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Early Life History Comparison of the Green Sturgeon, *Acipenser medirostris*, and White Sturgeon, *Acipenser transmontanus*, of the Sacramento-San Joaquin River Delta, California

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U.S. Department of the Interior
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by

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U.S. Department of the Interior
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Byron, California

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.

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Acknowledgment

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Introduction

This Tracy Technical Bulletin summarizes information concerning the early life stages of two fish species of concern in the Sacramento-San Joaquin River Delta (Delta) region of the Central Valley, California: the green sturgeon, *Acipenser medirostris*, and white sturgeon, *Acipenser transmontanus*. This information has been researched and used in the course of fish salvage operations conducted by the U.S. Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF), located in the South Delta near Tracy, California. This work is funded through the Tracy Fish Facility Improvement Program and operation and maintenance budgets for the TFCF. This information provides a guide that helps researchers and fishery personnel working in the Delta to identify and distinguish the early life stages of these two important species.

Family Acipenseridae: Sturgeons

Seven species of sturgeon have been reported in North America, and two of them are found in California inland waters: green sturgeon, *Acipenser medirostris*, and white sturgeon, *Acipenser transmontanus*. Both are anadromous and native to the Sacramento-San Joaquin estuary and river system (Ayers, 1854; Jordan and Snyder, 1906; Pycha, 1956; Skinner, 1962; Shapovalov et al., 1981).

Green Sturgeon, *Acipenser medirostris* (Ayers)

Green sturgeon is not common in the estuary and few juveniles are found in the Feather River, the Sacramento River above Red Bluff, the Delta, or at the Reclamation TFCF intake. Adults are rarely observed at the TFCF. In the last 8 years, only one adult (over 2 meters in total length) was caught on the TFCF trash rack in spring 2003. The spawning locations of the green sturgeon in the Delta are poorly understood. The early embryonic development and early life growth rate of the green sturgeon were documented by Deng (2000) using brood stock obtained from the Klamath River. Eggs from the Klamath River brood stock were obtained from Joel VanEenennam, Universtity of California at Davis (UCD), and incubated at 15.5 ± 1 ˚C. Figure 1 shows green sturgeon eggs, larvae, and juveniles.

Spawning

Locations: In upper Klamath River (Fry, 1973); in the Sturgeon Hole just above Orleans on the Klamath River (Moyle, 1976); the lower Klamath River (Deng, 2000); the upper Sacramento River and Feather River (based on collected larval green sturgeon) (Fry, 1973; Moyle et al., 1995). Juveniles were collected at the TFCF; however, it is unclear if they came from the Sacramento River or the San Joaquin River.

FIGURE 1 – Green sturgeon eggs, larvae, and prejuveniles. Green sturgeon eggs were provided by Joel Van Eenennaam, UCD, and incubated at 15.5 ˚C at the TFCF. TL = total length. Photographs are not to scale. Reclamation photographs by René C. Reyes.

Season:	March to July in the Klamath River (Moyle, 2002); May in the Klamath River by artificial method on site (Deng, 2000); green sturgeon eggs were obtained from the University of California at Davis (UCD) in May 2004.
Temperature:	8.0 – 14.0 ºC (Moyle, 2002); 15.7 ºC under laboratory conditions (Deng, 2000).
Substrate:	Large cobble, sand and bedrock (Moyle, 2002).
Fecundity:	60,000 – 140,000 (Moyle, 2002).

Eggs

Shape:	Spherical (Deng, 2000); fertilized eggs can be spherical, oval, and irregular.
Diameter:	Newly fertilized eggs 4.2 – 4.5 mm in diameter (Deng, 2000); 3.7 – 4.0 mm short axis and 4.0 – 4.3 mm long axis.
Yolk:	Newly fertilized eggs gray in general, animal pole whitish with dark center, vegetable pole darker than animal pole (Deng, 2000).
Oil globule:	None.
Chorion:	Clear and not thick (Deng, 2000); thin, clear.
Perivitelline space:	Overall narrow.
Egg mass:	Large numbers broadcasted in a short time into deep and fast running water (Moyle, 2002).
Adhesiveness:	Weak adhesiveness (Deng, 2000); some loss of adhesiveness prior to hatching, chorion dilated and developed into web-like texture.
Buoyancy:	Demersal.

Larvae

Length at hatching:	12.6 – 14.5 mm total length (TL) (Deng, 2000); larvae 8 – 19 mm (Emmett et al., 1991); 15.5 – 17.2 mm TL.
Snout to anus ratio:	62 percent for newly hatched prolarvae, decreasing to 50 percent 15 days after hatching, and returning to 55 percent in 28 – 45 days after hatching (Deng, 2000); newly hatched, 60 – 61 percent .
Yolk sac:	Ovoid, large.
Oil globule:	None.
Gut:	Straight.
Size at absorption of yolk – sac stage:	25.6 – 27.1 mm TL (Deng, 2000); 25.0 – 30.0 mm TL.
Teeth:	None.
Total myomeres:	63 – 71 (Deng, 2000).
Preanal myomeres:	36 – 41 (Deng, 2000).
Postanal myomeres:	27 – 31 (Deng, 2000).
Last fin(s) to complete development:	Pelvic and anal fins at 35 mm TL.
Pigmentation:	Grayish in trunk and yellowish in the ovoid yolk sac; gray to dark in upper trunk and entire postanal regions, whitish ventral head and midventral; overall pigmentation is much lighter compared to white sturgeon of similar life stage; ventral head and midventral covered with light pigmentation when the yolk sac is absorbed; eye developed (Deng, 2002).
Distribution:	Upper Sacramento River, Feather River.

Juveniles

Dorsal fin rays:	33 – 42 (Miller and Lea, 1972); 33 – 35 (Scott and Crossman, 1973); 33 – 36 (Hart, 1973; Moyle (1976); 40 – 44 (Deng, 2000).

Anal fin rays:	22 – 29 (Miller and Lea, 1972); 22 – 28 (Scott and Crossman, 1973; Hart, 1973; Moyle, 1976); 26 – 32 (Deng, 2000).
Pectoral fin rays:	31 – 34, pectoral spine is fused by 2 – 3 pectoral rays; 33 – 38 (Deng, 2000).
Dorsal bony plates:	8 – 11 (Miller and Lea, 1972; Moyle, 1976); 9 – 11 (Scott and Crossman, 1973); 7 – 11 (Hart, 1973); 8 – 10 (Deng, 2000); 9 and started to develop at 25 mm TL .
Lateral body plates:	23 – 30 (Miller and Lea, 1972 Scott and Crossman, 1973; Hart, 1973; Fry, 1973; Moyle, 1976; Wydoski and Whitney, 1979); 24 – 28 (Deng, 2000).
Ventral body plates:	7 – 10 (Miller and Lea, 1972; Scott and Crossman, 1973; Moyle, 1976); 7 – 11 (Hart, 1973); 5 – 6 (Deng, 2000); 5 – 6 and developed at 30 – 35 mm TL .
Mouth:	Ventral, directed down, transverse (Hart, 1973); toothless, protractible, and sucker-like, on ventral side beneath the eyes (Hart, 1973); mouth located on ventral side slightly behind the eye in juvenile .
Distribution:	The Delta (including the south Delta in the vicinity of the TFCF), Suisun Bay, San Pablo Bay, and San Francisco Bay.

Reference Specimens Used in this Study

1) Laboratory specimens obtained from UCD by René Reyes in 2004 (Original research on incubation and initial feeding was done by Deng in 2000).

2) TFCF salvager and intake trash rack catch (mostly in winter months), 1991 – 2005.

3) Reclamation Red Bluff Pumping Plant in Sacramento River (Borthwick, 2002).

Life History

The green sturgeon has been reported from Ensenada, Mexico, north to the Bering Sea and Japan (Miller and Lea, 1976). They are also found along the Pacific coasts of Korea, China and the Amur River of Russia (Berg, 1948; Hart, 1973), and have been observed as far south as Taiwan (Matsubara, 1955). Some of these sturgeons, however, may belong to the Sakhalin sturgeon or the another Asian species closely related to the green

sturgeon (Moyle, 2002). Green sturgeons have been reported in San Francisco Bay (Aplin, 1967), San Pablo Bay (Ganssle 1966; Miller 1973), the lower San Joaquin River, and elsewhere in the Delta (Radtke, 1966). Since the 1970's, green sturgeons have been seen more often in the upper Sacramento River and Feather River areas (Fry, 1973; Moyle et al., 1995); however, they have also been reported in Tomales Bay (Bane and Bane, 1971), and Bodega Bay (Standing et al., 1975).

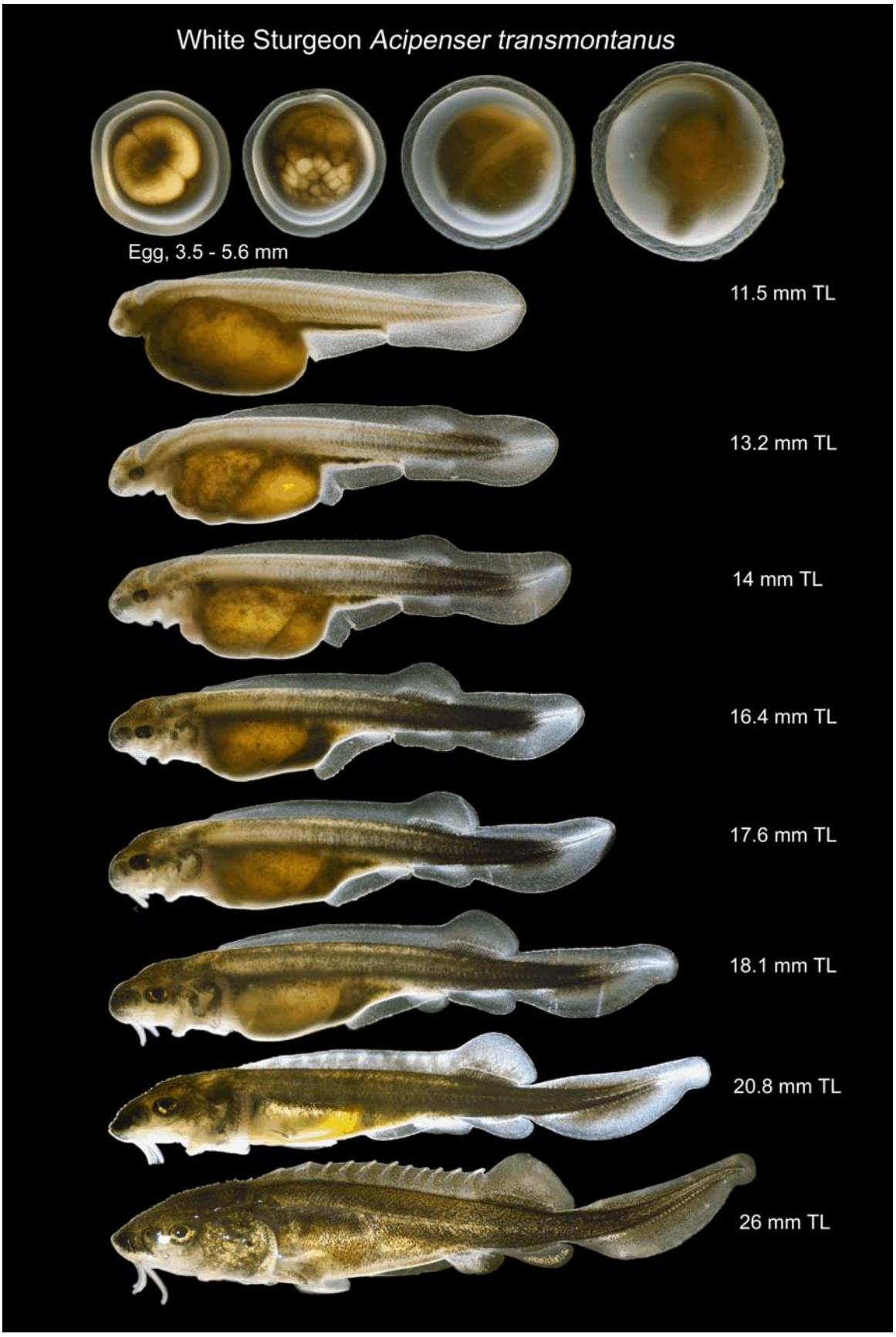
Based on larval sturgeons collected during salmon out-migrant trap sampling, Moyle (2002) estimated that green sturgeon might spawn in the lower Feather River and the main body of the upper Sacramento River. Green sturgeons were not collected in the rotary screw trap and beach seining studies in the Feather River during 1999 – 2001 (Seesholtz et al., 2004), but small green sturgeon have been reported near Red Bluff in the Sacramento River (Borthwick, 2002). Green sturgeon spawning locations in the Sacramento and Feather Rivers have not yet been observed, though juvenile green sturgeons have been collected in those areas.

The embryonic development, hatching and growth rate of the green sturgeon under laboratory conditions (brood stock obtained from Klamath River) were described by Deng (2000). The incubation period is 10 days at 15.7 ºC. Green sturgeon have a much larger and longer hatch-out larva (12 – 15 mm TL, compared to 10 – 11 mm TL, white sturgeon) and shorter preanal length (60 – 62 percent of TL vs. 68 – 70 percent of TL for white sturgeon). Larval green sturgeon swim near the bottom (Deng, 2000), unlike the white sturgeons which are initially pelagic (Beer, 1981; Deng, 2000). The newly hatched yolk-sac larvae swim actively near the bottom of the hatching jar, resting dorso-ventrally and occasionally on their sides. Green sturgeon larvae reside in the crevices of rocks on the spawning ground (Deng, 2000). At 25 – 30 mm TL, they feed at the bottom when the yolk sac still exists, and swim to the surface when hungry. Historically, the smallest of the fish identified as green sturgeon were 20 – 22 mm fork length (FL) and were captured by gill net and trawl during 1963 – 1964 by Radtke (1966). Most of the small sturgeons collected in the field by Radtke were identified as Acipenser sturgeons, or perhaps misidentified as the white sturgeon.

Juvenile green sturgeon reach full metamorphosis at average TL of 74 mm (Deng, 2000). Large juveniles are distributed in scattered patterns in San Francisco Bay and Delta. They were collected at Suisun Bay and the west Delta areas by various resource agencies and private consulting firms such as Ecological Analysts in 1978 – 1981. Based on Delta collections by the California Department of Fish and Game (CDFG), Moyle (2002) estimated the green sturgeon population to range between from 140 to 1,600 for the . years 1954 – 1987. The Delta is believed to be the southernmost of its reproductive range; however, the life history of the green sturgeon in this area remains poorly documented. Juvenile green sturgeon consume mostly amphipods and mysid shrimps as their regular diets in the Delta (Radtke, 1966).

Green sturgeon are harvested by commercial fishermen and Native Americans in the Columbia River and Klamath River (Fry, 1973; Moyle, 2002). Recreational anglers that fish for green sturgeon often refer to this species as 'sturgeon.'

FIGURE 2 – White sturgeon eggs, larvae, and prejuvenile. Eggs provided by Stoltz Sea Farm, Galt, California. Eggs and larvae incubated at 16 ˚C and raised at the TFCF at 18 – 19 ˚C. TL = total length. Photographs are not to scale. Reclamation photographs by René C. Reyes.



White Sturgeon, *Acipenser transmontanus* (Richardson)

The life history of the white sturgeon has been well studied (Doroshov et al., 1983; Conte et al., 1988), and commercial fish farming of the white sturgeon was established in California during the 1980's (Beer, 2002). Eggs from the Central Valley brood stock were obtained from Stoltz Sea Farm in Galt, CA and incubated at 16.0 ± 1 ˚C. Larvae were reared at 18 - 19 ˚C in Delta water. Figure 2 shows white sturgeon eggs, larvae, and juveniles.

Spawning

Locations: Upper Sacramento River and lower Feather River (Stevens and Miller, 1970); Upper Sacramento River (Fry, 1973); mostly in the Sacramento River between Knights Landing and Colusa (Kohlhorst, 1976); some may also spawn in San Joaquin River (Kohlhorst, 1976; Kohlhorst et al., 1991); eggs were collected in the Sacramento River between Freeport and Rio Vista; major spawning was reported between Freeport and Colusa on Sacramento River (Lutes, 1982); eggs and larvae were collected in the upper Sacramento River, up to Colusa ; some white sturgeon eggs and larvae were observed in Cache Slough to the mouth of the Sacramento River, and larvae in the vicinity of Port Chicago at Suisun Bay. (CDFG fish egg and larvae [E&L] sampling, 1988 – 1995; North Bay Aqueduct (NBA) fish E&L sampling, 1993 – 2004).

Season: Mid-February to late May (Kohlhorst, 1976); late February to early June (Moyle, 2002); somewhat late in the northern Pacific coastal rivers, in May and June (Scott and Crossman, 1973). Eggs and larvae were collected in the CDFG's fish E&L survey in the Sacramento River in March and April; major spawning occurs in late winter and early spring.

Temperature: 7.8 – 17.8 ºC, peaking at 14.4 ºC (Kohlhorst, 1976); 8 – 19 ºC (Moyle, 2002); ambient temperature at hatchery 12 – 16 ºC (Beer, 2002); UCD sturgeon hatchery water temperature 12 – 19 ºC (Lutes, 1982); 14 – 15 ºC in the field during the peak of catch of *Acipenser spp.* larvae (Stevens and Miller, 1970); estimated 13.0 – 13.5 ºC when the eggs were collected (Wang, 1986); at 15.7 ºC, egg will hatch in 176 hours (Deng, 2000).

Salinity: Freshwater.

Substrates: Gravel and rock bottoms (Moyle, 2002); over sandy or muddy bottoms (Doroshov, 1980); hard clay and other various substrates (Lutes, 1982); various available substrates in high flow channel.

Fecundity:	3 – 4 million (Migdalski, 1962); 700,000 (Scott and Crossman, 1973); 3 million eggs for a 3-m (FL), 50-year-old female (Dees, 1961); over 200,000 eggs from a 1.5-m FL female (Moyle, 2002); 3,000 – 12,000 eggs per kg per batch, and several batches of eggs can be produced by a single female during spawning (Lutes, 1982).

Eggs

Shape:	Spherical, oval, or slightly irregular (Beer, 1981); slightly pear-shaped in early development due to the holoblastic and unequal cleavages.
Diameter:	Fertilized eggs with a thick layer of jelly coat, short axis 3.8 mm and long axis 4.0 mm (Beer, 1981); fertilized eggs 3.3 – 3.5 mm and long axis 3.5 – 4.0 mm for eggs obtained from Ken Beer, (Wang, 1986); field collections 3.2 – 3.8 mm (CDFG samples); 3.7 – 4.2 mm on short axis and 4.1 – 4.3 mm on long axis (laboratory brood stock obtained from UCD).
Yolk:	Overall, slate gray, animal pole whitish (Beer, 1981); brown (Scott and Crossman, 1973); dark gray brown with light yellow spots at animal pole for hatchery stock (Wang, 1986); overall dark gray in field collections .
Oil globule:	None (Cherr and Clark, 1982).
Chorion:	Clear, thick with 4 layers (Cherr and Clark, 1982); twice as thick compared to green sturgeon (Deng, 2000); clear, with multiple layers .
Perivitelline space:	Prominent at animal pole (Beer, 1981); overall, very narrow (Wang, 1986).
Egg mass:	Assumed broadcasted singly, and spawn in batches (Lutes, 1982).
Adhesiveness:	Adhesive (Beer, 1981); sticky (Scott and Crossman, 1973); more substrates attached to the vegetable pole; egg diameter dilated as early as late morula stage and becomes less adhesive over time. Egg can dilate up to 7.0 – 7.5 mm prior to hatching and chorion turns into web-wrinkled texture.
Buoyancy:	Demersal; eggs can be carried downstream in the fast current or high flow after chorion dilates and detaches from the substrates

(CDFG samples collected in Lower Sacramento River, 1993 and 1995).

Larvae

Length at hatching:	Mean length 11.0 mm TL (Beer, 1981); 10.0 – 11.1 mm TL (Wang, 1986); 10.7 – 11.3 mm TL for batch of hatchery stock obtained from UCD; 11.1 mm TL was the smallest larva collected in the field at sampling station #726 in Miner Slough on February 23, 1997 (CDFG/NBA Project fish E&L sampling).
Snout to anus length:	68 – 70 percent of TL of prolarvae at 10.0 – 11.1 mm TL; 56 – 59 percent of late prolarvae at 16.7 – 17.8 mm TL; 53 percent of TL of juvenile at 31.0 mm TL (Wang, 1986); newly hatched in 0 – 1 day old 66 – 69 percent; decreasing to 56 – 57 percent in 10 – 15 days old larvae; becoming 60 percent after 21 – 45 days (Deng, 2000).
Yolk sac:	Ovoid, light pigmentation ventral surface; dark pigmentation on dorsal and posterior portion (Beer, 1981); gray – yellowish, very large, extends from jugular to mid-abdominal region (Wang, 1986).
Oil globule:	None.
Gut:	Straight.
Size at absorption of yolk-sac stage:	15.5 – 15.8 mm TL (Beer, 1981); 17.6 – 18.5 mm for *Acipenser spp.* larvae (Stevens and Miller, 1970; Kohlhorst, 1976); 18 – 20 mm TL .
Total myomeres:	Newly hatched larvae, 55 – 60 somites (Beer, 1981); 60 to >70 for sturgeon less than 31 mm TL, estimation due to the postanal myomeres jammed at the end of the tail (Wang, 1986).
Preanal myomeres:	37 – 40 (Wang, 1986); 40 – 45.
Postanal myomeres:	25 to >30 (up to the base of urostyle; Wang, 1986).
Last fin (s) to complete development:	Pelvic and anal.
Pigmentation:	Newly hatched larvae, scattered melanophores on side of body and head (Beer, 1981); prolarvae, scattered melanophores on head, body and lateral portion of the yolk sac, postanal region

may have a dark band, and a dark strip attached to the ventral of urostyle; eye is a dark pit; late postlarvae, melanophores on head, body, and the finfolds except the ventral side of yolk sac and barbels; in postlarvae, pigment covers entire body.

Distribution: Initially pelagic (Beer, 1981; Deng, 2000); becoming demersal when pectoral fins are fully developed (Beer, 1981; Deng, 2000); channels and deep waters near the bottom in lower reaches of the Sacramento and San Joaquin Rivers, and the Delta (Stevens and Miller, 1970); near the bottom in upper Sacramento River (Kohlhorst, 1976); judging by the larval taken, the distribution is known mostly in the deeper waters from the Colusa of the Sacramento River to Port of Chicago at Suisun Bay, uncommon on the San Joaquin River side of the Delta (CDFG fish E & L sampling, 1988 – 1995); laboratory observations, larvae swim in the various levels of the water column .

Juveniles

Dorsal fin rays: 44 – 48 (Miller and Lea, 1972; Scott and Crossman, 1973; Hart, 1973; Moyle, 1976); 40 – 44 (Deng, 2000).

Anal fin rays: 28 – 31 (Miller and Lea, 1972; Hart, 1973; Moyle, 1976); 28 – 30 (Scott and Crossman, 1973); 26 – 32 (Deng, 2000).

Pectoral fin rays: 33 – 38 (Deng, 2000); I, 35 – 39. The pectoral spine consists of at least 3 fused pectoral rays.

Lateral body plates: 38 – 48 (Miller and Lea, 1972; Scott and Crossman, 1973; Moyle, 1976; Wydoski and Whitney, 1979); 34 – 40 (Deng, 2000).

Ventral bony plates: 9 – 12 (Miller and Lea 1972; Scott and Crossman, 1973; Moyle, 1976); 8 – 11 (Deng, 2000).

Mouth: Ventral, toothless, wide and transverse (Scott and Crossman, 1973; Hart, 1973); on ventral side, a short distance behind the eyes (Fry, 1973).

Distribution: From San Francisco Bay to Sacramento and San Joaquin Rivers and the Delta, most of them concentrating in the upper estuary (Wang, 1986).

Reference Specimens Used in this Study

1) Eggs, larvae, and research information were obtained from Ken Beer, 1981 – 1982.

2) Eggs, larvae and research information were obtained from Xing Deng, 2000 – 2001.

3) Eggs and larvae field specimens were obtained from CDFG fish E&L sampling, 1988 – 1995, and then at the NBA fish E&L sampling, 1995 – 2004.

Life History

White sturgeon have been reported from Ensenada, Mexico, northward to the Gulf of Alaska by Miller and Lea, (1972); from Monterey, California to Cook Inlet in northwestern Alaska by Wydoski and Whitney, (1979); but are rarely found south of Monterey (Fry, 1973). In California, white sturgeon have been reported in San Francisco Bay (Aplin, 1967), San Pablo Bay (Pycha, 1956; Ganssle, 1966), Carquinez Strait (Messersmith, 1966), the lower reaches of the Sacramento and San Joaquin Rivers and elsewhere in the Delta (Radtke, 1966; Stevens and Miller, 1970; Miller, 1972a, 1972b, 1972c); the Sacramento River drainage (Kohlhorst, 1976), and at the TFCF intake channel during winter and spring months.

Spawning occurs from February through June (Kohlhorst, 1976; Moyle, 1976). Suitable water temperatures are 12 – 15 ºC (Beer, 1981); with a wider range of 8 – 19 ºC reported by McCabe and Tracy, (1991). The major spawning locations are in the Sacramento Rivers between Freeport and Colusa (Kohlhorst, 1976; Lutes, 1982). They may also use the Feather River as spawning ground (Kohlhorst, 1976). White sturgeon eggs collected in the Cache Slough and mouth of the Sacramento River near Collinsville suggest that spawning moves to the lower Sacramento River during high freshwater flow as seen during the wet years of 1993, 1995, and 1998. Because most eggs were observed in the deeper river channels, white sturgeon may seek deeper water as their preferred spawning ground. Wang (1986) collected white sturgeon eggs and yolk-sac larvae during 1978 in the Sacramento River channel between Freeport and Rio Vista at depth of 10 m.

The eggs are adhesive (Scott and Crossman, 1973; Beer, 1981). The egg chorion is very thick and has 3 – 15 micropiles (Cheer and Clark 1982). The details of the embryonic development and early life stages of the white sturgeon were documented by Beer (Beer, 1981). Eggs hatch in a little over 4 days at 16 ºC (Beer, 1981) or 8 – 12 days at 12 ºC (Lutes, 1982); and 5 – 6 days at room temperature 18 – 20 ºC . The sizes artificially spawned and hatched white sturgeon eggs and larvae are identical to those collected from the wild.

The average total length of newly hatched larvae is 11.0 mm TL, with a large yolk sac, and small, underdeveloped eyes (Beer, 1981), and 10.7 – 11.3 mm TL was observed in this study. Newly hatched larvae swim vertically and then switch to horizontal position

within one day. The initial vertical swimming is believed to be the result of downstream drifting (Beer, 1981) similar among other sturgeon species (except the green sturgeon). When the pectoral fin is well developed, the white sturgeon larvae swim near the bottom (Beer, 1981). The yolk sac is absorbed after 7 – 10 days, depending upon water temperature.

The majority of the white sturgeon larval population is believed to be in the upper Sacramento River. Stevens and Miller (1970) collected 85 yolk-sac larvae and larvae of *Acipenser spp.* in the lower reaches of the Sacramento River, the lower San Joaquin River, the Delta, and Suisun Bay during their 1966 – 1967 sturgeon survey. Kohlhorst (1976) collected 9 eggs and 246 larvae of *Acipenser spp.* between the mouth of Feather River and Colusa on the Sacramento River in 1973. The majority collected were identified as white sturgeon (Stevens and Miller, 1970; Kohlhorst, 1976). Wang (1986) reported that 2 sturgeon eggs and 11 larvae were collected between Freeport of Sacramento River and Suisun Bay during April and May 1978 (a wet water-year), with most collected in the section between Freeport and Rio Vista on the Sacramento River. Sturgeon larvae were also collected between Colusa on the Sacramento River and near Port Chicago in Suisun Bay (CDFG 1988 – 2004, unpublished data). More white sturgeon larvae were observed in Suisun Bay and Montezuma Slough during wet water-years. Sturgeon eggs were also observed in the lowest reaches of the Sacramento River indicating that some spawning may occur in the lower Sacramento River. White sturgeon eggs and larvae were uncommon in the lower San Joaquin River in 1988 – 1995 compared to an earlier study (Kohlhorst, 1976).

Juvenile sturgeon attain fully developed bony plates in the wild at about 40 mm TL and in the laboratory at about 30 mm TL. Juvenile sturgeon this size and larger were commonly captured by trawl in Montezuma Slough, in the vicinity of the Contra Costa and Pittsburg power plants, and in the lower reaches of both the Sacramento and San Joaquin Rivers (Wang, 1986). Larger juveniles were also collected at the TFCF in late winter and spring. Pycha (1959) reported that young sturgeon are nonmigratory, but Bajkov (1951) and Scott and Crossman (1973) have suggested that juveniles move upriver in late summer and fall and move downriver in spring and summer. The primary purpose of the movement may be for feeding. In the estuary, Moyle (1976) described young sturgeon living mostly in the upper reaches of the San Francisco Bay estuary. McEnroe and Cech (1987) found that young sturgeon prefer the upper reaches of the estuary suggesting that salinity tolerance increases with size. Juvenile white sturgeon were occasionally observed in the upper Napa River.

The white sturgeon is an anadromous fish; however, their migration patterns are only now being understood. Fishes tagged in the San Pablo Bay (Chadwick, 1959), and Columbia River (Wydoski and Whitney, 1979) showed white sturgeon moving randomly or not at all.

Juveniles feed on mysid shrimps, amphipods (Schreiber, 1962), small clams, polychaetes, and fish eggs (Ganssle, 1966; Radtke, 1966); and also overbite clams, *Corbula amurensis* reported in recent years (Moyle, 2002). Juveniles feed mainly during the night and rest during the day (Lutes, 1982).

Female white sturgeon mature at 12 – 16 years, and male at 10 – 12 years (Kohlhorst et al., 1991). Males, in general, reach sexual maturity at a smaller size than females

(Moyle, 1976). In captivity, the male white sturgeon reaches sexual maturity as early as 3 – 4 years, and female at about 5 years (Lutes, 1982). White sturgeon may not spawn every year, with some indications that females reserve energy for developing larger ova. The interval between spawning is about 4 years for young females and 9 – 11 years for older females (Scott and Crossman, 1973); however, a small fraction of the breeding population may spawn each year (Moyle, 2002). Spawning frequency may also depend on food availability.

White sturgeon supports an important sport fishery in the Delta, however, commercial caviar fishing is illegal. White sturgeon has been successfully cultured and the cultured caviar market is now established in the Sacramento area (Beer, 2002).

Taxonomic Characteristics Distinguishing Green Sturgeon and White Sturgeon:

I. Egg size (diameter): Refer to figure 3 for images comparing green and white sturgeon eggs.

Green sturgeon: 3.0 – 4.2 mm for newly fertilized eggs, dilates to 5.7 – 6.3 mm (short axis) and 6.7 – 8.4 mm (long axis) before hatching.

White sturgeon: 4.0 – 4.5 mm for newly hatched eggs, dilates to 6.0 – 6.4 mm before hatching.

II. Larval Characteristics - Refer to figures 4 and 5 for images comparing green and white sturgeon larvae and juveniles.

	Green sturgeon	White sturgeon
Hatching Size	12 – 14 mm TL	10 – 12 mm TL
Ratio of Gut Length:TL	61 – 62 percent	66 – 69 percent
Eye Development	Good - with lens	Poor - with eye pit
Yolk Sac	Very Large, ovoid (distal end closer to anus)	Small, ovoid (distal end not close to anus)

III. Juvenile Characteristics

	Green sturgeon	White sturgeon
Lateral body bony plates	23 – 30	38 – 48
Barbels	4, near mouth	4, near snout
Shape of snout	Narrow (Crocodile–like)	Wide (Alligator–like)

FIGURE 3 – Comparing the eggs of green (left) and white (right) sturgeons. Green sturgeon eggs were provided by Joel Van Eenennaam, UCD, and incubated at 15.5 ˚C. White sturgeon eggs were provided by Stoltz Sea Farm, Galt, California, and incubated at 16 ˚C. Eggs developed and were photographed at the TFCF at 18 – 19 ˚C. dps = days post spawn. Reclamation photographs by René C. Reyes.

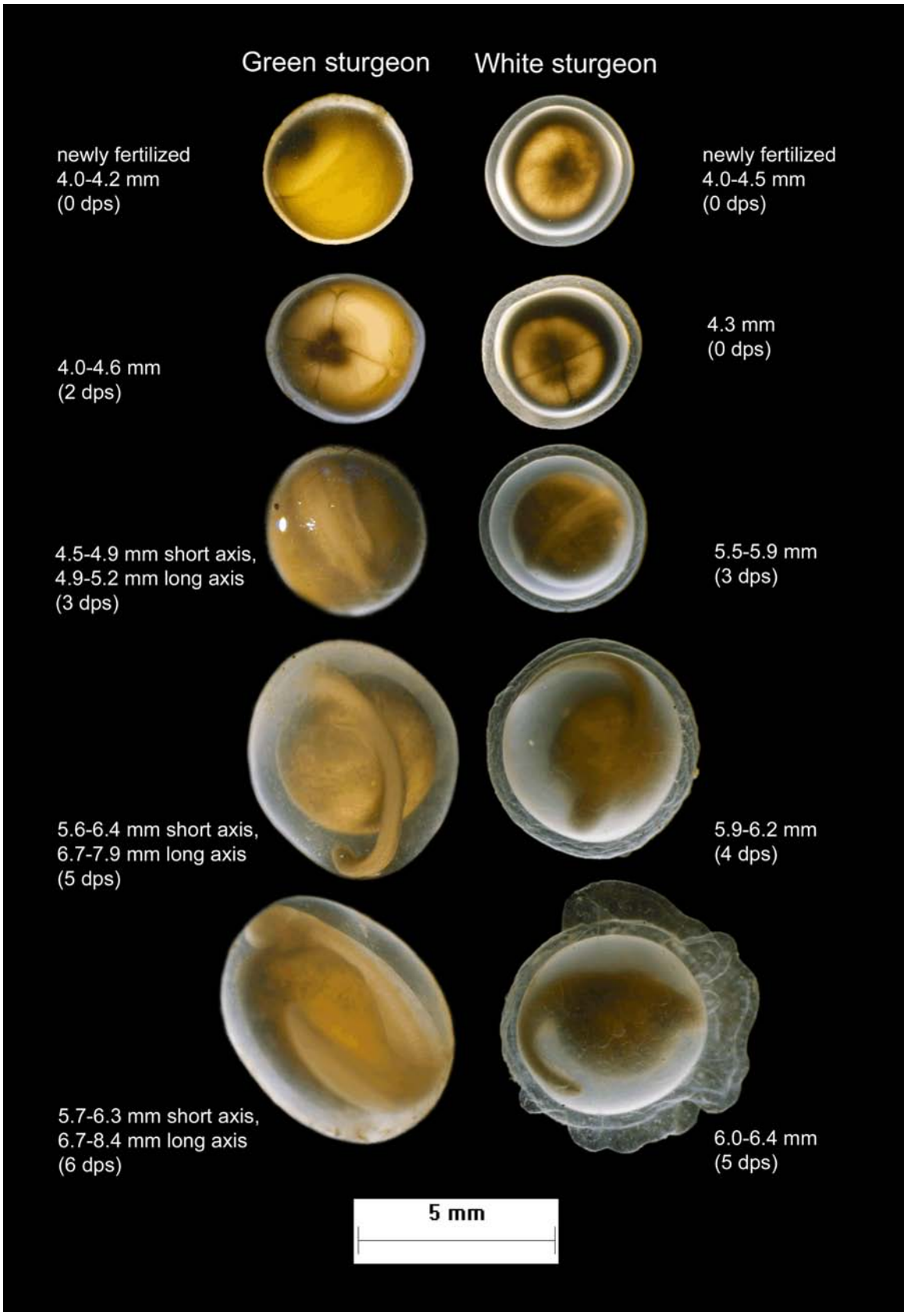
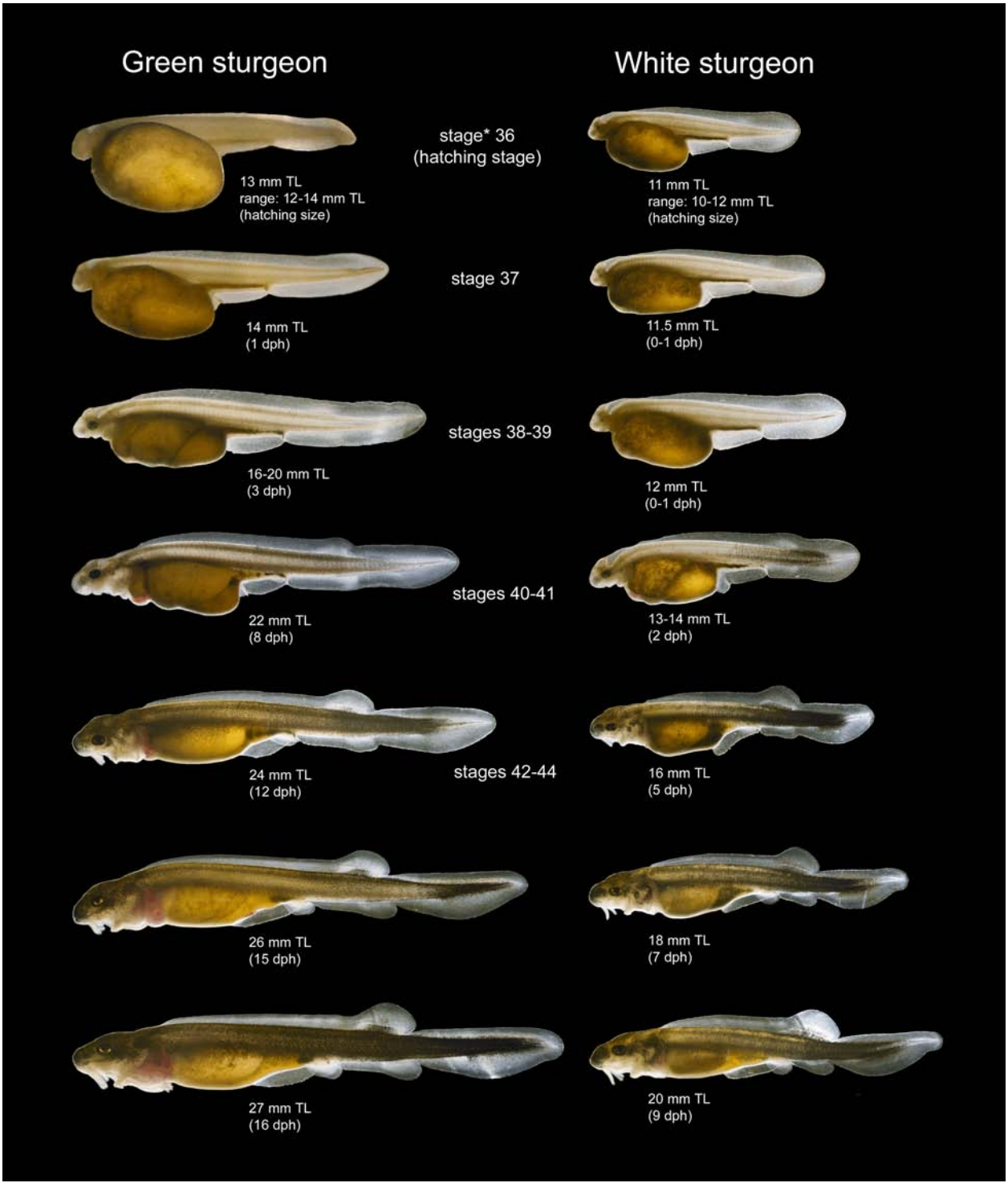


FIGURE 4 – Images comparing same-sized larval green (left) and white (right) strugeons. Specimens were raised at 20˚ ± 1 ˚C at the TFCF. mm TL = millimeters total length. Reclamation photographs by René C. Reyes.

FIGURE 5 – Images comparing same life stages of green and white sturgeon larvae. Life stages are based on Dettlaff, et al., (1993). Reclamation photographs by René C. Reyes.



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