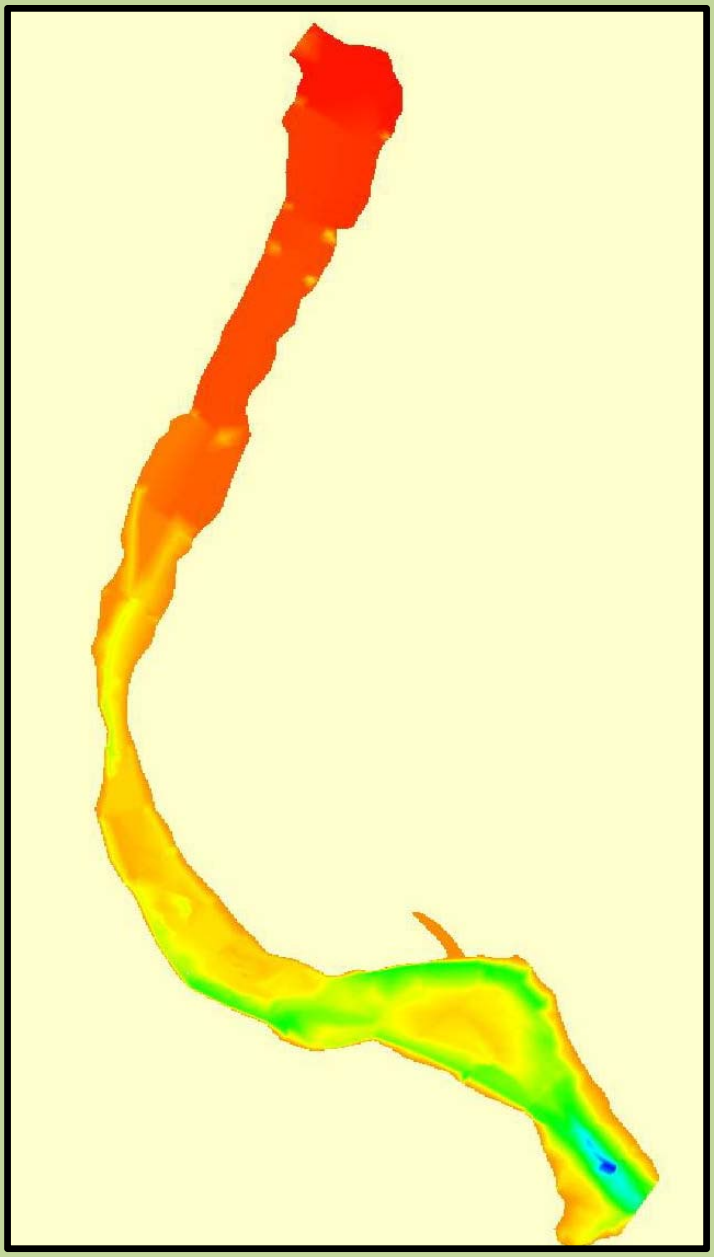
Fisheries and Habitat Assessment of the Big Sur River Lagoon, California



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INTRODUCTION

The California Department of Fish & Game (DFG) considers the Big Sur River and its associated lagoon as an important watershed for maintaining returns of wild steelhead (*Oncorhynchus mykiss*) in coastal California streams south of San Francisco Bay (DFG 2009). Steelhead are currently listed as a federally "threatened" species in the south-central California coast Distinct Population Segment (NMFS 1997, 2006). Normandeau Associates, Inc. (Normandeau) was contracted by DFG through a grant from the Ocean Protection Council to the Pacific States Marine Fisheries Commission to assess the fisheries and habitat characteristics of the Big Sur River Lagoon (lagoon), in support of the ongoing instream flow assessment in the Big Sur River.

Lagoons and small estuaries are widely known to be important rearing areas for anadromous salmonids in Pacific coast streams (Reimers 1973, Allen and Hassler 1986, Miller and Sadro 2003, Quinones and Mulligan 2005), including steelhead in central California (Shapovalov and Taft 1954, Smith 1987, Bond 2006, Atkinson 2010). Lagoons can provide extended rearing and improved growth opportunities for pre-smolt steelhead, which can lead to increased ocean survival and greater returns of adult spawners (Ward and Slaney 1988, Bond et al. 2008). The importance of lagoons to rearing steelhead is dependent in part on the lagoon's habitat characteristics, including its persistence, area and volume, water chemistry, invertebrate prey abundance, and instream cover (Smith 1987, Zedonis et al. 2007, Hayes et al. 2008). These habitat characteristics are in turn affected by streamflow, particularly high flow events with associated recruitment of sediments, woody debris, and fish.

STUDY AREA

For most of its length the Big Sur River falls within the Andrew Molera State Park (including the lagoon), the Pfeiffer Big Sur State Park, or the Ventana Wilderness Area, with its headwaters designated as a Wild and Scenic River (Figure 1). Consequently, the lagoon and most of the watershed is undeveloped and protected, however in 2008 the Basin Complex Fire burned approximately 85% of the 60 mi^2 watershed (DFG 2009). Following the fire, high streamflow events occurring over the winters of 2009 and 2010 resulted in widespread erosion of streambank areas and flushed sediments downstream into the lagoon. By the spring of 2010, recruited sediments had significantly enlarged a midchannel bar that demarcated the upper boundary of the 1,650 ft lagoon, and the upper 800-1,000 ft of the lagoon resembled riffle and run habitat rather than pool habitat. Although tidal effects were most apparent in the lower half of the lagoon, for the

remainder of this report the "lagoon" references the entire 1,650 ft study area, not just the lower, tidally influenced zone.

METHODS

The physical, chemical, and biological characteristics of the Big Sur lagoon were assessed on three separate site visits in 2010: 18-19 May, 18-19 July, and 7-8 October. Fifteen cross-sectional transects were established in May to represent the longitudinal changes in channel character and complexity of instream habitat, with the upstream-most transect (No. 10) placed just above the riffle terminating the original lagoon boundary (Figure 2). Lagoon physical habitat characteristics monitored during this study included bathymetry, temporal/spatial changes in tidal heights, tidal changes in water's edge, substrate/cover mapping, transect velocity characteristics, and estimated river inflow. Monitored chemical parameters included water temperature, water salinity, and dissolved oxygen. Biological monitoring involved dive counts of steelhead (and other species) along standardized cross-sectional and bank-oriented transects. Photographs were taken across each transect and at various other locations within the lagoon at different tidal heights. Digital photographs were taken during each trip to depict general lagoon characteristics, transect profiles, substrate composition, and cover types, and are available on CD upon request.

Lagoon Bathymetry

Lagoon bathymetry was assessed in the lower, deeper areas of the lagoon in July 2010 using a 1200kHz TRDI Rio Grande Acoustic Doppler Current Profiler (ADCP) mounted on a Oceanscience trimaran. ADCP data was collected by traversing the trimaran across the stream channel in a zigzag manner, with location data recorded on a Trimble Pathfinder Pro DGPS (Figure 3). The GPS antenna was mounted directly over the ADCP with location data streamed via radio modem to a Panasonic Toughbook laptop running WinRiver® software. Manual depth measurements and GPS locations were collected at 3-5 ft intervals along cross-sectional transects in the upper half of the lagoon where shallow depths (<1 ft) made use of the ADCP infeasible. All depth measurements were related to local water surface elevations (WSEL) and converted to relative elevation by reference to established benchmarks distributed near the top and bottom of the lagoon. Water surface elevations were measured with an auto level and stadia rod.

Elevation maps were created in GIS software (Global Mapper) by combining ADCP depth data, transect depth data, and measured water surface elevations. Depths at all measured points were converted into local bed elevations based on bench mark number 1 (elevation 100.00 ft) and using water surface elevations measured at each transect. Elevation contours were created using a linearly interpolated triangulated network (TIN). Based solely on the raw data, a TIN can produce unrealistic contours at some locations. For example high points along the bank may connect to a low point in the thalweg, when in fact there is an intervening toe of the bank slope that is not accounted for in the initial TIN. Breaklines were used to connect points of known elevation and force the TIN to follow more realistic contours.

Tidal Changes in Water Surface Elevation (WSEL)

Changes in tidal height were regularly monitored by measuring relative WSEL with an auto level and stadia rod at the cross-sectional transects and by measuring depths over three instream reference pins established in the lower, middle, and upper portions of the lagoon (Figure 2). Tidal changes in WSEL were also measured in October by monitoring depths over four temporary reference pins located in the middle portion of the lagoon.

Tidal Changes in Water's Edge

Changes in the water's edge of the lagoon were assessed at low tide and high tide during the May survey by recording a tracklog with the Trimbol GPS unit while walking along the lagoon margin and encircling any midchannel bars. Changes in the high tide water's edge over the lower half of the lagoon were assessed in July by recording a tracklog in a Garmin handheld GPS unit.

Substrate and Cover Mapping

Substrate types were mapped throughout the lagoon according to the particle size categories listed in Table 1. Areas containing a predominant particle size were mapped by encircling each patch while recording a tracklog on the Garmin GPS receiver. Cover types (Table 1) were assessed along each margin by recording waypoints at the upstream and downstream edges of each type, with isolated cover types (e.g., large woody debris) individually marked with unique waypoints as they occurred.

Streamflow

Streamflow in the Big Sur River was measured during each site visit at Transect #10, just above the riffle demarcating the head of the lagoon. Streamflow was measured by recording depth and mean column velocity at 20 or more stations using the wading rod and velocity meter described above.

Transect Velocity Characterization

Mean column velocities were measured at manual depth locations along all transects during the May survey, and along the lower transects during the July survey, using a Marsh-McBirney flow meter on a four-ft top-setting wading rod. Velocity measurements represented low and high incoming tides during May, and high tide or mid-ouotgoing tides in July.

Water Temperature, Salinity, and Dissolved Oxygen

Water quality parameters were measured periodically throughout the lagoon using an YSI 30 meter for water temperature and salinity and an YSI 550 meter for dissolved oxygen. Water temperature and salinity data were collected in the lower lagoon during the middle

of the incoming tide in May, and in the lower and middle reaches of the lagoon during two high tides and one low tide in October (Figure 4). Dissolved oxygen and conductivity data were recorded only during the May survey. Water quality data were recorded along transects at one to five locations across each transect and at one or more depths. Measurements were typically taken at a single mid-column or bottom reading in shallow water (<2 ft), at surface and bottom positions for depths 2-4 ft, and at surface, mid-column, and bottom positions at depths >4 ft. In some locations swift and deep water prevented multiple readings. Additional measurements were made in small pockets and scour holes between transects, downstream of the transects in the outlet channel, and in the surf zone just south of the lagoon.

Fish Dive Counts

Dive counts were conducted by one or two snorkelers in order to estimate a seasonal index of abundance of juvenile steelhead in the Big Sur lagoon. Dive counts were conducted along the 10 primary cross-sectional transects (those not labeled with a "B" in Figure 2), as well as along the intervening margin areas in a zigzag pattern. Counts conducted along cross-sectional transects were labeled with an "X", whereas counts conducted along alternating left bank or right bank transects (looking upstream) were labeled with a "L" or "R" (e.g., 0X, 0R, 1X, 1L, 2X, 2R,… 9L, 10X). The same set of transects were surveyed during each day of the three site visits, for a total of six dive counts. A second diver conducted dive counts along alternating transects during the spring survey, otherwise all dive counts were conducted by the same diver. The fork lengths of individual steelhead were eye-estimated to the nearest cm on transects having low abundance; on transects with high abundance counts were made according to size class (≤10cm or >10cm). Other aquatic species were noted when observed. Beginning and ending dive times were recorded and underwater visibility was estimated in order to assess the effective search width of each transects dive count.

An estimated index of abundance of juvenile steelhead in the Big Sur lagoon was calculated by expanding the cross-sectional transect counts to the total number of available cross-sections. The number of available cross-sections available during each dive count was calculated by dividing the total length of the lagoon by the mean diver search width across the cross-sectional transects. Although the transects were initially selected purposively in order to characterize the full range in available lagoon habitat, the estimated abundance and associated confidence intervals were calculated using Simple Random Sampling (SRS) estimators (Cochran 1977), which assumes random selection of transects. Because dive count are typically not considered to enumerate all fish that are present in the sampling areas, the calculated abundance estimates should be considered as indices of abundance, not as total abundance.

RESULTS

Measured streamflows in the Big Sur River immediately above the lagoon (at transect #10) ranged from 127 cfs during the mid-May survey, 41 cfs in mid-July, and 23 cfs in the early October survey (Table 2). The predicted range in tidal heights (based on

Monterey Bay tide tables) during sampling was 6.4 ft in May, 5.2 ft in July, and 6.8 ft in October (Table 2). Maximum high tides were highest in October at 6.2 ft, intermediate in July at 5.8 ft, and lowest in May at 5.4 ft (Figure 5).

Lagoon Physical Habitat Characteristics

The Big Sur lagoon encompassed approximately 143,150 ft^2 at a high tide of about 5.8 ft and an inflow of 41 cfs, including the large midchannel bar in the upper third of the lagoon (Figure 2). Bathymetry mapping during the July high tide produced relatively fine-scale elevation data downstream of transect 7 where depths were sufficient to deploy the ADCP (Figure 6). Above transect 7 the bathymetry was based on manual depth measurements at the five remaining transects and consequently the lower resolution was insufficient to accurately delineate the small scour holes that existed along the south bank. The bathymetry also delineates only the lower end of the long split channel that occurred from transects 7 to 9, but the single dominant channel from transects 4 to 6B and the two channels between transects 2 to 4 are clearly evident. The low elevation pocket between transects 0 and 2 was formed in part by the summer build-up of a sand berm along the south bank of the lagoon mouth. This berm is evident in Figure 7 which shows tidal and seasonal changes in the water's edge between the May, July, and October surveys.

A comparison of water surface elevations (WSEL) at different flows and tidal heights showed that tidal influences did extend upstream as far as the uppermost reference pin (RPtop), about 150 ft below the upper boundary (Figure 8). During the May and July surveys when inflow was relatively high but tidal heights were not particularly high, changes in WSEL at the RPtop location were minimal, with an estimated change of less than 0.1 ft. During the low inflow/high tide conditions in October, the WSEL at RPtop changed by 0.17 ft. Given the high maximum tide and the low summer flows that existed during the October survey (Table 2), it is likely that the observed change in WSEL at RPtop is close to the annual maximum value, and it is unlikely that high tides would have a noticeable influence on the riffle that demarcates the upper lagoon at transect 10 (Figure 2). Changes in WSEL at the middle reference pin (RPup) were more substantial, with a low tide:high tide difference of 1.1 to 1.6 ft in both May and October. The lowest reference pin (RPlow) was buried by the summer build-up of the sand-spit, but showed a WSEL change of 1.7 ft in May.

The substrate characteristics of the Big Sur lagoon are illustrated in Figure 9, which shows the dominance of gravel-sized particles throughout the length of the lagoon. Gravel-dominated substrate accounts for approximately 74% of the survey area, whereas sand-dominated and cobble-dominated substrates account for approximately 17% and 8% of the lagoon habitat, respectively. Bedrock substrate only occurred along the north bank of the lagoon mouth, whereas the south bank of the mouth was composed of wave-deposited sand (not shown on map). Note that the substrate polygons represent areas with a common dominant particle size, but other substrate types may occur within a polygon (e.g., sand and cobble are interspersed within many gravel bars).

Instream and overhead cover was assessed along the lagoon margins and revealed that a combination of in-water and overhead vegetation (woody branches extending into the water column) was the dominant cover type, representing 39% of the available margin habitat (Figure 10). Margins lacking significant cover accounted for 36% of the available margin habitat, much of which occurred along the large midchannel bar from transects 7-10. Margins lacking cover also occurred along the sand spit on the south bank of the sand spit, and along eroded bank areas near the lagoon head and along the north bank trail at transect 5. Overhead cover alone (branches not extending into the water) and emergent vegetation (rushes and cattails) accounted for 11% and 7% of the available stream margin, respectively. Unembedded cobble (6%) and undercut bank (1%) cover types were available but relatively rare in the Big Sur lagoon, and 14 pieces of large woody debris were distributed throughout the lagoon along margins and midchannel bars.

Current velocities were measured along cross-sectional transects to demonstrate the riverine character of the Big Sur lagoon during periods of high inflow and moderate to low tides. During the May survey, the average velocities along transects 1-5 under relatively high inflow (127 cfs) and low tide exceeded 1.5 fps, with maximum velocities of 2.5-5.0 fps (Figure 11). Velocities at high tide were not measured in the lower lagoon, but mid to high tide velocities in the upper lagoon (transects 5b-10) also averaged over 1.5 fps, with peaks of over 6 fps. In July, transect velocities were measured in the lower lagoon during a higher tidal height and lower inflow than in May, and showed much lower velocities averaging less than 0.5 fps with peak velocities of 1.7 fps. Mean transect velocities were particularly low (<0.25 fps) along transects 1-3, with a slight increasing trend in transects 4 and 5. Figure 8 shows that under summer low flow conditions and a particularly high tidal cycle (>6 ft, Table 2), the WSEL increases by 1-1.5 ft as far upstream as transect 7, however photos taken shortly after high tide in July (at tidal heights of ~5.5 ft) clearly showed downstream velocities at transects 6 and 7 (Figure 12).

Lagoon Water Quality Characteristics

During the May survey under high flow conditions (127 cfs) and midway through the incoming tide, salinities were near zero (~0.1 ppt) across the lower three transects as well as in the outlet channel below transect 0 (Figure 4). By high tide (at 4.0 ft, Table 2), salinities increased to 30 ppt at bottom locations in the outlet channel below transect 0, but were <3 ppt at surface locations and remained near zero at all depths above transect 0. Water temperature, specific conductivity, and dissolved oxygen in the freshwater locations were consistent at 15°C, 280 µS/cm, and 6.4 mg/l, respectively. Under the moderate spring inflow and moderate high tide elevation experienced during the May survey, the Big Sur lagoon appeared to remain fully freshwater upstream of the outlet channel.

The October survey occurred during much reduced inflow (23 cfs) and much higher maximum tide (6.0-6.2 ft); consequently seawater extended much farther upstream. The build-up of the sand berm at the lagoon mouth (Figure 7) also may have influenced the distribution and retention of seawater. Salinities up to 20 ppt were recorded in the outlet channel and at bottom locations (at depths of 3-6 ft) along transects 1 and 2, with

maximum salinities of 16-17 ppt along transects 3 and 4 (Figure 4). Salinities were typically 0.2-0.4 in the upper 2 ft of the water column at all sites. Maximum salinity continued to decline in the upstream direction, with bottom salinities reaching 11 ppt at transects 5 and 6, and a lingering pocket of elevated salinity (2.8 ppt) in the bottom of the north bank thalweg approximately 80 ft upstream of transect 6. Although WSELs were influenced upstream of this point, seawater did not appear to intrude beyond transect 6B. Water temperatures were relatively constant at 13.0 to 13.4^{o}C in the lower 3 transects and throughout the water column, with a maximum surface to bottom difference of 0.3^{o}C (colder in bottom saline water). Water temperatures were higher (13.5-14.2^{o}C) along transects 4-6, with minimal differences from surface to bottom.

Fish Dive Counts

Six dive counts were conducted along a standardized series of cross-sectional and bank transects. The two May counts were conducted during the periods of high tide, the July counts were made during low tides, and the October counts were split between a low tide and a high tide (Figure 5). The total number of juvenile steelhead observed on each dive ranged from a low of 9 fish on 18 May to a high of 313 fish on 7 October (Table 3). Large differences in steelhead abundance were apparent between the two consecutive-day counts in each survey period. For example, counts of steelhead in May increased from only 9 fish on the 18th during a high outgoing tide, to 41 fish on the 19th during a high incoming tide. In July, both surveys occurred during low incoming tide, but 180 fish were observed on the 18th versus only 41 fish on the 19th. In October, abundance of steelhead was much higher during the low tide on the 7th at 313 fish, versus 137 fish at high tide on the 8th. The reason for the large differences in consecutive-day counts is unknown, since water clarity was excellent during each dive and the May and July counts were conducted at similar times of day under similar flow, tidal stage, and water temperature conditions. In contrast, the October counts did occur at different tidal stages and different time periods.

To further compare the spatial and temporal differences in steelhead abundance, counts for each transect were averaged between the two consecutive-day dive counts (Figure 13). Index counts were separated between cross-sectional transects and the intervening bank transects, and also between size classes. Several patterns are readily evident, such as the higher abundance of smaller steelhead juveniles (<10cm) in comparison to larger juveniles, the lower counts along cross-sectional transects than along bank transects (although bank transects were typically longer), the increase in abundance over time, and the broader distribution of steelhead throughout the lagoon over time. The increased abundance in October in the lower lagoon is especially evident, which was also noted by DFG biologists during a site visit and snorkel survey conducted in late October (Robert Holmes, DFG, personal communication). During the 7-8 October described in this report, juvenile steelhead were observed actively feeding on the water's surface throughout the lower lagoon, including the vicinity of transects 1 and 2 which contained a surface layer of freshwater overlying a zone of seawater. During dive counts across these transects, small groups of juvenile steelhead averaging 8-12 cm in length were observed roaming throughout the midchannel area within the freshwater lens, and well as within

and below the saltwater interface. The occurrence of juveniles down in the saline areas was unexpected as none of the juveniles appeared to possess smolting characteristics.

Approximate index estimates of abundance by survey date were derived by expanding the daily-averaged dive counts across cross-sectional transects (and associated transect widths) to the length of the entire lagoon area. The index estimates for steelhead juveniles (≤10cm) increased from only 15 fish in May to 1,250 fish in October (Figure 14). The index abundance in October was significantly greater than the May abundance, based on non-overlap of confidence intervals. However, the smaller fry in May were largely restricted to the bank habitat, and clusters of fry were observed along the lagoon margins that were not encompassed by the cross-sectional dive counts (e.g., 38 fry were counted along bank transect 6R on 19 May, Table 3). Consequently, the May index estimate for fry is known to be too low.

Juvenile steelhead >10cm in length were likely 1+ or older fish in May, but some counts of >10cm fish in July and (particularly) October may have included larger young-of-year fry. Index estimates of abundance of fish >10cm were similar in May and July at 22-30 fish, but were significantly more abundant in October at 241 fish (Figure 14). Note that many of the fish >10cm observed in October were likely young-of-year fry that had grown out of the smaller size class. Most of the steelhead in this size class were <15cm, but steelhead up to 20cm in length were observed during each dive count. No steelhead were observed that possessed the silvery coloration and black-edged fins associated with smolting.

Combining all steelhead together produced index estimates of 45 fish, 490 fish, and 1,492 fish during May, July, and October, respectively (Figure 14). These abundance estimates produce estimated densities of 0.03 fish/100ft^2 in May, 0.34 fish/100ft^2 in July, and 1.04 fish/100ft^2, based on high tide surface area of 143,150 ft^2.

Other aquatic species observed throughout the lagoon included stickleback, sculpins, crayfish, and turtles. Juvenile surfperch and a small flatfish were also observed near the lagoon mouth.

DISCUSSION

Although the importance of coastal lagoons to anadromous salmonids has not been frequently studied in California, the available evidence supports northern studies that show small estuaries can provide accelerated growth of juvenile pre-smolt salmonids, which can then lead to enhanced ocean survival and return of adult spawners (Shapovalov and Taft 1954, Reimers 1973, Smith 1987, Ward and Slaney 1988, Miller and Sadro 2003, Quinones and Mulligan 2005, Bond 2006, Bond et al. 2008, Atkinson 2010). Improved growth and survival in estuaries may be associated with several factors, including high productivity of brackish-water prey species, abundant low velocity habitat for feeding and deep water habitat for refuge from predators, emergent wetland vegetation with associated cover and invertebrate species, and, in southern climates, ocean-moderated temperature regimes.

Juvenile steelhead were observed in the Big Sur lagoon during each site visit and at all tidal heights, and were particularly abundant in the fall when juveniles were distributed throughout the entire length of the lagoon. Estimated abundance in October was within the range reported from other California lagoons (Bond 2006, Bond et al. 2008, Hayes et al. 2008, Atkinson 2010), but was higher than estimates made in the (upper) lagoon by Hanson (Hanson 2011). Hanson reported that many juveniles in the upper lagoon and lower river reaches possessed smolt-like appearance, however all juveniles observed in this study were highly pigmented and lacked smolt characteristics. Like Hanson (2011), water quality data collected in the lagoon during spring, summer, and fall for this study did not show evidence of poor water quality. However salinities in the lower lagoon in October did demonstrate high salinities of up to 20 ppt in the deeper portions of the lower pool (along transects 1 and 2), as well as moderate salinities (>10 ppt) in deeper pockets of transects 3-6. No evidence of elevated salinity was detected above transect 7.

The limited extent of sea-water influence, in combination with the bathymetry map and water velocity data, indicates that classic lagoon characteristics (e.g., deep water, slow velocities, and brackish bottom water) were only present in the lower 500-600 ft of the survey area during low flow conditions. This is in contrast to many other California lagoons, which typically close-off from the ocean due to low flows and build-up of an enclosing sand spit. The Big Sur lagoon typically does not close-up during the summer or fall (Smith et al. 2008), although a build-up of the sand spit was observed and by July the still-open sand spit did result in greater pooling and increased depths below transect 3. The open lagoon mouth continued to allow tidal changes in upstream WSELs, but did not pool-up the lagoon to the extent that riffle and run habitats were completely flooded during high tide. Consequently, the upper 1,000-1,200 ft of the lagoon remained predominantly riverine, with its associated depth, velocity, substrate, cover, and (presumably) invertebrate prey characteristics.

The intense fires in 2008 and the subsequent recruitment of sediments down into the lagoon area may have resulted in a reduction in the deeper, slower habitat typically associated with lagoons. A GIS survey of the lagoon mouth and lagoon head conducted in 2008 after the fire but prior to the first winter rains suggested that the large mid-channel bar near the lagoon head was much smaller in extent than observed in 2010, however the 2008 elevation plot does suggest that the lagoon head contained abundant shallow water areas and isolated scour holes characteristic of riverine habitat (Smith et al. 2008). The post-fire conditions monitored in this study may represent a lagoon that has been somewhat transformed into a more riverine, albeit tidally influenced, habitat. Although juvenile steelhead were abundant in the lower, more lagoon-like habitat in October, fewer individuals were observed in the lower lagoon in July, and it is unknown if the Big Sur lagoon currently provides habitat characteristics that might lead to enhanced growth and survival of pre-smolt steelhead, as has been found in other, closed lagoon systems.

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Table 1. Substrate and cover definitions.

Variable	Size (in)	Description
Fines	<0.5	
Gravel	0.5-2.5	
Cobble	2.5-12	
Instream Veg		live instream woody branches
Overhead Veg		out-of-water veg w/in 18 in of water surface
Emergent Veg		emergent aquatic vegetation (rushes, cattails)
Undercut Bank		
Large Woody Debris	>48 long x >4 diam	dead, unattached wood
Cobble	>2.5	unembedded instream cobble

Table 2. Physical conditions during sampling.

Survey Date	Inflow cfs	Tide	Time	Elevation ft
18-May-10	127	H	1:15 AM	5.43
		L	8:57 AM	-0.94
		H	4:11 PM	3.74
		L	8:27 PM	2.78
19-May-10		H	2:16 AM	5.02
		L	9:50 AM	-0.66
		H	5:02 PM	4.00
		L	9:57 PM	2.60
18-Jul-10	41	H	4:48 AM	3.41
		L	10:07 AM	1.56
		H	5:00 PM	5.65
19-Jul-10		L	12:22 AM	0.60
		H	6:32 AM	3.15
		L	11:02 AM	2.12
		H	5:54 PM	5.77
7-Oct-10	23	L	4:08 AM	0.85
		H	10:20 AM	6.00
		L	4:57 PM	-0.28
		H	11:13 PM	4.89
8-Oct-10		L	4:47 AM	1.28
		H	10:57 AM	6.22
		L	5:47 PM	-0.60

Table 3. Dive counts of juvenile steelhead according to date, transect, and size class.

Date	Transect	# ≤10cm	# >10cm	Date	Transect	# ≤10cm	# >10cm
18-May	0X	0	0	19-May	0X	0	0
	0R	0	0		0R	0	0
	1X	0	0		1X	0	0
	1L	0	0		1L	1	0
	2X	0	0		2X	0	0
	2R	2	0		2R	2	0
	3X	0	0		3X	0	0
	3L	0	0		3L	0	0
	4X	0	0		4X	0	0
	4R	0	0		4R	1	0
	5X	0	0		5X	0	0
	5L	0	2		5L	0	0
	6X	0	2		6X	-	-
	6R	0	0		6R	38	0
	7X	0	0		7X	0	0
	7L	2	0		7L	-	-
	8X	0	0		8X	2	0
	8R	0	1		8R	-	-
	9X	0	0		9X	0	0
	9L	0	0		9L	-	-
	10X	0	0		10X	0	0
18-Jul	0X	0	0	19-Jul	0X	0	1
	0R	0	0		0R	-	-
	1X	0	0		1X	0	1
	1L	0	0		1L	-	-
	2X	0	0		2X	0	0
	2R	0	0		2R	-	-
	3X	0	0		3X	0	0
	3L	20	4		3L	-	-
	4X	2	0		4X	2	0
	4R	3	1		4R	-	-
	5X	1	0		5X	1	0
	5L	33	5		5L	-	-
	6X	3	0		6X	9	0
	6R	8	2		6R	-	-
	7X	7	0		7X	5	0
	7L	52	0		7L	-	-
	8X	3	1		8X	6	0
	8R	23	4		8R	-	-
	9X	8	0		9X	15	0
	9L	0	0		9L	-	-
	10X	0	0		10X	1	0
7-Oct	0X	7	0	8-Oct	0X	0	0
	0R	0	0		0R	2	0
	1X	25	0		1X	10	1
	1L	8	8		1L	0	0
	2X	25	5		2X	3	0
	2R	5	1		2R	0	0
	3X	31	4		3X	15	0
	3L	2	3		3L	1	2
	4X	25	7		4X	8	2
	4R	31	6		4R	3	1
	5X	18	7		5X	9	2

5L	9	5	5L	11	8
6X	10	3	6X	0	0
6R	20	9	6R	20	4
7X	1	3	7X	0	1
7L	4	0	7L	7	2
8X	2	2	8X	3	0
8R	12	8	8R	9	8
9X	7	0	9X	2	2
9L	0	0	9L	0	0
10X	0	0	10X	1	0

Figure 1. Area map of the lower Big Sur watershed (map from DFG 2009).

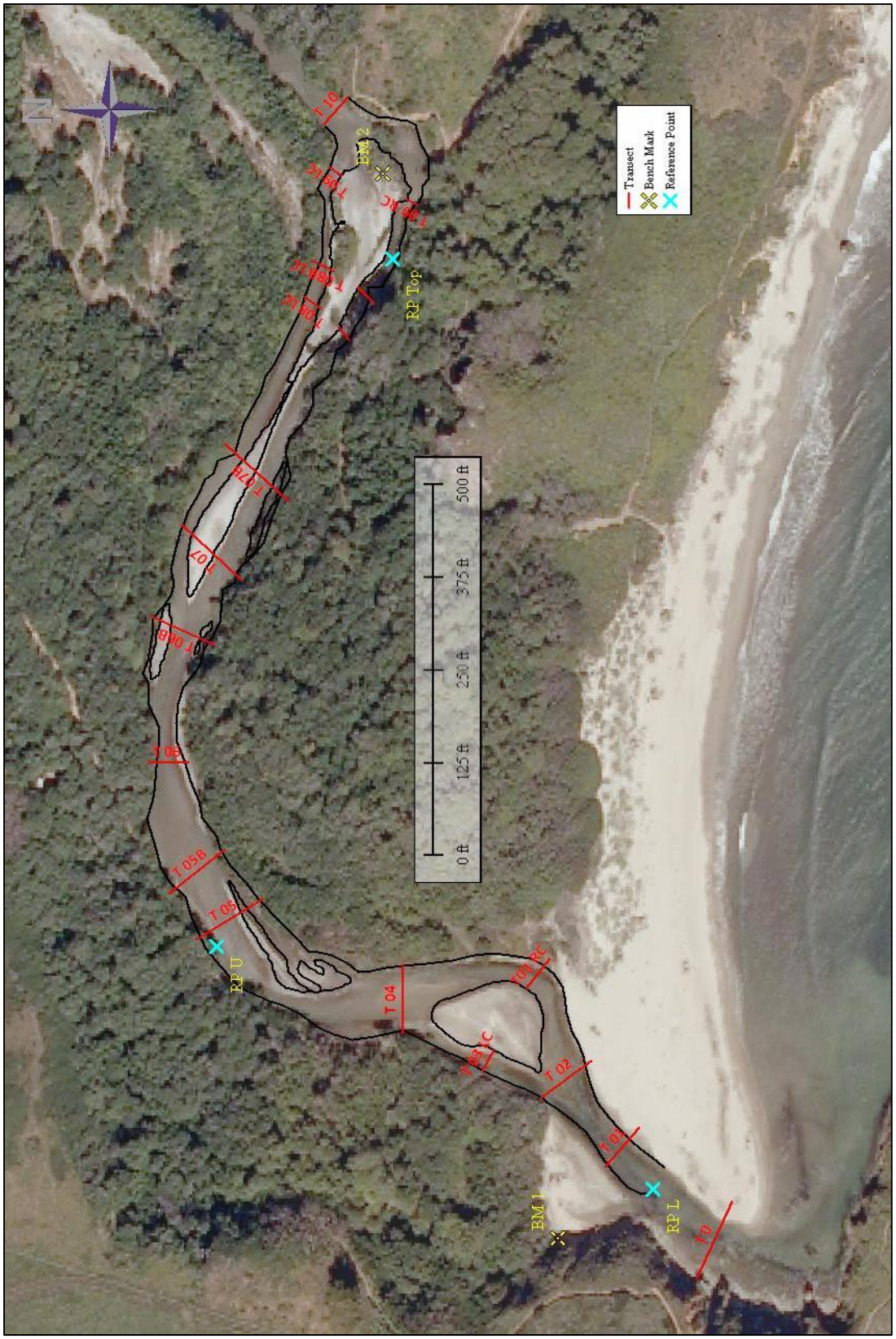

Figure 2. Big Sur lagoon showing cross-sectional transects, benchmarks, reference pins, and May low tide water's edge (aerial photo spring 2010).

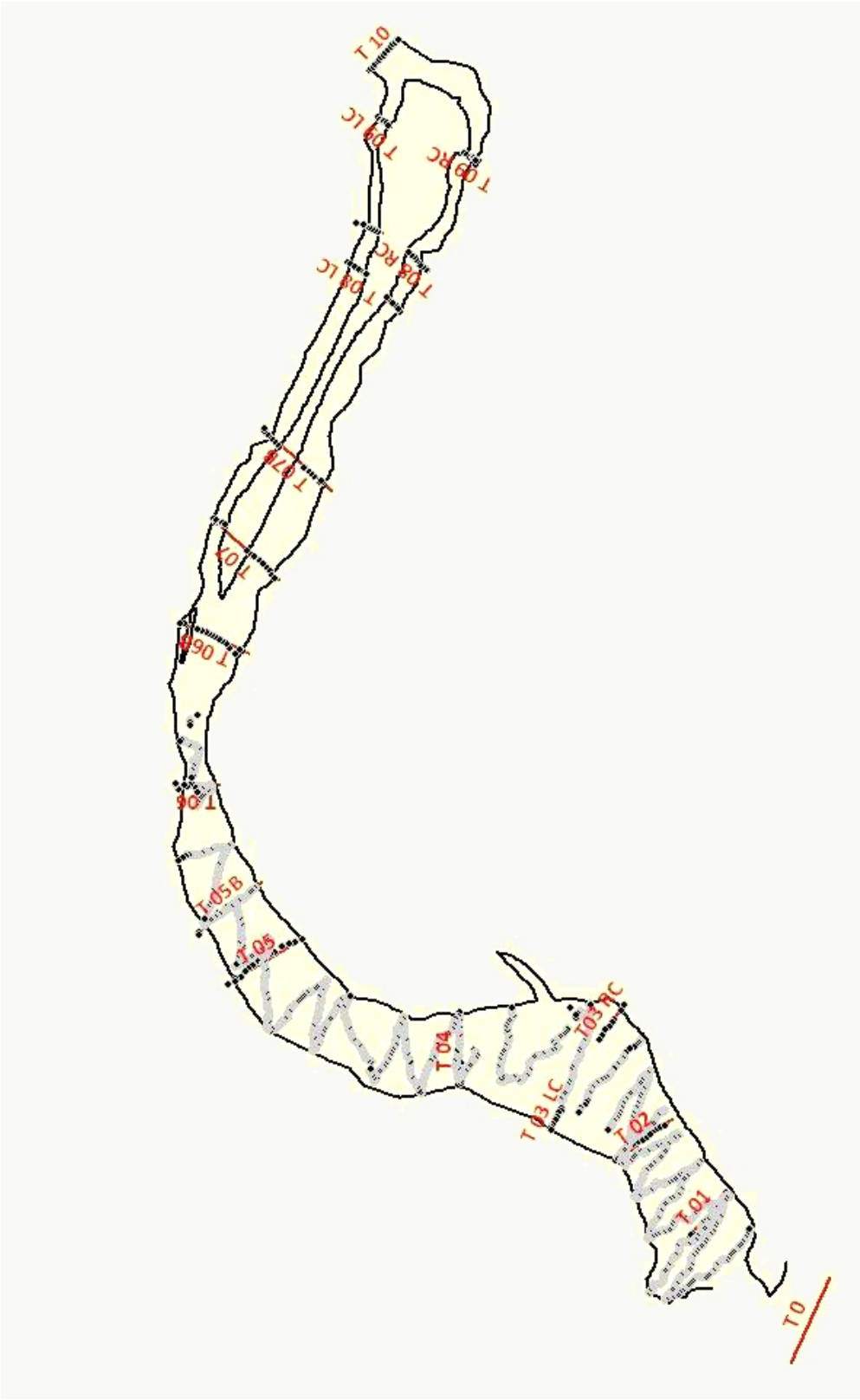

Figure 3. Water's edge during July high tide showing ADCP sampling points in the lower lagoon (grey lines) and manual sampling points (black dots) along cross-sectional transect in the upper lagoon.

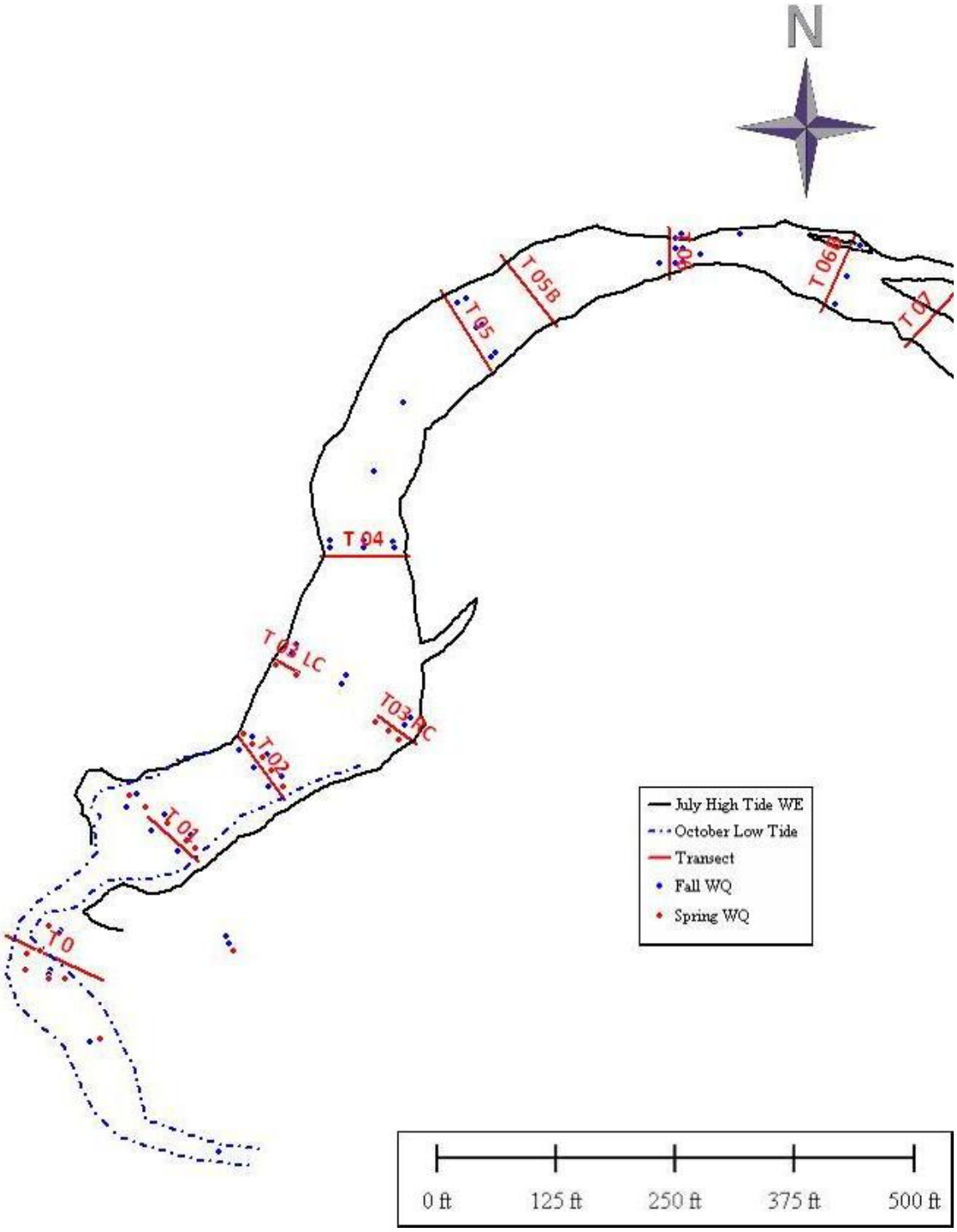

Figure 4. Approximate location of May and October water quality sampling points in the lower lagoon, lagoon outlet (dashed line below mouth), and surf zone (3 isolated points).

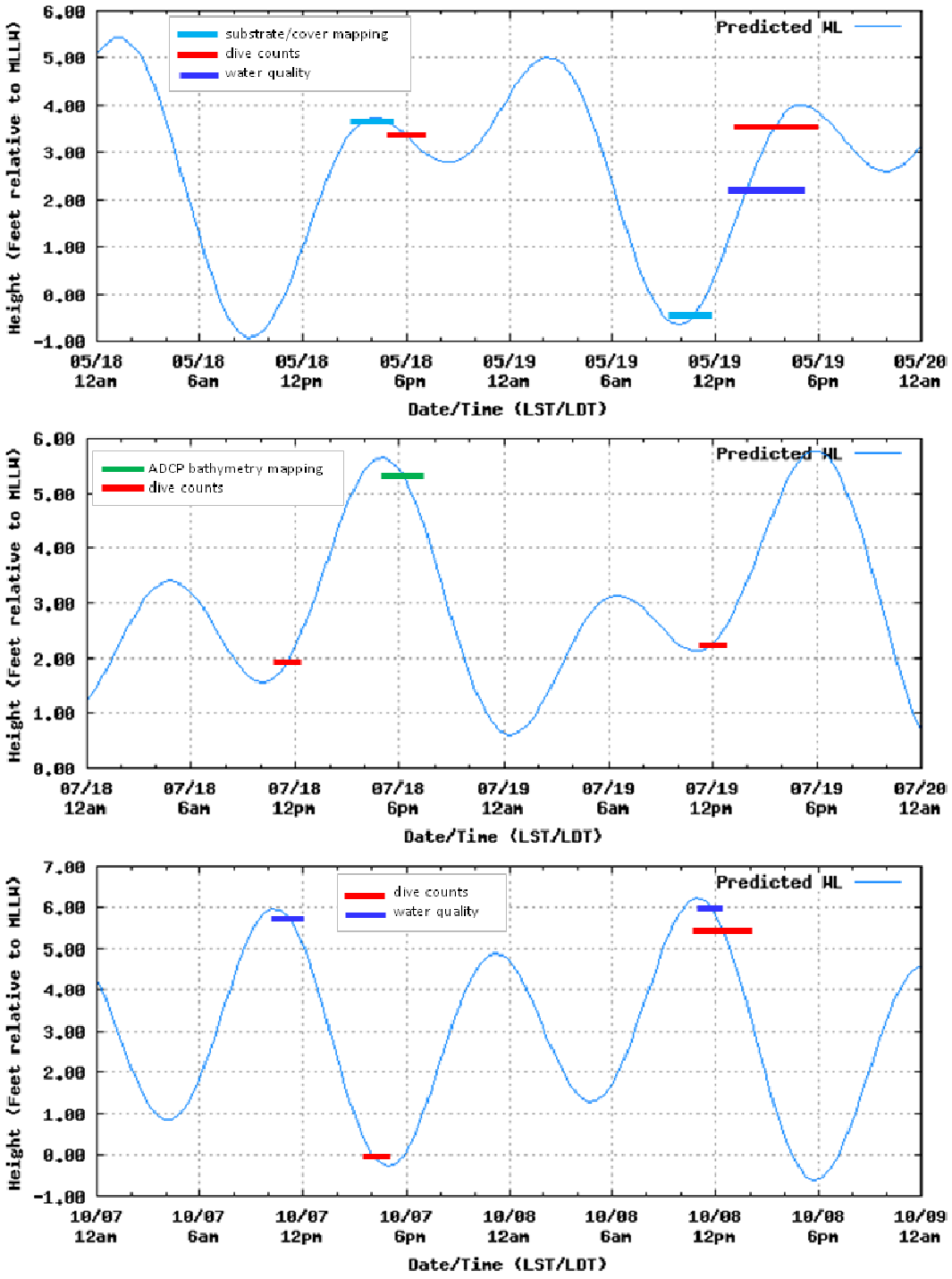

Figure 5. Tidal cycles and periodicity of specific lagoon tasks during May, July, and October surveys. Periodicity for measuring WSELs, upper transect depths, and inflow are not shown (predicted tides from NOAA at Monterey Bay).

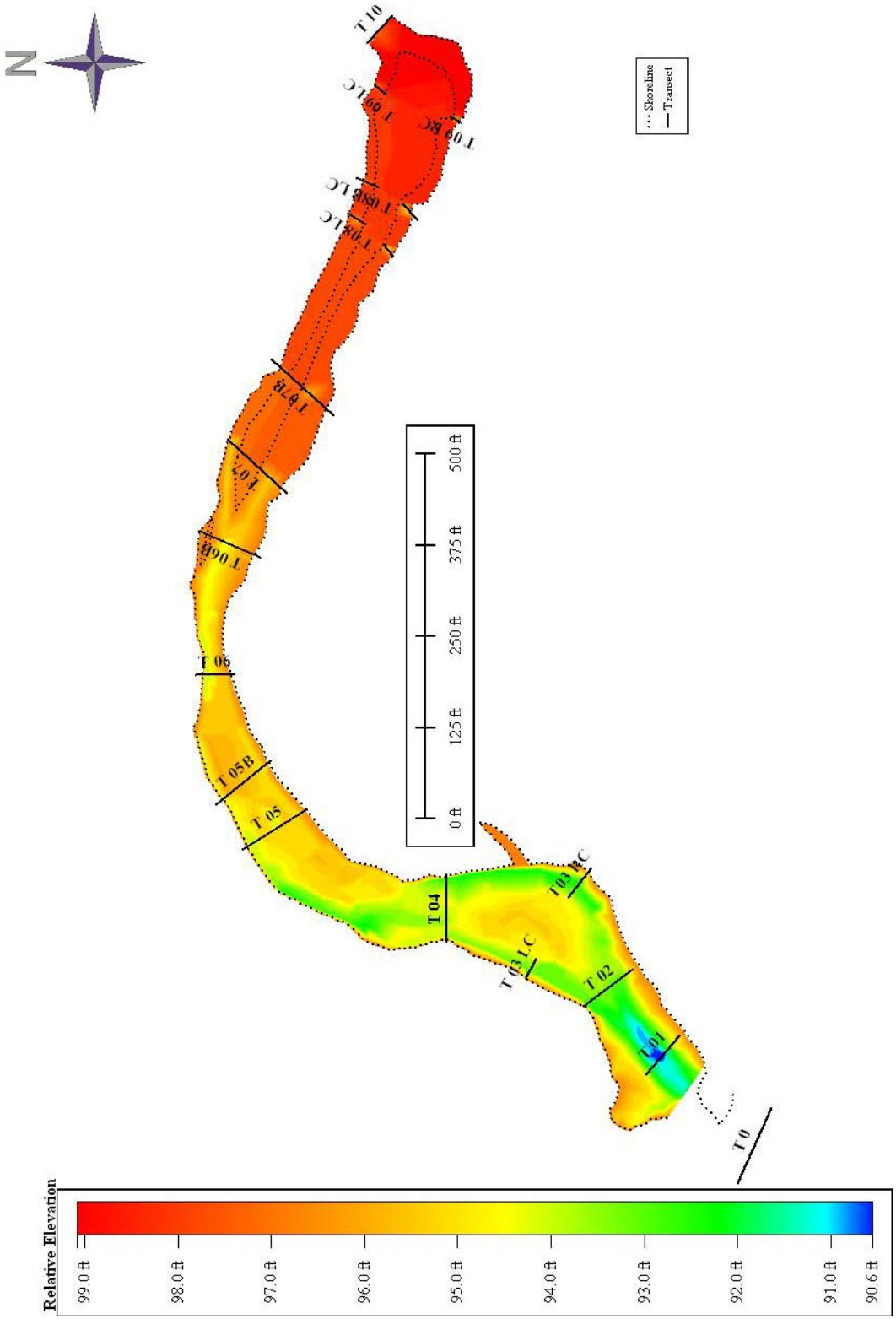

Figure 6. Relative elevation map of Big Sur lagoon with July high tide water's edge.

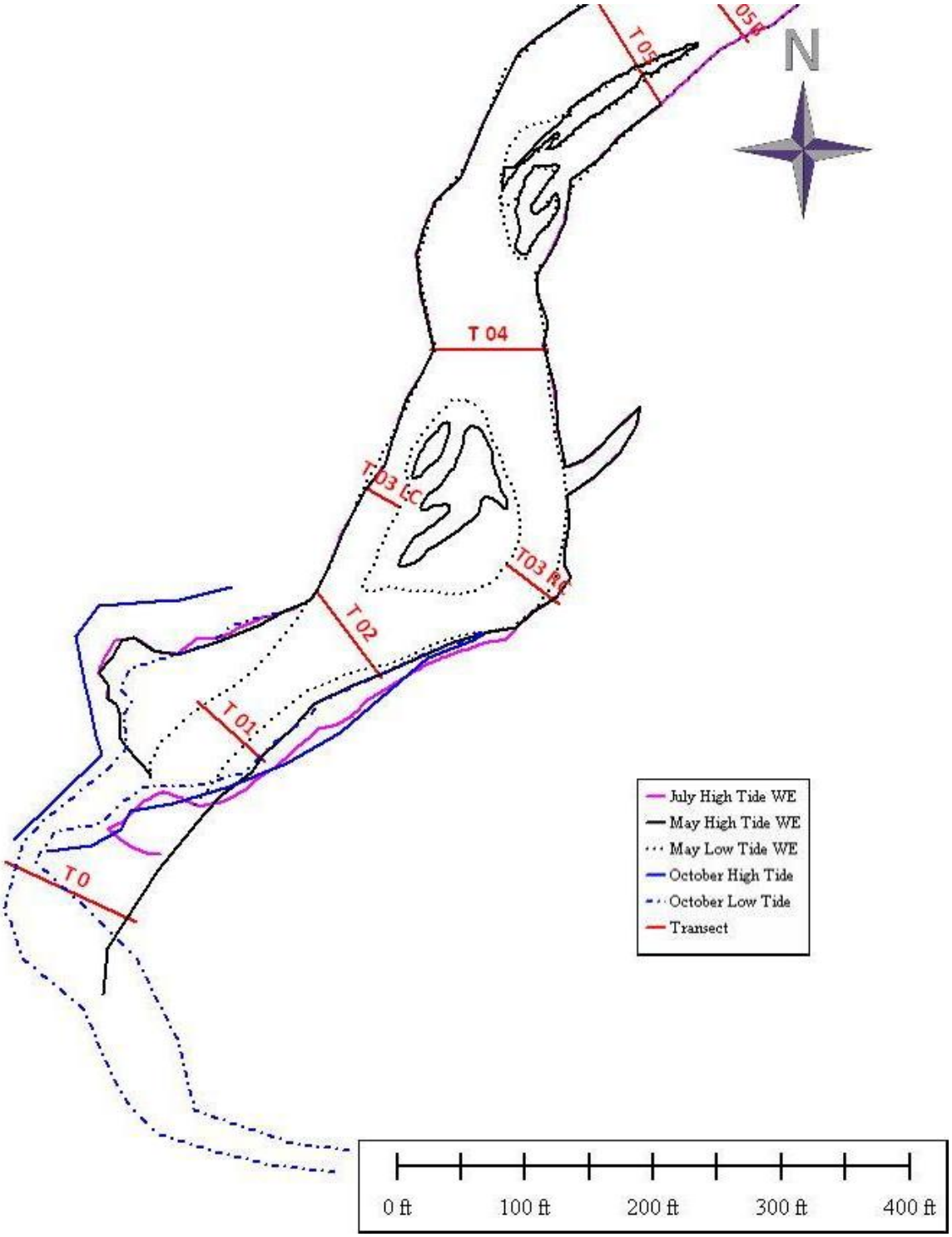

Figure 7. Comparison of water's edge in the lower lagoon according to month and tide. Changes in waters edge in upper lagoon were minimal.

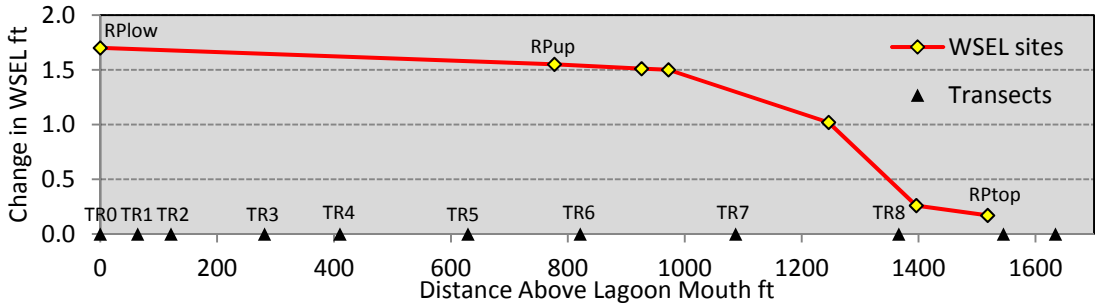

Figure 8. Magnitude of changes in WSEL during October high tide versus low tide according to distance above mouth. Unlabeled reference pins were temporary pins.

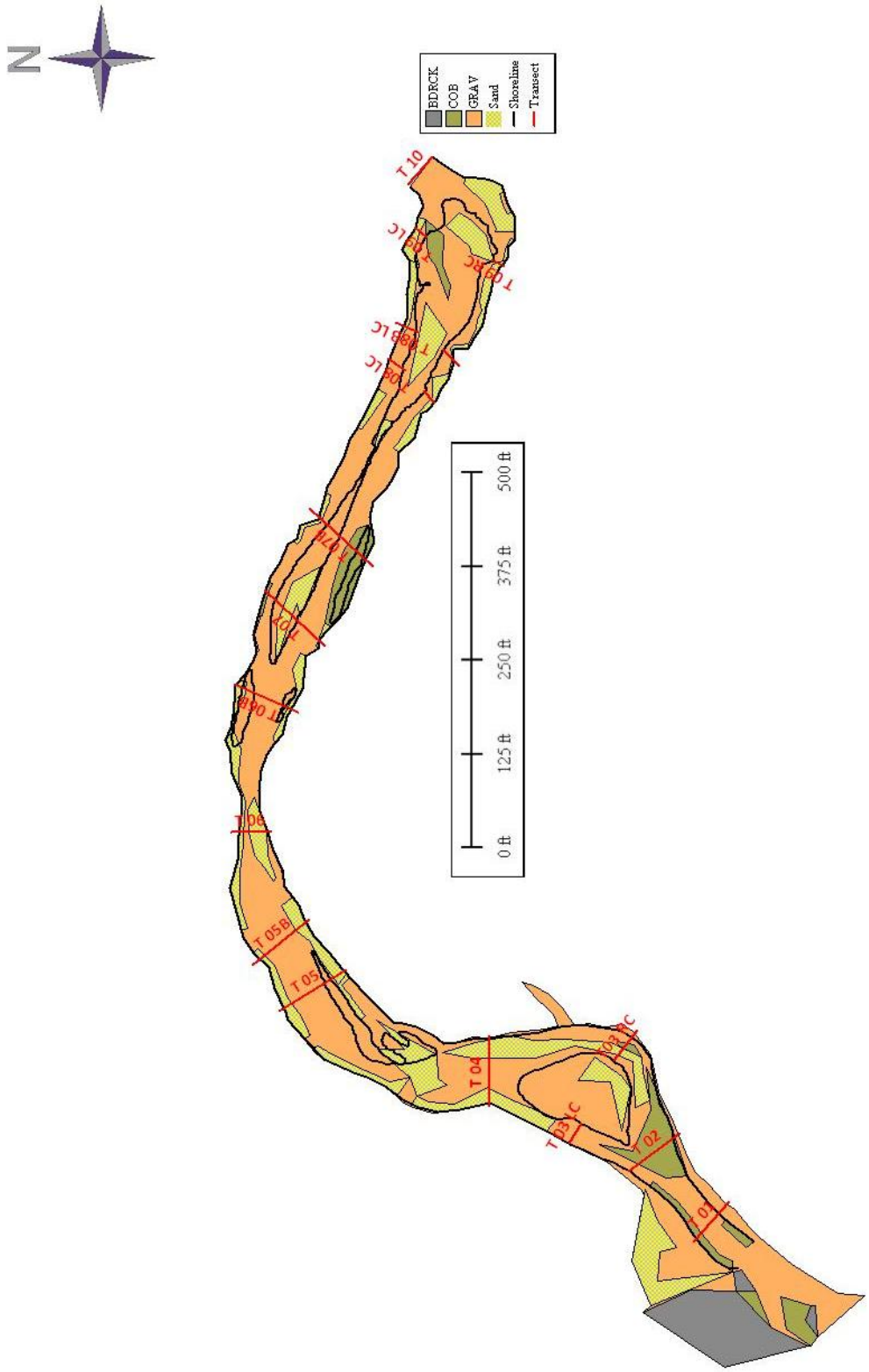

Figure 9. Distribution of dominant substrate types in the Big Sur lagoon in May 2010.

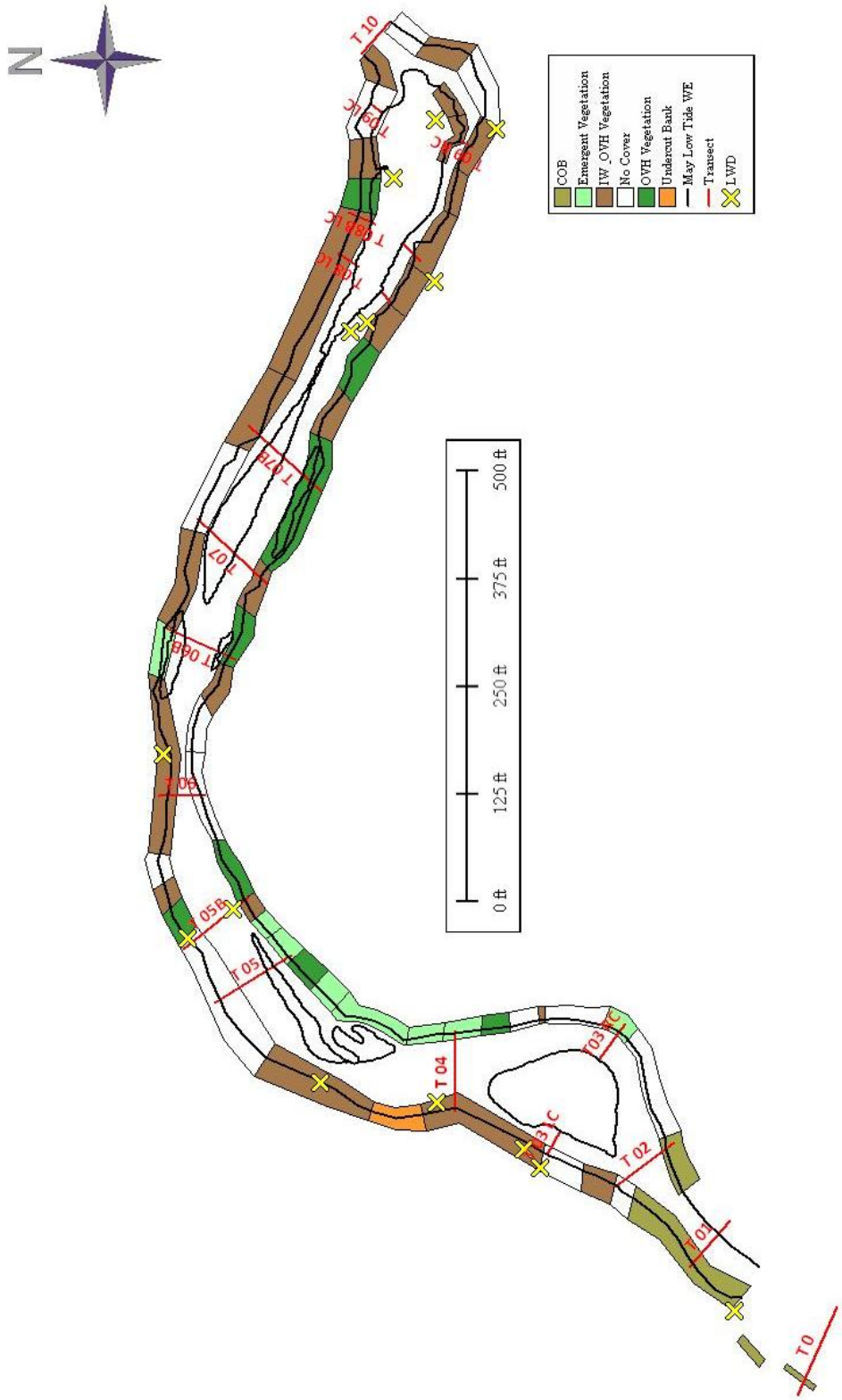

Figure 10. Distribution of cover types in the Big Sur lagoon in May 2010.

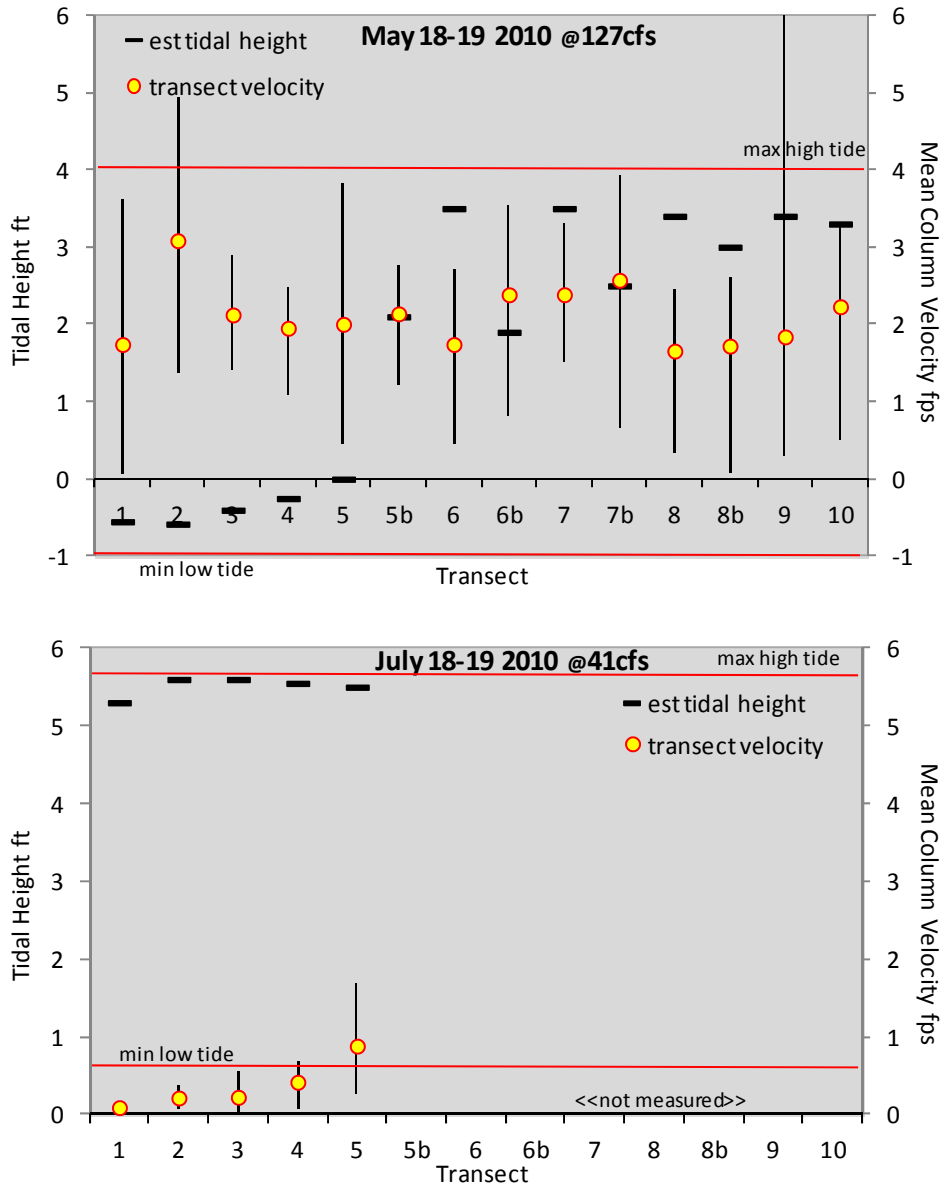

Figure 11. Mean column velocities (average, maximum, and minimum) measured along transects according to survey period and tidal height. Daily maximum and minimum tides are also shown.

Figure 12. Photos showing depth and velocity characteristics along transects 6 (top) and 7 (bottom) during July high outgoing tide.

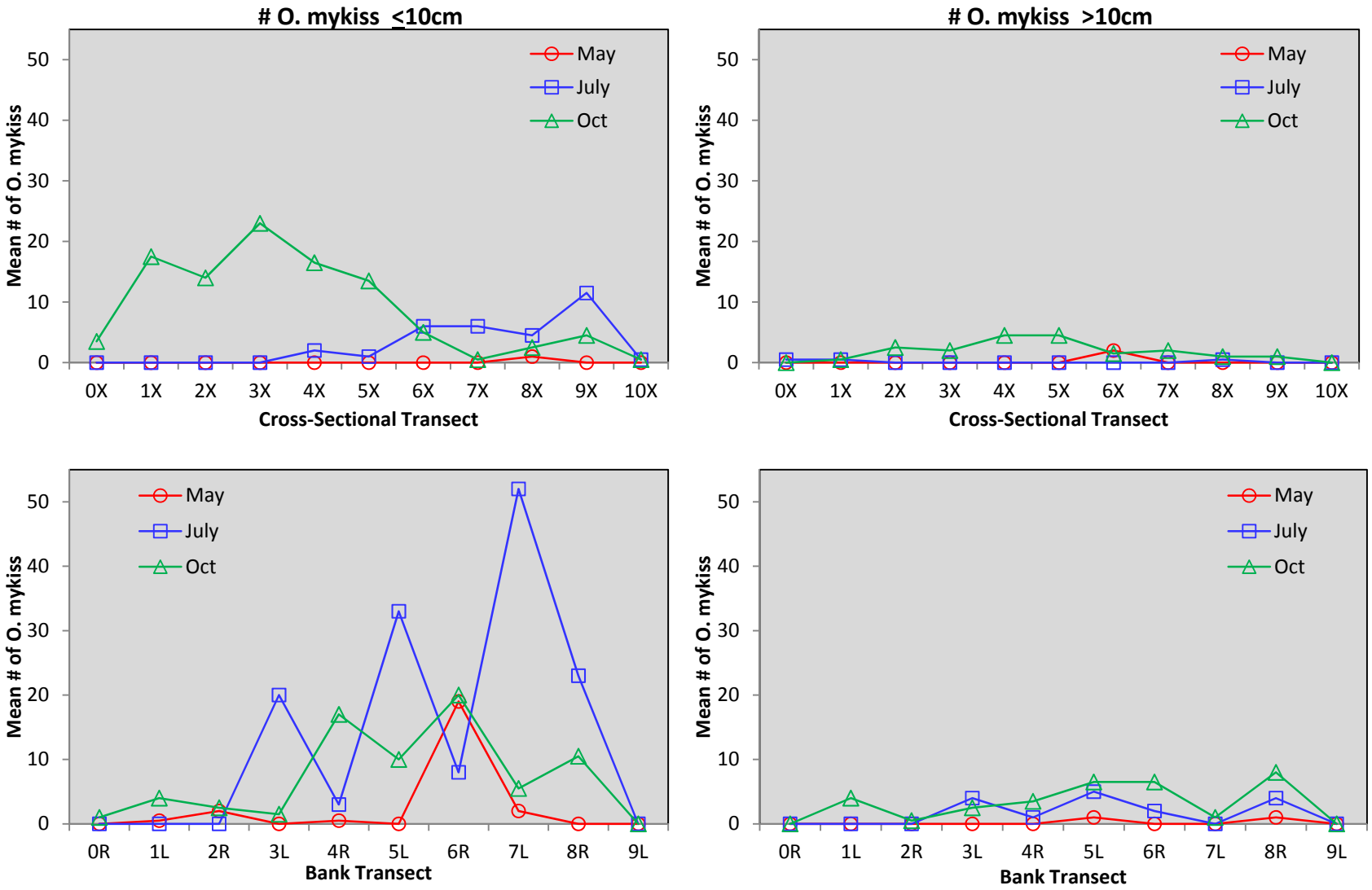

Figure 13. Dive counts of juvenile steelhead in the Big Sur lagoon according to size class, transect, and survey period.

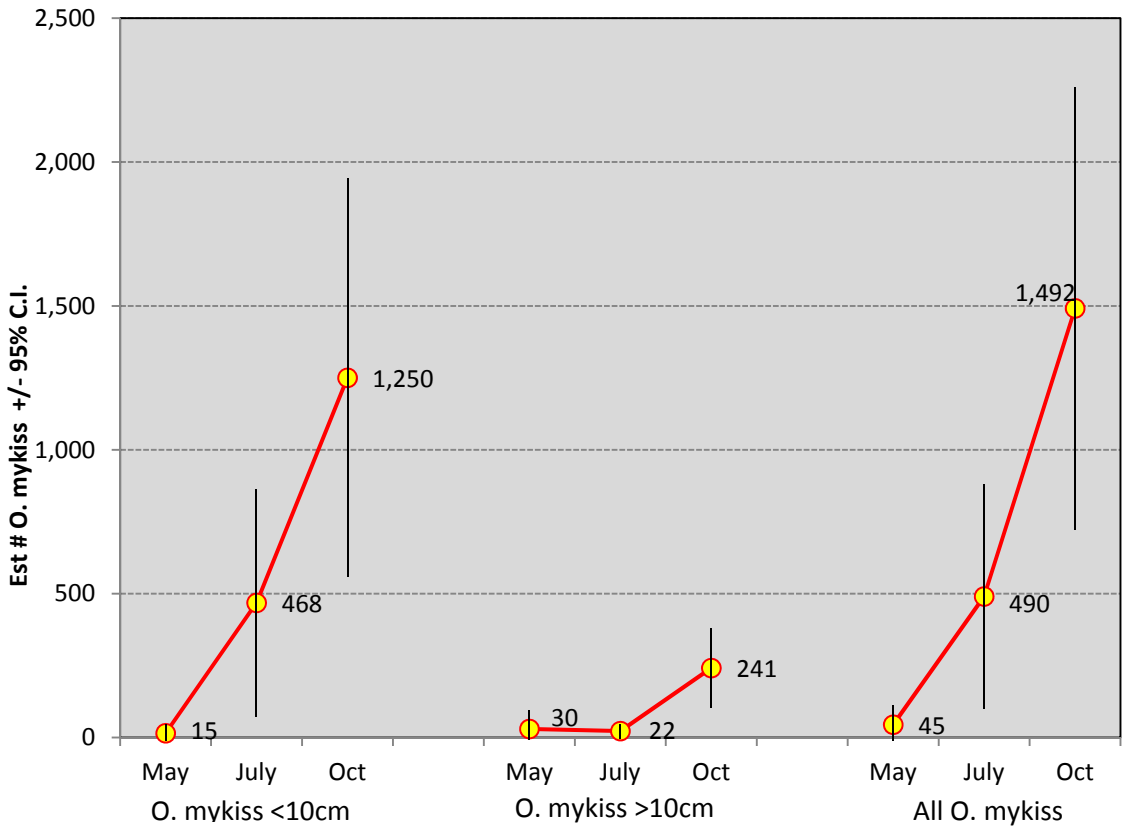

Figure 14. Estimated index of abundance of juvenile steelhead in the Big Sur lagoon according to size class and sampling period.