MIGRATION OF GREEN STURGEON *ACIPENSER MEDIROSTRIS* IN THE SACRAMENTO RIVER

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by

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San Francisco, California

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CERTIFICATION OF APPROVAL

I certify that I have read *MIGRATION OF GREEN STURGEON ACIPENSER MEDIROSTRIS IN THE SACRAMENTO RIVER* by Joseph Heublein, and that in my opinion this work meets the criteria for approving a thesis submitted in the partial fulfillment of the requirements for the degree: Master of Science in Biology: Ecology and Systematic Biology at San Francisco State University.

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MIGRATION OF GREEN STURGEON *ACIPENSER MEDIROSTRIS* IN THE SACRAMENTO RIVER

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I certify that the Abstract is a correct representation of the content of this thesis.

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Introduction

The green sturgeon is one of two species of sturgeon spawning in western North America. They exhibit the most wide ranging ocean migration of any member of the sturgeon family (Moyle et al 1992). Green sturgeon are known to spawn in only three rivers. Only the Rogue River in Southern Oregon, the Klamath River in Northern California, and Sacramento River in Northern California have evidence of spawning populations (Moyle et al 1994). Sport fisheries exist for green sturgeon in California, Oregon, and Washington. Commercial fisheries currently exist in Oregon and Washington and tribal fisheries persist in California and Washington (Adams et al 2002).

Age at first reproduction for male green sturgeon is 15-17 years, and 20-25 years for females (pers comm J. Van Eenenaam University of California, Davis [UCD] Department of Animal Science). Green sturgeon are known to initiate upriver spawning migrations in the spring. Tagged green sturgeon were detected migrating up the Rogue River in March, April, and May (Erickson and Webb 2006). Green sturgeon were also detected migrating up the Klamath River from April to June (Benson et al 2006). They have been observed in the Rogue and Klamath Rivers to aggregate in low-velocity reaches during the summer, and to migrate downstream in late fall to early winter when flow increases occur (Erickson and Webb 2006, Benson et al 2006).

Observations of green sturgeon spawning have not been documented. Green sturgeon potentially spawn on rocky bottoms in high-velocity, river habitats. Sturgeon spawning in swift water produce eggs with comparatively high adhesiveness (Vorobyeva and Markov, 1999). Initially, green sturgeon artificially spawned in a laboratory setting, were reported to have low egg adhesiveness (Van Eenennaam et al 2001). Upon further investigation, green sturgeon eggs were observed to exhibit high adhesiveness (pers comm. J. Van Eenennaam UCD, Department of Animal Science). Larval green sturgeon have higher growth rates and lower mortality when reared on slate or glass substrate than on cobble or sand substrates (Nguyen and Crocker 2006). These laboratory studies suggest green sturgeon larvae and egg adaptation to rock bottoms and high water velocities.

Our understanding of the timing and location of spawning in the Sacramento River is based primarily on anecdotal reports. Two green sturgeon eggs were collected directly below the Red Bluff Diversion Dam (RBDD) and one larva below Bend Bridge (above RBDD on the Sacramento River, Sac. R.) in June and July of 2001 respectively; and these two observations imply that the sturgeon migrate upriver during spring (Brown 2006). Additionally, sub-samples of 517 sturgeon larvae in 1994, and 291 between 1996 and 2000, were collected in rotary screw traps below RBDD. All were identified as green sturgeon by the Center of Aquatic Biology and Aquaculture (CABA) at UCD (Johnson and Martin 1997, Gaines and Martin 2001). The presence of eggs and early-stage larvae at RBDD indicates the presence of a spawning population of green sturgeon in the Sacramento River upstream of RBDD.

The Red Bluff Diversion Dam was constructed in 1966. RBDD is a seasonal dam with flow-control gates installed annually between 15 May and 14 Sep. A fish ladder (for salmonid passage) and narrow gap (<.5 meters) between the river bottom and flow-control gates are the only opportunities for passage during closure periods. No green sturgeon have been observed migrating up the fish ladder, and extreme water velocities below the flow-control gates prevent any upstream passage below the dam (Brown 2006). It is thus assumed that the fish ladder is not functional for sturgeon passage, and no green sturgeon pass upstream of RBDD after the 15 May closure. Consistent observation of sturgeon directly below the RBDD after the gates are closed annually on 15 May suggest that sturgeon are potentially impeded in up-migration (pers comm Kurt Brown). Catches of green sturgeon exhibiting post-spawn gonad condition near the Glen Colusa Irrigation District (GCID) pumping facility before the 14 Sep opening of the control gates imply that green sturgeon pass downstream, below flow-control gates, after spawning (ongoing tagging efforts of green sturgeon, 2001 to present, Matt Manual, Glen Colusa Irrigation District). Spawning in reaches below the RBDD is also indicated by the mature gonad condition exhibited by some of these sturgeon.

Most observations of green sturgeon, aside from those directly below the RBDD, occur near GCID. It is unknown what attracts and sustains sturgeon in this section of the river, but it holds the largest known aggregation of green sturgeon in the Sacramento River. Over 50 adult green sturgeon are captured and tagged here annually, with numerous others observed and caught by sportfishermen (per comm. Matt Manual, GCID).

The green sturgeon is considered Species of Special Concern by the California Department of Fish and Game, and the United States Fish and Wildlife Service. The National Marine Fisheries Service listed the Southern Distinct Population Segment (green sturgeon spawning South of the Eel River in California) as Threatened under the Endangered Species Act (NOAA Federal Register April 2006). This proposal was initiated due to limited amounts of known green sturgeon spawning habitat and historic and current low population estimates.

With the limited knowledge I had available on the Southern DPS of the green sturgeon, I formulated a study to improve understanding of the green sturgeon’s behaviors in the Sacramento River. The goals of this study are to identify the timing of green sturgeon spawning migration in the Sacramento River, describe spawning habitat above the Red Bluff Diversion Dam, and locate aggregations and impediments throughout the spawning migration.

My hypothesis is: green sturgeon enter the Sacramento River between March and May, migrate beyond the Red Bluff Diversion Dam prior to the 15 May closure, and spawn in high velocity reaches over rock substrate. After spawning, sturgeon migrate below the RBDD flow-control gates to reaches adjacent to the GCID pumping plant between July and October, and migrate out of the Sacramento River in November and December. Some green sturgeon entering the Sacramento River after April experience a barrier to upstream migration at RBDD, and potentially spawn in reaches below RBDD.

Methods

Collection

Green sturgeon were collected over five sampling periods between 2004-2006: Spring 2004, Fall 2004, Spring 2005, Fall 2005, and Spring 2006. All periods lasted for 40 days with the exception of Spring 2006 which lasted for 18 days (Table 1). Sampling was continuous over the season unless weather prevented effective collection on a particular day.

Collection was carried out by a commercial herring gill net boat (*F/V Intrepid*) in San Pablo Bay. The monofilament gill nets used ranged in length from 274-365 meters, and in mesh size from 19 to 24 centimeters. The gill nets ranged in depth from 18 to 35 mesh, depending on mesh size (Appendix 1). The selected collection gear was based on the ongoing mark and recapture white sturgeon project by the California Department of Fish and Game, Bay Delta Program.

All but eight of the 178 10-h fishing days were carried out from approximately 0400 hrs to 1400 hrs. Most days involved a one hour journey from the Vallejo Marina to and from the fishing grounds in San Pablo Bay. Gill netting commenced at 0530 hrs in the morning in 2-4 m of water. Fishermen averaged three gill net sets per sampling day, with 1.5 h of fishing for each set. Removing fish from the net took on average 0.5-1.0 h, and resetting took 0.5-1.0 hr. We recorded the number of individuals per species captured and released, and undersized green sturgeon were measured and released.

The minimum size of the tagged fish was usually 130 cm TL. However, when catches were high, the minimum size of fish tagged was increased to 140 cm in order to enhance chances of tagging spawning sturgeon. When catches were low, the minimum size of fish tagged was reduced to 120 cm to allow for implantation of all tags.

Green sturgeon above the selected minimum size were transported back to the Vallejo Marina in the 500L holding tank at the completion of the fishing day.
Green sturgeon tagged in South-Western Washington, by other cooperative studies, were also included in this analysis. These sturgeon were collected with similar gill-netting methods in Willapa Bay, Grays Harbor, and the lower Columbia River from 2003-2005. These studies were administered by Mary Moser and Olaf Langness of the Oregon and Washington Departments of Fish and Wildlife and Steven Lindley of the National Oceanic and Atmospheric Administration. Sturgeon were also tagged with similar techniques described below.

Tagging

Green sturgeon were anesthetized in the onboard holding tank while at dock at the Vallejo Marina. During Spring 2004, Fall 2004, and Spring 2005, tricaine methane sulphonate (MS-222) was used as an anesthetic. Preparation for surgery involved draining the holding tank to 100 L and adding 7.5 g of MS-222 using a concentration of 0.075g MS-222 per L. After approximately five min, the fish were rolled to an inverted position with their mouth and gills still below the water surface. The ventral surface of the fish was exposed, and swabbed with iodine disinfectant. A 4 cm longitudinal incision was made with a sterile scalpel adjacent to the third or fourth scute, and offset from the midline. The peritoneal cavity was inspected to determine, when possible, the sex of the fish and the maturity of the gonads, and an ultrasonic pinger (V16, Vemco Ltd.), which was 106 mm long, 16 mm in diameter, and 16 grams weight, was inserted into the peritoneum. The incision was closed using PDSII monofilament sutures with 3-4 knots depending on incision length and the sturgeon was returned to a ventral-side down position. The fish was resuscitated in fresh water pumped into the tank along with diffused oxygen. An overnight holding period followed the surgery, and sturgeon were checked for normal ventilation rate and good suture condition prior to release at the site of capture.

I used identical methods during Fall 2005 and Spring 2006 except sodium bicarbonate and acetic acid (buffer) were used as anesthetic. The holding tank was again drained to 100L and 270g of $NaCO3$ and 100 mL of acetic acid were mixed in 5 L of ambient water and introduced into the holding tank (Peake 1998).

Monitor Placement

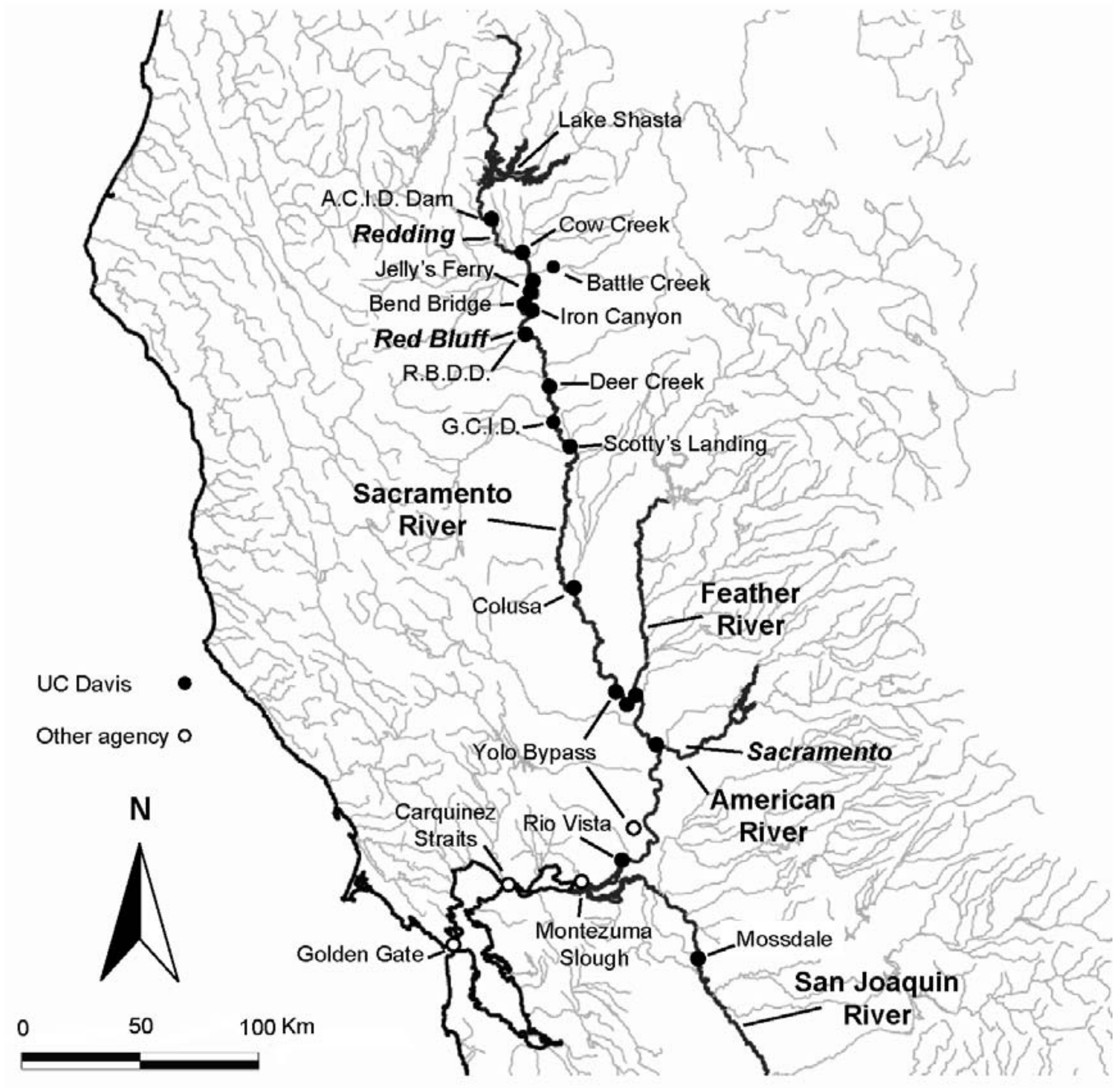
Tagged green sturgeon were detected by an array of automated data-logging monitors (VR2, Vemco Ltd.) deployed between the Sacramento/San Joaquin River Delta and the Anderson-Cottonwood Irrigation District (ACID) water diversion dam in Redding, CA. The array consisted of approximately 30 monitors, depending on loss and theft (Figure 1, Table 1). Monitor moorings were installed by fastening one end of a 20 yard-long 0.25" stainless steel cable to the bank, usually around a large diameter tree, and extending the other end perpendicularly out into the river where it was attached to a 40 pound lead pyramid river anchor (Appendix 2). Also shackled to the anchor was 3 feet of 0.38 inch diameter polypropylene rope which was fastened to a buoy. Heavy gauge cable ties and stainless steel hose clamps were used to attach the VR2 onto the poly rope mid-way between the anchor and buoy with the hydrophone oriented towards the water's surface to maximize detection range.

Monitor sites were selected based on a number of factors. Tag detection ranges by VR2 monitors, when the seas are calm and the ambient noise is low, extends to over 500 meters (UC Davis Biotelemetry Lab, unpublished data). The Sacramento River only exceeds this width in the most downstream monitor sites; however, background noise, bottom contour and obstructions, and the observation that sturgeon swim near the bottom when moving against the current (Kelly et al., in press) likely reduced the detection ranges of the monitors used in this study to less than this optimum value. Monitors were usually set in pairs to avoid missed detections and were sited based on possible migration routes, potential spawning tributaries, aggregation sites, and migration impediments. Positions of some monitor sites were also adjusted later, because of theft and loss.

The Sacramento San Joaquin Delta was not the primary focus and for that reason I installed only two monitors in this area. One VR2 was placed at Mossdale, on the San Joaquin River (see figure 1), to ensure that sturgeon were not migrating in this drainage. A monitor was installed at Brannan Island to detect sturgeon both moving up the San Joaquin River, and also possibly moving into the Sacramento River bypassing the Rio Vista Bridge monitor station via the Delta Cross Channel. The Brannan Island monitor was later placed upriver after the 2005 tracking season.

The Rio Vista Bridge was the first monitor site -- two monitors were set here for best coverage. Another monitor was placed at the confluence of the Sacramento River and Deep Water Ship Channel to assess which path sturgeon moved up the Sacramento River. However, a sturgeon moving through Steamboat Slough, Miner Slough, and at high water, the Yolo Bypass, could bypass of this monitor. California Department of Water Resources maintained a limited number of monitors in the Cache Slough and Deep Water Ship Channel to further investigate movements in the Yolo Bypass (figure 1).

Figure 1: Map of VR2 monitor sites. Solid circles indicate monitors maintained for green sturgeon tracking. Open circles indicate monitor maintained by other agencies.



One monitor was temporarily set in the American River at its confluence with the Sacramento River, but was moved after the monitor at this location was found to have poor reception during 2005. One monitor was set in the Sacramento River at the American River confluence, but it was lost after the high winter flows in 2005 eroded the bank. A monitor was moored in the Feather River at the Sacramento River confluence along with one in the Sacramento River at the confluence (this monitor was also lost in 2005).

Two monitors were set at the base of the upper river at Knight’s Landing. Butte Creek received one monitor at the confluence and one in the Sacramento River at the confluence (this was lost in 2005). Scotty’s Landing on the Sacramento River was maintained as a monitor site when possible. Theft contributed to some missed detections and the monitor was later replaced as this area was a purported green sturgeon aggregation site on the river. Above the Glen Colusa Irrigation District (GCID) pumping facility on the Sacramento River, UCD maintained one monitor year-round starting in 2006 along with several monitors set seasonally by GCID, and a further two monitors were set above and below Thomes Creek on the Sacramento River. Though continually subject to theft and loss, 2 monitors were maintained above and below the Red Bluff Diversion Dam.

The river above Red Bluff Diversion Dam was intensively studied based on earlier collection of green sturgeon eggs and larvae in that region (Brown 2006, Johnson and Martin 1997, Gaines and Martin 2001). Long stretches of high velocity bedrock runs are present in the Sacramento River upstream of RBDD in reaches such as China Rapids and Table Mountain. River morphology and water temperature are similar to the green sturgeon spawning habitat described in the introduction (these conditions are not as prevalent below RBDD). Monitors were placed throughout this reach to identify potential spawning habitat. Monitors were set in pairs on either side of the Sacramento River below China Rapids and Bend Bridge. Monitors were also set in pairs at Jelly's Ferry, above the Battle Creek confluence, and at the Cow Creek confluence. Upriver of Cow Creek confluence, one monitor was maintained in the Bonnyview area, along with one below Anderson Cottonwood Irrigation District (ACID) Dam.

Our main supplemental array for this study was at the Golden Gate Bridge, and maintained by the National Oceanic and Atmospheric Administration (Steven Lindley). Yolo Bypass monitors, maintained by California Department of Water Resources Division of Environmental Services (Zoltan Matica and William Harrell), also recorded detections in our first year of study. Carquinez Straight and Montezuma Slough monitor arrays, temporarily set in 2004 by California Department of Fish and Game Bay Delta Branch (Robert Vincik), recorded detections also included in the results. One set of detections from the Monterey Canyon array, maintained by Rick Starr of the Moss Landing Marine Laboratory is also included.

Data collection

Monitors in our array were downloaded once every 2-3 months. Extreme high and low water prevented access to the monitors during some seasons, and flows during summer months generally permitted for more routine downloads.

Monitors recorded detections by time of day, but given the large distances between monitors, and inherent variability in detection frequency, I used a by-day basis for my analyses. The locations of monitor stations were are given river kilometers (Rkm) (Table 2). Rkm “zero” was in the West Delta at its confluence with the San Joaquin River. Monitoring stations below this location were given negative values in Rkm, and simply represented the closest water distance between the monitor location and Sacramento River mile zero.

Table 1: Selection of VR2 monitor locations by river kilometer

monitor station name	Rkm
Golden Gate Bridge	-94
San Pablo Bay release site	-54
Carquinez Strait	-44
Montezuma Slough	-19
Brannan Island	23
Rio Vista Bridge	21
Sacramento River at confluence with Ship Channel	22
Cache Slough (lower)	25
Cache Slough (upper)	31
Knight's Landing	145
Scotty's Landing	317
Adjacent to GCID diversion	331
Thomes Creek (below)	359
Thomes Creek (above)	365
Below Red Bluff Diversion Dam	391
Above Red Bluff Diversion Dam	393
China Rapids (below)	404
Bend Bridge (below)	414
Table Mountain	422
Jelly's Ferry	430
Battle Creek (above)	438
Cow Creek (below)	451

Sturgeon detected at or above the Knight’s Landing monitor station were categorized as spawning migrants. Knight’s Landing is well upstream of the Delta and potential unrelated movements driven by factors such as forage. First detections of green sturgeon at or above the Knight’s Landing were retroactively established as indicators of up-migration. No immature green sturgeon were detected at Knight’s Landing during this project. All sturgeon detections at Knight’s Landing, after the completion of the UCD array, were followed by a substantial upstream migration and sustained residence in potential spawning reaches. Detections of fish at the highest monitor station upriver was used as a guideline for establishing these spawning reaches. Final detections of individuals at Knight's Landing were indicators of out-migrating sturgeon. No green sturgeon remained at Knight's Landing for more than two days and a rapid downstream migration to the ocean usually followed final detections at the Knight's Landing site.

The movements of migrating green sturgeon can be compared to environmental changes. Verona (Rkm 135), at the confluence of the Sacramento and Feather Rivers, is the most downstream station that records year-round flow measurements in cubic feet per second (CFS) (California Data Exchange Center CDEC). The Red Bluff Diversion Dam is the most downstream CDEC water temperature recorder. The flows from these stations are displayed with sturgeon migrations well below RBDD. Bend Bridge was a CDEC station located in a known area of green sturgeon egg collection above RBDD (Brown 2006). Water temperature and flows at Bend Bridge were plotted together with sturgeon movements above RBDD. Woodson Bridge has the CDEC flow recorder closest to the GCID facility. It is incorporated into the analysis of sturgeon detected in the vicinity if GCID.

Sturgeon codes were based on the location and date of capture. For example, SPB1 was the first sturgeon tagged in San Pablo Bay that was detected by the UCD array, and WB4 was fourth sturgeon tagged in Willapa Bay that was detected by the UCD array (Table 3).

Results

Capture and tagging

We fished for green sturgeon on a total 178 days during five tagging periods from 16 April 2004 to 19 March 2006 (Table 2). In all, 212 green sturgeon were captured, and 96 were tagged. Catches for individual periods are summarized in appendices 3-7. Sixty of the 96 green sturgeon tagged during this study were detected by VR2 monitors.

Table 2: San Pablo Bay green sturgeon capture and tagging summary

Season	Number of days fished	Number of green sturgeon caught	Number of green sturgeon tagged
Spring 2004	40	40	20
Fall 2004	40	92	35
Spring 2005	40	24	8
Fall 2005	40	53	31
Spring 2006	18	3	2
Total	178	212	96

I report here only on green sturgeon movement in the Bay-Delta and the Sacramento River (Table 3). A collaborative paper including ocean migration of sturgeon tagged in this study is forthcoming. Fifteen sturgeon (eight tagged in San Pablo Bay, four in Willapa Bay, and three in the Columbia River) were analyzed in the first season. Only three of the 15 sturgeon exhibited spawning migrations well upstream of Knight's Landing for sustained periods in the Sacramento River. Two spring/summer 2004 potential spawning sturgeon were also detected, although the array was incomplete during this period.

Table 3: Biological information of green sturgeon detected in the Sacramento River and Bay/Delta

Code	Date captured and tagged	Region captured and tagged	Total length (cm)	Fork length (cm)	Sex (M/F)	Repro-ductive state (mature/ immature)
SPB1	19-Apr-2004	San Pablo Bay	183	165	F	Mature
SPB2	27-Apr-2004	San Pablo Bay	144	128		Immature
SPB3	25-May-2004	San Pablo Bay	153	144	F	Immature
SPB4	9-Aug-2004	San Pablo Bay	128	114		
SPB5	27-Aug-2004	San Pablo Bay	130	118		
SPB6	31-Aug-2004	San Pablo Bay	131	118		
SPB7	8-Sep-2004	San Pablo Bay	149	136		
SPB8	11-Apr-2005	San Pablo Bay	186	166		
SPB9	28-Aug-2005	San Pablo Bay	156	145		
SPB10	31-Aug-2005	San Pablo Bay	204	194	M	Mature
SPB11	19-Mar-2006	San Pablo Bay	206	189	F	Mature
CR1	13-Jul-2004	Columbia River	184		M	
CR2	10-Sep-2004	Columbia River	210	186	F	
CR3	13-Sep-2004	Columbia River	168	156	M	
WB2	2-Sep-2003	Willapa Bay	160	155		
WB3	5-Sep-2003	Willapa Bay	144	131	F	
WB4	26-Aug-2003	Willapa Bay	186		M	
WB5	28-Aug-2003	Willapa Bay	137			
WB6	30-Jun-2004	Willapa Bay	132			
GH1	29-Jun-2005	Grays Harbor	190	174		
GH2	20-Jul-2005	Grays Harbor	172			
GH3	20-Jul-2005	Grays Harbor	167	155		
GH4	3-Aug-2005	Grays Harbor	193			
GH5	3-Aug-2005	Grays Harbor	165	150		
GH6	19-Aug-2005	Grays Harbor	184	166		
GH7	1-Sep-2005	Grays Harbor	188			

Ten sturgeon (seven tagged in Greys Harbor and three in San Pablo Bay) were analyzed in the second season (2006 to present detections). All 10 exhibited spawning migratory behavior in the Sacramento River.

2004-2005 tracking results

The movements of all 15 2004-2005 green sturgeon are represented in tabular form in Tables 4-9. Tables indicate the location of sturgeon at a particular monitor location by day. Table 4 refers to sturgeon which were detected with temporal and geographic relation, but with limited meaning outside of a greater ocean migration context. Most monitors in the West Delta were only temporarily set and the tables involving these sturgeon are incorporated to display presence in the system, rather than spawning migratory behavior.

Table 4: Unrelated Delta detections
Monitor locations are specified on the top row by name and river kilometer. Dates indicate detections by day of specific sturgeon (shown by code in left column)

	Golden Gate Br. (-94)	Carquinez Straight (-44)	Montezuma Slough (-19)	Brannan Island (23)	Rio Vista Br. (21)
SPB7		8-Oct-2004			
SPB3			12-Oct-2004		
SPB6					12-Sep-2004
SPB4	4-Jun-2005 9-Jun-2005			24-Aug-2004 25-Aug-2004 28-Aug-2004 30-Aug-2004 31-Aug-2004 5-Aug to 16-Aug 2004 20-Sep-2004 25-Sep-2004 26-Sep-2004 26-Oct-2004 28-Oct-2004	

Table 4 (cont'd): Unrelated Delta detections

Monitor locations are specified on the top row by name and river kilometer. Dates indicate detections by day of specific sturgeon (shown by code in left column)

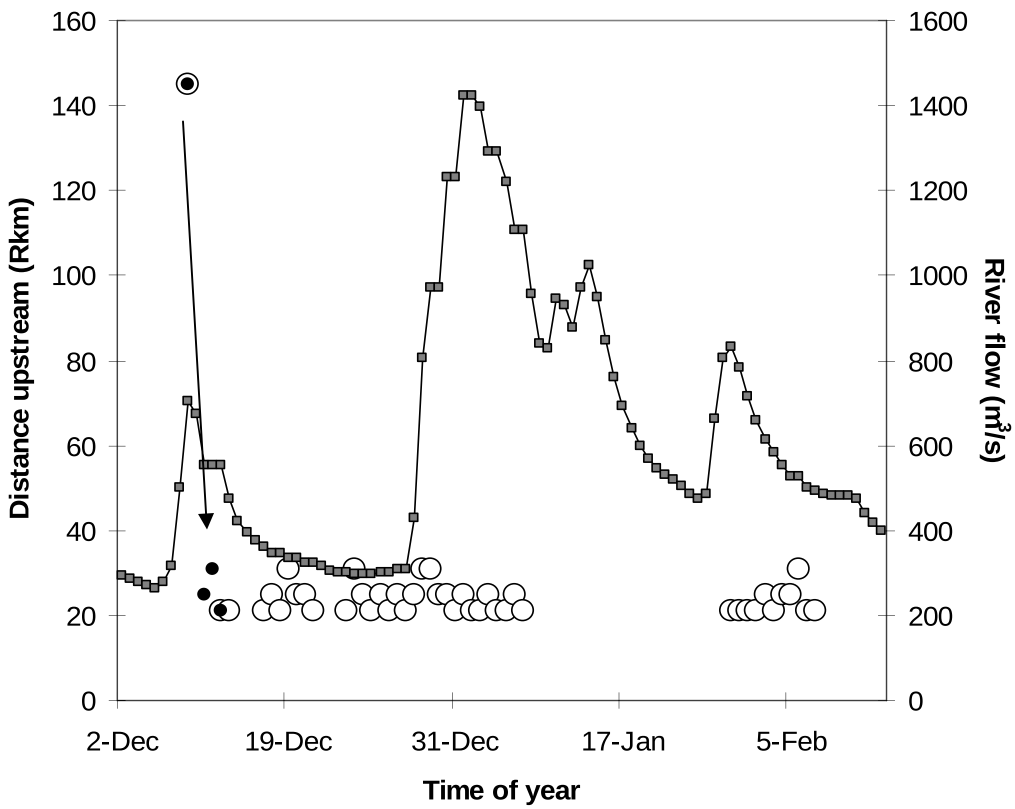
	Golden Gate Br. (-94)	Brannan Island (23)	Rio Vista Br. (21)	Cache Slough (lower) (25)	Cache Slough (upper) (31)
SPB2	*Monterey Canyon 16-Mar-2005* 20-Mar-2005 5-Apr-3005 14-May to 19-May-2005 2-Jun-2005 6-June to 9-June-2005 20-Nov-2005 18-Dec to 21-Dec-2005		19-Apr-2005 20-Apr-2005	20-Apr-2005	
WB2	26-Jul-2005			2-Nov to 9-Nov-2004	
CR1	24-Feb-2006 26-Feb-2006		27-Feb-2004		9-Apr-2005
WB6					4-Apr-2005
SPB5		12-Nov-2004 5-Dec to 6-Dec-2004 9-Dec to 10-Dec-2004			

Table 5: 2004-2005 Sacramento River limited downstream migration
Monitor locations are specified on the top row by name and river kilometer. Dates indicate detections by day of specific sturgeon (shown by code in the left column)

	SPB release site (-54)	Rio Vista Br. (21)	Cache Slough (lower) (25)	Cache Slough (upper) (31)	Knight's Landing (145)
SPB1	*Tagged in SPB*	12-Dec-2004	18-Dec-2004 to 1-Jan-2005	19-Dec-2004	10-Dec-2004
	19-Apr-2004	23-Dec-2004	3-Jan-2005	25-Dec-2004	
		17-Dec-2004	5-Jan-2005	29-Dec-2004	
		18-Dec-2004	3-Feb-2005 to 5-Feb-2005	30-Dec-2004	
		20-Dec-2004		5-Feb-2005	
		24-Dec-2004 to 27-Dec-2004			
		31-Dec-2004 to 3-Jan-2005			
		5-Jan-2005			
		30-Jan-2005 to 3-Feb-2005			
		5-Feb-2005			
		6-Feb-2005			
WB4		12-Dec-2004	12-Dec-2004	12-Dec-2004	10-Dec-2004

Two tagged sturgeon detected in 2004 produced interpretable data regarding freshwater migrations. These individuals were detected in Knight's Landing on 10-Dec-2004 (Table 5). This was followed by a downstream migration of a minimum of 125 km to the Rio Vista Bridge in >2 days. This suggests both sturgeon initiated out-migration from the river system in relation to a similar cue. This downstream migration corresponds closely with the first spike of winter flow in the Sacramento River and a general downward trend in temperature (Figure 2).

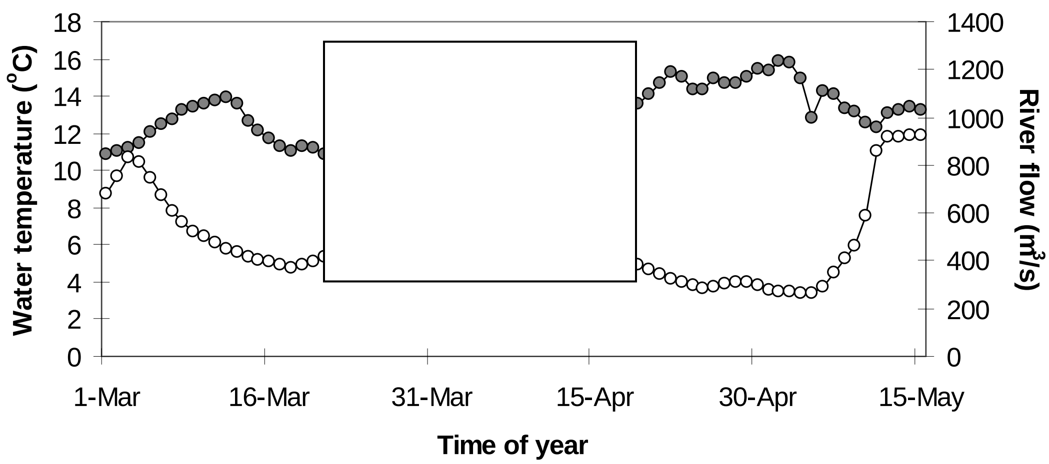
Figure 2: 2004-2005 Sacramento River limited downstream migration graphed with Verona flow. Sacramento River flow at Verona is represented cubic meters per second (m^3/s) as solid squares. Sturgeon position is represented in river kilometer (Rkm) by day. The open circle represents SPB1, WB4 is represented by a solid circle



2005 Sacramento River spawning migration

Three green sturgeon showed spawning migratory behavior in 2005 (Table 6, Figure 3). It is very difficult to assess the possible effects of Sacramento River water temperature and flow on the initiation of this migration. These environmental cues are heavily attenuated by the time they reach the Golden Gate and typically widely varying at downstream monitor sites (Figure 4). Based on the short time interval between when the fish were tagged in San Pablo Bay or detected passing Golden Gate Bridge, and when they were detected up-river, it seems unlikely environmental factors played a role in spawning migration after the sturgeon enter the system.

Figure 4: 2005 RBDD temperature and Verona flow
Water temperature in Celsius is represented by solid circles and flow in cubic meters per second (m^3/s) is represented by open circles. Rectangle contains the temperature and flow at first detection



Fish detections during the spring season 2005 season were poor. There were few monitor detections above Thomes Creek during this period (Table 6). CR2 and SPB8 could have migrated above the RBDD before the 15 May closure, but detection rates are not conclusive in these reaches. All sturgeon had a long period lacking detection around the farthest upstream movement of the up-migration (Table 6, Figure 3).

By late June to mid-July all three sturgeon were detected moving downstream to the GCID aggregation site. A gradual increase in flow and temperature occurred during this period (Figure 5 & 6). All sturgeon had a prolonged residence time in the GCID aggregation area (Figure 4). I did not record any detection of SPB8 after 10 September 2005. Based on a total lack of detections after this point, it is probable that this sturgeon was no longer providing a signal (tag failure, tag expression, or mortality).

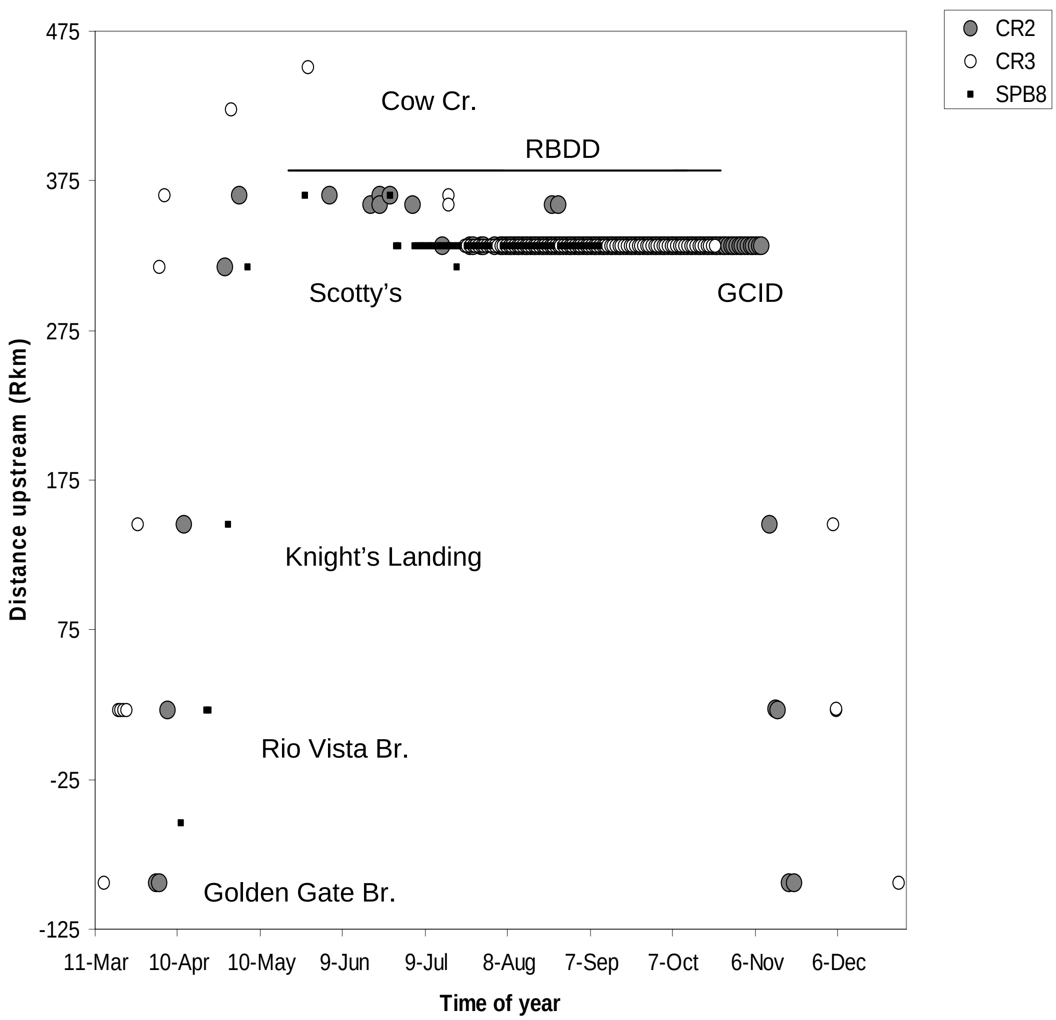
Table 6: 2005 Sacramento River spawning migration
Top row - monitor station locations by name and river kilometer
Left column – sturgeon code

	Golden Gate Br. (-94)	Rio Vista Br. (21)	Sacramento R. (22)	Cache Slough (upper) (31)	Knight's Landing (145)
CR2	2-Apr 3-Apr 18-Nov 20-Nov	6-Apr 14-Nov	13-Nov		12-Apr 11-Nov
CR3	14-Mar 28-Dec	19-Mar to 22-Mar 5-Dec	5-Dec		26-Mar 4-Dec
SPB2	*Released SPB 12-Apr-2005*	20-Apr 21-Apr		22-Apr	28-Apr

Table 6 (cont'd): 2005 Sacramento River spawning migration
Top row - monitor station locations by name and river kilometer
Left column – sturgeon code

	Scotty's Landing (317)	GCID (331)	Thomes Cr. (below) (359)	Thomes Cr. (above) (365)	Table Mtn. (422)	Cow Cr. (below) (451)
CR2	27-Apr	15-Jul 25-Jul 26-Jul 29-Jul 30-Jul 3-Aug 5-Aug to 8-Nov	19-Jun 22-Jun 4-Jul 24-Aug 26-Aug	2-May 4-Jun 22-Jun 26-Jun		
CR3	3-Apr	23-Jul To 22-Oct	17-Jul	5-Apr 17-Jul	29-Apr	27-May
SPB2	5-May 20-Jul	28-Jun 29-Jun 5-Jul To 21-Jul 24-Jul To 1-Aug 6-Aug To 24-Aug 27-Aug To 10-Sep	26-May 26-Jun			

Figure 3: 2005 Sacramento River spawning migration
Sturgeon position by river kilometer (Rkm) is plotted with date. The legend indicates which symbol corresponds with a particular sturgeon code. Selected locations are named slightly to the right and below sturgeon symbols. RBDD gate presence is indicated by the horizontal line



Out-migration from the GCID aggregation site by CR2 and CR3 occurred in early November and early December respectively. Both sturgeon appeared to have exited the river in response to separate, surges in river flow (Fig 7).

Figure 7: CR2 and CR3 out-migration graphed with Woodson Bridge flow
River flow in cubic meters per second (m^3/s) is represented by filled squares. CR3 location is indicated in river kilometer (Rkm) graphed with day as a solid circle symbol. CR2 is represented by an open circle

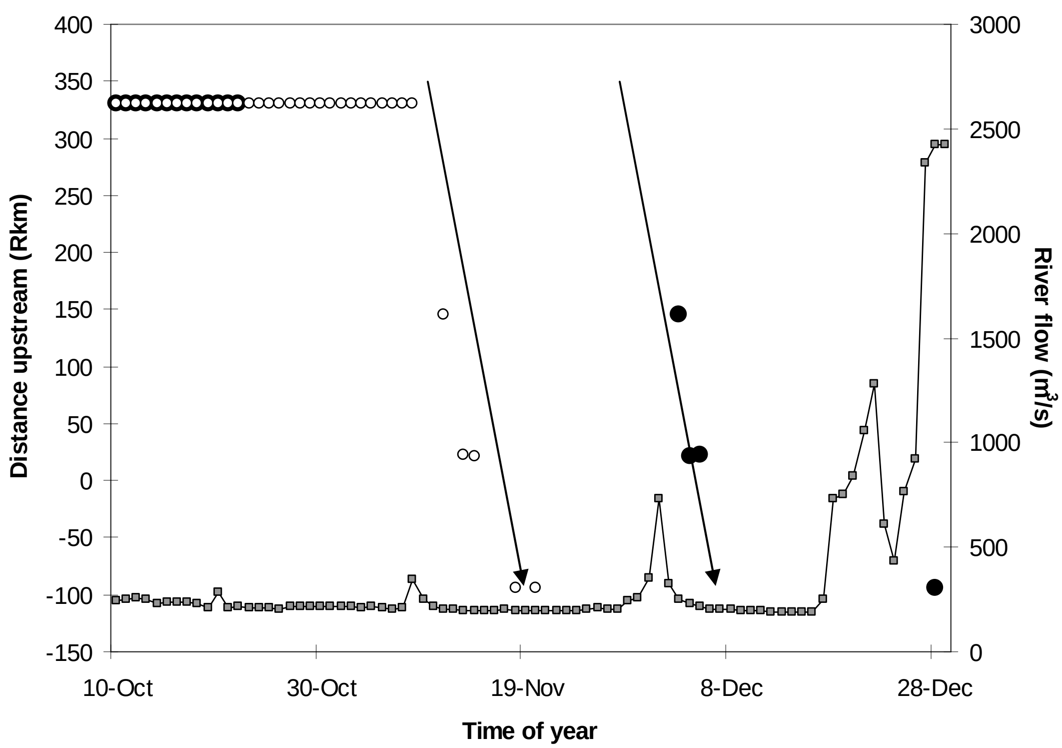


Figure 5: 2005 Bend Bridge temperature and flow
Solid circles represent temperature in Celsius and open circles represent flow in cubic meters per second (m^3/s). Rectangle contains temperature and flow during migration to GCID by CR3

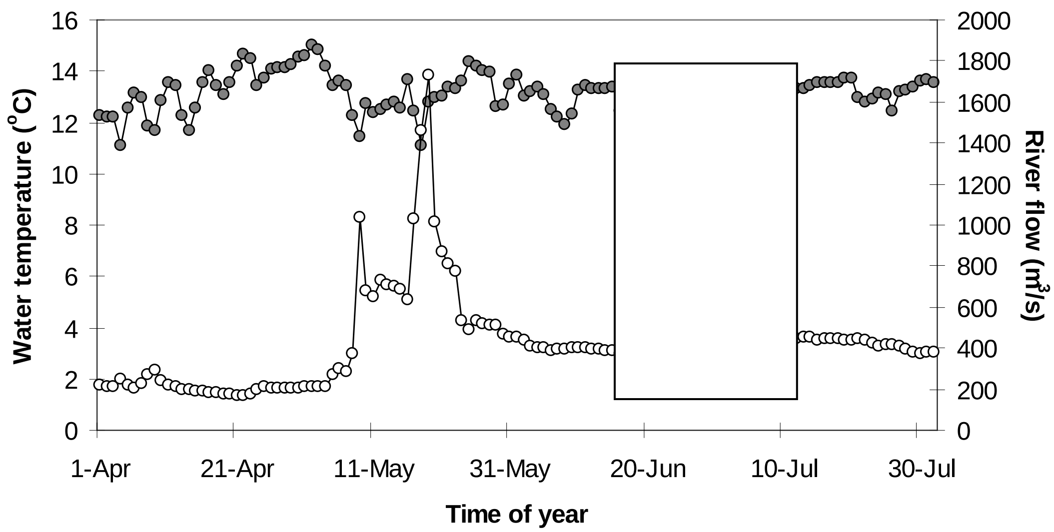
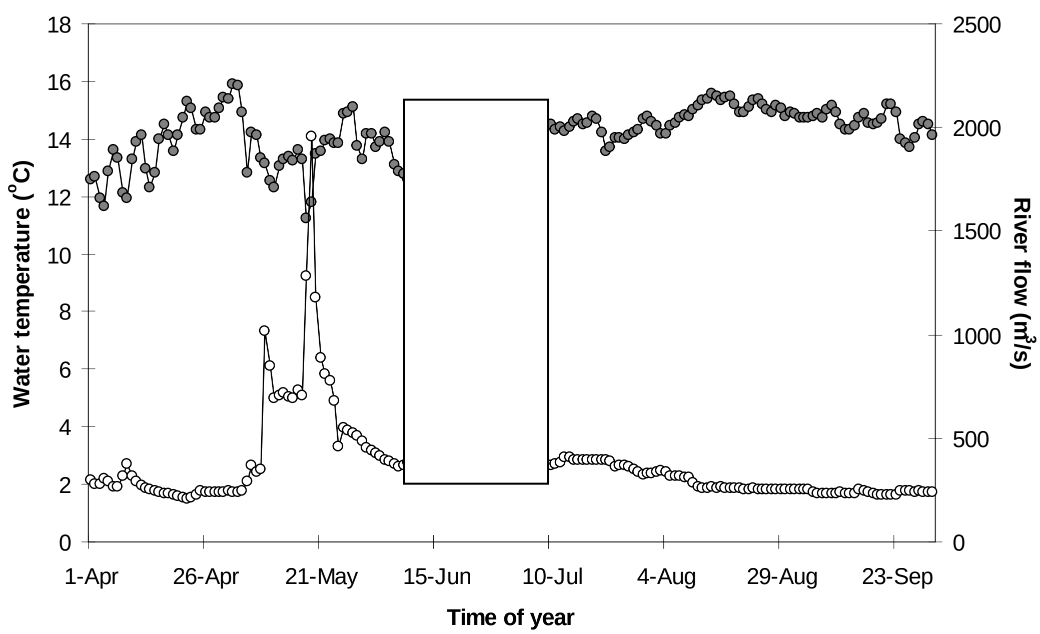


Figure 6: 2005 RBDD temperature and Woodson Bridge flow
Solid circles represent temperature and open circles represent flow. Rectangle contains flow and temperature during CR2 and SPB8 migration to GCID



2006 Sacramento River spawning migration with detections above RBDD

Ten green sturgeon were detected migrating upriver during the 2006 spawning season. Of the ten, three fish tagged in SPB and one in Grays Harbor exhibited similar behavior in achieving passage of RBDD (Table 7, Figure 8). All four sturgeon appear to have entered the watershed in early/mid-March, coincident with an rapid increase in flow (Figure 9).

Figure 9: 2006 RBDD temperature and Verona flow
Solid circles indicate temperature and open circles indicate flow. Rectangles contain flow and temperature at first detections of sturgeon that “A” achieved passage of RBDD, or “B” did not achieve passage of RBDD

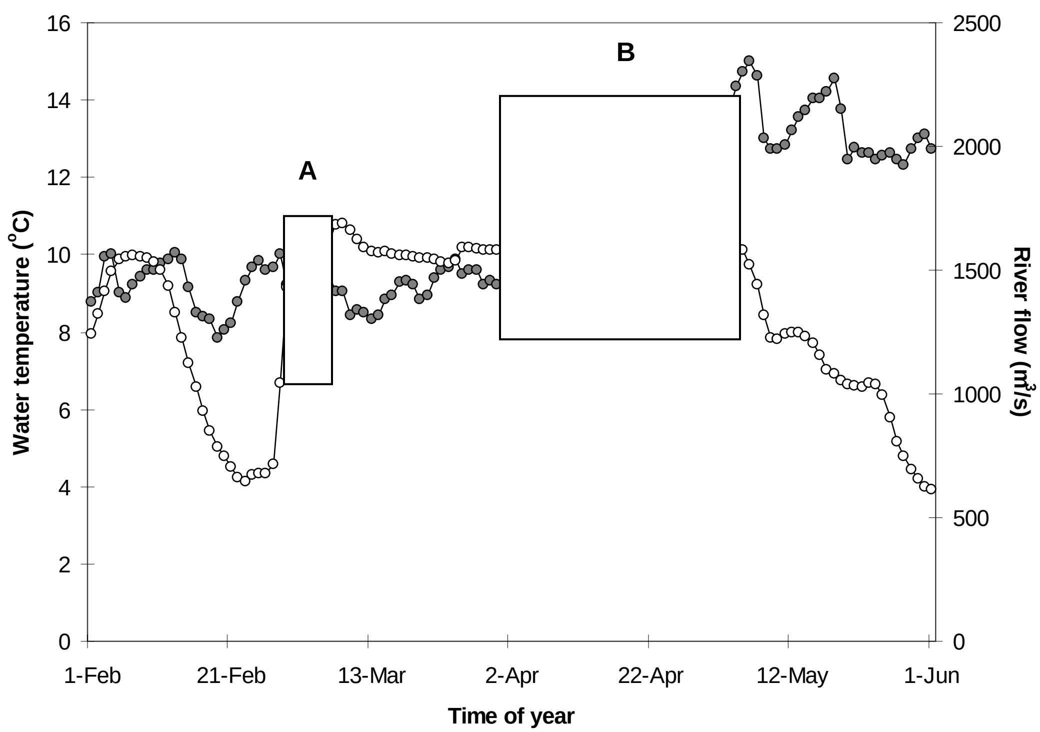
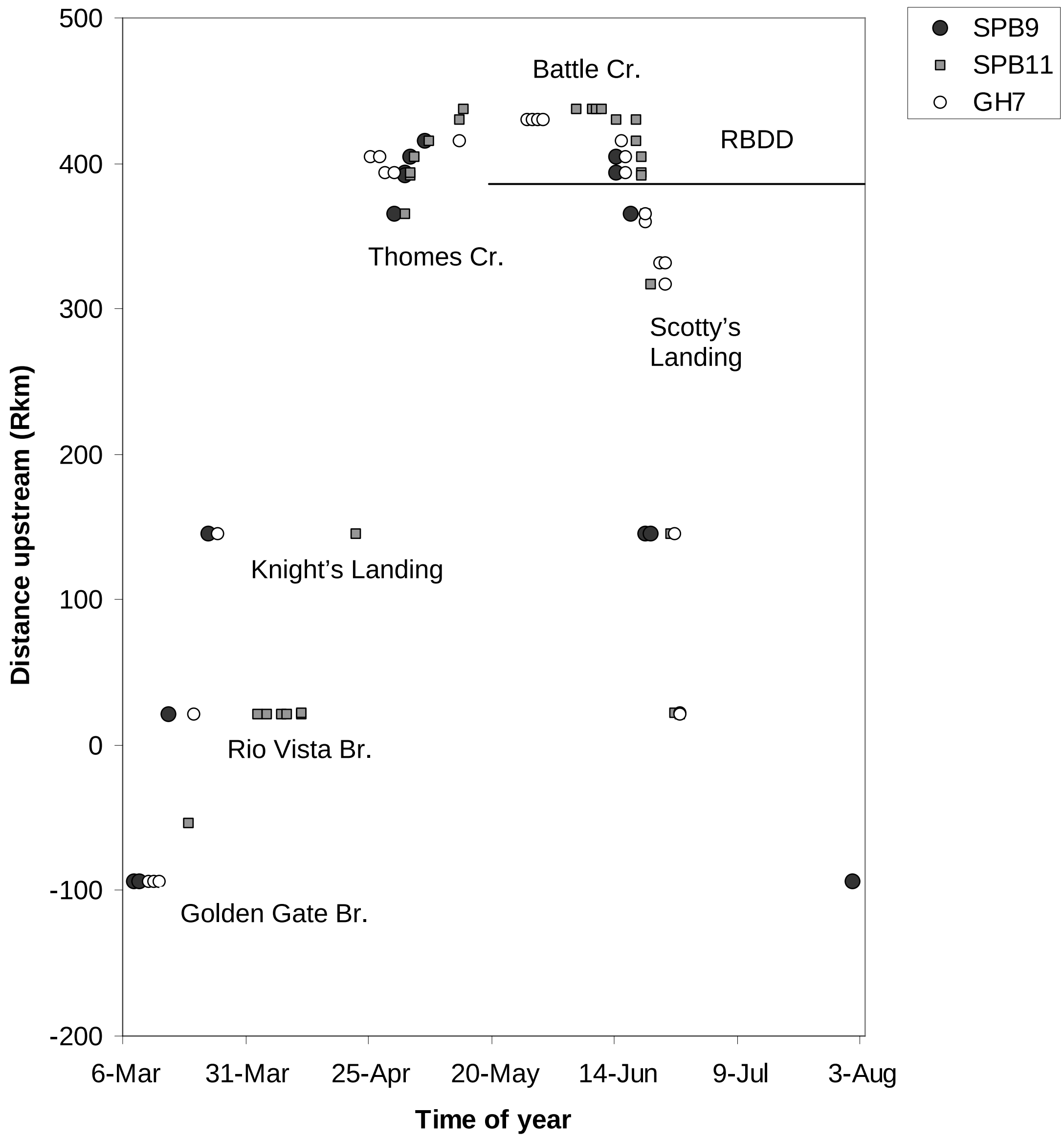


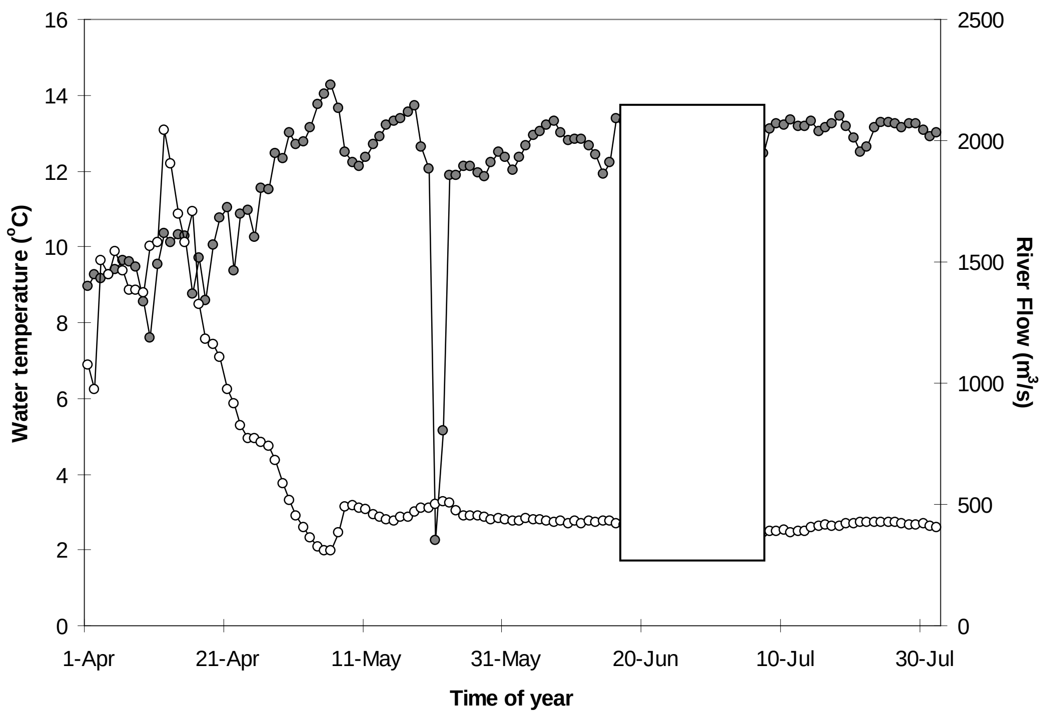
Figure 8: 2006 Sacramento River spawning migration with detections above RBDD

Sturgeon position by river kilometer (Rkm) is plotted with date. The legend indicates which symbol corresponds with a particular sturgeon code. Selected locations are named slightly to the right and below corresponding sturgeon symbols (Battle Cr., above corresponding symbols). RBDD gate presence is indicated by the horizontal line



The movements of the three green sturgeon tagged in San Pablo Bay showed exceptionally close temporal relation; for instance, all detections at RBDD occurred within the same 26 hour period. Detections by VR2 monitors above the RBDD appeared to be complete during 2006, making analysis of passage definitive (Table 7). Eggs were collected from one of these fish, SPB11, when it was tagged on 19 March 2006. Analysis of egg maturity at UCD CABA (J Van Eenennaam, pers. comm.) indicated the fish was likely to spawn in 2-3 months. That time frame coincides with the apex of the up-migration conducted by SPB11 in the reach above Battle Creek. This is the most definitive evidence we have collected for a specific green sturgeon spawning location on the Sacramento River.

Figure 10: Bend Bridge temperature and flow
Solid circles indicate temperature and open circles indicate flow. Rectangle contains flow and temperature during out-migration of fish which achieved RBDD passage



Out-migration of green sturgeon achieving RBDD passage was also tightly clustered in time. All tagged sturgeon initiated down-stream movements in mid-June, passing Knight's Landing within 10 days of one another. No holding period in the GCID aggregation reach was observed. The out-migration does not appear to coincide with a significant change in water temperature or flow; however, overall river flow was significantly higher, and water temperature significantly lower, than in previous study years (Figure 13&14). The timing of out-migration in late-June early-July in the four sturgeon detected above RBDD was consistent with all other green sturgeon detected in 2006, except GH1 (described in the "2006 spawning migration outliers" section).

Table 7: 2006 Sacramento River spawning migration with detections above RBDD

	Golden Gate Br. (-94)	Rio Vista Br. (-21)	Sacramento R. (-22)	Knight's Landing (145)	Scotty's Landing (317)	GCID (331)	Thomes Cr. (below) (359)
SPB9	8-Mar 9-Mar 1-Aug	15-Mar	22-Jun	23-Mar 21-Jun			
SPB10	5-Mar 13-Aug	9-Mar		14-Mar 1-Jul	29-Jun	28-Jun	13-Jun
SPB11	*Released SPB 19-Mar-2006*	2-Apr 4-Apr 7-Apr 8-Apr 11-Apr 27-Jun	11-Apr 26-Jun	22-Apr 25-Jun	22-Jun		
GH7	11-Mar 12-Mar 13-Mar	20-Mar 27-Jun	27-Jun	25-Mar 26-Jun	24-Jun	23-Jun 24-Jun	20-Jun

Table 7 (cont'd): 2006 Sacramento River spawning migration with detections above RBDD

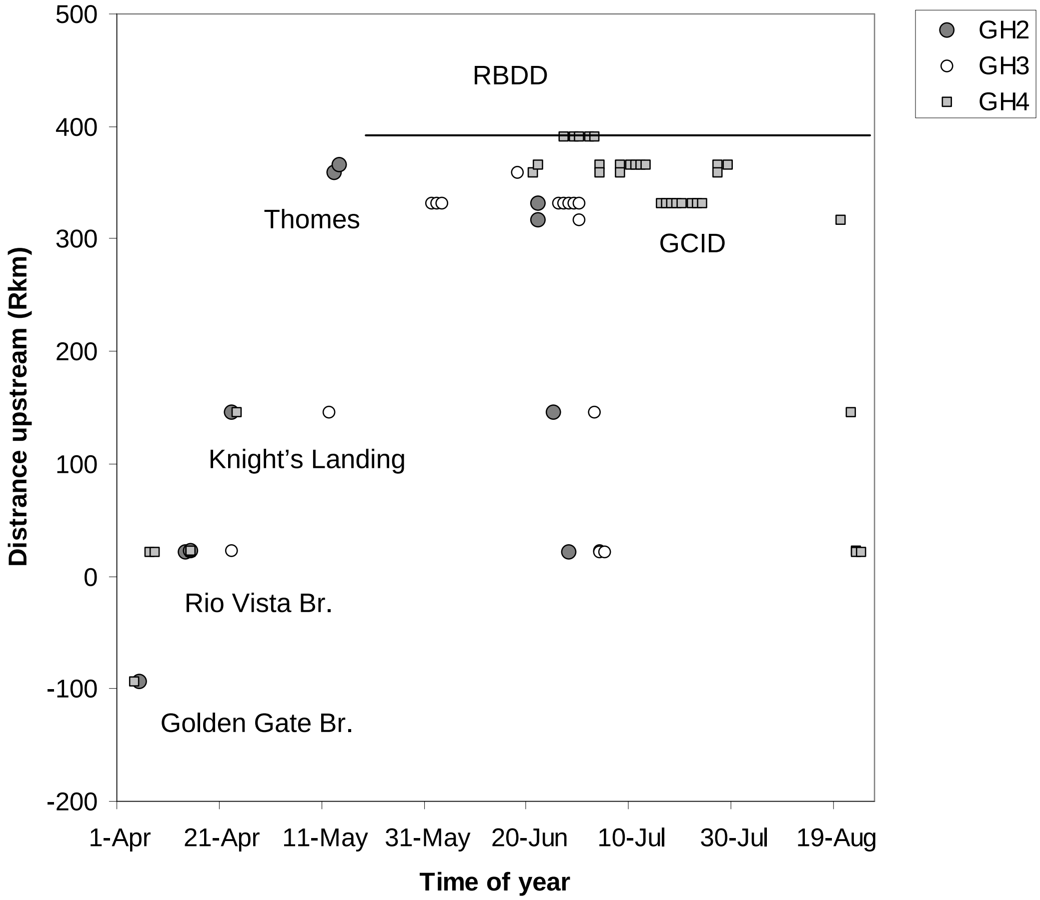
	Thomes Cr. (above) (365)	RBDD (below) (391)	RBDD (above) (393)	China Rapids (below) (404)	Bend Br. (below) (415)	Jelly's Ferry (430)	Battle Cr. (above) (437)
SPB9	30-Apr 2-May 17-Jun		2-May 14-Jun	3-May 14-Jun	6-May		
SPB10	27-Apr 29-May 31-May 10-Jun 13-Jun 20-Jun	3-May 27-May 4-Jun 15-Jun 17-Jun	3-May				
SPB11	2-May 20-Jun	3-May 19-Jun	3-May 19-Jun	4-May 19-Jun	7-May 18-Jun	13-May 14-Jun 18-Jun	14-May 6-Jun 9-Jun 10-Jun 11-Jun
GH7	20-Jun		28-Apr 16-Jun	25-Apr 27-Apr 30-Apr 16-Jun	13-May 15-Jun	27-May 28-May 29-May 30-May	

2006 Sacramento River spawning migration with no detections above RBDD

Spring 2006 green sturgeon that did not pass RBDD also exhibited close temporal relation in spawning up-migration. Up-stream movements occurred one month after sturgeon achieving passage, in early April through early May (Table 8, Figure 11). Another spike in Sacramento River flow is closely related to this up-migration (Figure 9 and 12).

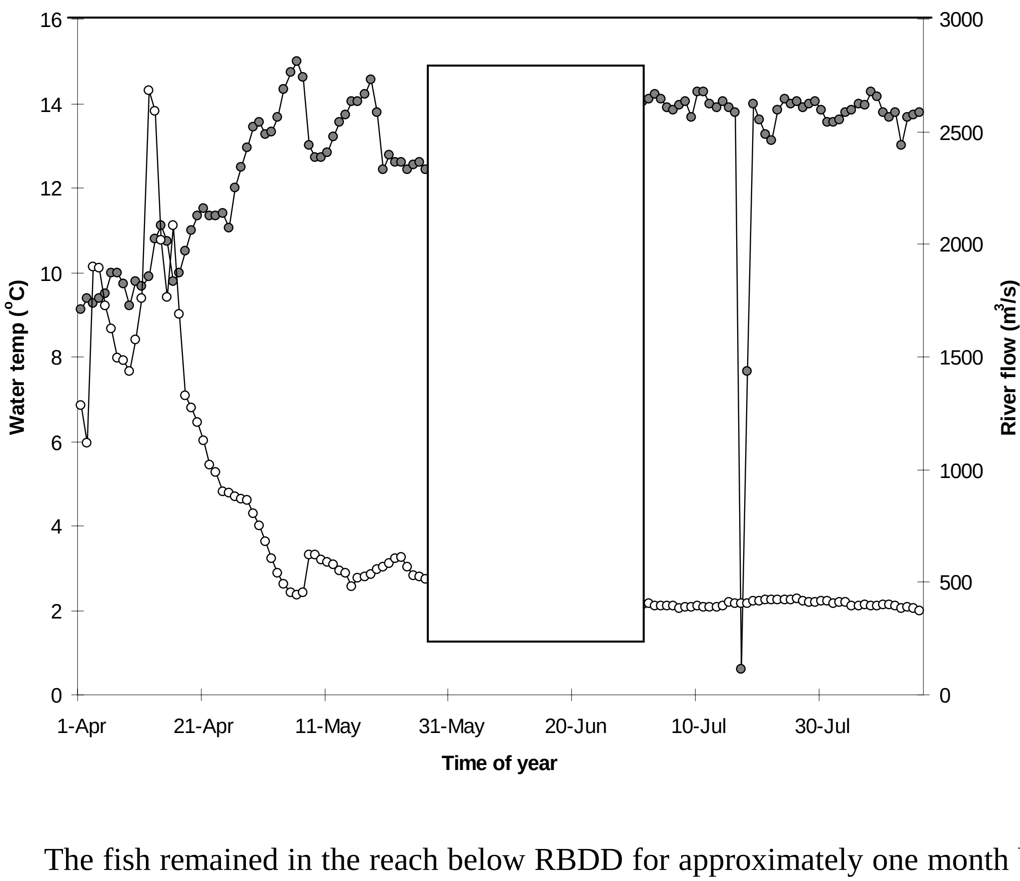
Figure 11: 2006 Sacramento River spawning migration with no detections above RBDD

Sturgeon position by river kilometer (Rkm) is plotted with date. The legend indicates which symbol corresponds with a particular sturgeon code. Selected locations are named slightly to the right and below corresponding sturgeon symbols. RBDD gate presence is indicated by the horizontal line



It is likely the four sturgeon reached the RBDD after the water diversion gates were closed on May 15. Spawning may have occurred in reaches below the RBDD between mid-May and late-June (Table 8, Figure 11). Water temperature and flow become significantly more consistent throughout the entire river after May 15 (Figure 12).

Figure 12: 2006 RBDD temperature and Woodson Bridge flow
Solid circles indicate temperature and open circles indicate flow. Rectangle contains flow and temperature during out-migration of fish which were not detected above RBDD



The fish remained in the reach below RBDD for approximately one month before GH2 and GH3 out-migrated (detected at Knight's Landing) within 8 days of one another on 25 June and 3 July, respectively. GH4 remained at the GCID aggregation site until 24 July. GH4 was detected at Scotty's Landing on 20 Aug, Knight's Landing on 22 Aug, and ultimately at Rio Vista on 23 and 24 Aug. GH6 also moved rapidly to GCID, where it remained for 4 days (16-20 May) and then promptly out-migrated 5 days later on 26 May (Table 8).

Table 8: 2006 Sacramento River spawning migration with no detections above RBDD

	Golden Gate Br. (-94)	Rio Vista Br. (21)	Sacramento R. (22)	Knight's Landing (145)
GH2	5-Apr	14-Apr 28-Jun	15-Apr	23-Apr 25-Jun
GH3		4-Jul 5-Jul	23-Apr 4-Jul	12-May 3-Jul
GH4	 4-Apr	7-Apr 8-Apr 15-Apr 23-Aug 24-Aug	15-Apr 23-Aug	24-Apr 22-Aug
GH6	3-May	6-May 27-May	6-May 27-May	9-May 25-May 26-May

Cont'd

	Scotty's Landing (317)	GCID (331)	Thomes Cr. (below) (359)	Thomes Cr. (above) (361)	RBDD (below) (391)
GH2	22-Jun	22-Jun	13-May	14-May	
GH3		1-Jun 2-Jun 3-Jun 26-Jun to 30-Jun	18-Jun		
GH4	20-Aug	16-Jul to 20-Jul 22-Jul 23-Jul 24-Jul	21-Jun 4-Jul 8-Jul 27-Jul	22-Jun 4-Jul 8-Jul 10-Jul to 13-Jul 27-Jul 29-Jul	27-Jun 29-Jun 30-Jun 2-Jul 3-Jul
GH6		16-May to 20-May			

2006 Sacramento River spawning migration outliers

Two tagged sturgeon exhibited different patterns of migration. GH1 entered the San Francisco Bay on 24 Feb (Table 9). Sacramento River flow increased substantially 21 Feb coincident with the time that GH1 started moving up-river. This sturgeon entered into the system earlier than any other green sturgeon during Spring 2006. No passage of the RBDD occurred, and out-migration occurred one month before any other sturgeon exited the river on 22 May.

GH5 entered the system on 7 May, later than any other green sturgeon during Spring 2006 (Table 9). A steep decrease in flow and increase in temperature occurred in the Sacramento River during this period (Figure 13). GH5 moved rapidly up-river and was detected on 28 May in the GCID aggregation site. GH5 was last detected at Thomes Cr. on 26 July, and at the last data collection had still not migrated out of the Sacramento River.

Table 9: 2006 Sacramento River spawning migration outliers

	Golden Gate Br. (-94)	Rio Vista Br. (21)	Sacramento R. (22)	Knight's Landing (145)	GCID (331)	Thomes Cr. (below) (359)	Thomes Cr. (Above) (365)
GH1	21-Feb 24-Feb	23-May		17-May 22-May	20-May	1-May 18-May	1-May 2-May
GH5	7-May	17-May	17-May	22-May	28-May	26-Jul	3-Jun 26-Jul

Discussion

Interpretation of 2004-2005 monitoring results

Prior to this study, very little was known of green sturgeon migration in the Sacramento River. Estimation of spawning location and migration timing could only be empirically based on egg and larvae collection. Only two green sturgeon eggs have been collected in the Sacramento River (Brown 2006). Green sturgeon larvae have been periodically sampled below RBDD. Interpreting larvae development stage to estimate spawning date or location does not yield a high level of accuracy. The results of 2004 had to be compared to subsequent data sets from this project to properly assess relevance.

In late fall 2004, two sturgeon rapidly migrated out of the Sacramento River coincident with the first large increase in river discharge. Green sturgeon exhibited the same out-migration phenomenon in 2005. Recent study of green sturgeon in the Klamath and Rogue Rivers also showed similar out-migration behavior to both 2004 and 2005 Sacramento River fish (Benson et al 2006, Erickson et al 2002). With the exception of our 2006 migration, all tagged green sturgeon appear to initiate out-migration with the onset of higher flows in the fall and early winter.

SPB1 was mature with ripe eggs, within 1-3 months of spawning (J. Van Eenennaam, UCD CABA, pers. comm.) when tagged on 19 April 2004 in San Pablo Bay. After capture on 6 February 2005, the angler reported that a few mature eggs remained in the abdominal cavity of SPB1, indicating a spawn had occurred in the previous months (J. Van Eenennaam, UCD CABA, pers. comm.). WB4 was above a minimum size length for maturity but was not thought to be mature when tagged (although this assessment was made in August of 2003).

It is likely that green sturgeon SPB1 and WB4 were not detected by monitors while moving into reaches of the Sacramento River that could have had appropriate water temperatures, upper limit 17.5 C, and habitat for spawning (Van Eennenaam et al 2005). The array was very effective in detecting salmonids tagged by other projects during in the late summer and early fall of 2004, indicating that the array was probably only capable of detecting downstream migration sturgeon during this period.

These are the only sturgeon displaying a river migration from the 2004 spawning season, and it is difficult to assess the array's effectiveness for detecting sturgeon during this period. Supporting arrays such as the Golden Gate Bridge array maintained by NOAA were not functional during this time. Based on the egg conditions of SB1, and the lack of future detections of any sturgeon at or above Knight's Landing that were not displaying spawning migratory behavior, these detections likely represent the first observations of the green sturgeon spawning migration in the Sacramento River.

Comparison of timing of entry, passage of the RBDD, and potential spawning reaches

The timing of the upstream migration in the Sacramento River appears to be similar to that of the Northern DPS in the Klamath and Rogue Rivers (Benson et al 2006 and Erickson et al 2002). Capture of sturgeon initiating spawning migrations in the Klamath River occurred between April and June in 2002, 2003, and 2004 (Benson et al 2006). Capture of sturgeon in the Rogue River occurred from May to July in 2000 (Erickson et al 2002). The initiation of green sturgeon spawning migration in the Sacramento River during this study was focused in March and April, slightly earlier than the Northern DPS (Table 10).

Table 10: Study summary of Sacramento River upriver migration
First migration detection category indicated the first detection of fish exhibiting spawning migratory behavior by location and date. Closest detection to RBDD indicated detection of sturgeon at highest upriver point below RBDD. Apex detection range indicates location of apex detections (farthest upriver) and date ranges, apex detection followed by detection at downstream site

	First migration detection	Closest detection to RBDD	Detection above RBDD (Y/N)	Apex detection range
SPB1	19-Apr-2004 (tagged SPB)			19-May to 19-Jul (est.)
SPB2	12-Apr-2005 (tagged SPB)	26-May (Thomes Cr.)	N	26-May to 28-Jun (Thomes Cr.)
CR2	2-Apr-2005 (Golden Gate Br.)	2-May (Thomes Cr.)	N	2-May to 4-Jul (Thomes Cr.)
CR3	14-March-2005 (Golden Gate Br.)	5-Apr (Thomes Cr.)	Y	27-May to 29-Apr (Cow Cr.)
GH1	21-Feb-2006 (Golden Gate Br.)	1-May (Thomes Cr.)	N	1-May to 18-May (Thomes Cr.)
SPB9	8-Mar-2006 (Golden Gate Br.)	2-May (RBDD)	Y	6-May to 14-Jun (Bend Br.)
SPB10	5-Mar-2006 (Golden Gate Br.)	3-May (RBDD)	Y	3-May to 4-Jul (RBDD)
SPB11	19-Mar-2006 (tagged SPB)	3-May (RBDD)	Y	14-May to 14-Jun (Battle Cr.)
GH7	11-Mar-2006 (Golden Gate Br.)	28-Apr (RBDD)	Y	27-May to 15-Jun (Jelly's Ferry)
GH2	5-Apr-2006 (Golden Gate Br.)	14-May (Thomes Cr.)	N	14-May to 22-Jun (Thomes Cr.)
GH3	23-Apr-2006 (Sacramento R.)	18-Jun (Thomes Cr.)	N	18-Jun to 26 Jun (Thomes Cr.)
GH4	4-Apr-2006 (Golden Gate Br.)	27-June (RBDD)	N	21-Jun to 4-Jul (RBDD)
GH6	3-May-2006 (Golden Gate Br.)	16-May (GCID)	N	16-May to 20-May (GCID)
GH5	7-May-2006 (Golden Gate Br.)	3-Jun (Thomes Cr.)	N	3-Jun to 26-Jul (Thomes Cr.)

All green sturgeon in this study which initiated up-migration in the month of March were detected above RBDD. All sturgeon entering the system in April and May (plus one outlier in February) were not detected above RBDD (Table 10). Both CR2 and SPB8 were potentially impeded by the closure of the diversion gates at RBDD in 2005. Poor detections in the first year potentially limited our accuracy in estimation of spawning reaches (Table 11).

Table 11: 2005 tabulation of VR2 array effectiveness
Top row shows monitor station by name. Potential detections indicate detections of specific sturgeon at monitors directly upstream and downstream of a particular monitor station. Actual detections indicated detections at a monitor station during the appropriate time frame (i.e. after the downstream monitor, and before the upstream monitor, or vice versa). A monitor which detected up-migration and out-migration of all three sturgeon in 2005 would have six detections. The Rio Vista Br. column has no values because it can be bypassed by way of the Delta Cross Channel. Knight's Landing column only has five potential detections because SP8 was lost prior to out-migration. The Scotty's Landing column only has three potential detections because was stolen prior to out-migration. The GCID column only has three potential detections because it was only functional after up-migration

2005 functional monitor station	**Rio Vista Br.**	**Knight's Landing**	**Scotty's Landing**	**GCID**	**Thomes Cr.** (below)
Potential detections		5	3	3	6
Actual detections		5	3	3	2
cont'd					
2005 functional monitor station	**Thomes Cr.** (above)	**RBDD** (above)	**Table mtn.**	**Jelly's Ferry**	**Cow Cr.** (below)
Potential detections	6	2	2	2	1
Actual detections	6	0	1	0	1

During the 2006 season the VR2 array was much more effective (Table 12). It is notable that only one sturgeon that was potentially impeded by the15 May closure of RBDD was detected at the dam (table 10). It is possible that an increase in sturgeon density in reaches below the dam after 15 May closure truncated green sturgeon up-migration. Mature green sturgeon could stop upstream migration upon reaching a large aggregation of conspecifics. White sturgeon have a strong tendency toward aggregation during impeded spawning migrations (personal observations, Yolo Bypass, CA). Alternatively, spawning could preferentially occur in reaches below the dam, although no documentation exists of this phenomenon.

Table 12: 2006 tabulation of VR2 array effectiveness
Top row shows monitor stations that were present for entire migration period by name. Potential detections indicate detections of specific sturgeon at monitors directly upstream and downstream of a particular monitor station. Actual detections indicated detection at a monitor station during the appropriate time frame (i.e. after the downstream monitor, and before the upstream monitor, or vice versa). *Incmp.* indicates an incomplete data set from a monitor station. A monitor which detected upmigration and outmigration of all ten sturgeon in 2006 would have twenty detections. The Knight's Landing column only has 19 potential detections because GH5 had not initiated outmigration at latest data collection

2006 functional monitor Station		**Knight's Landing**	**GCID** (*incmp.*)	**Thomes Cr.** (above)	**RBDD** (below) (*incmp.*)
Potential detections		19	10	10	9
Actual detections		19	8	9	6
cont'd					
2006 functional monitor station	**RBDD** (above)	**China Rapids**	**Bend Br.**	**Jelly's Ferry**	**Battle Cr.** (above)
Potential detections	7	6	5	3	1
Actual detections	7	6	5	3	1

Apex detections ranges in Table 10 indicates reach location and dates when spawning might have occurred during this study. The two sturgeon sampled for egg maturity during this study exhibited a spawning range from May to July. All apex detections ranges fall in these months (Table 10). Furthermore, spawning likely occurred in May or June in the only collection of green sturgeon egg(s) in the

Sacramento River (Brown 2006). In all apex detection ranges high water velocity and bedrock habitat exists. Water temperatures did not exceed 17 degrees Celsius in these reaches during this study, and normal green sturgeon larval development could have occurred without extensive downstream dispersal into warmer reaches (Van Eenennaam 2005).

Comparison of downstream migratory behavior and aggregation

Our first green sturgeon detected in the Sacramento River exhibited a rapid downstream migration in the fall, with close temporal relation to large increases in flow (Fig 2). All three sturgeon detected migrating in the Sacramento River in 2005 aggregated at the GCID site. One sturgeon was lost at the GCID site, and the remaining two migrated out of the system in the fall, after a minimum 90 day residence. This out-migration appeared to be initiated by large increases in flow (Fig 7). These behaviors are very similar to the Northern DPS. Summer aggregations in deep, low-velocity pools, followed by out-migration initiated by flow increases is documented in both the Klamath and Rogue Rivers (Erickson et al 2002, Benson et al 2006).

Table 13: Complete Sacramento River out-migration detections
Out-migration detection are defined by final detection at Knight's Landing

	Out-migration detection
SPB1	10-Dec-2004
WB4	10-Dec-2004
CR2	11-Nov-2005
CR3	4-Dec-2005
GH1	22-May-2006
SPB9	21-Jun-2006
SPB10	1-Jul-2006
SPB11	25-Jun-2006
GH7	26-Jun-2006
GH2	25-Jun-2006
GH3	3-Jul-2006
GH4	22-Aug-2006
GH6	26-May-2006

The behaviors of green sturgeon in the two segments of its range seem to differ in the water velocity of aggregation sites. The reach on the Sacramento River adjacent to GCID is an area of high water velocity. Aggregation sites on the Klamath River were described as scour pools created by high flows, which in turn exhibit low water velocity in the summer months (Benson et al 2006). Aggregation sites on the Rogue River exhibit little or no flow (Erickson et al 2002). The GCID site is over 5 m deep with structural current refugia and eddy formations. It could be assumed that sturgeon occupy these lower-velocity subsections of the site. Observations of sturgeon capture, and manual tracking estimates indicate that green sturgeon are found in, or in very close proximity to, high velocity areas. The presence of sturgeon exhibiting pre-spawn egg maturity, coupled with the GCID reach high water velocity could imply that green sturgeon spawn in this area (Matt Manual, GCID pers comm.). Throughout this study, river temperatures at RBDD (60 Rkm upstream of GCID) have remained below 17 degrees Celsius, indicating that normal larval development could occur in this reach (Van Eenennaam 2005). Of interest was the behavior of GH6, which migration rapidly to GCID where it remained for only four days before out-migrating (Table 8). It is possible that this movement represents a purposeful spawning event at GCID.

Alternatively, the GCID reach could be a post-spawn holdover site, as river aggregations are assumed to be in the Klamath and Rogue Rivers. In 2005, sturgeon with and without detections above RBDD resided at GCID for extended periods. Sturgeon exhibiting post-spawn egg maturity are also captured at the GCID site (Matt Manual, GCID pers comm).

Out-migration in 2006 was drastically different from both previous study years and Northern DPS literature (Erickson et al 2002, Benson et al 2006). Most sturgeon exited the system at of before 3 Jul; one fish remained until 22 Aug, and one fish remained upstream at last data collection (Table 13). One remaining fish has the opportunity to exhibit behavior similar to previous years (Table 9). Nine sturgeon from 2006 exited the system with no extended aggregation, or relation to fall flow increases.

Only two green sturgeon (without detections above RBDD) exhibited consistent detections in the GCID reach; these detection are very limited prior to early out-migration (Table 8). Sturgeon collection at GCID was low after September 2006, indicating a marked lack of fish when compared to previous sampling years (Matt

Manual pers comm.) The rapid out-migration of sturgeon in 2006, and the reduced aggregation at the GCID site could be a result of consistently higher flows and lower temperatures than previous study years (Fig 10). Alternatively, this could be a unusual behavior, unrelated to environmental cues, that had not been documented prior to this study.

All tagged green sturgeon passing RBDD prior to the May 15 closure out-migrated before the September 14 opening. Prior to this study, it was assumed that RBDD control gates were a barrier to downstream migration in sturgeon (Brown 2006). This does not appear to be the case, although the high velocity gap below the dam could be potentially harming to green sturgeon. Consistent striations on the ventral surface of green sturgeon captured at GCID might be a sign of trauma during discharge gate out-migration (these patterns are not observed in SPB green sturgeon captures). These marks could also be incurred during spawning, and further investigation is needed to elucidate causation.

Figure 13: 2005/2006 comparison of RBDD water temperature
Solid circles indicate 2006 water temperature, open circles indicate 2005 water temperature. The open rectangle indicates out-migration period in 2006

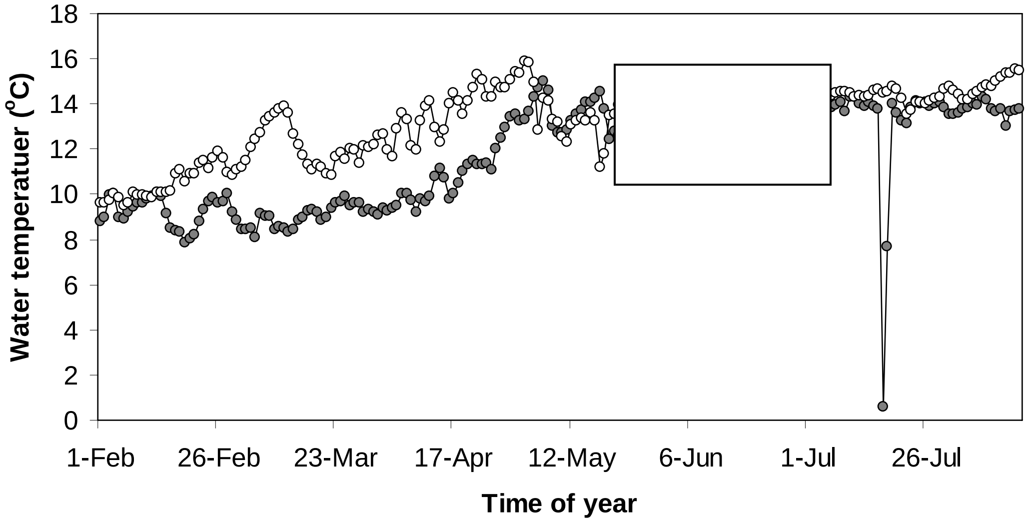
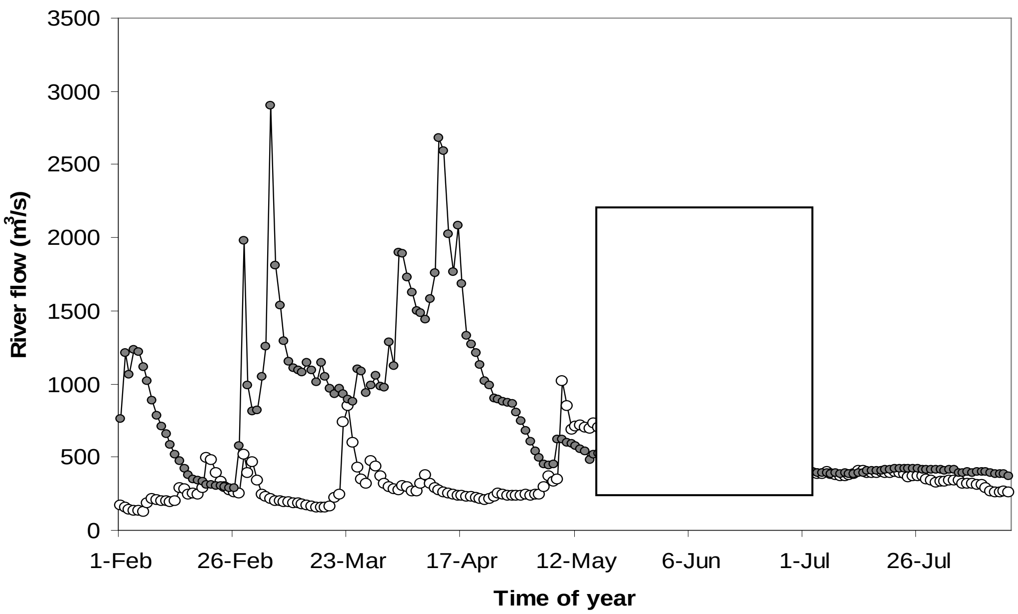


Figure 14: 2005/2006 comparison of Woodson Bridge flow
Solid circles indicate 2006 flow, open circles indicate 2005 flow, both measured in cubic meters per second (m^3/s). The open rectangle indicates out-migration period in 2006



Conclusions

The Southern DPS of the green sturgeon displays unique behaviors in sturgeon, even when compared to the Northern segment. This is not surprising given the Southern Segment's vast ocean migrations and ultimate navigation of the largest estuary on the west coast of North America. Even when only including the individuals in this study, we see the Sacramento River drawing in green sturgeon tagged in multiple studies and geographic regions. It is obvious from only this, that the Sacramento River is of vast importance to the green sturgeon population.

Further investigation of this species is necessary and feasible through simply continuing our current program. Knowledge gained of timing of migrations can allow us to focus tracking efforts at specific times and locations, and elucidate habitats where spawning actually occurs. Analysis of aggregation sites can be conducted to prove if spawning occurs at particular sites. Particle dispersal models can allow us to understand if spawning in a particular reach will disperse eggs into warm water reaches, where normal larvae development cannot occur.

Areas of high vulnerability have been documented in this study. The Sacramento River adjacent to the Glen Colusa Irrigation District pumping plant, holds an extremely large aggregation of green sturgeon. In this small area, green sturgeon are extremely vulnerable to sport angling and poaching. Protection of green sturgeon in the Sacramento River should be focused on this area.

The timing of the Red Bluff Diversion Dam control gates likely affects the migration of green sturgeon. Based on detections from this study, a closure delay of six weeks would allow all green sturgeon an opportunity for passage. Reaches above RBDD have consistently lower temperatures, and larger amounts of high-velocity bedrock habitats. Furthermore, the only physical evidence of spawning was collected at RBDD (Brown 2006). Examination of the risks of sturgeon passage below RBDD is also necessary. All green sturgeon achieving upstream passage of RBDD, migrated downstream prior to the fall opening of the control gates. This could be a vulnerable stage in green sturgeon downstream migration.

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Appendices

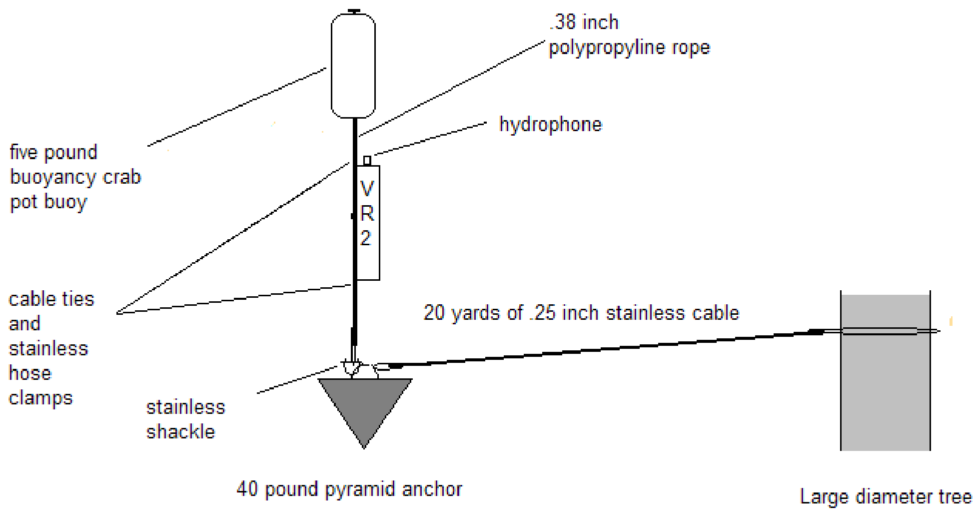
Appendix 1: green sturgeon gill netting specifics

Two to three sections in series compose the total net length. Mesh size is displayed centimeters, net depth is in number of mesh (realized net depth varies depending on water depth), and lengths are displayed in meters

Season	Spring 2004	Fall 2004	Spring 2005	Fall 2005	Spring 2006
number of days fished	40	38	33	40	18
number of nights fished	0	2	7	0	0
date range	16-Apr-25 May	7 Aug-22 Sep	16 Mar-13 May	1 Aug-10 Sep	10 May-2 Apr
Section 1 mesh size (cm)	19.1	19.1	22.9	22.9	22.9
Section 1 depth (number of mesh)	35	35	35	35	35
Section 1 length (m)	91.4	91.4	182.8	182.8	182.8
Section 2 mesh size (cm)	24.1	24.1	20.6	20.6	20.6

Section 2 depth (number of mesh)	18	18	35	35	35
Section 2 length (m)	182.8	182.8	91.4	91.4	91.4
Section 3 mesh size (cm)		21.3	21.3	21.3	21.3
Section 3 depth (number of mesh)		35	35	35	35
Section 3 length (m)		91.4	91.4	91.4	91.4
total net length (m)	274.3	365.8	365.8	365.8	365.8

Appendix 2: VR2 mooring schematic



Appendix 3: Spring 2004 catch total
"Y" in Tag column indicates tag implant

Date captured	Time captured	Total length (cm)	Fork length (cm)	Tag
16-Apr-04	13:00	105		
17-Apr-04	13:30	79		
17-Apr-04	13:30	139.5		Y
18-Apr-04	8:00	140.5		Y
19-Apr-04	12:30	183	165	Y
20-Apr-04	11:00	124	111	Y
23-Apr-04	7:30	85		
23-Apr-04	9:00	104		
23-Apr-04	11:00	125	107	Y
24-Apr-04	10:30	84		
24-Apr-04	12:00	115		
24-Apr-04	13:00	99		
26-Apr-04	9:00	124	110	Y
27-Apr-04	7:30	98		
27-Apr-04	12:00	144	128	Y
29-Apr-04	9:00	96		
30-Apr-04	11:00	112		
2-May-04	9:00	82		
3-May-04	11:00	112		
3-May-04	11:15	89		
7-May-04	10:00	120	101	Y
12-May-04	10:30			
14-May-04	12:45	171	156.5	Y
15-May-04	13:30	125	113	Y
16-May-04		79	69	
16-May-04		92	83	
16-May-04	12:00	185	171	Y
16-May-04	12:00	127	113	Y
16-May-04	12:00	136	123	Y
16-May-04	12:00	142	127	Y
18-May-04	8:30	77	71	
18-May-04	11:00	72	65	
19-May-04	7:50	85	75	
20-May-04	9:10	79	70	
21-May-04	6:30	73		
21-May-04	6:40	150	137	Y
24-May-04	9:00	118	109	Y
24-May-04	11:30	127	117	Y
25-May-04	9:00	153	144	Y
25-May-04	11:00	152	139	Y

Appendix 4: Fall 2004 catch total

“Y” in Tag column indicates tag implant

Capture date	Capture time	Total length (cm)	Fork length (cm)	Tag
7-Aug-04	7:30	107		
7-Aug-04	7:30	107		
7-Aug-04	7:30	130		Y
7-Aug-04	7:30	127		Y
7-Aug-04	7:30	114		Y
7-Aug-04	7:30	110		Y
7-Aug-04	7:30	110		Y
8-Aug-04	6:30	86		
8-Aug-04	6:30	107		
8-Aug-04	6:30	69		
8-Aug-04	6:30	104		
8-Aug-04	6:30	94		
8-Aug-04	6:30	155		Y
8-Aug-04	6:30	142		Y
8-Aug-04	6:30	112		Y
9-Aug-04	6:30	119	107	Y
9-Aug-04	6:30	162	150	Y
9-Aug-04	6:30	126	117	Y
9-Aug-04	6:30	119	107	Y
9-Aug-04	6:30	128	114	Y
9-Aug-04	6:30	114	109	Y
10-Aug-04	10:30	133	125	Y
11-Aug-04	7:00	114		
11-Aug-04	9:30	203		Y
14-Aug-04	8:30	109	99	
14-Aug-04	9:05	126	112	
14-Aug-04	11:45	118	110	
14-Aug-04	11:45	121	109	
14-Aug-04	11:45	88	80	
14-Aug-04	11:30	136	122	Y

Appendix 4 (cont'd): Fall 2004 catch total
"Y" in Tag column indicates tag implant

Capture date	Capture time	Total length (cm)	Fork length (cm)	Tag
16-Aug-04	8:30	114	103	
16-Aug-04	9:00	102	93	
16-Aug-04	11:45			
16-Aug-04	11:45			
16-Aug-04	11:45			
16-Aug-04	11:45			
16-Aug-04	12:15	178	150	Y
17-Aug-04	10:00	145	118	Y
17-Aug-04	8:30			
17-Aug-04	8:40			
17-Aug-04	8:45			
17-Aug-04	8:55			
17-Aug-04	9:10			
18-Aug-04	8:30			
18-Aug-04	9:30			
19-Aug-04	7:30	102		
19-Aug-04	9:40	127		
19-Aug-04	11:30	91		
19-Aug-04	13:15	119		
20-Aug-04	7:30	104		
20-Aug-04	8:15	111		
20-Aug-04	9:30	122		
20-Aug-04	9:45	124		
22-Aug-04	7:30			
22-Aug-04	8:15			
22-Aug-04	8:15			
23-Aug-04	8:30	100		
23-Aug-04	11:15	136.5	123.5	Y
25-Aug-04	10:45	117		
25-Aug-04	13:15	100		
25-Aug-04	13:25	107		
26-Aug-04	11:00	98		

Appendix 4 (cont'd): Fall 2004 catch total
"Y" in Tag column indicates tag implant

Capture date	Capture time	Total length (cm)	Fork length (cm)	Tag
27-Aug-04	12:45	98		
27-Aug-04	11:20	130	118	Y
27-Aug-04	12:45	128	120	Y
28-Aug-04	9:45	120	107	Y
28-Aug-04	11:45	134	117	Y
31-Aug-04	9:00	130	117	Y
31-Aug-04	9:30	131	118	Y
1-Sep-04	8:30	102		
1-Sep-04	10:15	90		
3-Sep-04	8:30	111		
3-Sep-04	10:30	118	105	Y
3-Sep-04	11:15	124	116	Y
4-Sep-04	11:15	112	116	
4-Sep-04	11:15	101	116	
4-Sep-04	9:30	131	117	Y
6-Sep-04	8:30	110		Y
7-Sep-04	9:15	99		
7-Sep-04	10:30	117	104	Y
7-Sep-04	8:30	126	118	Y
8-Sep-04	10:00	95		
8-Sep-04	9:30	149	136	Y
11-Sep-04	10:00	133	120	Y
13-Sep-04	8:30	92		
14-Sep-04	9:30	120	108	Y
15-Sep-04	10:00			
15-Sep-04	10:30			
15-Sep-04	11:00			
16-Sep-04	12:30			
21-Sep-04				
21-Sep-04				

Appendix 5: Spring 2005 catch total

Date captured	Time captured	Total length (cm)	Fork length (cm)	Tag
24-Mar-05		93		
24-Mar-05		93		
24-Mar-05				
25-Mar-05	12:40	120		
26-Mar-05	12:15	103		
28-Mar-05	10:30			
1-Apr-05	8:00	99		
2-Apr-05	16:30	121		
3-Apr-05	11:30	105		
3-Apr-05	11:30	108		
10-Apr-05		55		
11-Apr-05	19:45	186	166	Y
25-Apr-05	10:00	177.5	164	Y
27-Apr-05	9:00	120		
29-Apr-05	8:00	130		Y
29-Apr-05	8:30	142		Y
30-Apr-05	10:15	121	113	Y
30-Apr-05	10:30	143	132	Y
1-May-05	21:30			
2-May-05	21:30	198	182	Y
3-May-05				
4-May-05				
12-May-05	10:35	130	118	Y
12-May-05	10:35			

Appendix 6: Fall 2005 catch total

Date captured	Time captured	Total length (cm)	Fork length (cm)	Tag

1-Aug-05	7:00	102		
1-Aug-05	7:10	120		
1-Aug-05	9:45	147	143	Y
2-Aug-05	10:00	128	116	Y
3-Aug-05	7:30	135		
3-Aug-05	7:45	161	146	Y
3-Aug-05	8:00	200	183	Y
3-Aug-05	8:15	141	127	Y
4-Aug-05	9:30	125	114	
4-Aug-05	11:45	95		
5-Aug-05	7:30	114	103	
5-Aug-05	8:00	173	157	Y
5-Aug-05	8:15	135	124	Y
5-Aug-05	9:00	96	88	
6-Aug-05	7:30	165	148	Y
6-Aug-05	9:30	160	147	Y
6-Aug-05	9:45	125	115	
6-Aug-05	10:15	115	106	
7-Aug-05	10:00	106	100	
8-Aug-05	8:00	115	106	
9-Aug-05	8:00	148	133	Y
9-Aug-05	8:15	140	130	Y
9-Aug-05	8:30	178	163	Y
9-Aug-05	8:45	163	150	Y
10-Aug-05	8:00	168	153	Y
10-Aug-05	8:15	165	150	Y
11-Aug-05	8:00	156	141	Y
11-Aug-05	8:15	117	107	
11-Aug-05	8:30	135	126	Y

Appendix 6 (cont'd): Fall 2005 catch total

Date captured	Time captured	Total length (cm)	Fork length (cm)	Tag
12-Aug-05	11:15	104	94	
15-Aug-05	7:40	130	122	Y
19-Aug-05	7:40	100	92	
19-Aug-05	9:45	178	164	Y
19-Aug-05	10:15	99	89	
20-Aug-05	7:40	135	122	Y
20-Aug-05	10:00	139	124	Y
26-Aug-05	7:45	115	104	Y
26-Aug-05	8:15	116	105	Y
26-Aug-05	11:00	152	138	Y
27-Aug-05	9:45	115	98	
28-Aug-05	7:30	114	102	
28-Aug-05	8:00	156	145	Y
30-Aug-05	7:45	123	112	
31-Aug-05	7:45	204	194	Y
1-Sep-05	11:15	116	104	
2-Sep-05	7:20	153	140	Y
2-Sep-05	7:30	128	116	Y
5-Sep-05	8:40	130	120	Y
5-Sep-05	8:55	140	127	Y
6-Sep-05	7:25	110	100	
8-Sep-05	8:00	116	107	
9-Sep-05	11:00	125	113	Y
10-Sep-05	9:30	98	90	

Appendix 7: Spring 2006 catch total

Date captured	Time captured	Total length (cm)	Fork length (cm)	Tag
12-Mar-06	7:30	100	92	
19-Mar-06	7:30	120	112	Y
19-Mar-06	10:30	189	206	Y