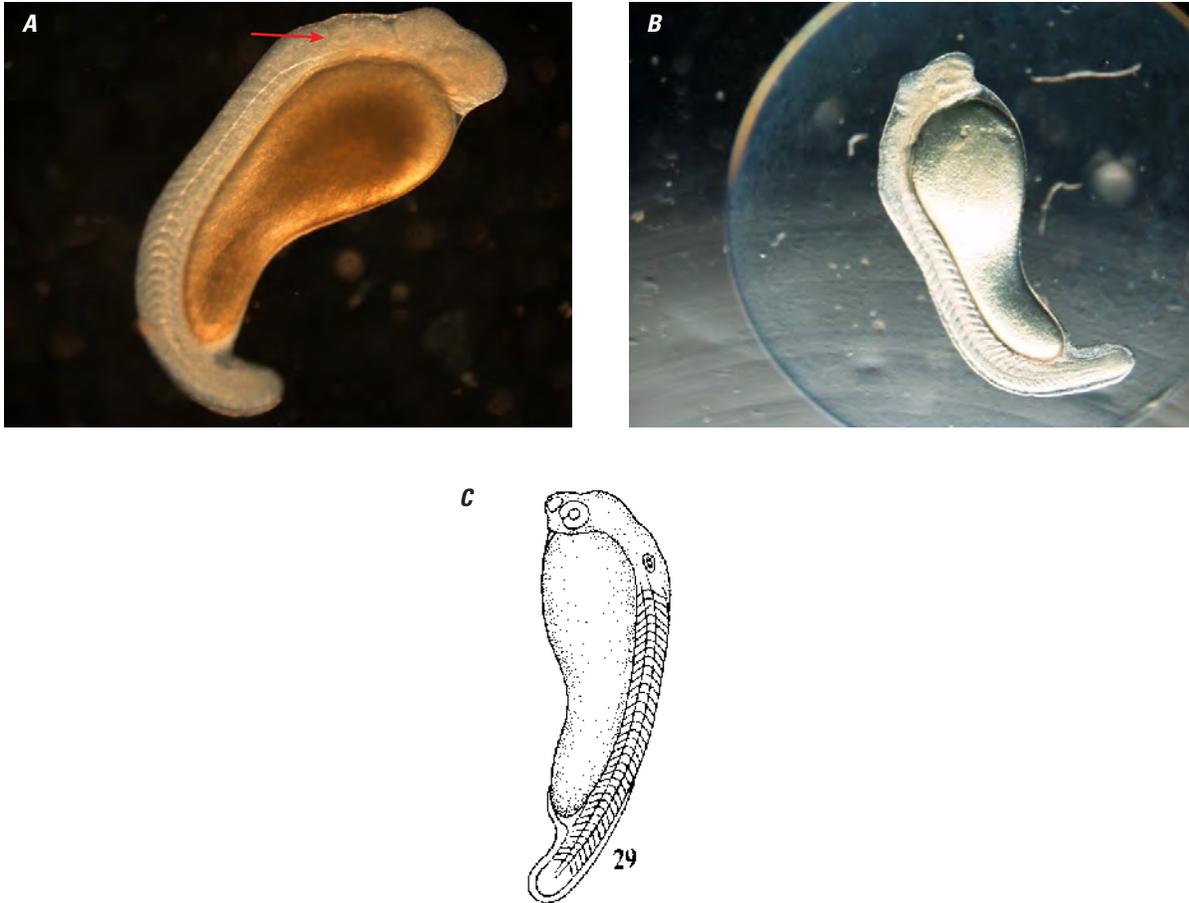
**Figure 2-26.** Stage 26: Lens formation stage of silver carp development. Eyes round, olfactory vesicle clearly visible. Embryo elongated, yolk further invaginated, 24–25 pairs somites present (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 27:38 post fertilization, picture taken with 40x magnification. *B*, Live specimen, high temperature treatment, 20:40 post fertilization, picture taken with 40x magnification. *C*, Line drawing of lens formation stage from Yi and others (1988).



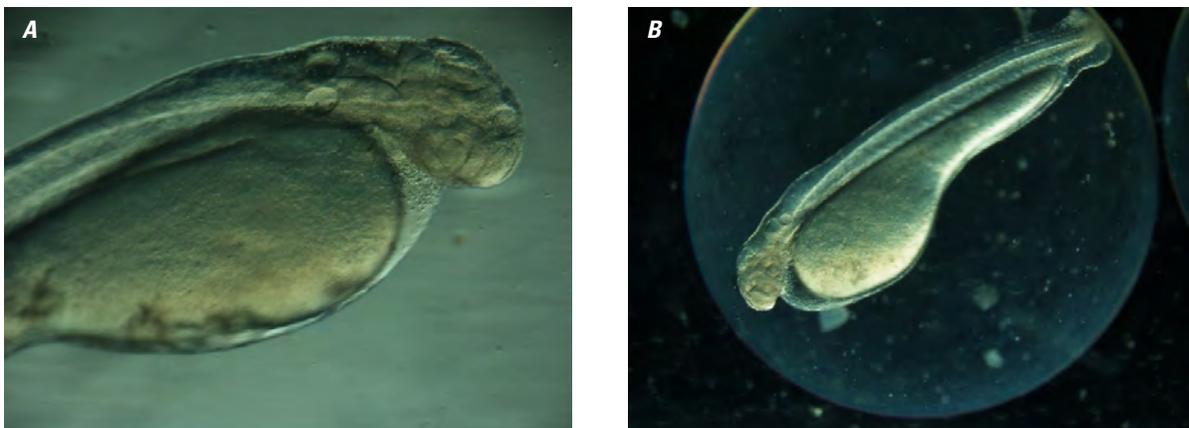
**Figure 2-27.** Stage 27: Muscular effect stage of silver carp development. Embryo elongating and lashing slightly. Tail vesicle disappears. Bump on brain area enlarged though not highly raised. End of yolk colorless, 26–28 pairs of somites present (Yi and others 1988). *A*, Live specimen, low temperature treatment, 31:03 post fertilization, picture taken with 30x magnification. *B*, Preserved specimen, high temperature treatment, 21:24 post fertilization, picture taken with 40x magnification. *C*, Line drawing of muscular effect stage from Yi and others (1988).



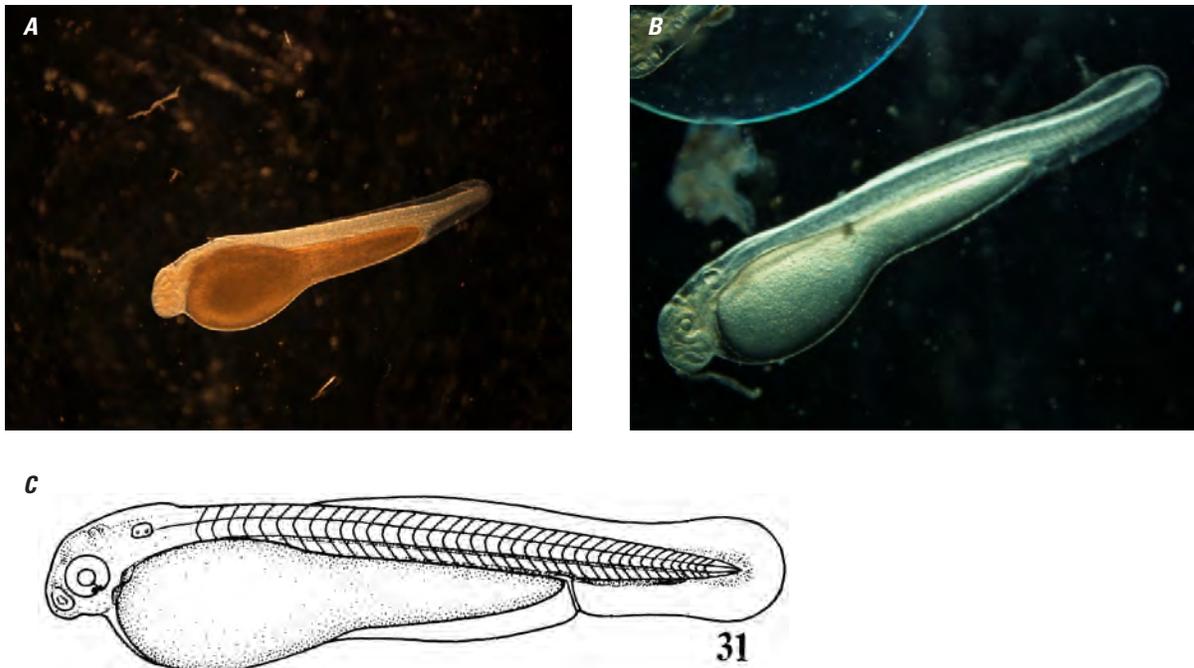
**Figure 2-28.** Stage 28: Heart rudiment stage of silver carp development. Heart rudiment appears. Occasional lashing, 25–30 pairs of somites present (Yi and others, 1988). Preserved specimen, high temperature treatment, 23:02 post fertilization, picture taken with 30x magnification.



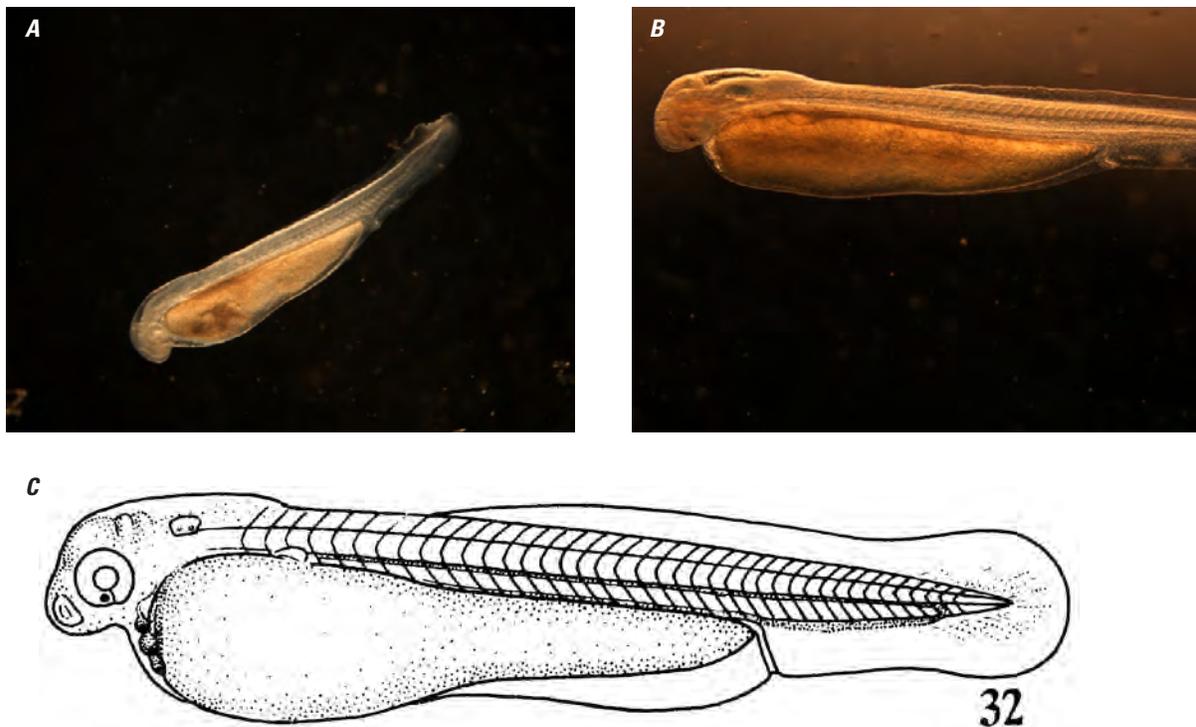
**Figure 2–29.** Stage 29: Otolith appearance stage of silver carp development. Embryo elongates further, moves continuously. Otolith appears, 31–35 pairs of somites present. (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 31:29 post fertilization, picture taken with 40x magnification. Arrow points to otoliths. *B*, Live specimen, high temperature treatment, 23:29 post fertilization, picture taken with 30x magnification. *C*, Line drawing of otolith appearance stage from Yi and others (1988).



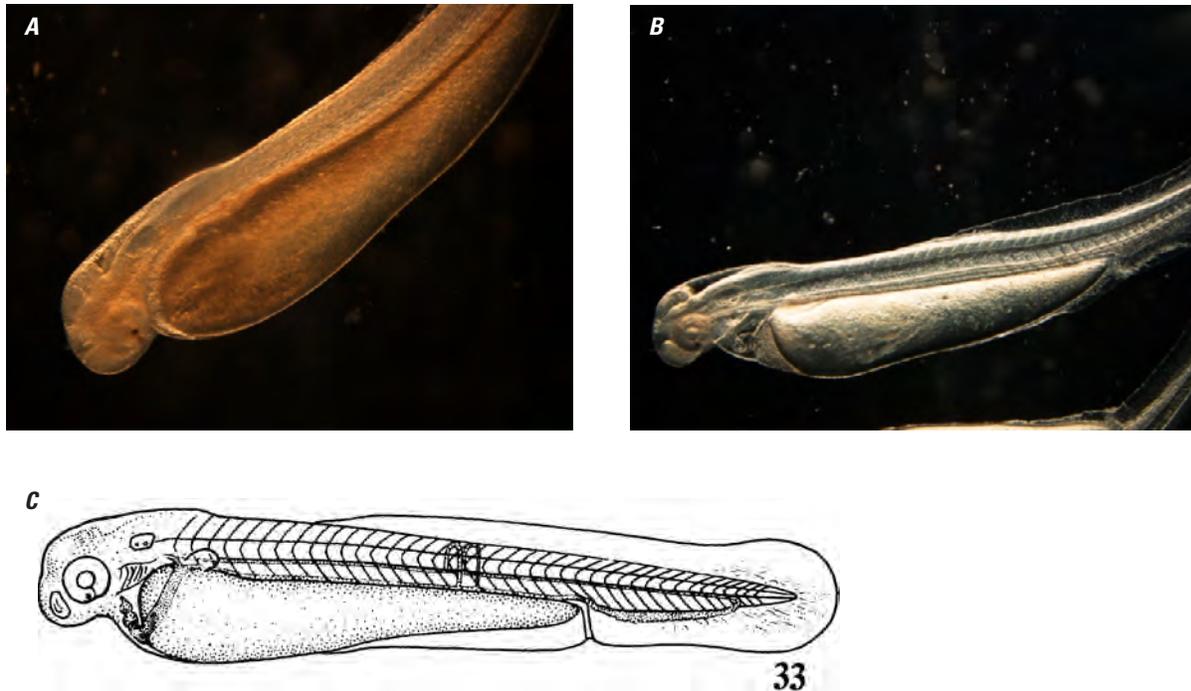
**Figure 2–30.** Stage 30: Heart pulsation stage of silver carp development. Heart pulsates, embryo rotates. Egg membrane softens, 36–37 pairs of somites present. Ready to hatch (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 42:34 post fertilization, picture taken with 70x magnification. *B*, Preserved specimen, low temperature treatment, 44:03 post fertilization, picture taken with 30x magnification.



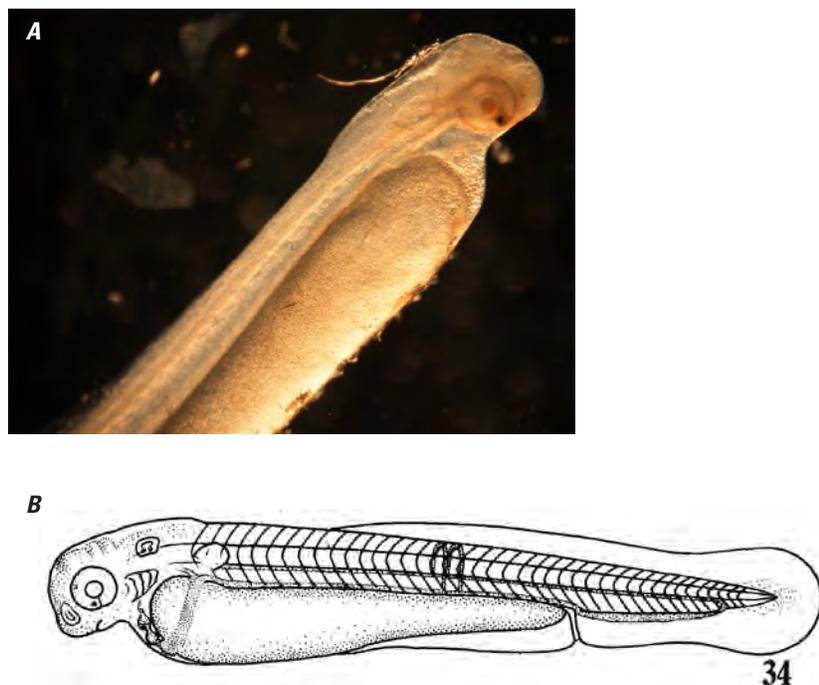
**Figure 2-31.** Stage 31: Hatching stage of silver carp development. The larvae is approximately 6.1 millimeters; caudal vein not obvious. Small otic capsule, 39 myomeres (Yi and others, 1988). The black spot below eye was not apparent until stage 32. *A*, Preserved specimen, high temperature treatment, 29:00 post fertilization, picture taken with 20x magnification. *B*, Live specimen, low temperature treatment, 45:17, picture taken with 30x magnification. *C*, Line drawing of hatching stage from Yi and others (1988).



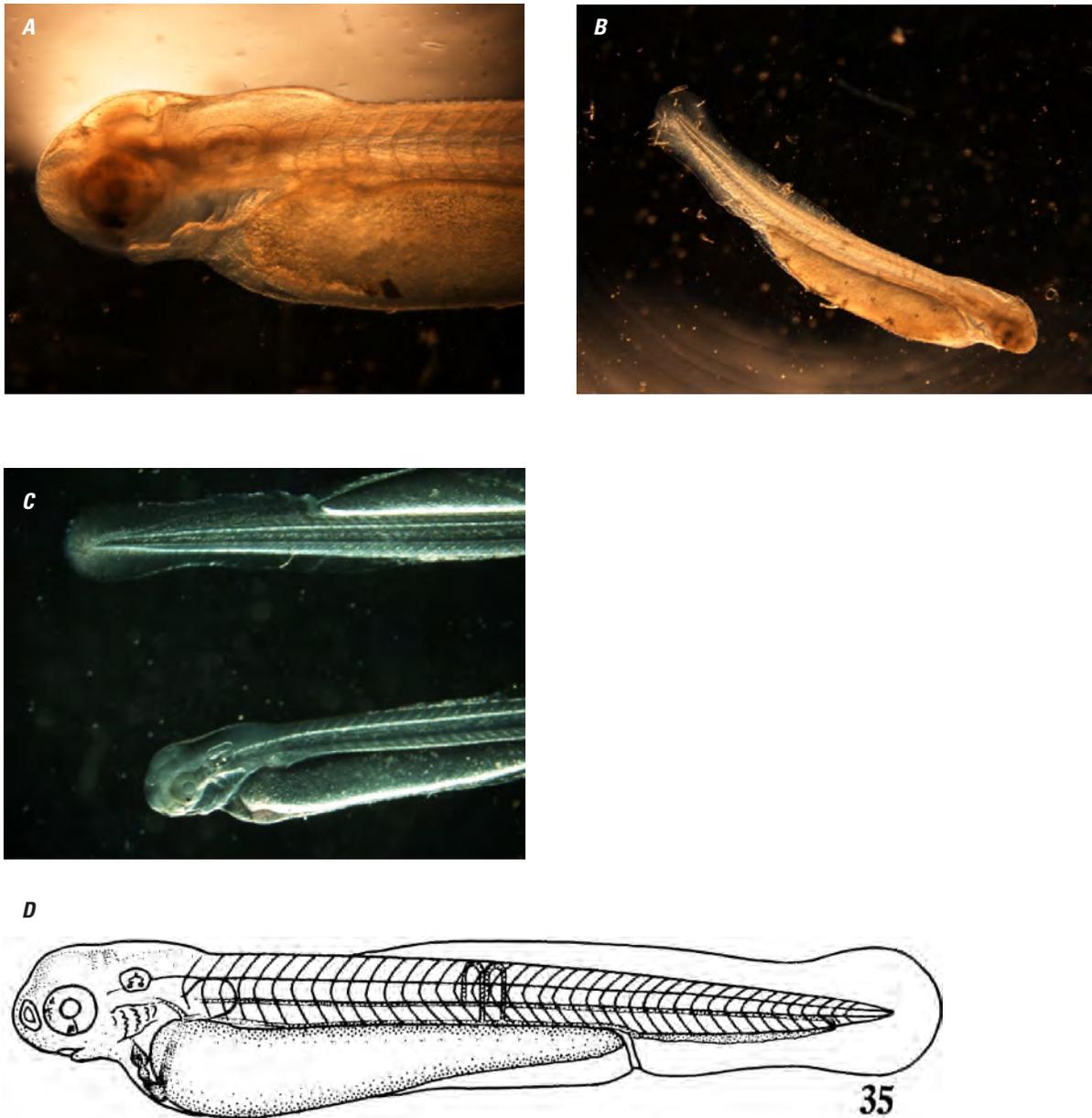
**Figure 2-32.** Stage 32: Rudimentary pectoral fin stage of silver carp development. The larvae are approximately 6.3 millimeters; rudimentary pectoral fin appears, 39 myomeres (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 41:37 post fertilization, picture taken with 20x magnification. *B*, Preserved specimen, low temperature treatment, 60:22 post fertilization, picture taken with 30x magnification. *C*, Line drawing of rudimentary pectoral fin stage from Yi and others (1988).



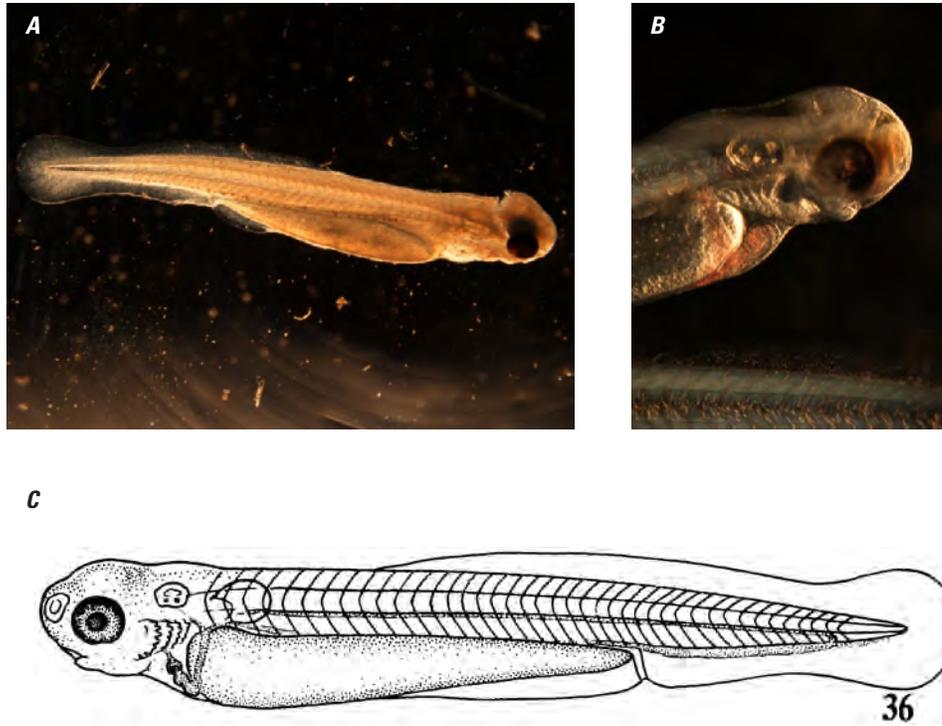
**Figure 2-33.** Stage 33: Gill arch stage of silver carp development. The larvae are approximately 6.83 millimeters; cuverian ducts on front side of yolk sac. Shrinking yolk sac, 40 myomeres (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 45:06 post fertilization, picture taken with 40x magnification. *B*, Live specimen, high temperature treatment, 49:06 post fertilization, picture taken with 30x magnification. *C*, Line drawing of gill arch stage from Yi and others (1988).



**Figure 2-34.** Stage 34: Xanthic eye stage of silver carp development. The larvae are approximately 7.2 millimeters; yellow pigmentation of eye appears, indentation of mouth, 40 myomeres (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 53:53 post fertilization, picture taken with 40x magnification. *B*, Line drawing of xanthic eye stage from Yi and others (1988).



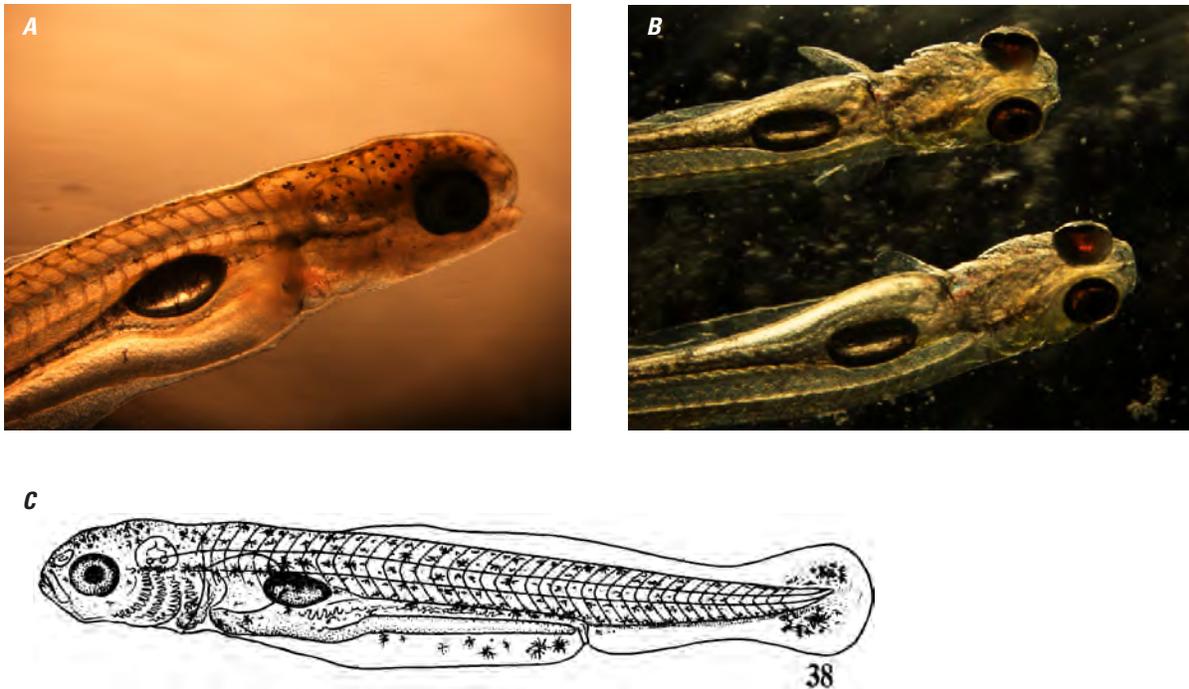
**Figure 2-35.** Stage 35: Gill filament stage of silver carp development. The larvae is approximately 7.5 millimeters, gill filaments extended. Melanophores increase, lower jaw movement begins (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 70:45 post fertilization, 6x magnification. *B*, Preserved specimen, low temperature treatment, 94:43 post fertilization, picture taken with 20x magnification. *C*, Live specimen, high temperature treatment, 60:31 post fertilization, picture taken with 30x magnification. *D*, Line drawing of gill filament stage from Yi and others (1988).



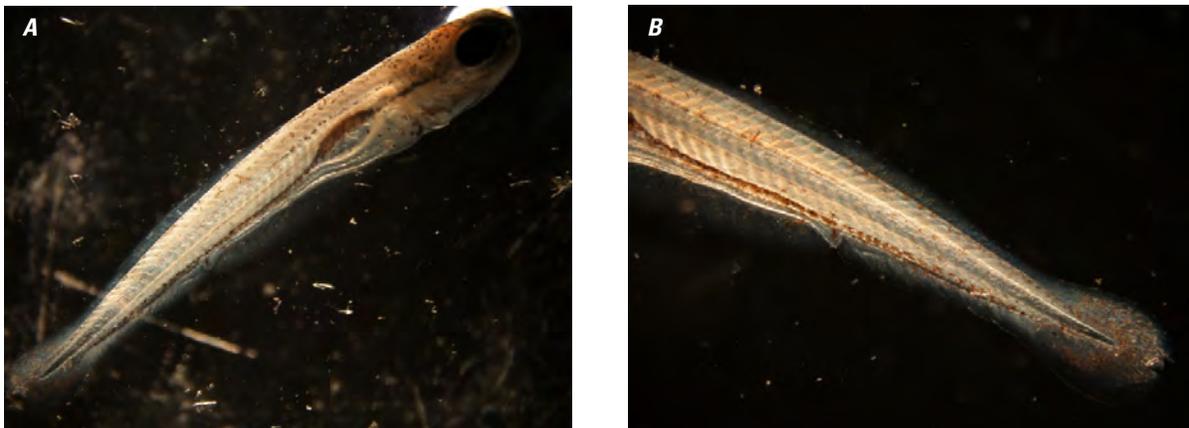
**Figure 2-36.** Stage 36: Melanoid eye stage of silver carp development. Melanophores all around the eye, otic capsule enlarges, mouth moves forward (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 127:55 post fertilization, picture taken with 20x magnification. *B*, Live specimen, high temperature treatment, 70:45 post fertilization, picture taken with 60x magnification (not completely developed). *C*, Line drawing of melanoid eye stage from Yi and others (1988).



**Figure 2–37.** Stage 37: Gas bladder emergence stage of silver carp development. The larvae is approximately 8.2 millimeters. Gas bladder begins to appear. Melanophores on gas bladder. Gut is continuous. Yolk sac is thin strip (Yi and others, 1988). *A*, Line drawing of gas bladder emergence stage from Yi and others (1988). *B*, Preserved specimen, low temperature treatment, 174:30 post fertilization, picture taken with 20x magnification. *C*, Preserved specimen, high temperature treatment, 127:55 post fertilization, picture taken with 30x magnification. *D*, Live specimen, high temperature treatment, 109:00 post fertilization, picture taken with 30x magnification.

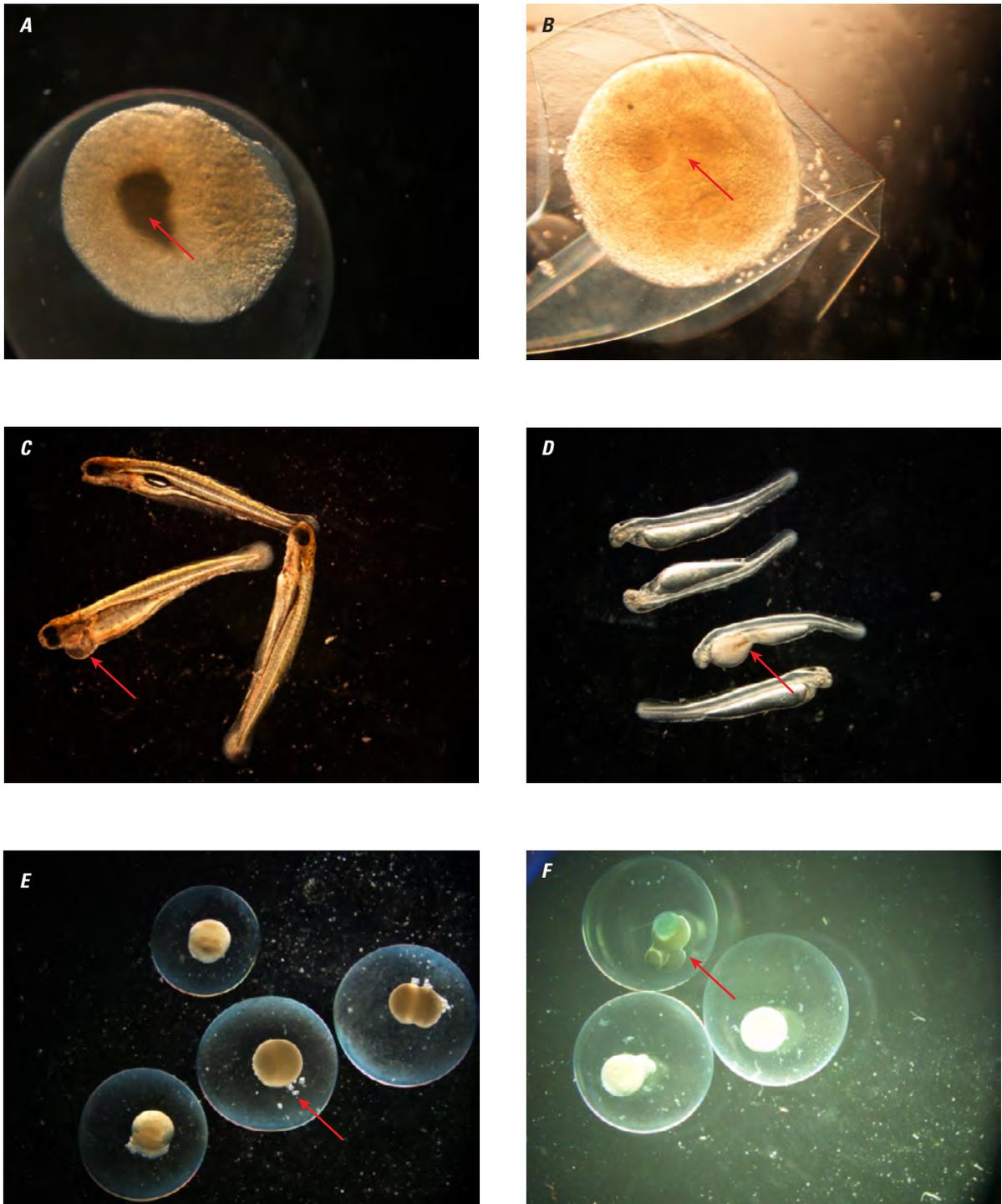


**Figure 2-38.** Stage 38: 1-chamber gas bladder stage of silver carp development, 40 myomeres, gas bladder oval shaped, terminal mouth, very little yolk sac remains. Greater pigment density (Yi and others, 1988). *A*, Preserved specimen, low temperature treatment, 191:14 post fertilization, picture taken with 40x magnification. *B*, Live specimen, high temperature treatment, 136:40 post fertilization, picture taken with 30x magnification. *C*, Line drawing of one chamber gas bladder stage from Yi and others (1988).



**Figure 2-39.** Stage 39: Yolk absorption stage of silver carp development. The larvae is approximately 8.7 millimeters; yolk sac exhausted; melanophores become darker and denser (Yi and others, 1988). *A*, Preserved specimen, high temperature treatment, 168:17 post fertilization, picture taken with 20x magnification. *B*, Preserved specimen, high temperature treatment, 168:17 post fertilization, picture taken with 30x magnification (melanophore detail).

Abnormalities



**Figure 2-40.** Developmental abnormalities of silver carp. *A*, Dark spots on yolk. *B*, Improper cell division (7 cell). *C*, Air bladder abnormalities. *D*, Yolk sac abnormality. *E*, Cells detached from embryo. *F*, Abnormal cell development.