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Central Coast Watershed Studies

CCoWS

Carmel River Lagoon Enhancement Project: Water Quality and Aquatic Wildlife Monitoring, 2004-5

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Preface

This is a report to the California Department of Parks and Recreation. It describes water quality monitoring during and after the construction phases of the Carmel River Lagoon Enhancement Project and includes preliminary analysis of the ecosystem created. This report marks the completion of the first year of monitoring water quality and aquatic habitat. These monitoring activities will continue for two more years as the enhancement project progresses.

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Executive Summary

In summer and fall 2004, the California Department of Parks and Recreation (DPR) conducted the Carmel River Lagoon Enhancement Project. The project involved excavation of a dry remnant Arm of the lagoon and adjacent disused farmland to form a significant new lagoon volume. The intention was to provide habitat, in particular, for two Threatened species: the California Red-Legged Frog, and the Steelhead Trout (South Central-Coastal California Evolutionary Significant Unit). DPR contracted with the Foundation of California State University Monterey Bay (Central Coast Watershed Studies Team, Watershed Institute) to monitor water quality and aquatic invertebrates in association with the enhancement, and to attempt to monitor steelhead using novel video techniques. The monitoring objective was initially to detect any possible adverse impacts of construction activities on the original lagoon, and then to assess whether the enhancement was successful in providing habitat with good water quality, adequate invertebrate food for steelhead, and ultimately the presence of steelhead.

During the construction phases of the project, silt curtains were installed between the construction areas and the original lagoon. While poor water quality persisted in the immediate vicinity of construction, only minor incursions of poor water quality escaped beyond the curtains into the original lagoon, and these did not disperse very far, or in such a way that would exclude the inhabitants of the lagoon. In particular:

- Stream flow receded earlier in 2004 than in most other years, leading to prolonged low water levels.
- From commencement of sampling in late July 2004, the fresh-to-brackish surface layer was deeper in the South Arm in 2004 for the same month in 2003. This was due either to the relative timing of tides, waves, stream flow cessation, and sandbar closure; or to the absolute timing of sandbar closure leading to an increased period during which the lagoon is apparently replenished by groundwater or local freshwater runoff.
- Salinity stratification remained typical for summer conditions, including a gradual freshening trend as was observed during the summer and fall of 2003.
- The effects on surface salinity of pumping fresh water into the lagoon appeared to be secondary to apparently lateral season-long freshening trend.
- Water temperatures were cooler and more even than in 2003, which again apparently related to the timing of sand bar closure.
- Morning dissolved oxygen in surface layers remained above a threshold of 5 mg/L in the surface layers, with occasional supersaturated conditions due to diffusion of oxygen from highly photosynthetic layers in the mid-water.
- Suspended sediment concentrations occasionally rose above a threshold of 50 mg/L, but not to a degree that exceeded natural levels (i.e. those prior to the excavation), and not further into the main lagoon than the pipe about 50 meters from the silt curtains.
- Turbidity remained below a threshold of 20 NTU at all original-lagoon sites except in inside the silt curtains in the active construction area, and briefly at nearby sites outside the silt curtains.
- Carbon dioxide remained below a threshold of 10 mg/L in all original-lagoon surface waters except briefly at the pipe site during the most intense construction. Carbon dioxide in deep waters increased during most of the construction period, for uncertain reasons.
- Hydrogen sulfide remained below a threshold of 25 μg/L, except during two events where water flowed past the silt curtains leading to sulfide levels that were most toxic immediately adjacent to the curtain, and greatly reduced 50 m away at the South Arm Pipe. It is likely that fish would have had the opportunity to flee these conditions into undisturbed waters to the north of the pipe.

The original lagoon dried to very low levels just after excavation of the new lagoon in summer 2004, but before connection of the two areas. In discussions among interested parties at the time it was hypothesized that the water that filled the new lagoon immediately after it was excavated had either directly or indirectly caused a reduction in stage in the original lagoon. Various attempts were made to refill the original lagoon, including a release of treated water from the nearby Carmel Area Wastewater District (CAWD) Treatment Plant and releases of groundwater pumped from a well on the Odello property. Our previous work in 2003 demonstrated that the lagoon water level in summer is primarily set by the ocean wave energy that has prevailed over the preceding few weeks, via a process of flow through the closed sand bar, and occasionally, waves washing over the sand bar. Our analysis of the 2004 data suggest that the low stage in the original lagoon in 2004 could also be explained by the coincidence of early sand-bar closure and low wave energy, and that the effect of excavation of the new lagoon was secondary to this at best. The low stage and its water quality consequences may have contributed to the mortality of one, possibly two, adult steelhead found dead in the lagoon in late July 2004; but other causal factors are possible (In the following year, 5 young-of-the-year and one approximately 14-inch steelhead were found stranded and dead as similarly low stages developed following a late breach in July 2005).

During the onset of winter (Phase 3), the lagoon became more saline and cool with the influx of ocean wave over wash. It remained oxygenated at sampling times, although the sampling frequency was insufficient to detect the possible occurrence of any brief oxygen crashes associated with kelp decomposition. Suspended sediment and turbidity remained within criteria.

Following storms, such as the storm that lead to sandbar breaching on December 29th (Phase 4), gullies eroded in the newly formed banks of the restored lagoon. This resulted in an exceedence of criteria for suspended sediment and turbidity. Other parameters remained within criteria, and followed normal seasonal trends. Unlike previous years, the breach itself did not completely de-stratify the lagoon. Rather, it wasn't until 4 more months of stream flow that the deepest parts of the lagoon became relatively fresh. The new lagoon is much larger than before, and for the first time exhibits clear lateral gradients in surface parameters such as salinity, temperature, dissolved oxygen. Isolated and shallower waters at the inland end of the restored area tend toward being fresh, warm, and less oxygenated. Waters closer to the sandbar and the river are either fresh, cold, and oxygen saturated (during river flow); or saline (during periods of ocean influence such as incoming tides, or high waves).

The newly excavated lagoon began as an un-stratified, freshwater system that was immediately colonized by a range of typical early successional freshwater aquatic invertebrates. This included five orders of insects as well as daphnid crustaceans, all of which are taxa that are characteristic of freshwater ponds and lakes, but uncharacteristic of brackish lagoons. Once construction was completed and the two lagoon areas were connected, the waters mixed and the newly excavated area become mildly stratified in its deepest sections, with a typically fresher layer at the surface. The freshwater fauna immediately disintegrated and were replaced by the four peracarid crustaceans (two amphipods, an isopod, and a mysid) that have dominated the lagoon in summertime at least since the early 1980s. The mysids may have consumed the daphnids that had not already expired from salinity. In turn, the four peracarids have been found in the guts of steelhead and are thought to be their preferred lagoon prey. The rains came in December, the river flowed, and the lagoon breached. This eventually resulted in an overall freshening of the entire lagoon, with stratification briefly disrupted in the new lagoon, but never fully disrupted in the original lagoon. It was a wet winter, and while river flow at the nearest USGS gage persisted into July (and perhaps beyond), clear signs of summer re-stratification began in late May. The four peracarids remained dominant during this period, although fluctuating in relative abundance due apparently to temperature-driven seasonality, and perhaps community interaction effects such as predation. Of note is that the newly enhanced lagoon often exhibited water quality and invertebrate densities that were superior to those of the original lagoon (from the perspective of steelhead).

We note that the newly enhanced part of the lagoon still lacks bank vegetative cover for steelhead, although rooted aquatic vegetation is prevalent throughout. Thus, while water quality and invertebrate densities were optimal in this first 9 months of the new lagoon's existence, predator risk may not have been.

Juvenile steelhead were found in the original lagoon in late June 2005, using both handheld and fixed underwater video cameras. They were also found in the new lagoon by seining. Fish, almost certainly steelhead, were observed feeding at the surface of the lagoon during spring and summer of 2005. Other than this, no information was able to be collected on steelhead presence between seining in Fall 2004 and July 2005, nor on comparative densities of steelhead between the original and new lagoon areas.

An automated underwater video system was developed in an attempt to provide this capability. To date, the system has not been able to locate steelhead whose presence was not already known. The principal limiting factor is visibility. Hand-held video was successful in finding previously unknown steelhead, but only in very shallow, clear conditions. It may be the case that at many times of year, poor visibility due to high turbidity prevents any form of visual, non-intrusive steelhead monitoring - although further refinements of the automated system would be possible if resources continued to be applied. Monitoring using acoustic cameras is a new technique that is untested in the lagoon, but which has significant potential in calm turbid waters such as those of the Carmel Lagoon.

1 Introduction

The Carmel Lagoon forms the mouth of the Carmel River, near the town of Carmel at the northern end of the Santa Lucia Range along the Central Coast of California. In the summer, the lagoon is a relatively small water body, being the surface expression of a larger aquifer and its interaction with the ocean. The Carmel River Watershed is considered critical habitat for the federally threatened steelhead trout (*Oncorhynchus mykiss*). Steelhead are anadromous rainbow trout, meaning they migrate from freshwater rivers to the ocean and back. The lagoon provides habitat for rearing and smoltification, the physiological process steelhead go through that enables them to move from freshwater to saltwater environments.

1.1 Project Description

The Carmel River Lagoon Enhancement Project (CRLEP) involves the excavation and planting of new lagoon, marsh, and riparian habitats. One of the primary purposes of this project is to create more habitat for two Federally Threatened species: steelhead trout and California red-legged frog (CRLF, *Rana Aurora draytonii*). Additional indirect benefits include increased habitat for migratory avifauna and western pond turtles (*Clemmys marmorata*) both a Federal and State Species of Special Concern.

The Carmel River Lagoon lies at the end of the Carmel River between two residential areas: Carmel By The Sea to the north and Carmel Meadows to the south (Fig. 1.1). At some point in the past, the south arm of the lagoon extended into a channel several hundred meters to the south of the river channel, running alongside the steep granite bluffs to the south of the lagoon. The land area between these two channels was farmed for many years by the Odello family, and eventually acquired by California Department of Parks and Recreation (CDPR). In recent years, the south channel has existed as a remnant channel – a willow-dominated muddy habitat, only submerged during the highest lagoon stages, and during the largest floods.

In the summer of 2004, the CDPR implemented the construction phase of the Carmel River Lagoon Enhancement Project (CRLEP). The project significantly expanded the pre-existing lagoon by excavating a new channel on former Odello farmland adjacent to the remnant south channel down to below sea level. Project plans were described in a Revegetation Mitigation and Monitoring Plan (RMMP) (CDPR, 2003).

Because the Carmel River Lagoon has steelhead and CRLF habitat in it, the effects of creating new habitat were monitored with respect to proper water quality parameters for the survival of these two threatened species (detailed in Section 3.2). As the enhancement project continues, it is important to monitor the suitability of this newly created habitat for the species for which it was created. The purpose of this report is to document the effects of the Carmel River Lagoon Enhancement Project on water quality and aquatic wildlife habitat during and after excavation and establish data collection and analysis methods for future monitoring in the lagoon.

1.2 Project Timeline

The creation of a new portion of the lagoon, marsh, and riparian habitat as an extension of the pre-existing South Arm was achieved by excavating the earth and allowing shallow groundwater to fill the resulting void. Excavation started approximately 30 – 40 m from the eastern bank of the South Arm and progressed eastward into the Odello portion of the property. An earth barrier separated the Odello arm from the South Arm until this primary excavation was completed.

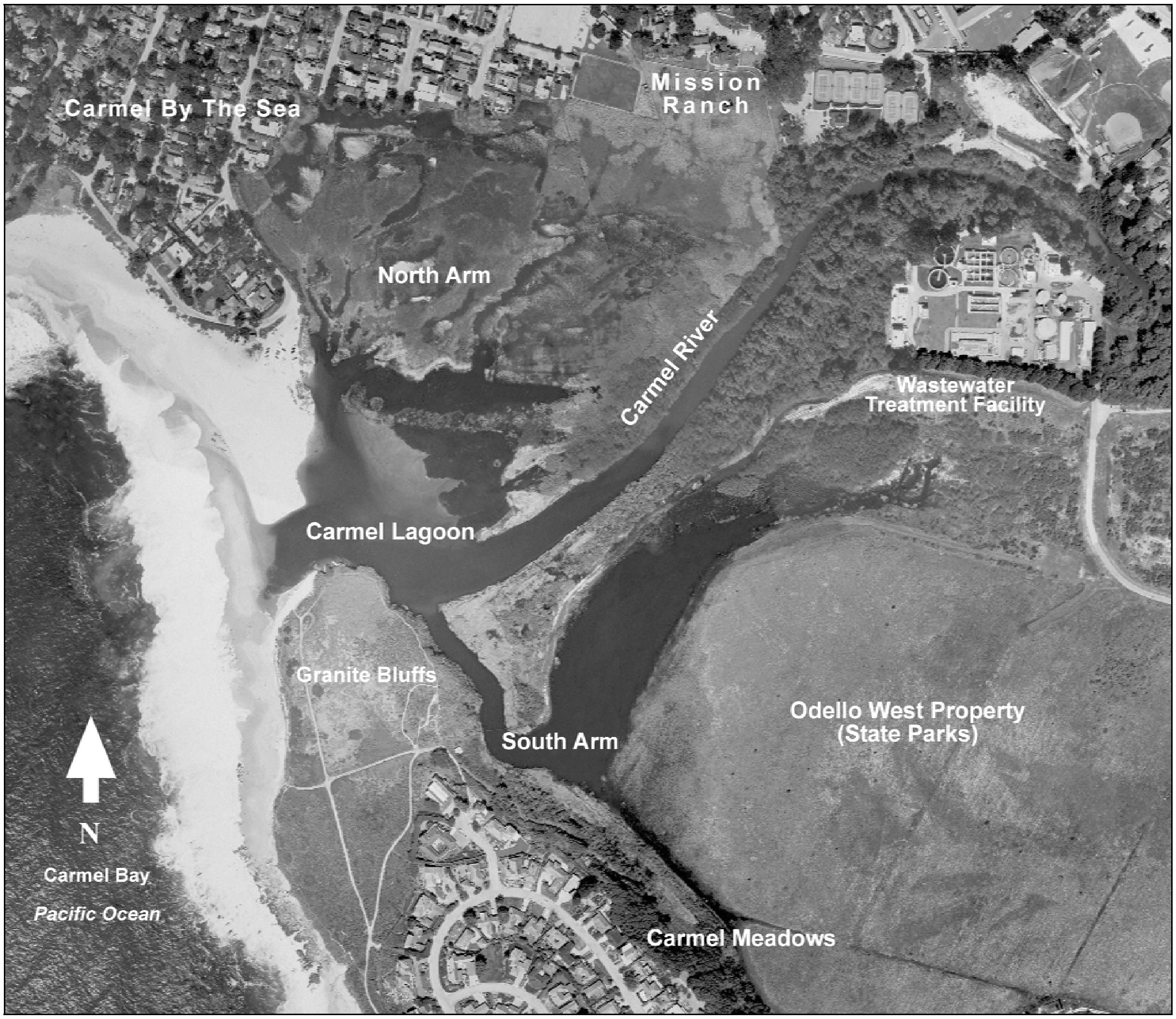


Figure 1.1. Map of Carmel River Lagoon and surrounding area (aerial photo was taken before the enhancement project) (from Casagrande & Watson, 2003).

Water quality monitoring began on 20 July 2004 several weeks after excavating of the Odello arm began. At this time, the lagoon stage was unusually low. Efforts to raise the water level began on 25 July 2004 by releasing treated water from the nearby water treatment facility (CAWD) into the dry riverbed to drain into the lagoon. Despite these efforts, on 28 July an adult steelhead ~0.5m long was found dead next to the gauge at the South Arm pipe. The cause of death remains unknown.

Other attempts at raising the water level were made by pumping water from the excavated Odello arm into the South arm. The first attempt was through a large-diameter pipe that traveled from one side of the earth barrier to the other over the ground. As the water exited this hose, it eroded dirt from the barrier and carried excess sediment into the South Arm. The next attempt was to attach the hose to a sprinkler system that sprayed water into the South Arm, simulating rain. The amount of water that was added to the lagoon through this mechanism was negligible.

The successful method for raising the lagoon stage was pumping fresh groundwater from an old well on the Odello property directly into the South Arm. The amount of water this added to the lagoon cannot be completely quantified, as the equipment was not always operational and the pumping rate was inconsistent and sporadic at times. This mechanism was still the most successful at increasing the volume of water in the lagoon.

After excavation of the Odello arm was completed, a few conditions had to be met before the earth barrier that separated the existing south arm and the new Odello extension could be removed:

- The South Arm had to be separated into an active digging area immediately next to the earth barrier, and a non-active area where no digging was to occur. Silt curtains intended to keep stirred up bottom sediment from entering and impairing pre-existing habitat designated this separation and served as a barrier between these two active and non-active zones. Water quality sampling occurred immediately inside and outside of these silt curtains.
    - Silt curtains were installed within the new Odello arm and at the northern edge of the South Arm, though these silt curtains were inconsequential to water quality.
- All steelhead had to be seined from the active digging zone (~ 15 young of the year were caught, identified, and released into the original lagoon area).
- The shallow portion of the original South Arm was dug deeper before being connected to the newly excavated Odello arm. This was achieved placing a temporary rock peninsula in the South Arm for the excavators to drive out on and dig in the middle of the water.
- The water level in the South Arm and in the Odello Arm had to be equal to avoid a violent rush of water from one portion into the other. This was achieved by pumping water from the excavated Odello arm directly into the South Arm.

Once these conditions were met, the earth barrier was removed and the entire Odello Arm was connected to the pre-existing South Arm and rest of the Carmel River Lagoon.

In the original plan, the silt curtains were to be removed as soon as the water quality inside the silt curtains was sufficient not to endanger steelhead, though on the morning of the 21st October, 2004, the silt curtains were found dislodged from the left bank of the South Arm. High stages had submerged the banks where the curtains were attached. This softened and loosened the dirt that the curtains were secured in. The curtains were then removed, concluding the construction of the new South Arm (figures on following pages).

1.3 Report Outline

The hydrologic dynamics of the lagoon drive the functioning of the ecosystem. The amount and quality of water in the lagoon determine the available habitat for significant species. The remainder of this report addresses three main topics: hydrology, water quality, and aquatic wildlife (macro-invertebrates and steelhead habitat).

(a) Excavating the new Odello arm. 28 Jul 2004

(b) Groundwater seeping in as dirt is removed. 28 Jul 2004

(c) Sampling for turbidity and SSC in water that has just entered the newly excavated arm. 28 Jul 2004

(d) View of excavation site from HWY 1 on 20 Jul 2004.

(e) View of Excavation site from HWY 1 on 29 Jul 2004.

Figure 1.2. Activities during construction phases.

(a) View of the new Odello Arm from the earth barrier that separated it from the South Arm. 21 Jul 2004

(b) Small channel draining into the South Arm during the CAWD water releases. 26 Jul 2004

(c) Dead steelhead found near gauge at South Arm pipe. 28 Jul 2004

(d) Dead Steelhead. 28 Jul 2004

(e) Hose feeding water from excavation site into the South Arm. 21 Jul 2004

(f) Sprinkler adding water to the South Arm. 6 Aug 2004

Figure 1.2. Continued. Activities during construction phases.

(a) Source of well water. 6 Aug 2004

(b) Pipe carrying well water. 6 Aug 2004

(c) Well water entering Corrugated pipe. 8 Aug 2004

(d) Corrugated pipe draining well water into the South Arm. 16 Aug 2004

(e) Silt Curtain in the South Arm as seen from north bank. 2 Sep 2004

(f) Aerial view. In the bottom left corner is the South Arm pipe. To the right of that are the silt curtains. The earth barrier can also bee clearly seen. This photo was taken during excavation in the South Arm.

Figure 1.2. Continued. Activities during construction phases.

(a) Seining fish in the South Arm. 31 Aug 2004

(b) Seining fish in the South Arm. 31 Aug 2004

(c) Seining fish in the South Arm. 31 Aug 2004

(d) Sorting catch. 31 Aug 31

(e) Sorting catch. 31 Aug 2004

(f) Seined steelhead. 1 Sep 2004

Figure 1.2. Continued. Activities during construction phases.

(a) Excavator on temporary rock peninsula. 14 Sep 2004

(b) Deepening of the original South Arm. 14 Sep 2004

(c) Deepening of the original South Arm. 14 Sep 2004

(d) Deepening of the original South Arm. 14 Sep 2004

(e) Sampling from kayak immediately outside of the silt curtains as excavators are digging in the South Arm. 16 Sep 2004

(f) View of excavation in the South Arm from “The Cross”. The white tent at the right is the mobile lab that was set up for water quality analysis. 15 Sep 2004

Figure 1.2. Continued. Activities during construction phases.

(a) Mudcat moving dirt to be carried away from the site. 16 sep 2004

(b) Earth Barrier before it was removed. 1 Oct 2004

(c) Small channel that connected the Odello Arm to the pre-existing South Arm. 1 Oct 2004

(d) This small channel was the only excavation that occurred in the South Arm on 1 Oct. The site was kept this way until 4 Oct to allow the water levels to equalize.

(e) During excavation the silt curtains bowed and surface water flowed toward the original lagoon away from the excavation. 1 Oct 2004

(f) High stages dislodged the silt curtains from the left bank as seen from the beach access road of off Calle De Cruz. 20 Oct 2004

Figure 1.2. Continued. Activities during construction phases.

2 Hydrology

2.1 Overview

The Carmel River flows in winter and is usually dry in summer. It terminates at the Carmel Lagoon, which is usually open to the ocean in winter and closed off by a sand bar in summer. Summer water levels and salinity are initially set in early summer by the relative timing of the final sand bar closure and cessation of river flow. Thereafter, water slowly flows back and forth through the sand bar during summer, so the water level is set by the ocean - due to tidal fluctuations and the height of ocean waves (Watson & Casagrande, 2004). The salinity is probably slightly increased by this exchange of water with the ocean, but this may be offset by a slight, continuous replenishment by shallow groundwater surrounding the lagoon. By late summer and fall, large waves often wash over the sand bar, causing rapid rises in water level and changes in lagoon chemistry.

The northern backwater (North Arm) section of the lagoon is circular (*c.* 300 m diameter) and comprises a system of channels and islands filled with aquatic vascular vegetation. The southern backwater (South Arm) was much more linear (*c.* 200 m before implementation of the enhancement project). A small hill with underlying bedrock confines the South Arm to a narrow channel that swells at high water into a wetland that was once used for agriculture.

The volume of the lagoon increases with the addition of increased stream flow during the wet season. This inundates terrestrial vegetation until the sandbar breaches naturally or is artificially breached (mechanically opened with a bulldozer in order to prevent flooding of nearby homes), and the lagoon and river can drain into the ocean. As the river flows into the lagoon and slows down, large sediment loads can be deposited. This quickly and significantly changes the bed and depth of the main lagoon.

Water levels in the lagoon are gauged using two NGVD staff plates located in the North and South Arms. The sandbar is mechanically breached when enough water accumulates behind it to raise the water level to a stage of ~10 ft. A stage greater than 10 ft has the potential to inundate surrounding residential areas. In 2002, CCoWS observed the artificial breach of the sandbar caused a rapid and complete draining of the lagoon (Casagrande et al, 2003), and in 2003 the breach of the sandbar had little effect on lagoon volume immediately after management as the lagoon stage lowered slowly (Watson and Casagrande, 2004). These differences may be due to multiple factors including bulldozing technique, sand bar height, wave height, and river flow.

2.1.1 Dynamic Wave Head

When the sandbar is closed and stream flow has declined, the water level in the lagoon is set by the ocean, as a dynamic equilibrium maintained by sub-surface flow back and forth through the sandbar (through-bar flow). This is a factor that is determined principally by the ocean and is independent of any activities within the watershed. The water level in the lagoon rises with periods of high waves and tides, and falls thereafter (Watson and Casagrande, 2004).

A computer model developed by Watson and Casagrande (2004) simulates the changes in daily surface water storage of the lagoon by estimating each of the primary fluxes into or out of the lagoon. One of the fluxes that can be estimated with this model is the effect of waves on lagoon stage with a calculation of *dynamic wave head*. In this calculation, the effect of waves is thought of as a hydraulic head imparted by the waves on the open lagoon waters through the sandbar. Effective wave heights are computed separately for closed and open lagoon conditions:

$$h_{c,t} = k_{h,c} + c_{h,c}h_t + c_{m,c}m_t$$
$$h_{o,t} = k_{h,o} + c_{h,o}h_t + c_{m,o}m_t$$

Where:
$h_{c,t}$ = effective wave height (closed sandbar) (m, NGVD)
$h_{o,t}$ = effective wave height (open sandbar) (m, NGVD)
$k_{h,c}$ = effective wave height constant (closed bar) = 0.75998 m (0.4 m *)
$k_{h,o}$ = effective wave height constant (open bar) = 0.706717 m
$c_{h,c}$ = effective wave height coefficient (closed bar) (–) = 0.350793
$c_{h,o}$ = effective wave height coefficient (open bar) (–) = 0.339155
h_t = dominant wave height in near-shore waters
c_m = tide coefficient (–) = 0.16
m_t = tide level (m, NGVD)

* Watson & Casagrande (2004) used a value of 0.75998 m for all years, but for the present work, a value of 0.4 m lead to a better prediction of the 2004 stage data

2.1.2 Geomorphology and River Discharge

The bathymetry of the lagoon is controlled by sedimentation, erosion, and excavation. Each year, sediment is brought into the lagoon by the river and by ocean wave action. Much of it is eroded away during the winter, but there is also a net-long term accumulation of sediment. When the flow of freshwater from the river is no longer significant to keep the sandbar open, the river quickly dries up immediately upstream of the lagoon.

2.1.3 Groundwater

Monitoring wells in the vicinity indicate a hydraulic gradient toward the lagoon from the lower Carmel River Valley. Thus, groundwater flow from the lower Carmel Valley Aquifer into the lagoon persists throughout the dry season, but the magnitude of this flow is unknown. It is an input that should not be overlooked when considering an overall water budget of the lagoon.

2.2 Hydrology During Study Period

The data presented here were obtained from many different sources (Table 2.1). Precipitation data from two weather stations (one in the upper Carmel River Watershed, and another coastal weather station in Castroville) were averaged together.

2.2.1 2004 hydrology compared to other years

2004 was a very dry year for the Carmel lagoon. Stream flow receded earlier in 2004 than in any year since 1994 (Fig. 2.1). By comparison, in 2003, flow persisted longer than any recent year except for the flood years of 1995 and 1998 when flow persisted throughout the entire summer. In most years, when the sandbar closes for the final time before the dry season, the lagoon stage swells with a final dose of freshwater and then gradually subsides as water gradually flows to the ocean through the sand bar over the next month or so. Eventually, the lagoon stage reaches a dynamic equilibrium controlled by the ocean, via back-and-forth flow of seawater and lagoon water through the sand bar. The freshwater swell usually occurs in late May, June, or July – but in 2004 it occurred in late April and early May (Fig. 2.2). This meant that the lagoon experienced an unusually long summer, with prolonged low stages.

Table 2.1. List of data sources.

Data Type	Data Source
Stage	Monterey Peninsula Water Management District (MPWMD)
Carmel River Discharge	USGS station 11143250 CARMEL R NR CARMEL CA, http://waterdata.usgs.gov/ca/nwis/current/?type=dailystagedischarge&group_key=county_cd
Precipitation	CA Dept of Forestry, HASTINGS weather station, http://cdec.water.ca.gov/cgi-progs/queryF?HTG
Precipitation	California Irrigation Management Information System, weather station Castroville#19, http://wwwcimis.water.ca.gov/cimis/logon.do?forwardURL=/frontDailyReport&selTab=data
Mean Sea Level	Center for Operational Oceanographic Products and Services, http://www.co-ops.nos.noaa.gov/data_res.html
Wave Height	National Data Buoy Center, NOAA, http://www.ndbc.noaa.gov/

2.2.2 July – December 2004

By 13 June 2004, the Carmel River at the USGS gauging station immediately upstream of the lagoon (11143250 CARMEL R NR CARMEL CA) had zero flow (Fig. 2.3). At this time, the river was no longer connected to the lagoon, and the sandbar had closed. The declining lagoon stage continued to decrease. The lowest stage was observed on 6 Aug 2004 (0.74 m, NGVD).

The dynamic wave head imparted by the ocean was computed from mean tidal level data and wave height data from a NOAA buoy in Monterey bay (Table 2.1). Figure 2.4 illustrate the moving 24-hour average of the dynamic wave head for a full year (April 2004 – May 2005). The figures show how the ocean controlled the lagoon water level both by slow through-bar flow in July and August, and by pulses of over-bar flow from September through November. In particular, the analysis indicates that the unusually low water levels in late July were caused by unusually low ocean wave energy and tidal levels at this time. Stages increased only after the dynamic wave head increased in late August, despite efforts to increase lagoon volume by pumping freshwater into the South Arm in late July and early August.

Large wave events began in late August, and evidence of over wash was observed on the sandbar (Fig. 2.7). After the earth barrier that separated the newly excavated portion from the pre-existing South Arm was removed (5 Oct), a large wave event significantly raised the stage, completely submerging the anchors of the silt curtains on the banks of the South Arm, and resulting in the silt curtains becoming dislodged.

The first significant rain event happened in the second half of October 2004, before the silt curtains were found dislodged (Fig. 2.6). However, the river did not connect to the lagoon until 28 Dec 2004, after a large amount of precipitation on the 27th. By the 29th of December, the stage in the lagoon reached ~10 ft and a channel was bulldozed through (Fig. 2.7).

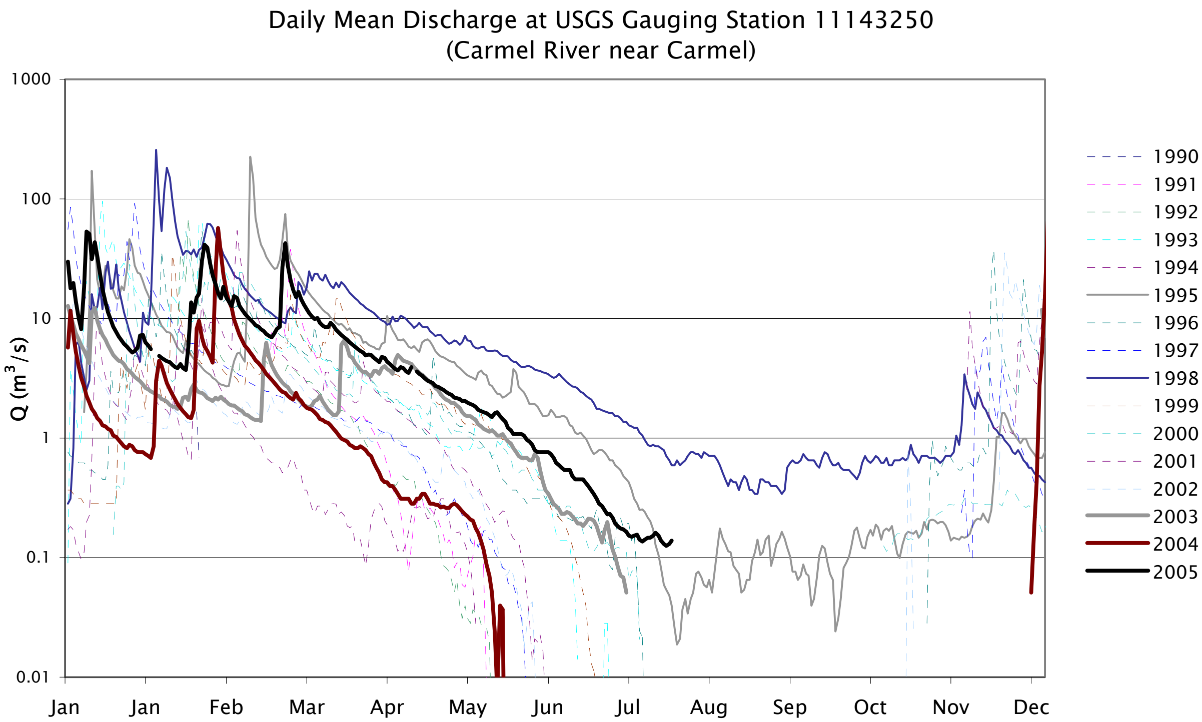


Figure 2.1. Inter-annual comparison of streamflow recession.

2.2.3 January – June 2005

Lagoon stages fluctuated significantly during the first of half of 2005 as flows from the river (Fig. 2.3) responded to episodes of precipitation (Fig. 2.6). The stage was also controlled by dynamic wave head during this time, although only in manner that was secondary to the influence of river flow (Fig. 2.5).

Days of intense rainfall were followed by an increase in river flow, which raised the stage of the lagoon in late December, mid February, and mid March. In early January, many gullies were present in the new portion of the South Arm as local runoff drained over un-vegetated banks into the lagoon (Fig. 4.2).

After the sandbar was breached, the main lagoon resembled the river channel. As the river entered the lagoon, it flowed up against the granite cliff that lines the south-western edge of the lagoon and the South Arm before turning northward, flowing into the ocean at a mouth located at the north end of the beach. The velocity of the river slowed as it entered the main lagoon, and sediment was deposited, re-filling any scour that had occurred during the breach. At low tide/stage, the river was a braided channel emptying into the ocean (Fig. 2.7).

Water in the river channel did not mix rapidly with water in the North and South Arms. The North Arm remained visibly darker next to the clear, flowing river water (Fig. 2.7). At the opening to the South Arm, sediment deposition from the river accumulated forming a temporary sandbar between the South Arm and the main lagoon during low stage (Fig. 2.7). This has also been observed in previous years (Watson & Casagrande, 2004).

By mid-summer 2005, the Carmel River was still connected to the lagoon by a small flow (~15 cfs). The sandbar had closed and re-opened. Analysis of the lagoon under closed sandbar conditions will be reported on at a later date.

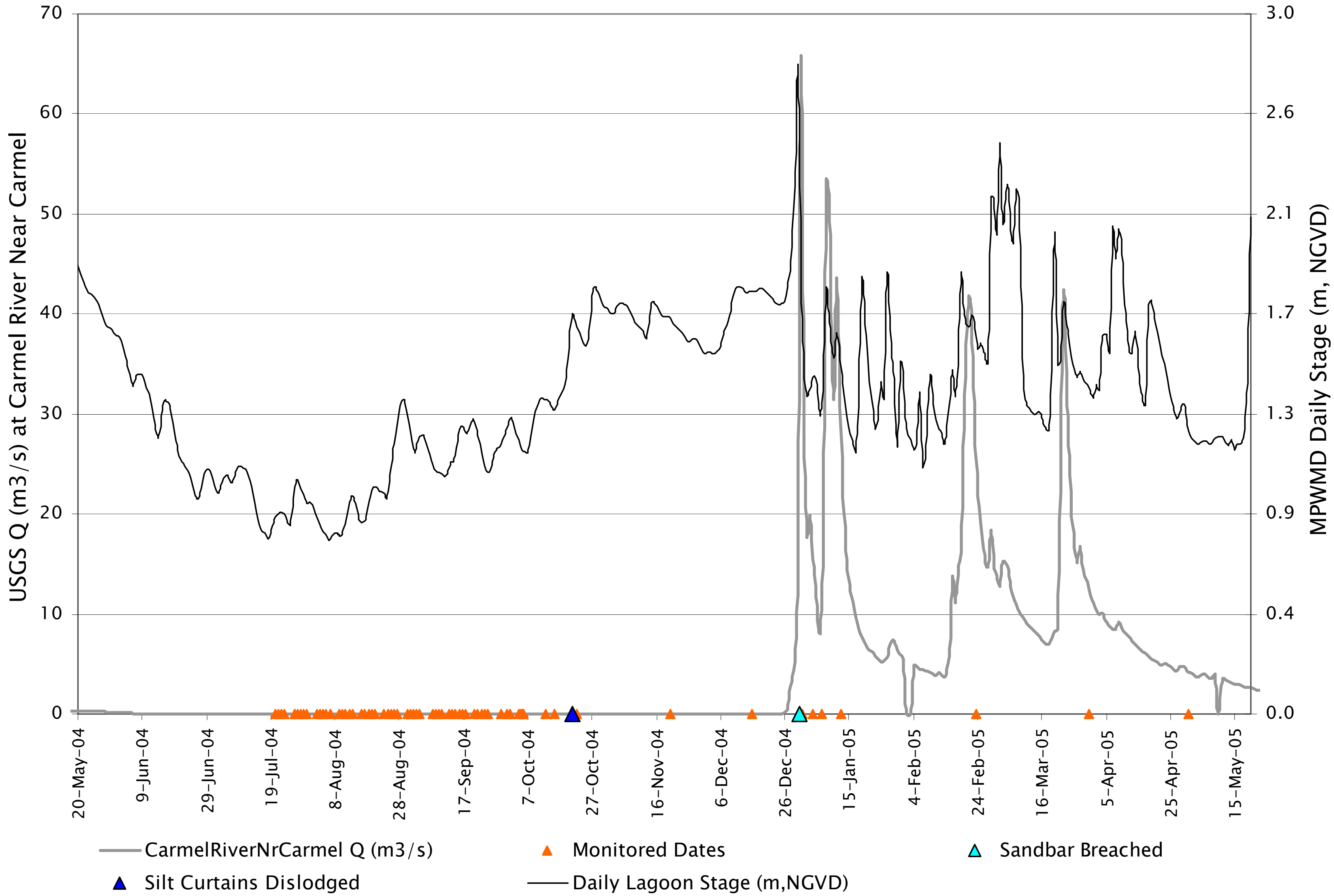


Figure 2.3. Time series of discharge from the Carmel River and lagoon stage.

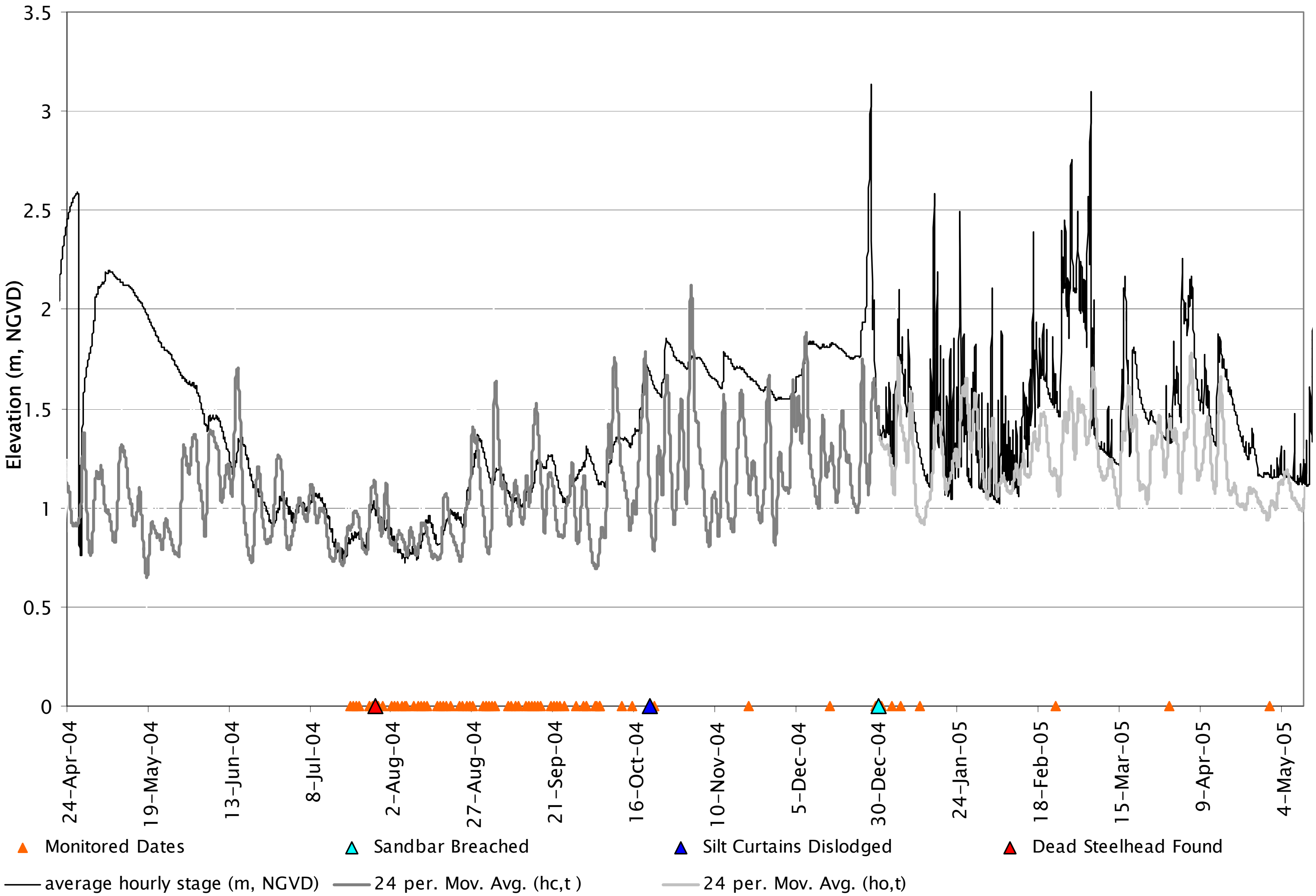


Figure 2.4. Time series of moving average of the dynamic wave head vs. lagoon stage for the entire study period.

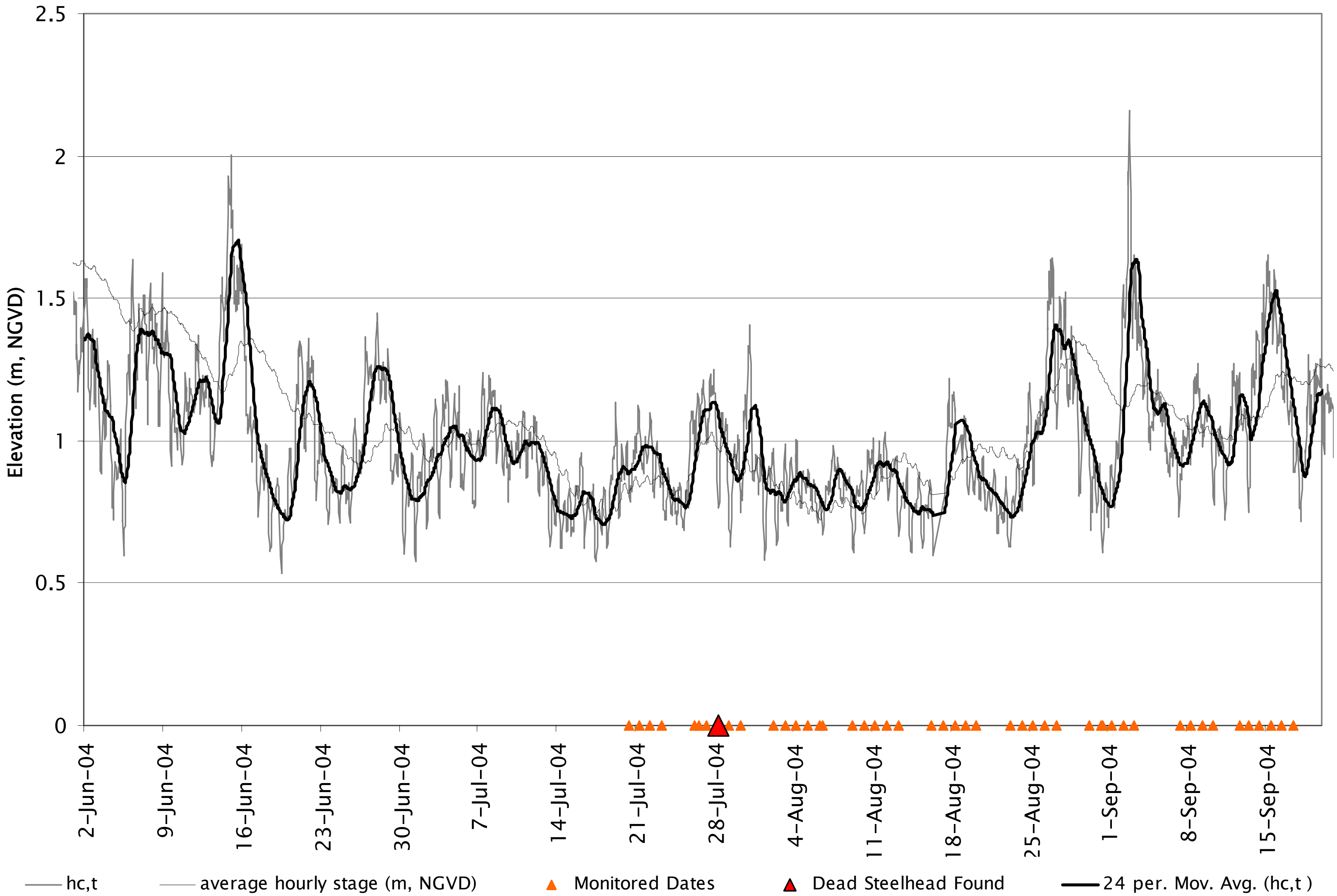


Figure 2.5. Time series of dynamic wave head and moving 24-hour average vs. lagoon stage from June - September 2004.

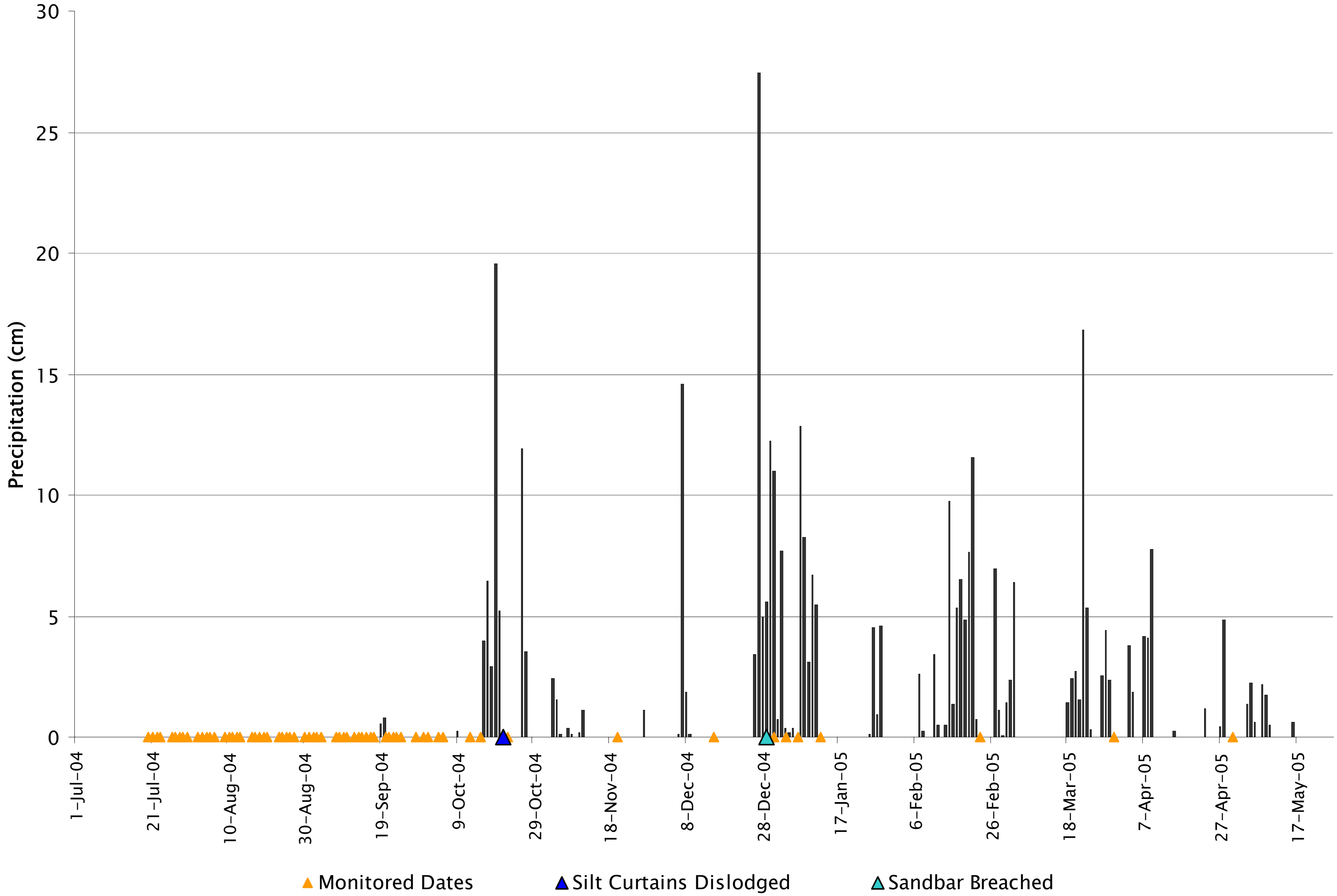


Figure 2.6. Precipitation from July 2004 – June 2005.

(a) Evidence of waves washing over the sandbar into the main lagoon (the ocean is to the right of this photo). (Larson, 30 Aug 2004)

(b) Waves washing over the sandbar. 23 Feb 2005

(C) Initial sandbar breach. 30 Dec 2004

(d) Braided river channel emptying into the ocean. 21 Jun 2005

(e) The North Arm appears visibly darker compared to the main river channel flowing next to it. 30 Apr 2005

(f) Temporary sandbar that formed at the entrance to the South Arm. 31 May 2005

Figure 2.7. Sandbar and lagoon conditions pre- and post breach.

3 Water Quality: Methods, Analysis, and Criteria

In broad terms, desirable water quality parameters for steelhead in lagoons include: large volume, low to mild temperatures, high dissolved oxygen (DO), and low salinity. These parameters are met when the lagoon reaches optimal rearing conditions at the onset of the flow season (Casagrande et al, 2003). At this time, there is a large volume, low temperatures, high DO, and low salinity. During the dry season there is reduced volume, higher temperatures, and higher salinity resulting in a less optimal, stratified water column. Specific water quality criteria are detailed in Section 3.2.

During summer and fall, the Carmel Lagoon is typically highly stratified by salinity and temperature. A layer of relatively fresh water is normally maintained near the surface of the lagoon. This originates from the residual flows of the spring and early summer. It dissipates through the sand bar to the ocean, and is replenished to some extent by slow groundwater inputs during the summer. The deepest parts of the lagoon exhibit a dark, perennial saline lens, comparable to seawater. This is a result of the overall bathymetry of the lagoon. Saline waters are essentially trapped at the bottom of the South Arm because of the significant differences in depth between the main lagoon and the deeper portions of the South Arm. Because of pronounced density stratification and relatively minor surface wind energy, this water never mixes and is completely isolated from the atmosphere. The mid-water often acts a solar collector, receiving sunlight energy, but rarely dissipating it back to the atmosphere through surface cooling. This leads to pronounced algal production, super-saturated afternoon oxygen levels, and occasionally severe oxygen minima in the mornings, especially below the mid-water levels.

3.1 Sampling and Analytical Methods

The water quality parameters that were measured are temperature, salinity, dissolved oxygen (DO), pH, Carbon Dioxide (CO_2), turbidity, suspended sediment concentration (SSC), and hydrogen sulfide (H_2S. Many parameters were measured *in situ* and some were taken from samples. Many measurements and samples were taken from a kayak; these are outlined in the site description section.

The parameters measured *in situ* were taken with an YSI Environmental 556 MPS Multiprobe System in 0.25 m interval depth profiles. These parameters are listed in Table 3.1 with the instrument specifications for each parameter. The YSI MPS was calibrated according to manufacturer's instructions weekly during the construction phases of the project.

Samples were collected from the surface and from a depth that was within one meter above the bottom using a horizontal alpha water sampler. For a more extensive overview of CCoWS laboratory procedures, see Protocols for Water Quality and Stream Ecology (Watson et al, 2005). Samples were analyzed for CO_2, turbidity, SSC, and H_2S.

CO_2 concentrations were measured from surface and column samples using a HACH Digital Titrator (Model 16900). In this method, the acidity due to CO_2 in a sample is titrated with sodium hydroxide to a phenolphthalein end point. This test was conducted in the lab as well as in the field, depending on the phase of the project. The range of this test is 10 – 1,000 mg/L as CO_2.

Turbidity was measured from surface and column samples using a HACH Portable Turbidimeter (Model 2100P). Measurements made with this instrument have an accuracy of ± 2% of reading plus stray light from 0-1000 Nephelometric Turbidity Units (NTU), a range of 0 – 1000 NTU, and a resolution of 0.01 NTU. This test was also conducted in the lab as well as in the field, depending on the phase of the project.

SSC analysis was done on every sample collected by vacuum filtration in the lab.

Because of the instability of H_2S in solution, samples were analyzed in the field within 45 minutes of collection. A mobile lab was set up to do this lab analysis on site (Fig. 3.1). For this reason, and because the only source of H_2S in the lagoon was the disturbance of bottom sediments, surface and column samples were only tested for H_2S while there was digging in the South Arm of the lagoon (at this time CO_2 and turbidity were also analyzed in the field lab). A HACH ODESSEY Spectrophotometer DR/2500 was used to analyze samples for H_2S using a methylene blue method. The range of this test is from 5 – 800 μg/L.

Table 3.1. Water quality parameters measured with the YSI MPS and specifications of this instrument.

Parameter / Sensor	Accuracy	Range	Resolution
Temperature (YSI Precision TM thermistor	± 0.15 °C	−5 to 45 °C	0.1 °C
Dissolved Oxygen (DO, mg/L) (Steady state polargraphic)	0 to 20 mg/L, ± 2% of the reading or 0.2 mg/L, whichever is greater; 20 to 50 mg/L, ± 6% of the reading	0 to 50 mg/L	0.01 mg/L
Salinity (Calculated from conductivity and temperature)	± 1.0% of reading or 0.1 ppt, whichever is greater	0 to 70 ppt	0.01 ppt
PH (Glass combination electrode)	14 units	0.01 units	± 0.2 units

3.2 Criteria

The following section describes the criteria against which water quality data were to be compared. Table 3.2 summarizes these criteria. Each parameter is discussed in detail below.

Table 3.2 Summary of water quality criteria used for data comparison.

Parameter	Criteria
Temperature	< 26°C
Salinity	n/a
DO	> 5 mg/L
pH	6.5 – 9.0
CO_2	< 10 mg/L
Turbidity	2, 20, 200 NTU
SSC	< 50 mg/L
H_2S	< 25 μg/L

3.2.1 Temperature

Temperature directly effects fish metabolism, feeding, & survival (Hokanson et al, 1977; Smith & Li, 1983). Generally, as water temperature increases, metabolic rates increase; as the temperature decreases, metabolic rates decrease. In streams, the ideal water temperatures for trout are around 17°C (Hokanson et al, 1977); temperature becomes potentially lethal for trout at about 26°C (Hunter, 1991), although this may depend on acclimation time and latitudinal variation. There is evidence that trout have higher temperature tolerances in lagoons, because the higher metabolic rate and food demand can be sustained by the abundant invertebrates typical of lagoons (mysids, amphipods etc.).

3.2.2 Salinity

Coastal lagoons are often stratified, containing saltwater at depth, and fresher water at the surface. This provides a transitional environment with respect to salinity, that may facilitate the physiological smoltification process that steelhead undergo in order to move from freshwater to saltwater environments.

3.2.3 Dissolved Oxygen

Dissolved oxygen arises from two sources: direct diffusion at the air-water surface interface (Morris, 1992), and photosynthesis. DO levels that are less than 5mg/L have the potential to harm fish (Morris, 1992). This is the criterion used to evaluate the potential for harm that could come to fish in the lagoon as the construction proceeded. DO levels are highest in the late afternoon, as aquatic plants and algae have been photosynthesizing for most of the day. At night, photosynthesis ceases, plankton and fish consume oxygen through respiration; so DO levels are lowest just after dawn (Hargreaves, 1996). Casagrande and Watson (2004) documented diurnal DO minima in the Carmel Lagoon occurring typically around 9:00 AM. Dissolved oxygen was specified to remain above 5 mg/L during the project, as directed by NMFS Biological Opinion.

3.2.4 pH

In the Central Coast Regional Water Quality Control Board document Compilation of Water Quality Goals, the USEPA national recommended ambient water quality criteria for freshwater aquatic life protection is cited as a range for instantaneous levels of 6.5 – 9.0 (RWQCB, 2004).

3.2.5 Carbon Dioxide

Carbon dioxide concentrations are highest when DO concentrations are lowest (Hargreaves, 1996). In the daylight, CO_2 used during photosynthesis, and at night it is produced by respiration. CO_2 is released into water by almost all living aquatic organisms through respiration & decomposition. Some CO_2 bubbles to the surface, some dissolves in the water. It is this dissolved CO_2 that was measured from water samples.

High CO_2 concentrations are usually found near the bottom of the lagoon as dead organisms sink, in the autumn as dead algae and plants decompose (Morris, 1992). Evidence suggests that high CO_2 by itself is not harmful, but it becomes toxic when it is present in high concentrations in association with low DO (Morris, 1992). Surface waters normally contain less than 10 mg free CO_2 per liter (Clesceri et al., 1998). Water that supports fish populations generally has less then 5mg/L CO_2 (Morris, 1992). Note that the lower detection limit of the lab method is 10 mg/L.

3.2.6 Turbidity and Suspended Sediment Concentration

Turbidity is the cloudiness of water, which is related to the inverse of its transparency. In lagoon environments, turbidity is increased both by suspended mineral sediments, and by phytoplankton and other organic matter. Suspended solids include clay, silt, finely divided organic and inorganic matter, and plankton and other microorganisms (Clesceri et al, 1998).

The water quality objective for SSC is <50mg/L, according to NMFS biological opinion. Many studies have examined impacts of suspended sediment on fish and aquatic invertebrates. Hager et al. (2003) reviewed the literature that is broadly applicable to the Central Coast Region. They arrived at the following guidelines, providing a baseline for comparison of turbidity levels (NTU) and SSC (mg/L) and the associated effects primarily on rainbow trout:

- Up to **2 NTU** or **10 mg/L**: not likely to adversely affect fish and invertebrates
- Up to **20 NTU** or **100 mg/L**: potential change in behavior and / or slight decrease in survival
- Up to **200 NTU** or **1,000 mg/L**: stress, physiological changes, and potentially lethal effects

3.2.7 Hydrogen Sulfide

Hydrogen sulfide (H_2S) is produced by anaerobic decay of organic matter (breakdown of sulfur-containing proteins; amino acid degradation) aided by bacteria. It is released during the decomposition of organic matter in bottom deposits (WHO, 1981; Mattson, 2000; ATSDR, 1999; Sand, 1997; and Smith & Oseid, 1972). It is soluble in water but its short residence time removes it rapidly from water (Smith & Oseid, 1972) as it is released into the atmosphere.

Since H_2S is a gas, most toxicological information pertains to air pollution (WHO, 1981). It is considered to be a broad-spectrum poison (ATSDR, 1999) that affects the nervous and respiratory systems (Morris, 1992). When dissolved in water, H_2S adversely affects fish in two ways. Firstly it is toxic to fish (Clesceri et al, 1998). Secondly, it reacts with DO, thus lowering DO levels (Van Handel, 1987). When bottom sediments are disturbed, H_2S may be dispersed throughout the sediments and water column causing adverse impacts – particularly to invertebrate fish prey species and fish eggs and fry in the epibenthos (Smith & Oseid, 1972).

The National Water Quality Standard for H_2S is based on the Criterion Continuous Concentration (CCC)[1] of 2.00 μg/L in both fresh water and salt water (EPA, 1976). This criterion is based on toxicities to a variety of species in aquatic communities. In particular, Smith and Oseid (1972) measured rainbow trout egg mortality, finding median tolerance levels (TL_{50}) between 55 and 80 μg/L over 72 hours, 49 μg/L over 96 hours. These authors also summarized that population maintenance would be greatly inhibited at levels approaching 25 μg/L (based on testing of walleye, sucker, trout, and northern pike). No studies were found documenting more temporally acute toxicity thresholds for juveniles and adults over relatively short time spans that would be more relevant to the possible effects of construction activities.

[1] CCC's are estimates of the highest concentration of a pollutant an aquatic community can be continuously exposed to without adverse effects. 'Aquatic community' is defined to include "the vast majority of aquatic communities in the U.S."

4 Water Quality Monitoring Sites

To facilitate comparison of past and present data collected in specific parts of the lagoon, Casagrande et al. (2003) divided the lagoon into discrete sampling zones. These zones were adjusted for the present study to include the newly excavated portions of the lagoon. Figure 4.1 shows the layout of zones and the specific sampling sites used during the present study. The 'N' sites are in the North Arm zones, the 'R' sites are in the River zones, the 'S' sites are in the South Arm zones, and the 'O' sites are in the newly excavated Odello zones. Sites were selected in consultation with NOAA Fisheries (J. McKeon, pers. comm.). Detailed descriptions appear below, and photos of these sites are presented in Figure 4.2. Sampling phases are summarized in Table 5.1.

Figure 4.1 Sampling zones and sites (red dots) at the Carmel River Lagoon (new excavation not shown). Note: sites S4O and S4I are in the same spot.

4.1 R1N: River Section 1 North

Two sites immediately next to the sandbar were sampled to establish the quality of the water flowing through the sand bar to and from the ocean or from large wave events at the request of John McKeon (NIMFS). R1N was a site in the northern corner of the sand bar and was sampled throughout Phase 1.

4.2 R1S: River Section 1 South

The other site next to the sand bar close to the beach is in the southern corner of the main lagoon. This site was also sampled throughout Phase 1. These two sites in River Section 1 changed significantly after sandbar management.

4.3 R2: River Section 2

The main channel of the lagoon, R2, occupies a large surface area and is exposed to continuous wind action and is therefore subject to more mixing than other places in the lagoon. This is where the river passes through the lagoon when the river and the lagoon are connected. During Phase 1, R2 (not connected to the river) was sampled by wading 3-4 meters from the northern shore of the main lagoon halfway between the river confluence and the sand bar at the beach. From the 22nd October 2004 on, this site was sampled in the middle of the channel from a kayak. The channel dimensions at this site changed significantly after the river connected to the lagoon and sediment deposition decreased the depth of the water (Fig. 2.7)

4.4 N1: North Arm Section 1

The North Arm and main lagoon were sampled for a reference of what the rest of the lagoon during excavation in the South Arm. At the time these sites started to be sampled (26th of July), the North Arm was in two different ponds isolated from the main lagoon. This condition changed on the 25th of August when both ponds were connected to each other and the main lagoon.

N1 is in the bottom of the western isolated pond of the North Arm. This site was sampled throughout Phase 1, and on the 15th and 22nd of October (the 22nd was monitored from a kayak). It was also included in the sampling scheme for Phase 4.

4.5 N2: North Arm Section 2

N2 is in the bottom of the eastern isolated pond of the North Arm. This site was sampled throughout Phase 1, and on the 15th and 22nd of October (the 22nd was monitored from a kayak).

4.6 S2: South Arm Section 2

The wastewater treatment plant outfall pipe that crosses the South Arm of the lagoon is a primary historic sampling site that is close to the excavation Data were collected from this site at each visit to the lagoon from about the middle of the pipe. Aeration pumps were operating throughout the first two phases of the sampling period. There is a staff plate and gauging station that is operated by the MPWMD. Surface grab samples were taken directly into sample bottles. In addition, from 30th August, an Alpha Sampling Bottle was used to collect samples within 1 m of the bottom (the lagoon is typically about 3 m deep at this point). A kayak was used at this site during Phases 2, 3, and 4.

4.7 S4: South Arm Section 4

Beginning on the 28th of July for the duration of Phase 1, measurements were taken in the shallow water adjacent to the north side of the earth barrier separating the original lagoon from the new excavation, close to the frog pond confluence. Samples from this location were subject to sediment released into the water by construction and monitoring crews walking through it for access to the silt curtains. YSI measurements were made at a single depth, since the water was too shallow for depth profiles. Phase 2 began when this site was dug deeper before the earth barrier separating the pre-existing South Arm from the newly excavated portion.

4.8 S4O: South Arm Section 4, Outside of silt curtains

Four silt curtains were installed side by side in the South Arm starting 24 August 2004 to contain the poor water quality that resulted from excavation in the South Arm during Phases 2 and 3 (Fig. 1.2). These curtains were held in place by large chains that lined the bottom of each curtain and were submerged into the lagoon substrate. Samples were taken from both sides of the curtains to document any transfer of poor water quality from the active digging zone inside the silt curtains to the habitat outside the silt curtains.

At times the curtains bowed inward, as digging in the South Arm and removal of the earth barrier pulled the water toward the barrier where dirt under the water was being removed. At other times, particularly when ocean waves receded and lagoon water flowed out through the sandbar, the curtains bowed outward. The top of the downstream curtain tended to submerge. This was also influenced by wind speed and direction. On more than two occasions when water flowed from inside the excavation area out into the original South Arm, the tops of all four curtains were submerged by the flow – allowing free exchange of water across the curtains.

All measurements and samples from these sites were taken from a kayak. During phase 2, these sites were sampled 3 times each day. During Phase 3, these sites were sampled 2-3 times per day.

S4O was the sampling site outside of the silt curtains. Measurements and sample results from this site would give the first indication that the silt curtains were not working to block polluted water from entering potential habitat.

4.9 S4I: South Arm section 4, Inside of silt curtains

S4I was the sampling site inside the silt curtains. This water was expected to be very dirty as it was closest to the excavators. Excavation began very close to the sampling point at the beginning of Phase 2 and receded back away from the curtains as Phase 2 and 3 progressed and the earth barrier was removed.

4.10 FP: Frog pond

The pond just west of the earth barrier was a priority-monitoring site because it supported California Red-legged Frogs, as well as tree frogs and bullfrogs. It is a small freshwater pond with very steep banks and filled with tules. At high stages this pond is connected to the rest of the South Arm and is difficult to access.

Sampling in this frog pond began on the 23rd of July and continued through Phases 2a and 2c. Samples were taken by wading into the deeper portion of the pond, which resulted in some sediment being disturbed. Suspended sediment samples were taken as surface grabs directly into storage bottles, visually avoiding apparent clouds of disturbed sediment. Throughout 2005, this site was not sampled because access points had grown over with vegetation.

4.11 OØ: New Odello extension Section 0

Four main sampling sites were established in the newly excavated portion of the South Arm. The first of these sites was immediately southeast of the earth barrier and was sampled throughout Phase 1. This site was monitored the same way as R2. This site was located immediately next to the earth barrier in the excavated arm and was only monitored while the earth barrier was in place (Phase 1).

4.12 O1: New Odello extension Section 1

The deepest part of the main body of the newly excavated channel was monitored from the kayak on four separate dates throughout the first two Phases, and regularly during Phases 3 and 4. This site was only monitored from kayak. Flags on the bank of this new arm marked the position of the sampling point. During periods of high wind velocities, it was difficult to keep the kayak in one spot for the depth profile. At times, the kayak would drift away from the deepest part despite efforts to keep it in the same place for the entire depth profile.

4.13 O2: New Odello extension Section 2

O2 is in the north branch of the newly excavated channel and was sampled from a kayak on the same dates as O1. At low stages, a freshwater spring can be seen at the top of this site. It is recommended that this site be included in the list of regular monitoring sites (i.e. monitored at all times) to document the effects of this slow freshwater input into the lagoon.

4.14 O3: New Odello extension Section 3

O3 is in the southern branch of the newly excavated channel and was sampled from a kayak on the same dates as O1 and O2 during Phases 1 and 2. This site was also monitored regularly through Phases 3 and 4.

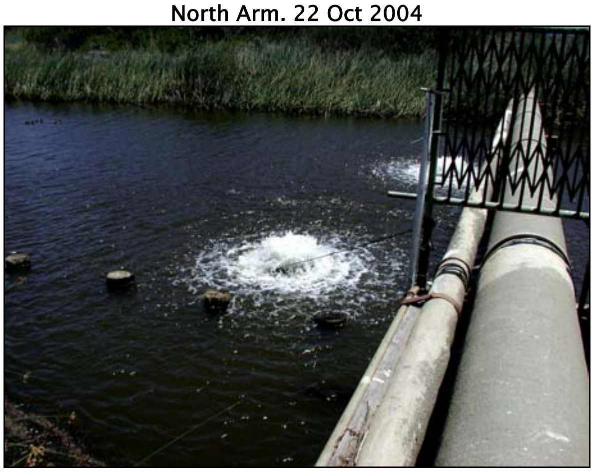
There is a small densely vegetated channel that runs parallel to the new Odello portion of the South Arm towards the Frog Pond. After the first storms of the wet season, this small creek jumped its banks and started draining into the new Odello portion, creating large gullies that formed on the banks of the newly excavated portion of the South Arm at this site.

(a) R2 in the main lagoon. 26 Aug 2004

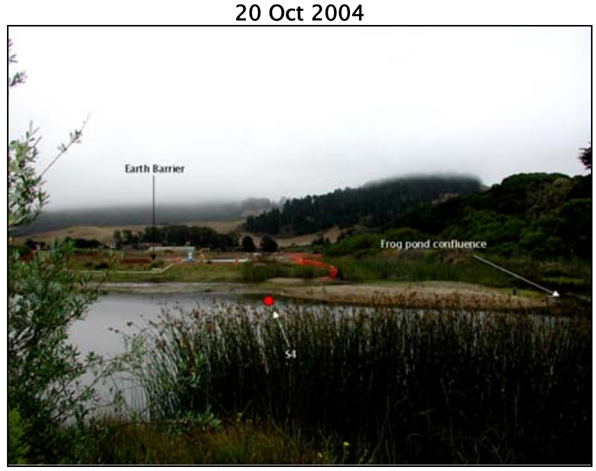
(b) N1 looking up the western branch of the North Arm. 22 Oct 2004

(c) N2 looking downstream from the eastern pond of the North Arm. 22 Oct 2004

(d) View of S2 from beach access road off of Calle De Cruz. 20 Oct 2004



(e) Aeration pumps on at S2. 20 Jul 2004



(f) S4 taken from the right bank of the South Arm. 26 Aug 2004

Figure 4.2. Sampling sites and equipment


(g) FP. 4 Aug 2004


(h) O1. 22 Oct 2004


(i) Site O2. 22 Oct 2004


(j) Freshwater spring at the top of O2. 21 Jun 2005


(k) Site O3. 22 Oct 2004


(l) Gullies formed from small creek draining into the new Odello portion of the South Arm after a storm. 3 Jan 2005

Figure 4.2 Continued. Sampling sites and equipment

5 Water Quality Monitoring Schedule

Water quality monitoring was conducted in several phases, as described in Table 5.1. Four Phases have been designated by construction activities and water quality monitoring regimes. Phase 1 took place before any excavation in existing habitat; Phase 2 took place during excavation in existing habitat through to the end of excavation in the lagoon. Table 5.2 displays the sites that were sampled during these first two phases.

There were fewer monitoring sites for Phases 3 and 4, only S2, R2, O1, and O3 were sampled during the wet weather and dry weather sampling regimes. FP was not monitored because of lack of access points at high stages. By the end of May, the access point to FP was completely grown over with vegetation. N1 was sampled during the dry weather sampling run in April because of a marked difference in the appearance between the water in the North Arm and the water in the main lagoon (Fig. 2.7), and again in May because it was detached from the rest of the lagoon.

Table 5.1. Phases of CRLEP according to construction and water quality monitoring activities.

	DATES	SIGNIFICANT EVENTS	WQ MONITORING REGIME *
PHASE 1	20 July 04 – 10 September 04	Excavation of the new Odello portion before removal of earth barrier separating this new channel from the existing lagoon.	Once daily
PHASE 2a	13 September 04 – 30 September 04	Excavation in South Arm.	3 times daily
PHASE 2b	1 – 5 October 04	Removal of earth barrier.	2 – 3 times daily
PHASE 2c	12 – 22 October 04	After removal of earth barrier and before removal of silt curtains.	2 days: 12th and 15th October
PHASE 3	29 December 2004 – 6 January 2005	Wet weather monitoring during a storm and sandbar management (coincided)	Surrounding the initial annual mechanical breaching of the lagoon, before and after a significant storm event
PHASE 4	Dec, and Feb – May 2005	Dry weather monitoring while river is flowing with the sandbar open	Once monthly
* 'daily' refers to weekdays when construction teams were working.			

Table 5.2. Monitoring schedule for Phases 1 and 2. Shaded boxes indicate when sites were sampled.

date	Phase	S2	S4	O0	FP	N1	N2	R2	R1N	R1S	S4O	S4I	O3	O2	O1
20-Jul-04	1	■													
21-Jul-04		■		■											
22-Jul-04		■		■											
23-Jul-04		■		■	■										
24-Jul-04															
25-Jul-04															
26-Jul-04		■		■	■	■	■	■							
27-Jul-04		■		■	■	■	■	■							
28-Jul-04		■		■	■	■	■	■							
29-Jul-04		■		■	■	■	■	■							
30-Jul-04		■		■	■	■	■	■							
31-Jul-04															
1-Aug-04															
2-Aug-04		■		■	■	■	■	■							
3-Aug-04		■		■	■	■	■	■							
4-Aug-04		■		■	■	■	■	■	■	■			■	■	■
5-Aug-04		■		■	■	■	■	■							
6-Aug-04		■		■	■	■	■	■	■	■					
7-Aug-04															
8-Aug-04															
9-Aug-04		■	■	■	■	■	■	■	■	■					
10-Aug-04		■	■	■	■	■	■	■	■	■					
11-Aug-04		■	■	■	■	■	■	■	■	■					
12-Aug-04		■	■	■	■	■	■	■	■	■					
13-Aug-04		■	■	■	■	■	■	■	■	■					
14-Aug-04															
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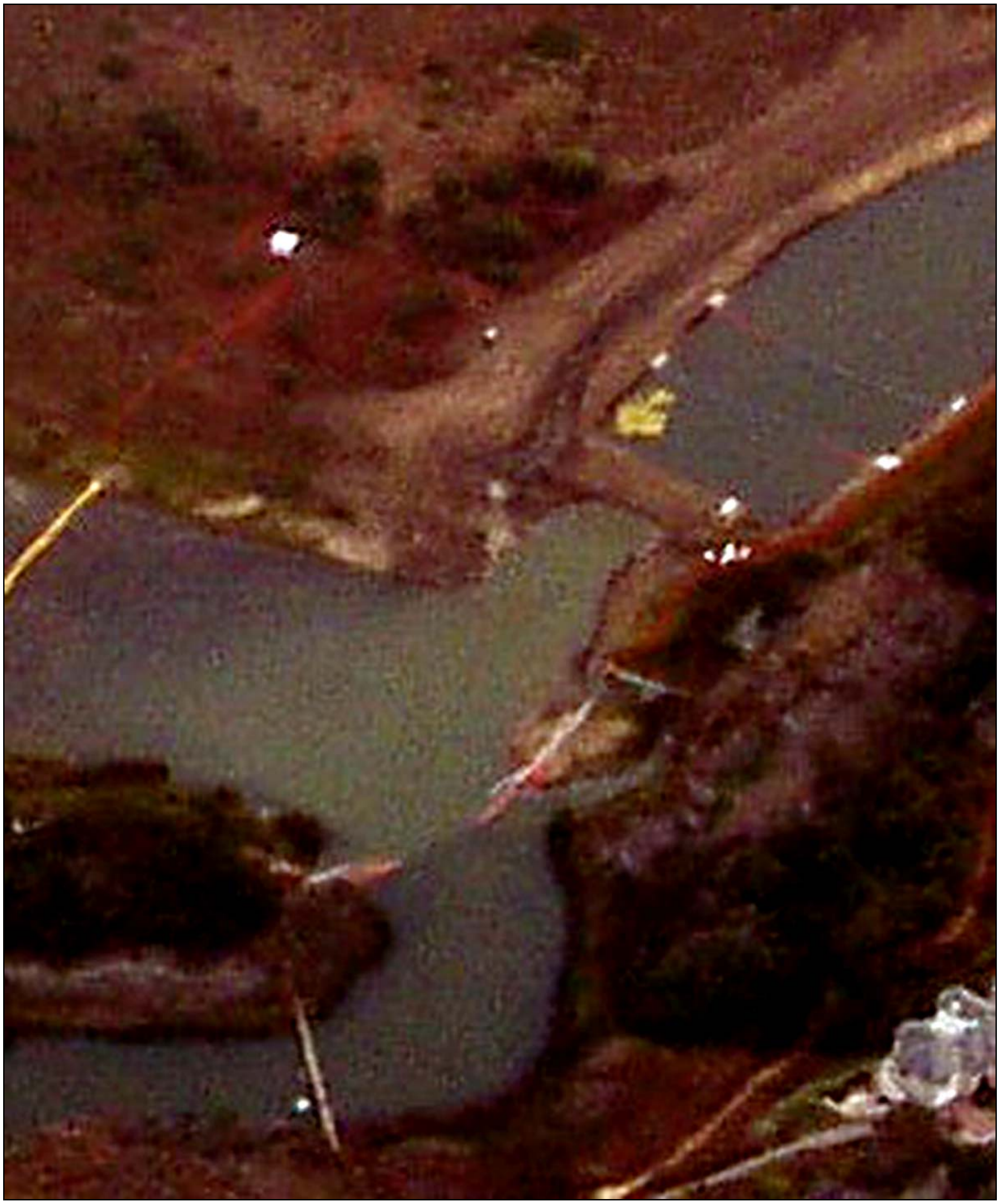


Figure 5.1 Aerial photo showing both sides of the silt curtains after excavation in the South Arm. S4O is to the bottom right of the curtains, S4I is to the left. 22 September 2004

6 Water Quality Monitoring Results

The results of all water quality monitoring are on a public website that is updated after every monitoring visit to the lagoon (http://science.csumb.edu/~ccows/2005/CRLEP). This section highlights key aspects of the monitoring activities.

6.1 Phases1 and 2

While the extension to the South Arm was being excavated, the major activity that was anticipated to impact lagoon water quality included removal of the earth barrier between the existing lagoon and the newly excavated portion of the lagoon. For this to be evaluated, consistent monitoring was conducted leading up to this barrier removal (Phase 1), and strategic monitoring was conducted intensely during barrier removal (Phase 2).

Due to the large amount of data that were collected during the construction phases, not all of the data collected are included in this report. The following sections summarize time series of surface data and some near-bottom data, while complete depth profiles are given in the Appendix. Surface data are focused upon, since impairment of these would be an indication of widespread impairment of the lagoon's habitat.

Key sites whose data are overlaid in the following sections are:

- S2 – the primary historic site at the outfall pipe close to the excavation and with the most complete data set from the sampling regimes of this project,
- S4O and S4I – both sides of the silt curtains and
- R2 in the main body of the lagoon. Note that R2 was only sampled for Phases 1 and 2c, and that H_2S was not measured here.
- N1 & N2 – in the North Arm
- O1 in the newly excavated lagoon
- and OØ, only included to illustrate salinity gradients

During Phase 2, results from S4I were expected to fail to meet water quality objectives, as it was located inside the silt curtains where excavation was occurring. S4O, the sampling site outside of the silt curtains, would give the first indication that the silt curtains were not working to block polluted water from entering potential habitat (Fig. 5.1). The next site in the existing lagoon closest to the excavation area was at S2. Excavation in the existing South Arm began very close to the silt curtains and receded from the curtains as Phase 2 progressed.

6.1.1 Salinity

Salinity profiles displayed clear stratification during Phase 1 and 2, which is broadly typical of lagoon conditions for this time of year (Figs 6.1 to 6.3 and Appendix B). Comparing 2003 and 2004, the fresh to brackish layer (<10 ppt) thickened during the summer and fall in both years, but the timing and volume differed. The thickening of this surface layer occurred much later in 2003, perhaps due to the late timing of stream flow recession and lagoon closure (Figs 2.1 & 2.2). No data are available for early summer 2004, but by late summer, a 1.5 m thick surface layer with salinity less than 10 ppt was present, and gradually freshened during fall. This layer may have always been present since bar closure, or may have developed during early summer just as a layer with the same characteristics developed later in the season during 2003. The initial salinity of the lagoon in summer is thought to be dependent on the relative timing of stream flow cessation, bar closure, and any late-season bar-breaches. Subsequent to this, Watson & Casagrande (2004, pages 32-33), suggested continual groundwater replenishment as a possible cause of freshening trends during summer. In 2004, the thickening freshwater lens was only disrupted once large waves washed over the sand bar in late October. Construction activities did not appear to affect salinity or the degree of stratification of the main lagoon.

During Phases 1 and 2, there was a clear lateral gradient of increasing salinity from the new excavation area (OØ), through the earth barrier to the inside of the silt curtains (S4I), across the to the outside of the silt curtains (S4O), along open water to the outfall pipe (S2), and finally to the river mouth area (R2). The gradient was much steeper over the very short distance across the curtains from S4I to S4O. Thus, the curtains were effective in reducing the movement of not only suspended sediment as they were intended, but also salinity. The lateral gradient also supports Watson and Casagrande's (2004) groundwater replenishment hypothesis.

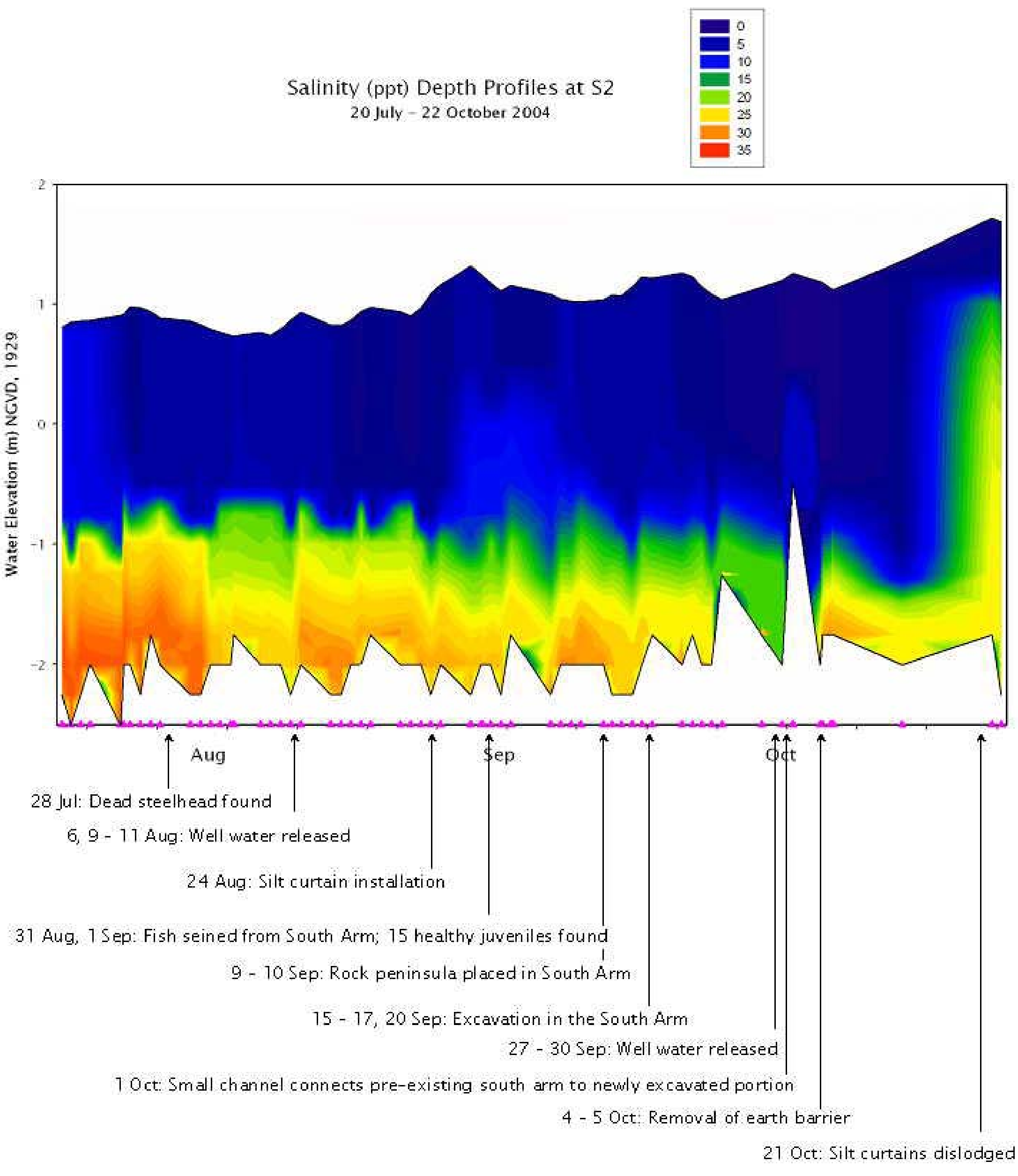


Figure 6.1. Salinity profiles at S2 during Phase 1 and 2, leading up to ocean wave input in late October.

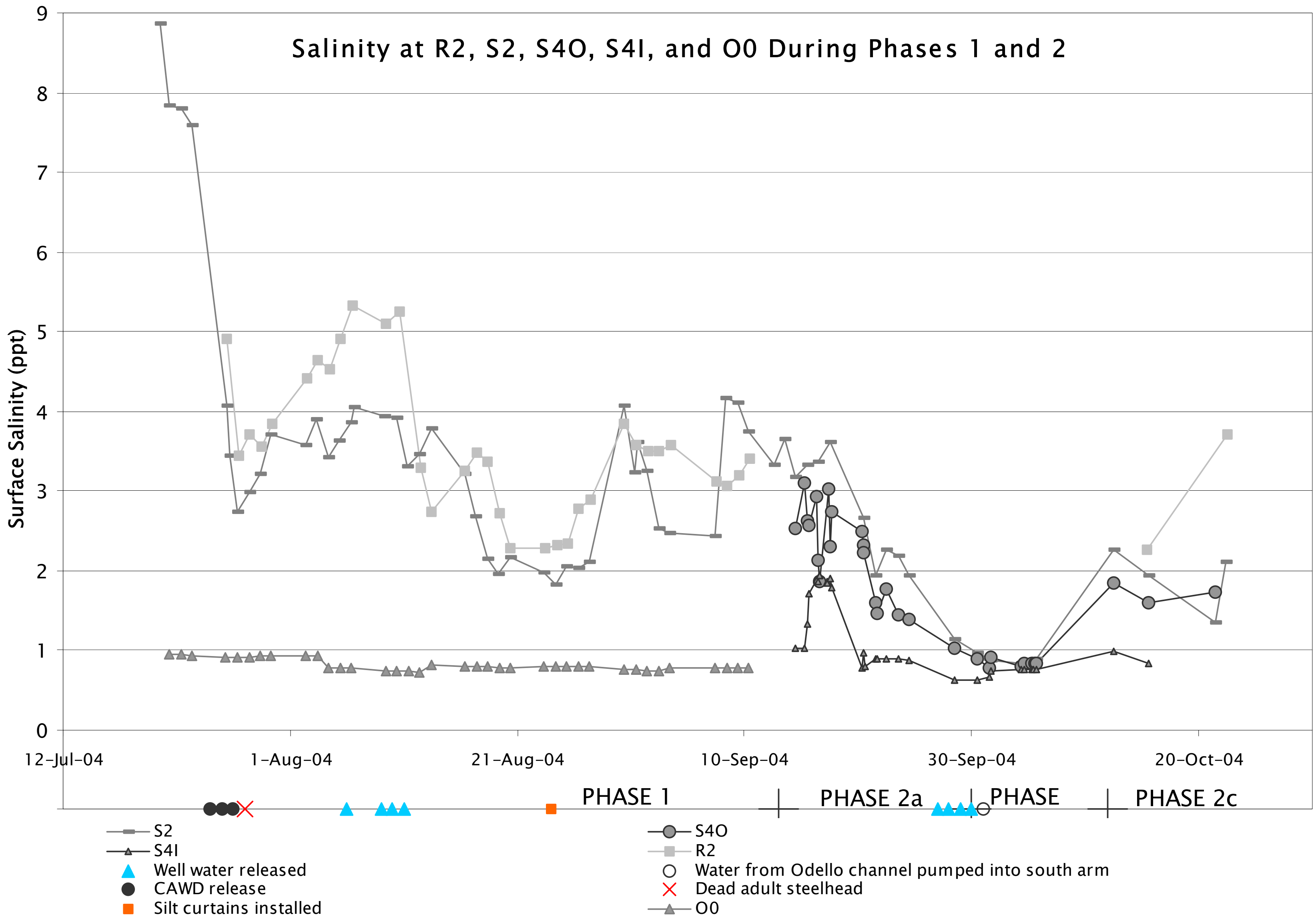


Figure 6.2. Time series of salinity surface measurements taken from S2, S4O, S4I, R2, and OØ during Phases 1 and 2.

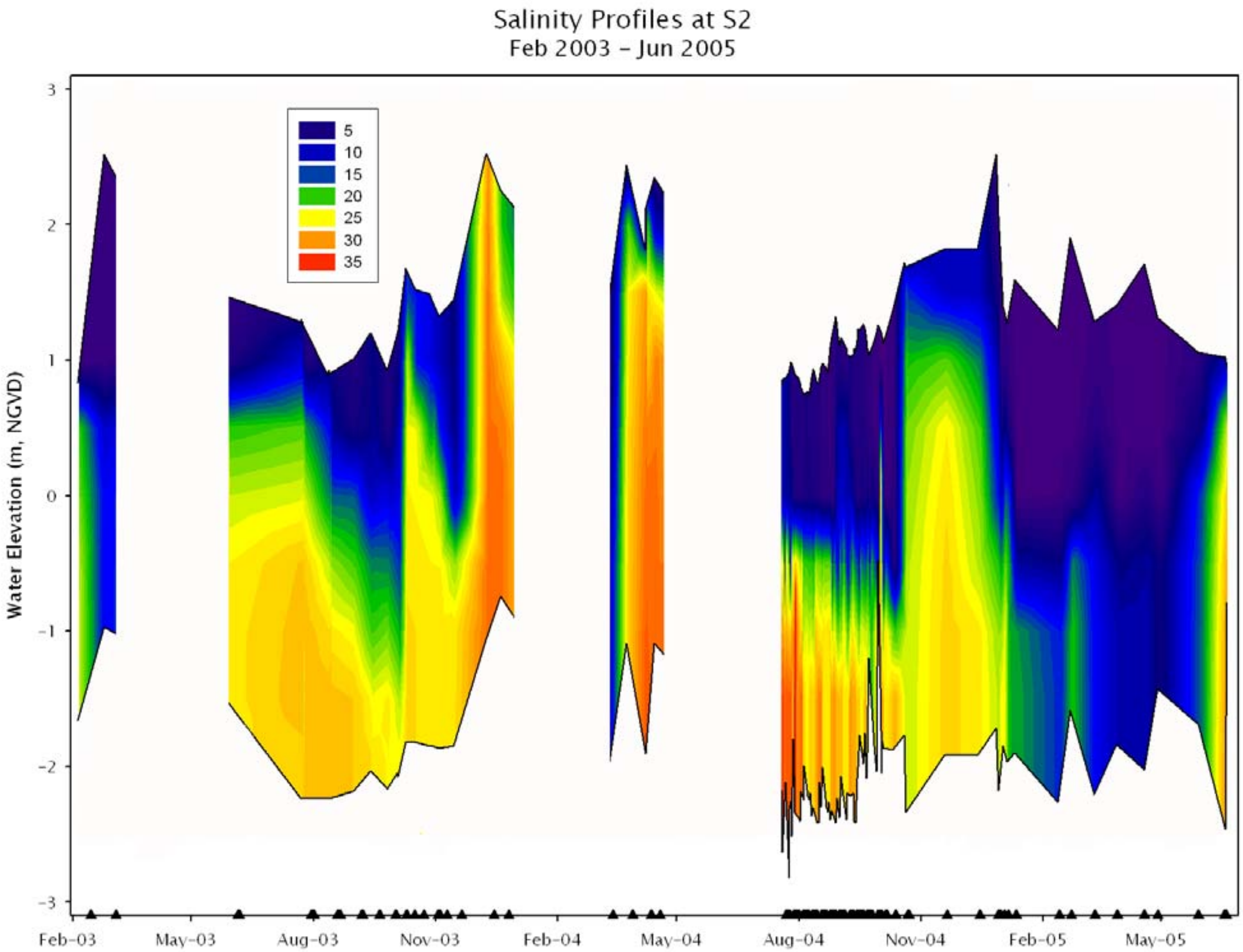


Figure 6.3. Time series of salinity profiles at S2 from 2003 to 2005.

6.1.2 Temperature

Temperature profiles during Phase 1 and 2 were generally cooler than for the same months in 2003 (Fig. 6.4). This also appears to be related to the markedly different timing of stream flow recession and sandbar closure between 2003 and 2004 (Figs 2.1 & 2.2). Density stratification was stronger near the surface in 2003, which appears to have enhanced the "solar collector" effect – whereby heat from solar radiation absorbed in the mid-water is trapped there because density stratification precludes advection of this heat to the surface where it would otherwise cool upon contact with the night-time air. As a result, the thermal maximum observed in 2003 was essentially absent in 2004 (at least from Phase 1 onwards). The shallow north arm was un-stratified (Appendix A), and warmer at the surface than the main lagoon. The frog pond was also un-stratified, and slightly cooler (perhaps due to the shade provide by the tules).

Effects of construction activities on temperature profiles were either non-existent, or slight enough to be overshadowed by external forces such as stream flow timing, fall cooling, and wind-mixing.

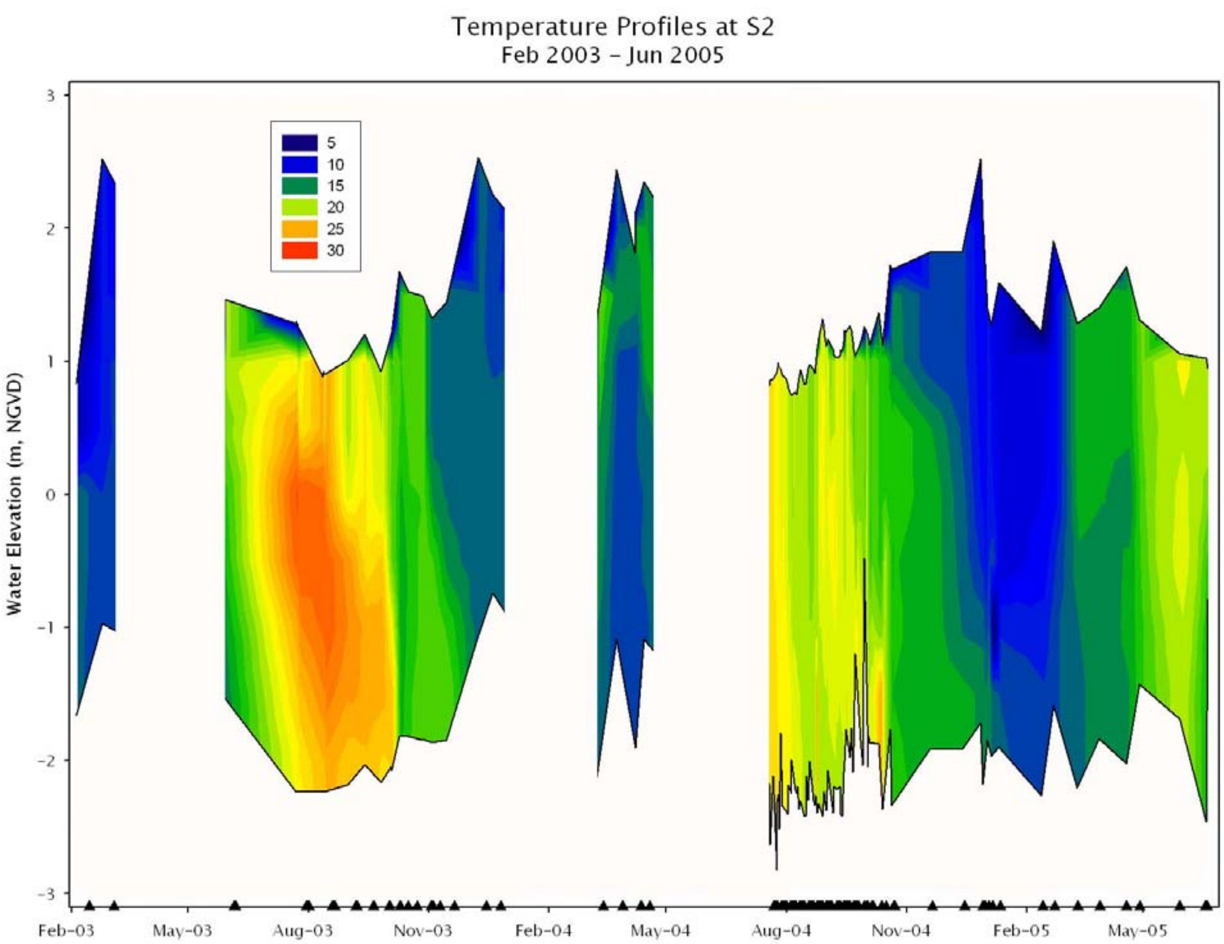


Figure 6.4. Changes in temperature through the water column at S2 from 2003 to mid 2005.

6.1.3 Dissolved oxygen

Profiles of dissolved oxygen (Fig. 6.5 & Appendix C) were driven by a photosynthetic layer typically at about -0.5 m NGVD. Oxygen produced at this layer super-saturated the water (above about 15 mg/L) and diffused vertically upward to eventually be released to the atmosphere. This is evidenced by the negative oxygen gradient toward the surface during periods of high oxygen in the mid-water. Mixing of atmospheric oxygen into the water apparently provided background saturated conditions (~8 mg/L) in the intervening periods. Below the productive layer, lay a thick, stable, anoxic layer typical of observations in previous years.

We note that the whole profile shifted upward slightly in late August and early September, when wave in-wash was strong enough to make the entire water column slightly cooler and more saline for about a week (and also possibly bringing in additional nutrients). The fact that the zone of oxygen production shifted upward at this time supports the hypothesis presented in our earlier work (Casagrande et al., 2003; Watson & Casagrande (2004) that the production is caused by phytoplankton that achieve optimal growth at 10 to 20 ppt salinity stratified water columns (as opposed to some fixed-elevation production mechanism such as macrophytes that to not move rapidly in response to changing salinity).

During Phase 1, sub-criterion oxygen levels only occurred at the base of N1 (other than the deep anoxic layer at S2) (Appendix C). This is consistent with respiration in the well-developed sediments and high organic content of the North Arm. Why the same cycles did not appear to occur at FP is not clear. Both FP and R1 remained well-oxygenated at all times and all depths, implying that the lower oxygen levels occasionally observed at N1 were local, rather than lagoon-wide effects. During the first week of main-lagoon construction activities (Phase 2a), the active excavation area inside the slit curtain (S4I) became oxygen-limited throughout (Fig. 6.6 & Appendix C). This effect was greatly diminished just outside the silt curtain (S4O), and unobservable a short distance away at the South Arm Pipe (S2). The frog pond (FP) also developed an anoxic bottom layer. This may have been due to disturbance from the nearby construction area, but an alternate hypothesis is that it was actually due to disturbance of bottom sediments caused by the act of wading into the pond to take samples and measurements.

In contrast, there is some evidence that various construction activities stimulated high oxygen levels in the main lagoon. Photosynthetic production in the mid-water increased for several days after seining in the South Arm, emplacement of the rock peninsula in the South Arm, and excavation in the South Arm. All of these activities stirred up considerable amounts of sediment in the South Arm, which may have released nutrients into the water column that gradually diffused through the silt curtains into the original lagoon and lead to enhanced photosynthetic production for a few days. But the evidence is not unequivocal. It is possible that variations in production could also be explained coincidentally by natural processes driven by variations in air temperature, wind, and ocean waves.

We also observe a slight concurrence between releases of well water and CAWD water, and low oxygen levels for a day or two thereafter. Again, cause and effect is not clear.

None of this variation led to sub-criterion oxygen levels in the main lagoon, so it is clear that construction activities did not impair the main lagoon in this way.

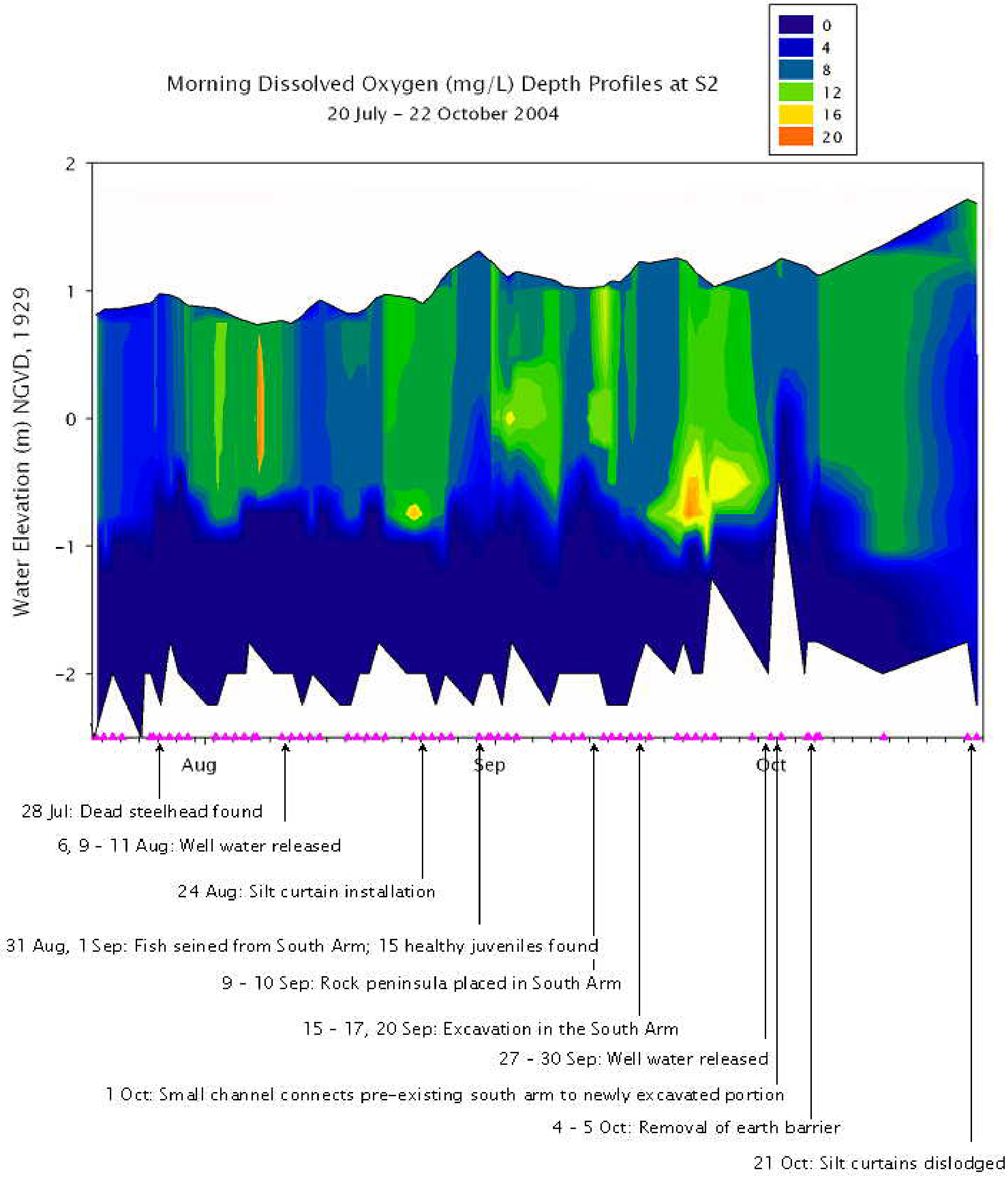


Figure 6.5. Time series of dissolved oxygen profiles during Phases 1 & 2 at S2.

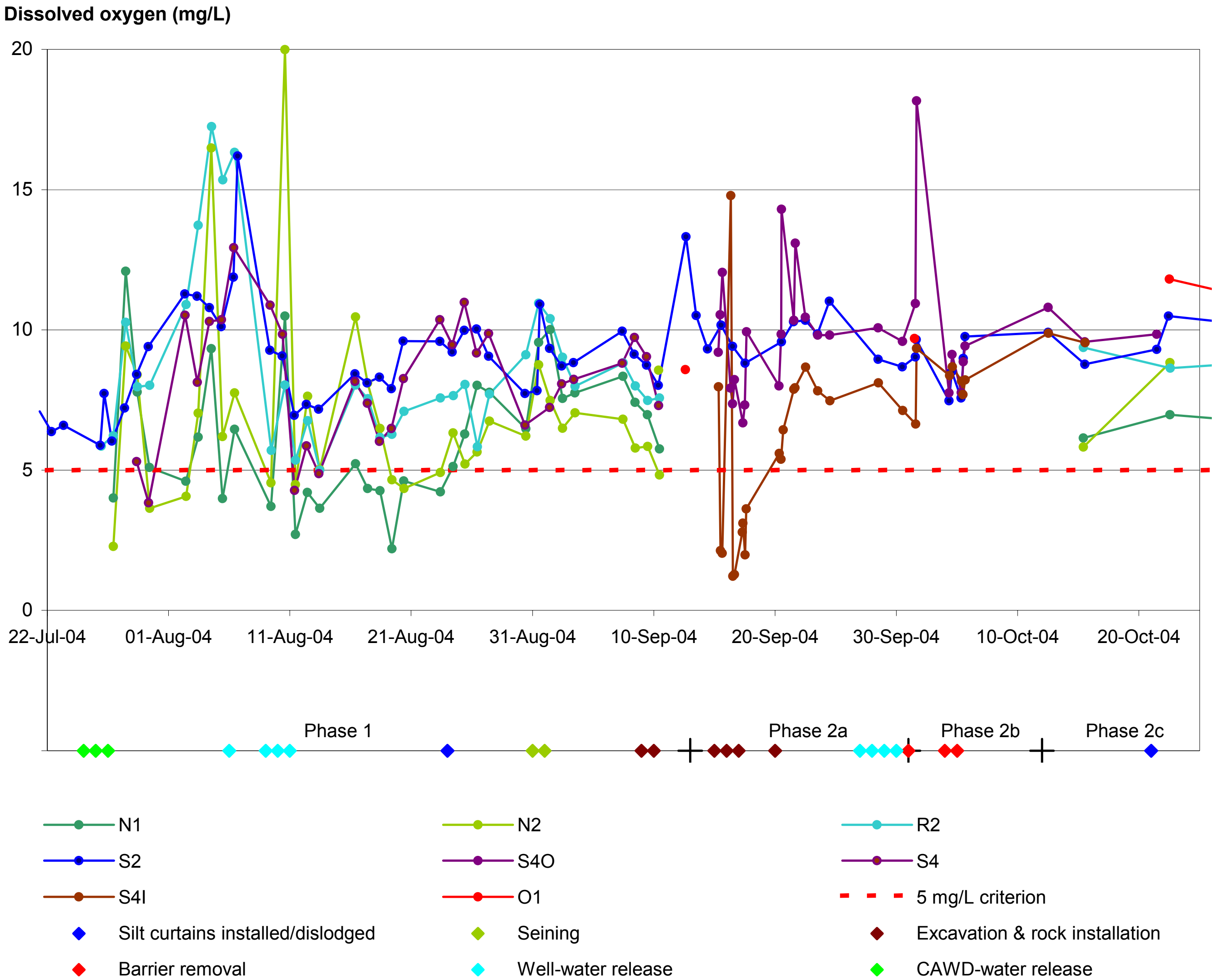


Figure 6.6. Time series of DO surface measurements taken from S2, S4O, S4I, and R2 during Phases 1 and 2.

6.1.4 Suspended sediment concentration

There were numerous occasions of where the SSC criterion was exceeded during Phase 1 (Fig. 6.7), but these may reflect essentially natural processes such as wind-driven turbulence and normal algal growth. Non-natural explanations are also possible, such as enhanced algal growth due to nutrient enrichment from CAWD water releases, or dust settling after having been blown off exposed soil in the excavation area. During the major construction activities of Phase 2, almost all of the samples collected from the surface inside the silt curtains (S4I) exceeded the criterion, whereas samples taken from outside the silt curtain only exceeded the criterion on two occasions. On the 15th September at 11:35 SSC at S4O spiked to 106 mg/L and thereafter decreased to 17 mg/L at 15:45. A second spike of 88 mg/L occurred on the 5th of October at 12:35, and by 15:50 had decreased to 69-mg/L. On the next sampling date 7 days later, SSC was 9mg/L. Thus, leakage across the curtains occurred occasionally, but was short-lived and of the same magnitude as levels recorded during Phase 1 when the system was most likely functioning naturally.

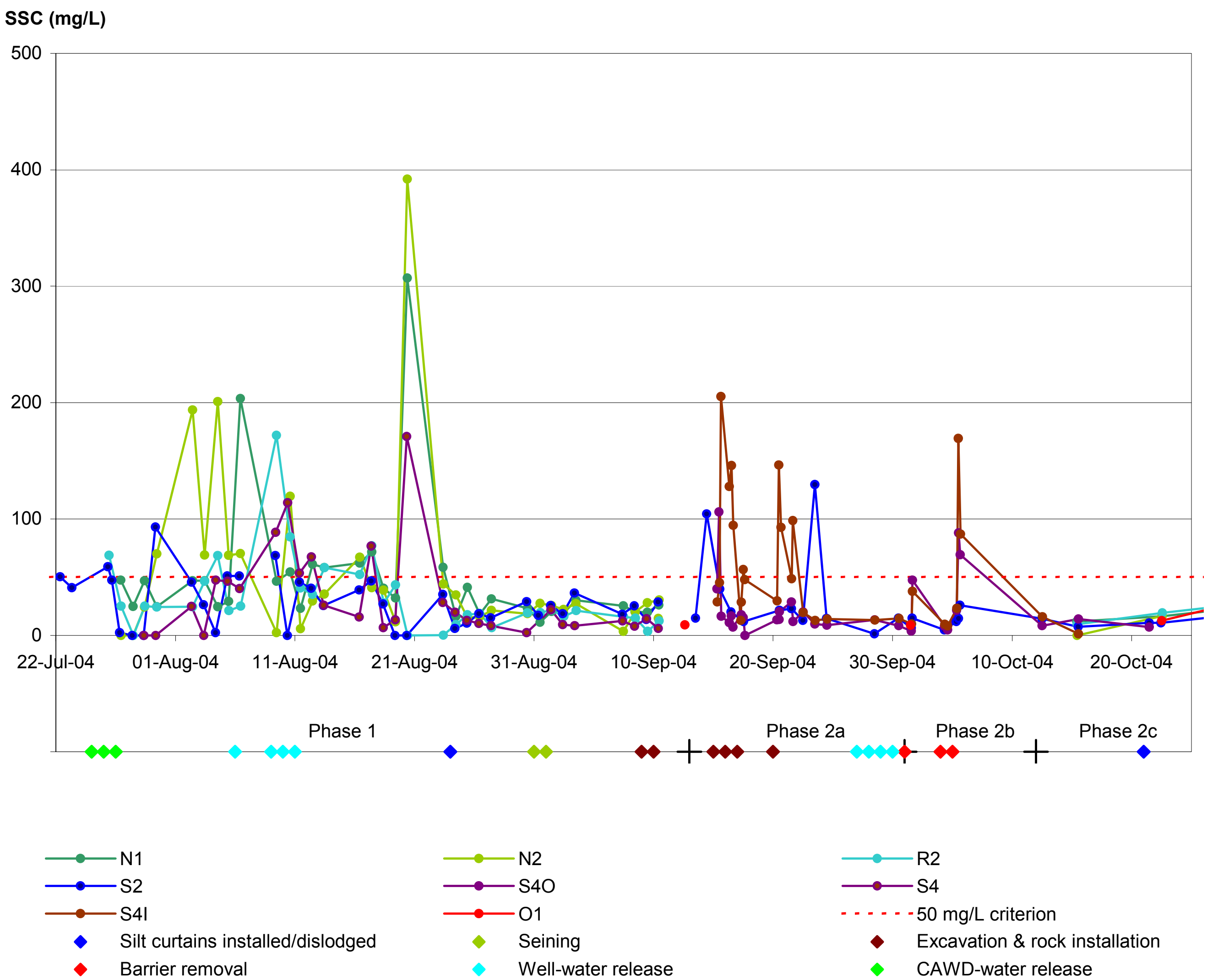


Figure 6.7. Time series of SSC from surface samples taken at selected sites during Phases 1 and 2.

6.1.5 Turbidity

Turbidity dynamics during Phase 1 & 2 correlated closely with SSC dynamics (Fig. 6.8). Minor exceedences occurred at N2 during Phase 1, apparently naturally. Significant exceedence occurred in the active construction area (S4I) during Phase 2, occasionally leaking through the curtains to S4O, and only to a limited extent as far as the South Arm Pipe (S2).

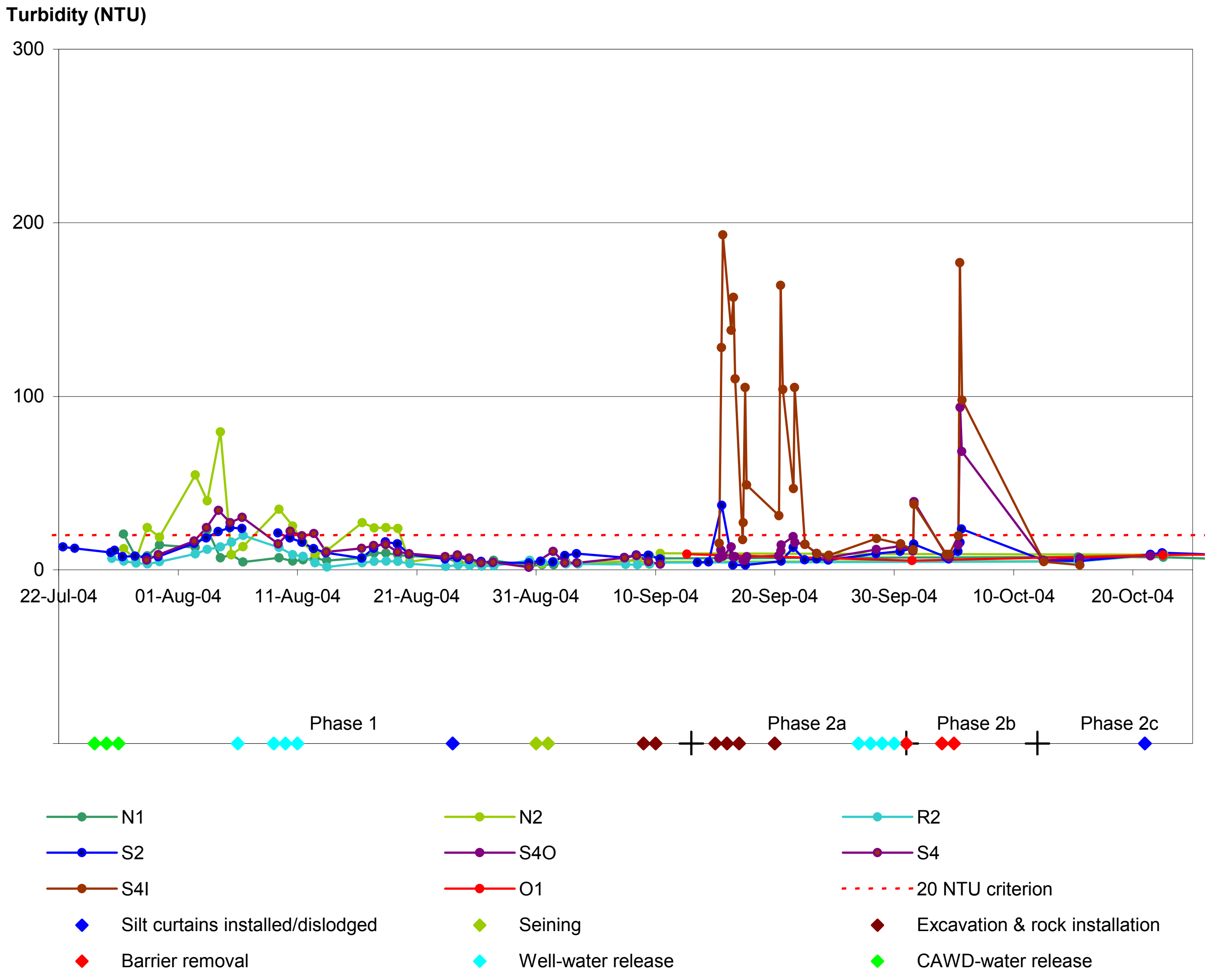


Figure 6.8. Time series of turbidity at various sites during Phases 1 and 2.

6.1.6 Carbon dioxide

At most sites, carbon dioxide levels remained within the 10 mg/L criterion in surface waters throughout Phases 1 & 2 (Fig. 6.9). This is not surprising, since CO_2 diffuses very easily into the atmosphere when above saturation levels of about 1 mg/L (Wetzel, 2001). The only exception was S4I, which experienced very high surface CO_2 inside the silt curtains during the most intense construction activity. In near-bottom waters, CO_2 levels were higher, which is an expected consequence of respiration exceeding production in bottom waters, combined with density stratification precluding any averted mixing of CO_2 from deep to surface waters. Deep-water CO_2 levels were within criterion during Phase 1, but then climbed above criterion during Phases 2a and 2b. It is possible that this is a natural seasonal phenomenon, as the photosynthetic production-respiration ratio subsides following summer. It may also have been caused by construction activities: either directly by advected transport of substances such as organic matter from the construction site, past the silt curtains, to S2; or indirectly by increased respiration of a higher density of organisms at S2 that would otherwise have been closer to the construction site. Note that the stated range for the HACH titration method used to analyze CO2 was 10-50 mg/L. Many of the values reported were below this range, but were deemed acceptable because of the consistency between independently analyzed sites and dates.

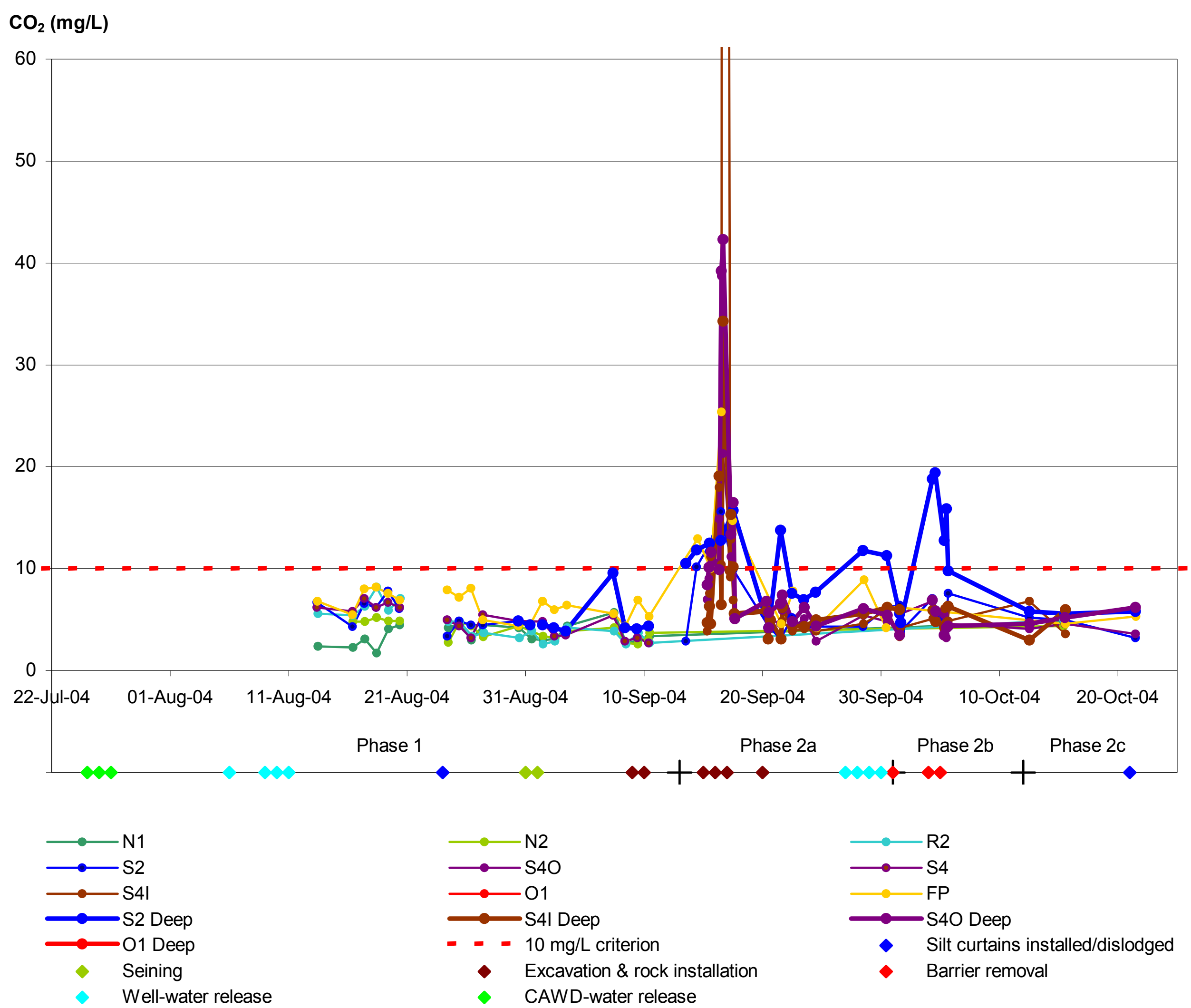


Figure 6.9. Time series of CO_2 at selected sites during Phases 1 & 2.

6.1.7 Hydrogen sulfide

Hydrogen sulfide concentrations during construction activities consistently failed to meet the 25 μg/L water quality objective inside the silt curtains, but usually met objectives at sampling sites outside the curtains in the original lagoon area (Fig. 6.10). Concentrations inside the curtains increased whenever underwater excavation occurred, and gradually declined to safer concentrations in the hours and days thereafter. Concentrations immediately outside the curtains failed to meet the objective on a few occasions, more so when the silt curtains were bowed outward – possibly a consequence of reduced wave and tidal action leading to a reduction in water level in the original lagoon. Concentrations gradually decreased moving away from the outside of the curtains toward the outfall pipe and the river mouth area of the lagoon (S2). The sharpest reduction in surface H_2S occurred over the silt curtains themselves. Note that the 25 μg/L objective reviewed for H_2S toxicity was based on 72-hour and 96-hour mortality tests on rainbow trout eggs. It is probable that smolts would tolerate higher concentrations, especially if these higher concentrations only lasted a few hours (less than 72 and 96) – as is the case for the data outside the silt curtains.

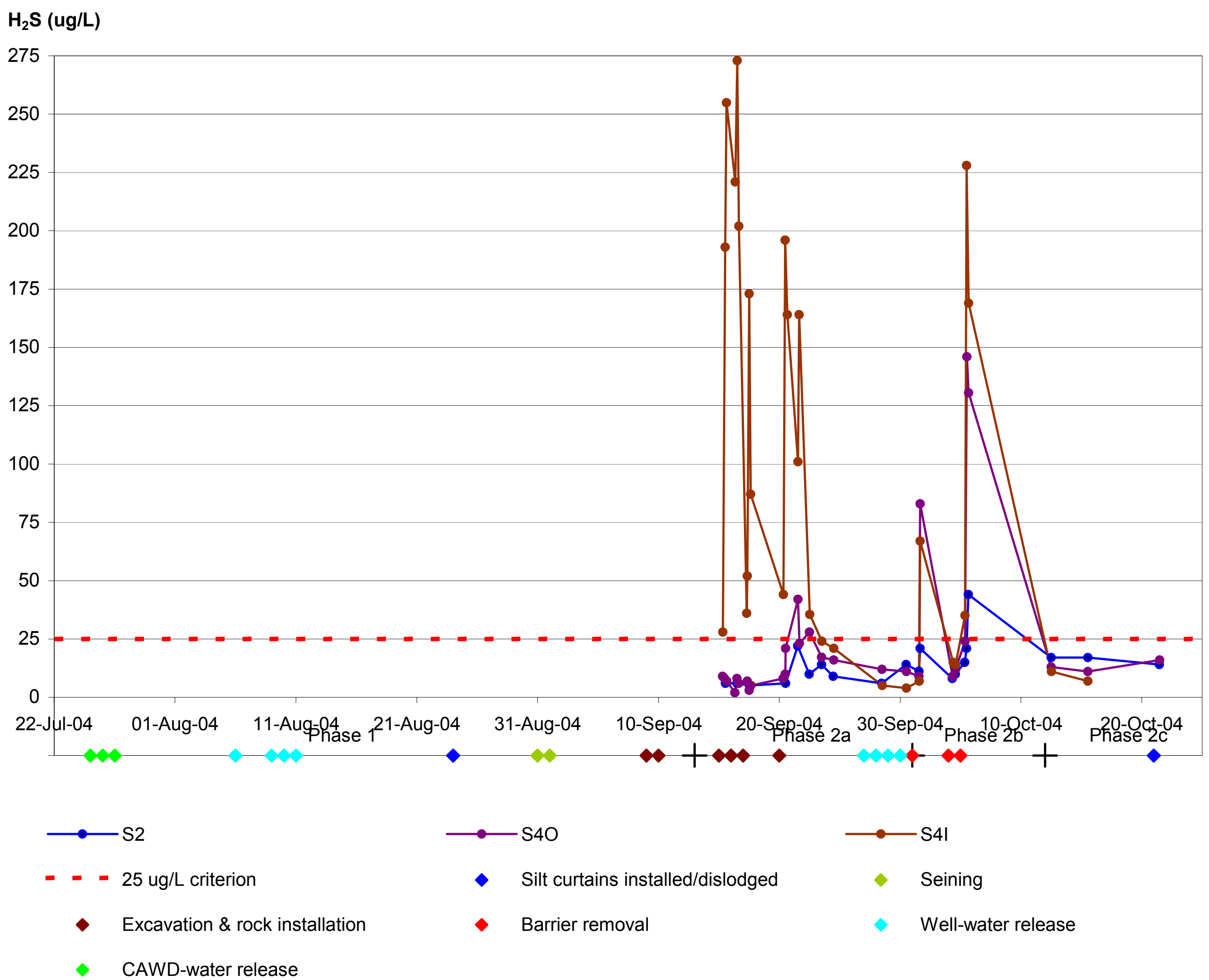


Figure 6.10. Time series of H2S surface measurements taken from S2, S4O, S4I, and R2 during Phases 1 and 2.

6.2 Phases 3 and 4

Surface trends during Phases 3 & 4 are given in the figures in this Section, and depth profiles are given in the Appendices. Significant storms occurred on October 19th and 26th, December 7th and 27th, January 7th, February 21st, and March 22nd. The river connected to the lagoon on December 27th, causing it to flood, necessitating manual breaching on the 29th. The lagoon water quality dynamics during Phases 3 & 4 were driven by a pre-winter build up of saline ocean wave over-wash, the breaching event on December 29th 2004, a long period of freshwater river flow conditions with the North and South Arms being somewhat isolated from the flow, and finally the stream flow recession and a period of oscillating sandbar closures between May and July 2005.

6.2.1 Salinity

After a relative fresh period in Phases 1 & 2, the surface waters were rather brackish (10 ppt) during the ocean wave over-wash season in November (Fig. 6.11 & Appendices). Upon river flow and sandbar breaching, all surface waters freshened, but the breaching turbulence did not appear to be strong enough to briefly freshen the deep water at S2 (as it has in previous years). Rather, the deep water gradually became fresher as the stream flow season progressed. The surface waters of the restored portion of the lagoon (O1) also exhibited a slightly dampened response to the breaching event – becoming fresh more slowly than the surface waters that were closer to the river flow. The lagoon is now large enough to exhibit lateral gradients in surface water salinity. By April 2005, almost the entire lagoon was fresh. Then, from early May onwards as stream flow influence subsided, salinity stratification gradually resumed. Commencing in late May, sampling in the deepest part of the newly restored area (O1) revealed that this area is clearly deep enough to exhibit pronounced salinity stratification. It thus provides typical lagoon habitat, as opposed to freshwater pond habitat.

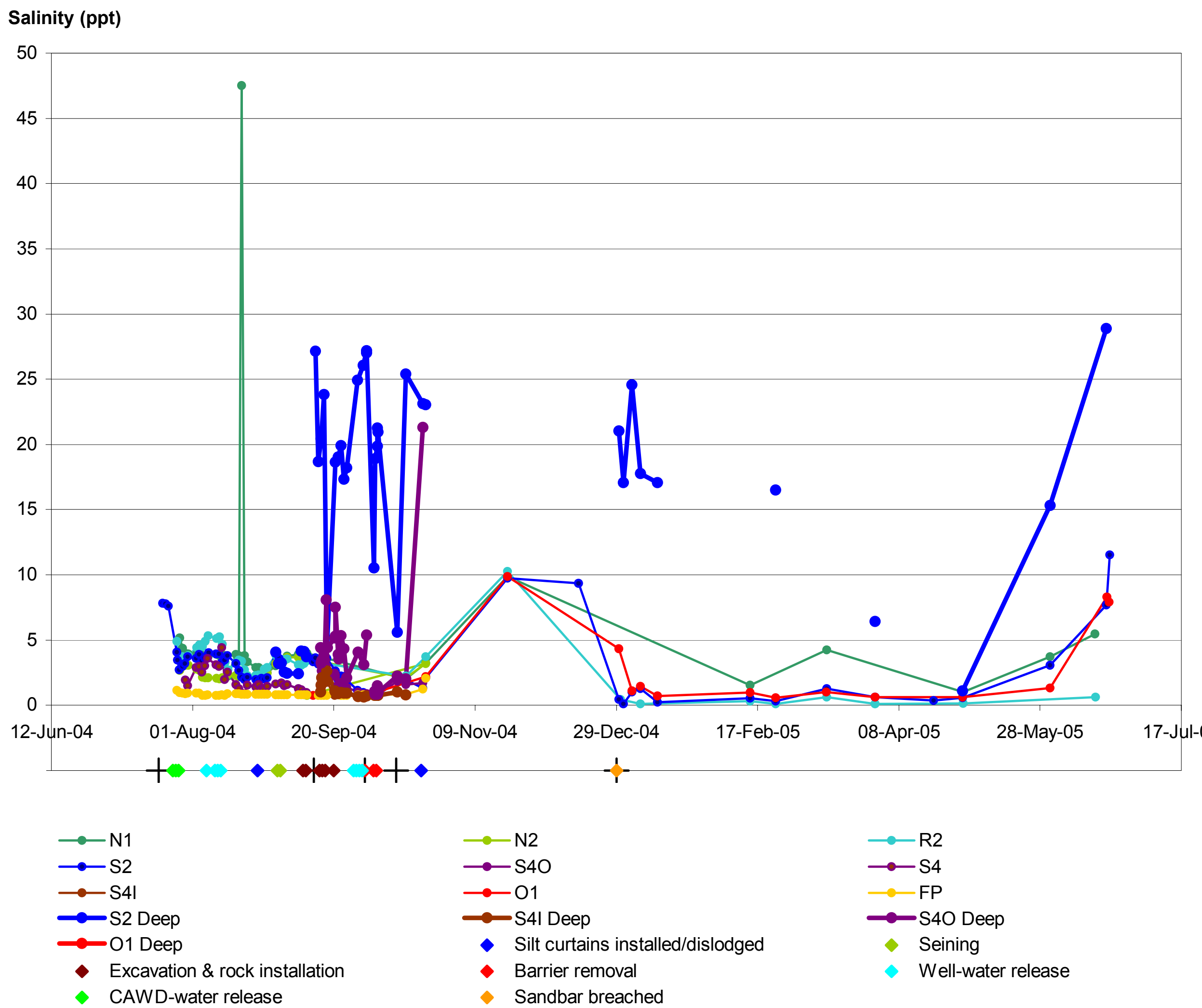


Figure 6.11. Time series of surface and near-bottom salinity at selected sites during Phases 1 to 4.

6.2.2 Temperature

Surface temperature followed the expected sinusoidal variation in air temperature during Phases 3 & 4 (Fig. 6.12), being largely controlled by river temperature, and perhaps to a limited extent by ocean temperature in deeper, more saline water at the time of breaching. Since density stratification was reduced or eliminated by stream flow in mid-winter, or low-stages in early spring, temperature profiles were for the most part iosothermal. Isolated sites farther from the stream flow (N1 & O1) exhibited higher temperatures than the more central sites at S2 at R1. As summer arrived, surface temperature at O3 exceeded the 26°C criterion on 20 June 2005 (see Appendix). This site is shallow and has no vegetative cover to provide shade.

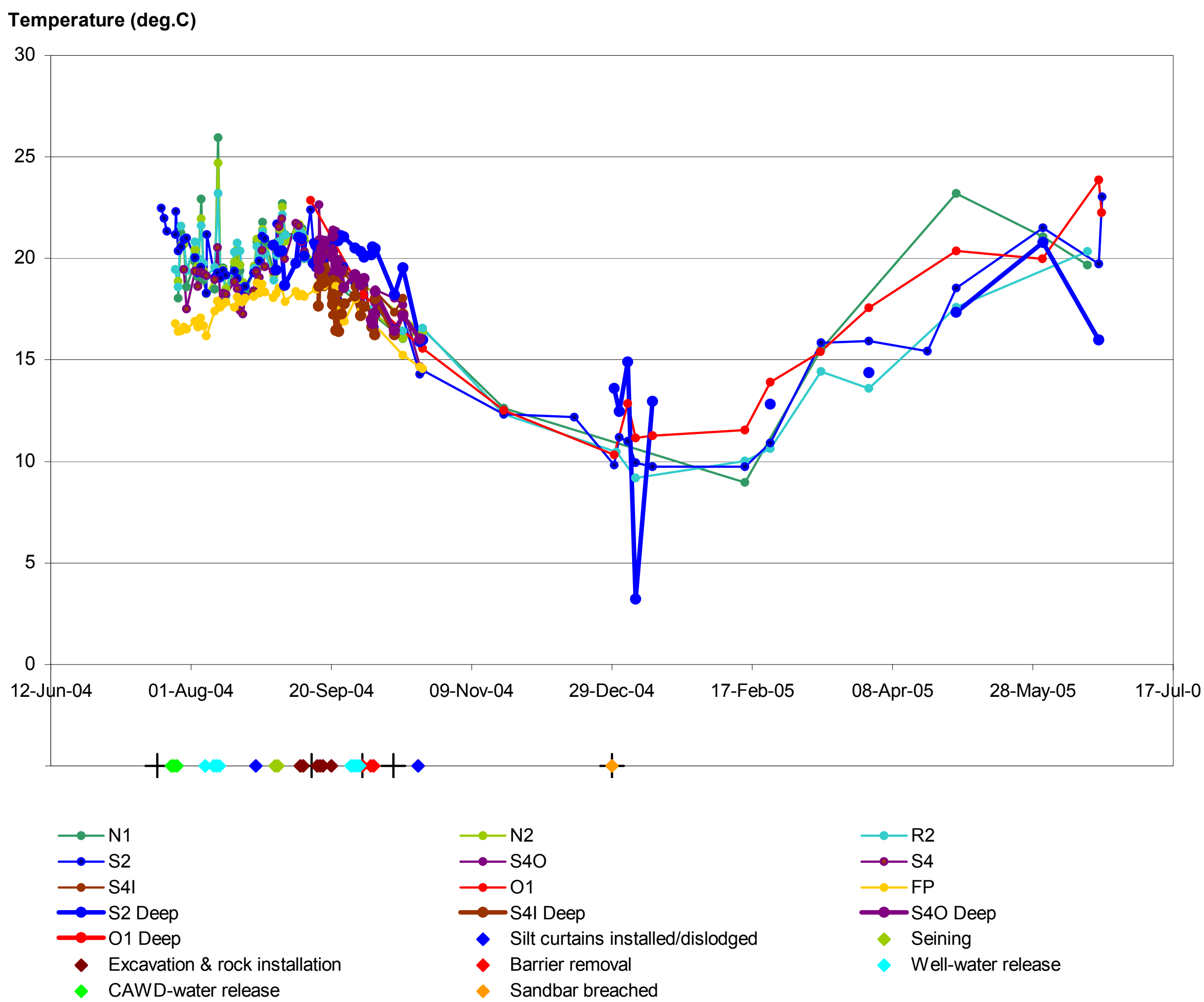


Figure 6.12. Time series of surface and near-bottom temperature during Phases 1 to 4.

6.2.3 Dissolved Oxygen

Surface dissolved oxygen remained near saturation levels throughout Phases 3 & 4 (Fig. 6.13 and Appendices). The highest levels were at sites nearest the river, since the river was well mixed with the atmosphere. Lower levels were measured at more isolated sites (such as in the newly restored area at O1), and were even below criterion at N1 on one occasion. This site is typical of many estuarine marshlands – a thickly vegetated area characterized by decomposing vegetation, organic sediment, and brown colored water. Deeper waters at S2 remained typically near anoxic levels during mid-winter as long as salinity stratification persisted, but apparently received an influx of oxygen as stratification broke down when finally overcome by stream flow in late April. The deepest part of the new lagoon (O1) became anoxic in the week following breaching, perhaps due to decomposition of organic matter washed in from its newly formed banks.

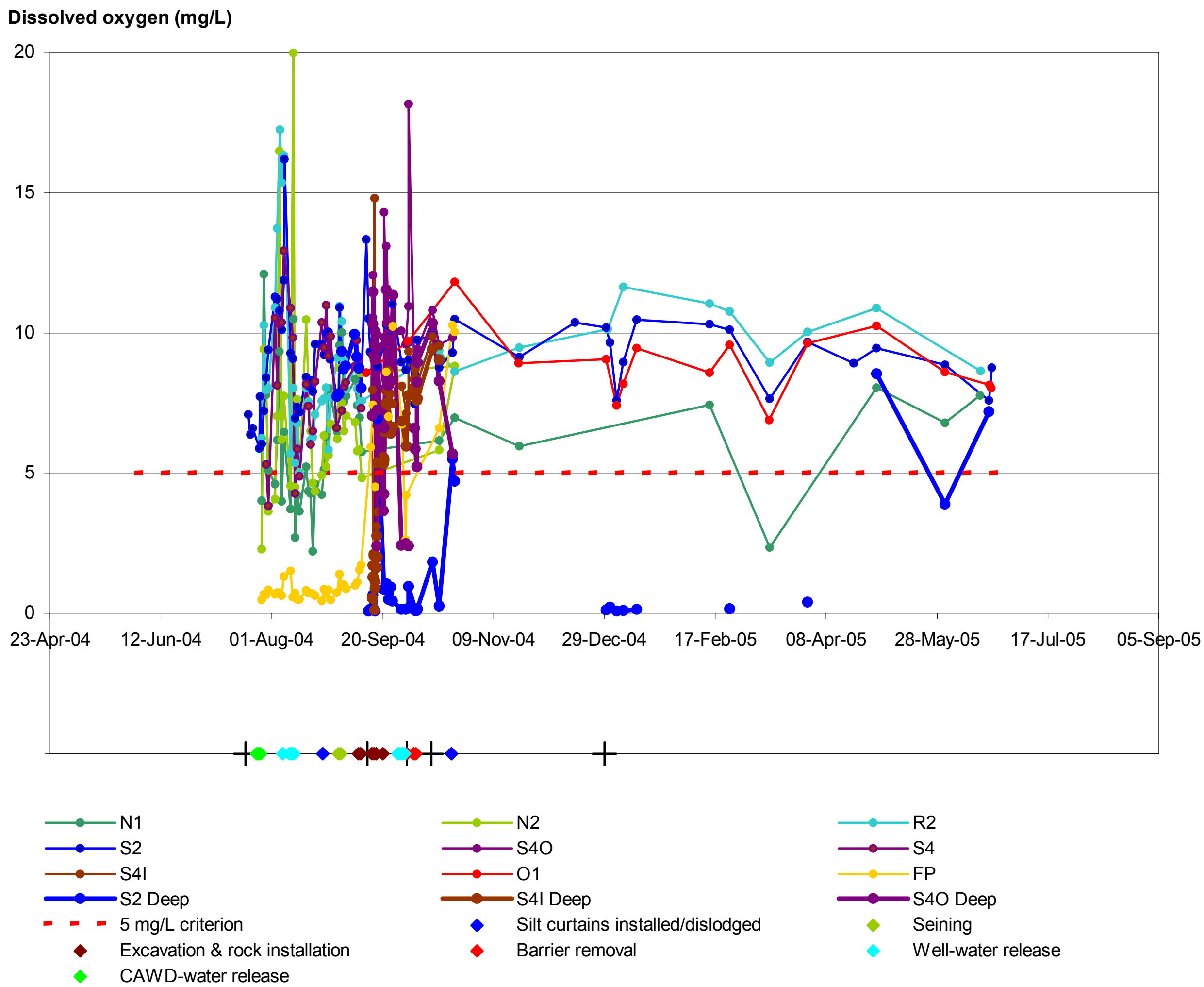


Figure 6.13.Time series of surface and near-bottom dissolved oxygen during Phases 1 to 4.

6.2.4 Suspended Sediment Concentration

Suspended sediment levels responded to storms during Phases 3 & 4 (Fig. 6.14). SSC exceeded the 50 mg/L criterion in the new lagoon (O1) and nearby in the South Arm (S2) on several occasions surrounding the storms that lead to breaching at the end of December. This is consistent with field observations at the time of local storm runoff eroding gullies into the newly created and largely un-vegetated banks (Fig4.2). The largest SSC was measured on 12 Jan 2005 at O3. The river itself (R2) was relatively free of suspended sediment at the surface. Previous snorkel observations suggest that a large proportion of the river's sediment load is often transported as coarse bed load that settles out in the lagoon immediately on either side of the river channel itself.

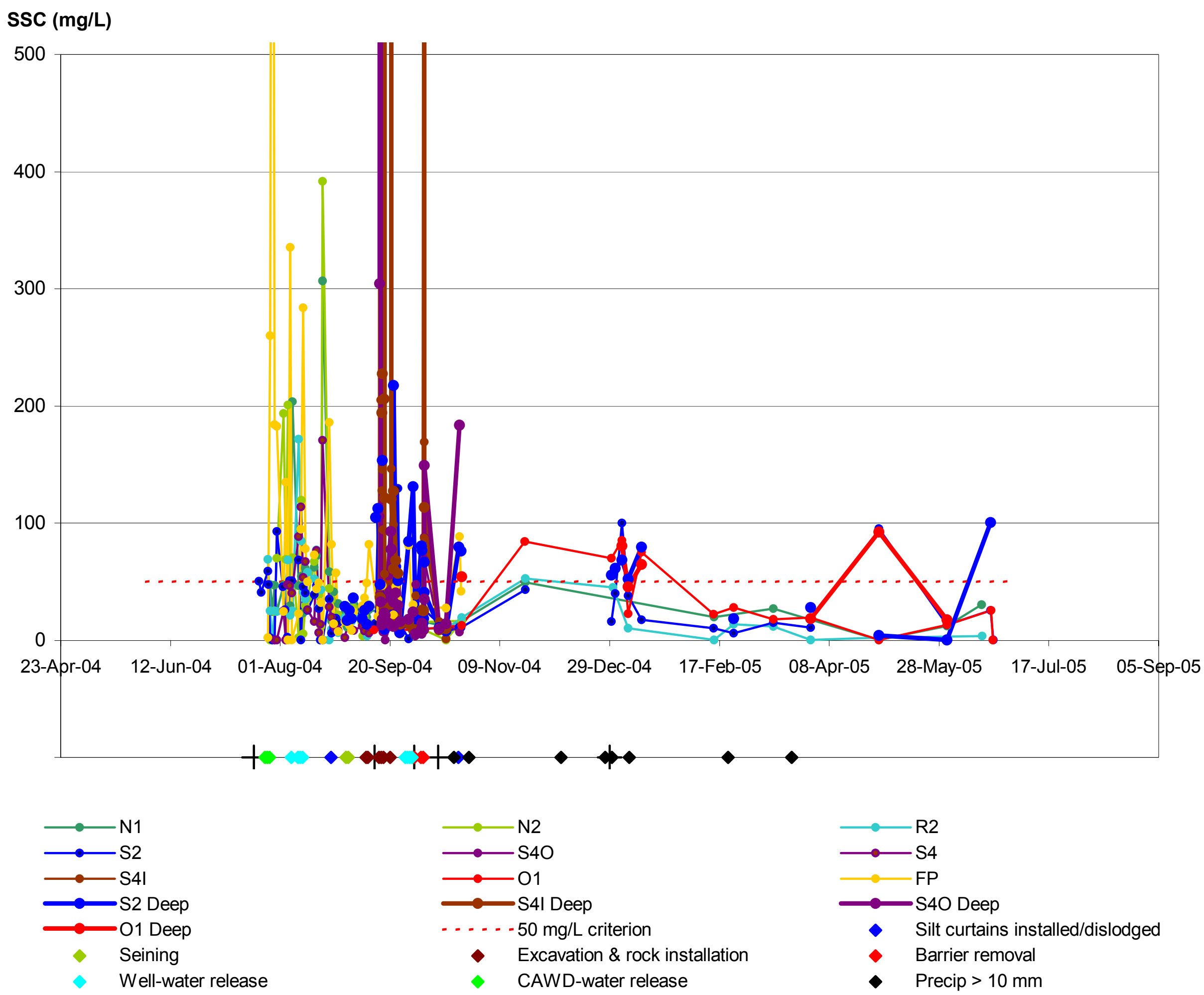


Figure 6.14. Time series of surface and near-bottom SSC during Phases 1 to 4.

6.2.5 Turbidity

Turbidity dynamics follows SSC dynamics (Fig. 6.15), characterized by exceedances of the 20 NTU criterion following storms, and relaxation to sub-criterion levels thereafter. This pattern was strongest in the new restoration (O1) but still apparent downstream at the South Arm (S2).

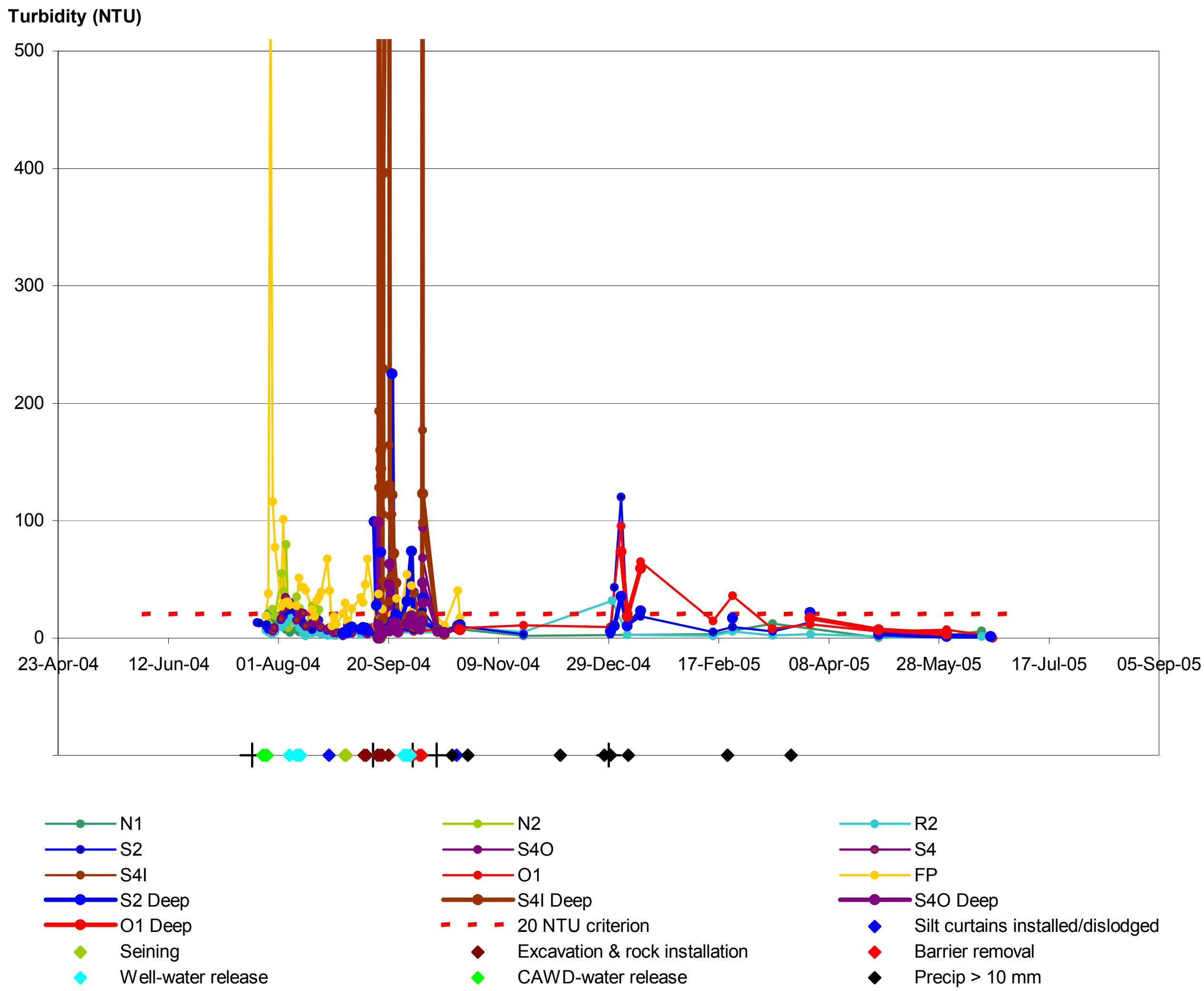


Figure 6.15. Time series of surface and near-bottom turbidity during Phases 1 to 4.

7 Macroinvertebrates

7.1 Introduction

In addition to water quantity and quality, an important factor in steelhead habitat development and success is adequate food abundance. Macroinvertebrates make up the majority of steelhead diet in a lagoon habitat, before they migrate out to sea.

Lagoon invertebrates were sampled over a 5-6 month period at 4 sites within the Odello portion of the lagoon, as well as 4 within the original lagoon. In order to examine primary succession and population development of macro-invertebrates, taxa abundance and diversity were compared between the original lagoon and newly excavated arm. This section describes the taxa found, and the response of the populations to the changing habitat.

7.1.1 Steelhead Feeding Habits

Macroinvertebrates are an invaluable source of food to steelhead and an abundance or lack of them can affect juvenile steelhead (Robinson, 1993). Depending on water quality conditions steelhead can grow substantially in lagoons with abundant invertebrates. Typically, lagoons with a robust and prolonged freshwater lens or those open to tidal mixing result in steelhead with quicker growth rates as opposed to closed and heavily stratified lagoons (Smith, 1990). Growth rates become reduced when temperatures are too warm due to meeting heightened metabolic demands. Optimal conditions for growth generally occur when temperatures are mild and invertebrate populations are abundant.

Lagoons support a wide array of macro-invertebrates due to microhabitats within the lagoon with varying degrees of salinity, substrate, and vegetation. Unlike streams, lagoon macro-invertebrates are dominated by scuds (*Amphipod*a), aquatic sowbugs (*Isopoda*), and opossum shrimp (*Mysidacea*) (Kitting, 1990). Several of the invertebrates found in streams are also found in the lagoon under freshwater conditions, making for relatively diverse invertebrate populations and an abundant food source.

Fields (1984) found that lagoon invertebrates are most likely the richest source of food in the Carmel River System. The primary invertebrates found in the stomachs of steelhead smolts were the amphipods *Anisogammarus* and *Corophium*, the isopod *Gnorimosphaeroma*, and the mysid *Neomysis*.

7.2 Methods

Through trial and error, we developed our own sampling protocols, since there does not appear to be a suitable previously established protocol for sampling small lagoons. Existing protocols for sampling macroinvertebrates tend to be designed for streams (Harrington and Born, 2000), marine environments, or much larger estuaries. The static net placements typically used in streams do not work because there is no flow to move water through them. Nets towed behind boats do not work because the lagoon is too small to maneuver boats consistently. Tow-nets thrown from the bank also do not allow consistent sampling of volume and depth in all wind conditions. Tow-sleds pulled along the bottom tend to get stuck and cause too much disturbance. Pump sampling would not sample enough volume. Sediment coring would not tend to sample free-swimming invertebrates sought by steelhead, and would be too destructive for repetitive sampling in such a small area. Thus, for the present project, Masek (2005) developed sampling protocols that could be used from the banks of small lagoons to collect macroinvertebrates both from the water column and the epibenthos, in both vegetated and non-vegetated areas.

Figure 7.1. D-net used for sampling macro-invertebrates.

7.2.1 Sample Collection

Macro-invertebrates were collected using a D-net (opening ~0.043 m^2, mesh size 500 μm) on a 1.5 m pole (Fig. 7.1). Samples were taken from standing on the bank or by wading a short distance into the water as the depth would allow. Each sample was collected by sweeping the D-net 3 times, then moving 2 meters along the bank and sweeping 3 more times, then moving 2 meters more and sweeping again – for a total of 9 sweeps. A total of 4 meters were traveled along the bank for each site. Towards the end of the sampling period most of the sites had decreased in depth and it was necessary to take samples by wading out to find sufficiently deep waters.

Two zones of the lagoon were sampled: the water column and the epibenthos. Epibenthic refers to anything living on or near the surface of the bottom sediments in a water body. A water column sample and an epibenthic sample were collected at each site with the exception of S2, where no epibenthic samples were collected there because of the depth of the water. At the other 7 sites, a total of 18 net sweeps were made during each visit (9 per sample x 2 samples).

The water column collection method consists of an 180° arc sweep of the net with the top of the net approximately 20 cm below the surface. The end of the pole was held against the sampler's body, ensuring precision in the arc sweeps. Figure 7.2 illustrates this sampling method and the equation that was used to determine the volume of water that was sampled. The volume obtained from this equation was multiplied by 9 to account for the total number of sweeps per sample. The volume of water per sample is calculated to be 2.53 m^3.

The epibenthic collection method consists of a sweep perpendicular to the bank: the net was extended out from the body, placed in the water, then gently pulled back towards the body across the bottom as lightly and quickly as possible in order to catch as many invertebrates as possible without greatly disturbing their habitat or allowing them to escape. Figure 7.3 illustrates this sampling method and the equation that was used to determine the area of eipbenthos that was sampled. The area obtained from this equation was again multiplied by 9 to account for the total number of sweeps per sample. The area of eipbenthos per sample is calculated to be 4.39 m^2.

Invertebrates were stored in glass jars and preserved with a 70% ethanol solution before being transported to the lab. Invertebrates were sorted from dirt and plant debris, separated according to order, and then identified down to the Family level for most Classes (roughly corresponding to Level 2 Taxonomic Effort according to Harrington & Born, 2000). The following keys were used: Merritt and Cummins, 1996; Harrington and Born, 2000; McCafferty, 1998; Smith, 2001; Fitzpatrick, 1983; NAMC, 2001; APHA, 1998). There was no sub-sampling; all invertebrates in each sample were identified.

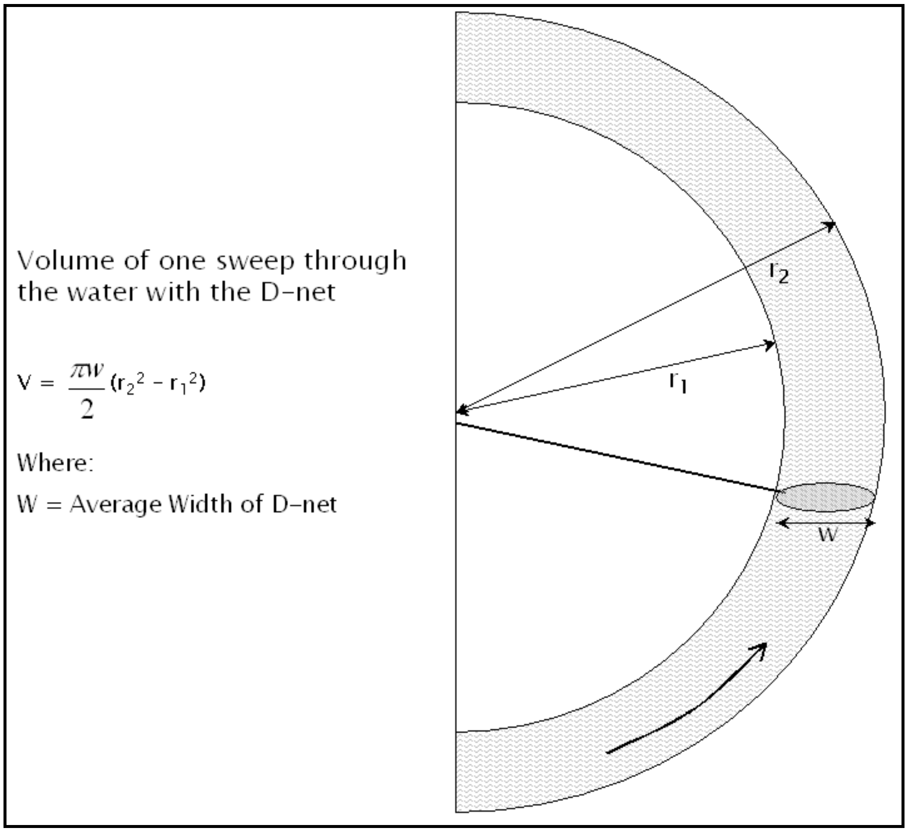


Figure 7.2. Geometry of sampling method for water column macroinvertebrates.

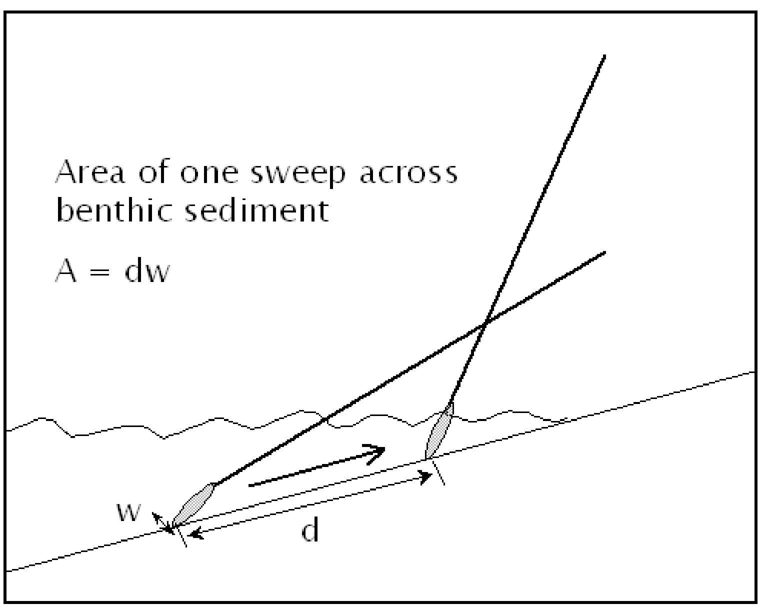


Figure 7.4. R4 was also sampled for macro-invertebrates. (14 Feb 2005)

7.2.2 Sampled Sites and Dates

A total of 8 sites were sites sampled for macro-invertebrates. In the pre-existing lagoon 4 sites were sampled, 3 of which are water quality monitoring sites: S2, (Section 4.1), R2 (Section 4.3), and N1 (Section 4.4). One site sampled that was not part of the water quality-sampling scheme was at the mouth of the Carmel River, named R4 (Fig. 7.4). 4 sites in the newly excavated Odello channel were also sampled for macro-invertebrates: O0 (Section 4.11), O1 (Section 4.12), O2 (Section 4.13), and O3 (Section 4.14).

Throughout the 6-month monitoring period, sampling for invertebrates was conducted around significant hydrologic events: before the removal of the earth barrier (13 Sep, and 1 Oct 2004), after removal of the earth barrier before the storm season & breaching of the sandbar (20 Nov 2004), after the sandbar was breached (14 Feb 2005) and towards the end of the storm season (13 Mar 2005) (Table 5.1). These events affected water levels, water quality, and sedimentation. On the 13th of September, samples were not taken at the R2, R5, or N1.

Sampling in September 2004 was conducted at fewer sites and habitats than on subsequent dates. So the September data were excluded from certain analyses that would have been biased by this (frequency and abundance), and included in less-sensitive analyses (diversity and salinity relations).

7.2.3 Data Analysis

A list of all organisms found is given with a brief description of their characteristics. Water column and epibenthic samples were generally analyzed separately, because of the different sampling units (volumetric versus areal).

To assess presence/absence differences between the original and new lagoon areas, the **frequency** of occurrence was computed as the number of samples in which each taxa occurred divided by the total number of samples. Data were grouped in to original lagoon sites (R2, N1, R5, and S2) and new Odello sites (O0, O1, O2, and O3) for this purpose.

Taxa **abundance** in the pre-existing lagoon was compared to taxa abundance in the newly excavated Odello sites. Abundance was measured as a volumetric density (for water column samples) or an areal density (for epibenthic samples). The total numbers of individuals per taxon from all water column samples in the pre-existing lagoon sites were summed by date, and then divided by the volume of water sampled (2.53 m^3). The same was done for sites Odello. The total numbers of individuals per taxon from all epibenthic samples in the Odello sites were summed by date, and then divided by the area sampled (4.39 m^2).

The **diversity** of organisms was measured using the Shannon-Weiner Index. This index reflects both the total number of organisms (richness) and an even distribution of numbers of organisms across all taxa. It is computed as:

$$H' = -\Sigma\, P_i \log P_i$$

Where:
$P_i = N_i \,/\, N$
N_i = number of individuals of taxa i in the sample
N = total number of individuals in the sample

Indices calculated for all of the pre-existing lagoon sites were averaged together for each sampled date, and indices for all of the Odello sites were averaged together for each sampled date. Change in diversity over time is presented by plots of diversity values obtained from the Shannon-Weiner Index vs. time for water samples, and again for epibenthos samples.

Additional insight into the ecology of aquatic invertebrate communities is gained by grouping organisms together into their **functional feeding groups,** based on morphological-behavioral food gathering mechanisms. Functional feeding groups measure an aspect of the functioning rather than just the structure of invertebrate communities (Merritt and Cummins, 1996) and provide information on the balance of feeding strategies in the community (Harrington and Born, 2000). Organisms were classified into one of four categories: shredders, collectors, filterers, and predators (no scrapers were present).

Shredders depend upon coarse particulate organic matter (CPOM) for their primary food resource; examples of CPOM include: twigs, leaves, fruits and flowers of terrestrial or aquatic vegetation (Merritt and Cummins, 1996). Trophically, these organisms are herbivores, detritivores, and gougers. Collectors and filterers depend upon fine particulate organic matter (FPOM) for their primary food resource. They gather or filter fine materials, including plant, animal, and fungal detritus, from the surfaces of substrates. Trophically, these organisms are detritivores (Merritt and Cummins, 1996). Predators require living prey organisms; some ingest whole animals, while others tear off and swallow large pieces (Merritt and Cummins, 1996). Others pierce tissues and cells and suck fluids.

To understand how the structure of communities differs between the pre-existing and new portions of the lagoon through time, the numerical proportions of shredders, collectors, filterers, and predators were examined over time. These proportions were averaged across all sites in both the original and new lagoon areas.

7.3 Results

7.3.1 Total Taxa Present

Table 7.1 shows the list of all taxa found in both the Odello sites and the old lagoon sites. Some taxa were only found once during the entire study: Diptera Ephydridae and Empididae, Odonata Libellulidae and Aeshnidae, and Nematoda. The numbers of invertebrates found at each site for each sample date are shown in Appendix F. Below are general characteristics for each taxon.

Table 7.1. List of all observed taxa.

Phylum	Class	Order	Family	Common Name
Arthropoda	Branchiopoda	Cladocera	Daphnidae	Water Flea
Arthropoda	Insecta	Coleoptera	Dytiscidae	Predaceous diving beetle
Arthropoda	Insecta	Diptera	Chironomidae	Midge larva
Arthropoda	Insecta	Diptera	Chironomidae (pupa)	Midge larva
Arthropoda	Insecta	Diptera	Ephydridae	Shore fly larva
Arthropoda	Insecta	Diptera	Empididae	Dance fly larva, Dagger fly larva
Arthropoda	Insecta	Ephemeroptera	Baetidae	Mayfly larva
Arthropoda	Insecta	Hemiptera	Corixidae	Water Boatman
Arthropoda	Insecta	Hemiptera	Notonectidae	Backswimmer
Arthropoda	Insecta	Odonata (Suborder = Anisoptera)	Libellulidae	Dragonfly larva
Arthropoda	Insecta	Odonata (Suborder = Anisoptera)	Aeshnidae	Dragonfly larva
Crustacea	Eumalacostraca	Isopoda	Gnorimosphaeroma	Isopod
Crustacea	Malacostraca	Mysidacea	Mysidae (Genus = *Neomysis*)	Opossum shrimp
Crustacea	Peracarida	Amphipoda (Suborder = Gammaridea)	Corophiidae (Genus = *Corophium)*	Scud
Crustacea	Peracarida	Amphipoda (Suborder = Gammaridea)	Anisogammaridae (Genus = *Eogammarus*)	Scud
Mollusca	Gastropoda	Basommatophora	Physidae	Aquatic snail
Nematoda				Round worm

7.3.1.1 Cladocera Daphnidae

Daphnidae (Fig. 7.5a) are tiny freshwater crustacea most abundant in spring with a marked population decrease in winter as the water temperature decreases. The length of their life cycle is highly variable, anywhere from 26-108 days (Smith, 2001). Gooderham and Tsyrlin (2002) note that eggs can be wind blown with sediment and are very long-lived; and that they can also be transported in the digestive tract of birds or hatch from sediments that have been dry for a long time. They could thus be expected to be rapid, primary successional colonizers of new, isolated freshwater water bodies such as the Odello Arm before connection to the original lagoon.

7.3.1.2 Coeloptera Dytiscidae

These are freshwater beetles that dwell on the surface and are predators (Fig. 7.5b). The adults can be quite large in size (up to 40 mm) and the larvae can be up to 70 mm in length (McCafferty, 1981; Merritt and Cummins, 1996). They can move between environments in a life cycle: following larval development, they move onto land and pupate in constructed cells in sediment (5 to 14 days) and then the adult generally returns to aquatic environment (Thorp & Covich, 2001). Many species can leave the water and fly to another water body (Smith, 2001).

7.3.1.3 Diptera Chironomidae / Ephydridae / Empididae

Species of chironomid (midge) larvae and pupae typically occur in benthic or epibenthic freshwater habitats and are about 1-20 mm long (Fig. 7.5c) (McCafferty, 1981). Species of ephydridae (shore fly / brine fly) larvae occur in freshwater through to hyper-saline habitats and are about 1.2-12 mm long (Fig. 7.5) (McCafferty, 1981). Most empididae (dance fly) larvae are terrestrial, but a few sub-families are epibenthically aquatic and are about 2-7 mm long (Fig. 7.5e) (McCafferty, 1981). The larvae of these taxa typically have multiple-year life cycles (Merritt & Cummins, 1996). They are an important source of food for many fish. The adult stage is short lived, lasting only a few days to several weeks. The main function in the adult stage is reproduction and dispersal; adults can fly, so they have mobility independent of water movement (Merritt & Cummins, 1996).

7.3.1.4 Ephemeroptera Baetidae

Baetidae (small minnow mayfly) larvae are small benthic freshwater invertebrates (Fig. 7.5f). The larval portion of their life cycle can last anywhere from 2 weeks to a year (McCafferty, 1981; Merritt & Cummins, 1996). "Nymphs of the family Baetidae usually produce two to three generations per year and hatch anywhere between April and October" (Harrington and Born, 2000). Harrington and Born also note "Baetids… are some of the first organisms to inhabit disturbed areas and can be quite tolerant of sedimentation and nutrient enrichment".

7.3.1.5 Hemiptera Corixidae / Notonectidae

Hemiptera (true bugs) of the families Corixidae and Notonectidae are aquatic in the adult stage (McCafferty, 1981). Corixidae are water bugs with flattened bodies and undeveloped wings (Fig. 7.5g) inhabiting both freshwater and brackish environments. They are surface dwellers and their life span generally lasts up to a year (McCafferty, 1981; Merritt & Cummins, 1996). Notonectidae are freshwater bugs that are morphologically similar to the Corixidae except they are deep-bodied instead of flattened and they swim upside down (McCafferty, 1981; Merritt & Cummins, 1996) (Fig. 7.5h). Both of these families are fully aquatic and spend most of their time under water. They are also excellent fliers and can move easily from one water body to another (Gooderham and Tsyrlin, 2002; Smith, 2001). As with Baetids, Harrington and Born (2000) note, "Corixids are one of the first aquatic invertebrates to inhabit new ponds and temporary pools of water".

7.3.1.6 Odonata (Anisoptera) Libellulidae / Aeshnidae

These are dragonfly larvae and are generally large and robust (10-60 mm) (Fig. 7.5). They are usually found in riparian areas of freshwater aquatic habitats and reproduce in the spring (McCafferty, 1981; Merritt & Cummins, 1996). They have a relatively long life cycle of 1-6 yrs, with flight in most species occurring during the summer months (Thorp & Covich, 2001; Harrington and Born, 2000).

7.3.1.7 Isopoda Gnorimosphaeroma

Isopods (sow bugs) are flattened peracarid crustaceans. They are detritovorous and primarily epibenthic (Fig. 7.5j). Reproduction is thought to occur throughout the year, and their life cycle is believed to last about one year. Estuarine Isopods regularly enter freshwater, so salinity does not seem to be a determining factor in their presence/absence (Smith, 2001).

7.3.1.8 Mysidacea Mysidae (Neomysis)

Mysids are small opossum shrimps, peracarid crustaceans found in oligotrophic lakes and estuaries (Fig. 7.5k). They are coldwater organisms that reproduce in summer. The mysid life cycle is thought to last approximately 3-4 years (Smith, 2001).

7.3.1.9 Amphipoda (Gammaridea) Corophiidae (Corophium) / Anisogammaridae (Eogammarus)

Corophia and Gammarids (scuds) are peracarid crustaceans found in abundance in estuarine environments (Figs. 7.5l & 7.5m). They are omnivorous and their primary means of locomotion are swimming and crawling. Reproduction occurs throughout the spring and summer months and their life cycle lasts approximately 30 months (Smith, 2001). They are generally more active at night (Harrington and Born, 2000).

7.3.1.10 Basommatophora Physidae

Physidae (tadpole snails and pouch snails) are small molluscs enclosed in a recognizable shell (Fig. 7.5n). Mollusks can be either freshwater or marine organisms and vary greatly in size. They travel by means of a muscular foot that projects from the shell and can be benthic or found in riparian growth. They reproduce sexually in the spring and fall and their life cycle is thought to last 9-15 months (Smith, 2001).

7.3.1.11 Nematoda

Nematodes are diverse, small pale un-segmented worms. They can survive anywhere there is moisture (Gooderham and Tsyrlin, 2002).

(a) Cladocera Daphnidae (Jessica Masek, 2005)

(b) Coleoptera Dytiscidae (Jessica Masek, 2005)

(c) Diptera Chironomidae (Jessica Masek, 2005)

(d) Diptera Ephydridae pupa (Jessica Masek, 2005)

(e) Diptera Empididae (Jessica Masek, 2005)

(f) Ephemeroptera Baeidae (Jessica Masek, 2005)

Figure 7.5. Macroinvertebrate taxa of the Carmel Lagoon.

(g) Hemiptera Corixidae (Jessica Masek, 2005)

(h) Hemiptera Notonectidae (Jessica Masek, 2005)

(i) Odonata (Anisoptera) (Jessica Masek, 2005)

(j) Isopoda Gnorimosphaeroma (Fred Watson)

(k) Mysidacea Mysidae (*Neomysis*) (Jessica Masek, 2005)

(l)Gammaridea Corophiidae (*Corophium)* (Jessica Masek, 2005)

Figure 7.5. Continued. Macroinvertebrate taxa of the Carmel Lagoon

(m) Gammaridea Anisogammaridae (*Eogammarus)* (Jessica Masek, 2005)

(n) Mollusca Gastropoda (Jessica Masek, 2005)

Figure 7.5. Continued. Macroinvertebrate taxa of the Carmel Lagoon.

7.3.2 Salinity relations

Based on the *limited data* available to date, most taxa displayed an apparent preference for specific salinity ranges (Table 7.2):

- Taxa that only ever occurred in fresh water (<2 ppt) included Daphidae, Baetidae, Notonectidae, Empididae, Corixidae, Dysticidae, and Libellulidae (water fleas, mayflies, backswimmers, true flies, water boatmen, beetles, and dragonflies).
- Mysids, Eogammarids, Corophium, and Gnorimosphaeroma ranged from 0-12 ppt, but with certain apparent preferences. Mysids (opossum shrimps) were more abundant in fresher water (0-6 ppt), while preference for more brackish water (8-12 ppt) was displayed by Corophium (scuds), and strongly by Gnorimosphaeroma (isopods).

These interpretations may have consequences for the ideal salinity range for steelhead rearing. Future years of sampling will help clarify the salinity ranges that favor each invertebrate taxon.

Table 7.2. Average densities of taxa for which concurrent salinity data were measured.

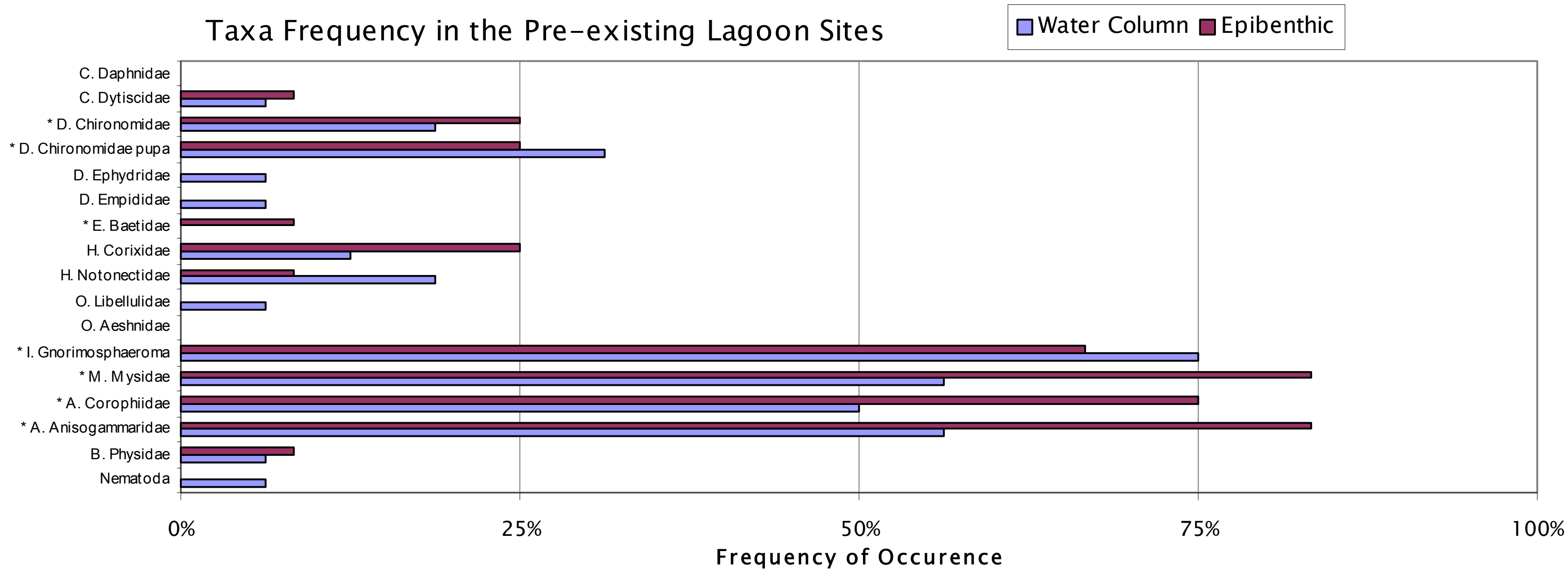
			Average density within given salinity range			
Taxon	**Habitat**	**Unit**	**0-2 ppt**	**4-6 ppt**	**8-10 ppt**	**10-12 ppt**
C. Daphnidae	wc	/m3	4.07	0.00	0.00	0.00
C. Daphnidae	eb	/m2	2.77	0.00	0.00	0.00
E. Baetidae	wc	/m3	0.98	0.00	0.00	0.00
E. Baetidae	eb	/m2	0.14	0.00	0.00	0.00
H. Notonectidae	wc	/m3	0.29	0.00	0.00	0.00
H. Notonectidae	eb	/m2	0.39	0.00	0.00	0.00
D. Empididae	wc	/m3	0.15	0.00	0.00	0.00
D. Empididae	eb	/m2	0.00	0.00	0.00	0.00
H. Corixidae	wc	/m3	0.04	0.00	0.00	0.00
H. Corixidae	eb	/m2	0.03	0.00	0.00	0.00
C. Dytiscidae	wc	/m3	0.00	0.00	0.00	0.00
C. Dytiscidae	eb	/m2	0.01	0.00	0.00	0.00
D. Chironomidae pupa	wc	/m3	0.10	0.00	0.00	0.00
D. Chironomidae pupa	eb	/m2	0.00	0.00	0.00	0.00
O. Libellulidae	wc	/m3	0.02	0.00	0.00	0.00
O. Libellulidae	eb	/m2	0.00	0.00	0.00	0.00
M. Mysidae	wc	/m3	10.01	0.79	0.79	1.18
M. Mysidae	eb	/m2	63.21	146.09	19.13	34.60
G. Eogammarus	wc	/m3	1.37	0.00	1.48	0.13
G. Eogammarus	eb	/m2	6.89	3.89	17.68	13.41
D. Chironomidae	wc	/m3	0.12	0.00	0.00	0.00
D. Chironomidae	eb	/m2	0.43	0.00	0.46	0.46
G. Corophium	wc	/m3	0.21	0.00	2.86	18.82
G. Corophium	eb	/m2	6.36	0.46	3.35	23.85
I. Gnorimosphaeroma	wc	/m3	0.52	0.39	3.65	0.92
I. Gnorimosphaeroma	eb	/m2	0.37	0.00	19.51	36.35

7.3.3 Frequency of Occurrence

Figure 7.6 illustrates the frequency of occurrence of all taxa in all samples in each of the two lagoon areas (original and Odello). The most common taxa in both areas were the peracarid crustaceans: amphipods, isopods, and mysids. There were the same taxa found in the steelhead stomachs by Fields (1984) – which is a broad indication that the invertebrate community of the entire lagoon remains suitable for steelhead.

In general, community composition was very similar between the original and the newly restored lagoons. The four dominant and most important taxa occurred with roughly equal frequency, and in the water column were slightly more commonly observed in the new lagoon.

Certain taxa were present in the original lagoon, but absent from the newly restored lagoon (Chironomidae pupa, Ephydridae, Empididae, Libellulidae, Nematoda, and Physidae). These taxa were mainly found before the two lagoons were connected, and so may be more indicative of sampling in brackish water at that time of year, than a persistent difference between the two areas. The next year's sampling will clarify this. Two taxa were present in the new lagoon but were never sampled in the original lagoon (Daphnidae and Aeshnidae). The Daphnia were only present while the newly restored lagoon was completely fresh and yet to be connected to the original lagoon.



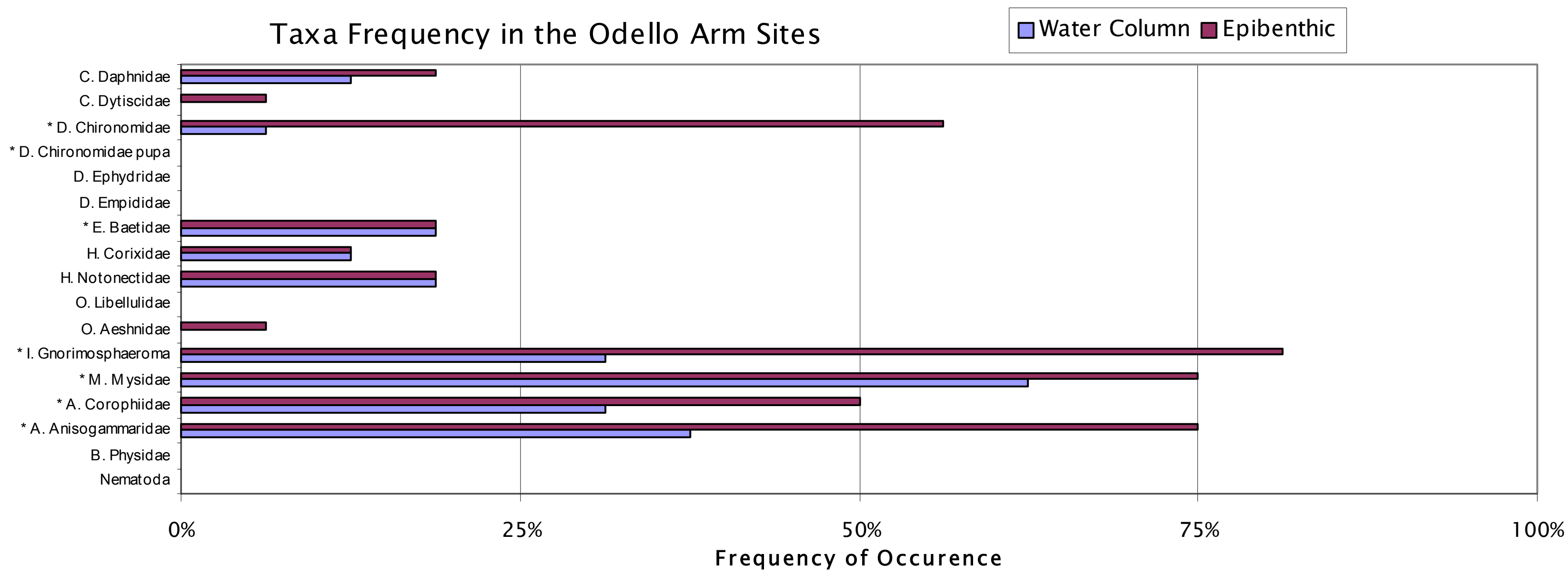


Figure 7.6. Taxa frequency in water column and epibenthic samples in the pre-existing and new portions of the lagoon.

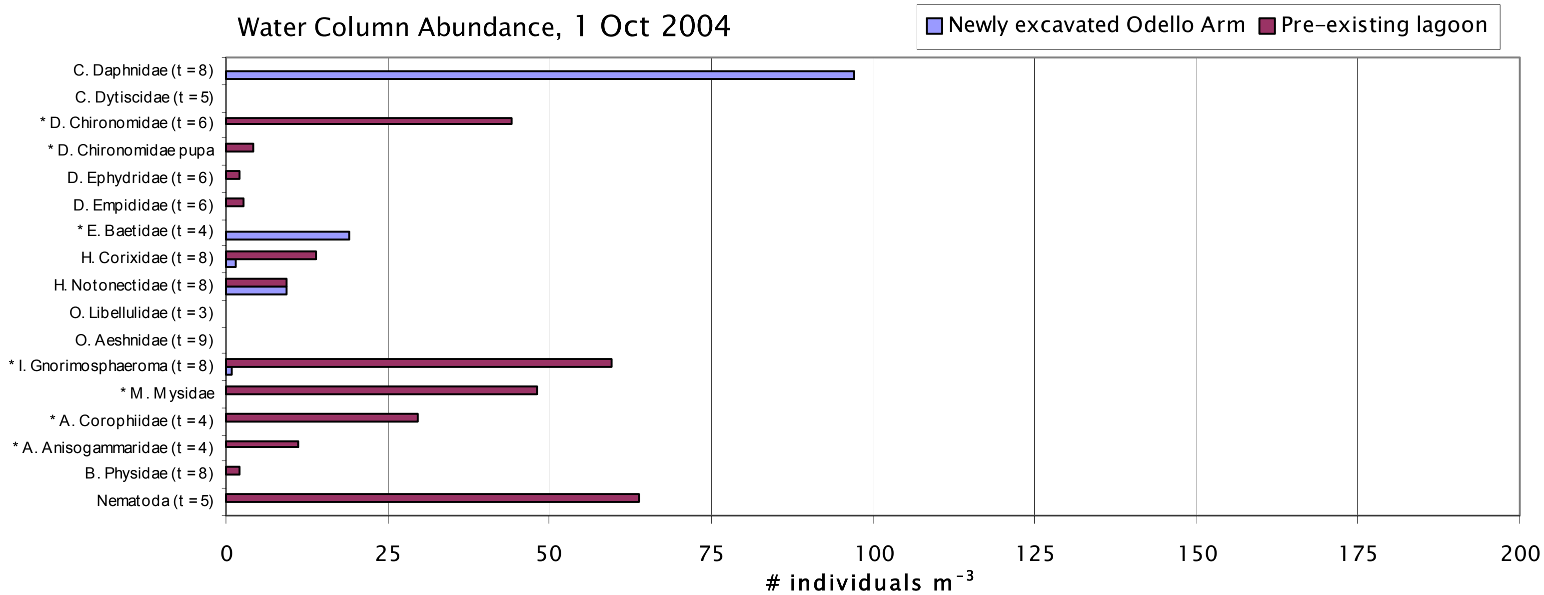
7.3.4 Abundance

7.3.4.1 Abundance in Water Column Samples

We discuss abundance in terms of densities of individuals per unit volume (water-column samples) or per unit area (epibenthic samples). The most abundant taxa, were the four peracarid crustaceans that are known to be food sources for juvenile steelhead (denoted by '*"in Figs 7.7 & 7.8). All other taxa disappeared or were present at insignificant densities after the new lagoon was connected to the original lagoon in early October, 2004.

Crustacean density generally declined throughout the study period. The initial decline between October and November may simply be attributable to dilution of the same total number of organisms into the much larger water volume of the enlarged lagoon. The lower densities in the large volume may not have been supplemented by additional recruitment since the bulk of reproduction may have already occurred during the warmer months. The seasonal timing of reproduction in these species is apparently undocumented, but is not unlikely to be minimal during late fall and winter.

Subsequent changes between November and March could be attributed to a number of factors. Mysids and gammarids peaked to maximum densities in the new lagoon on the February sampling date. The higher densities in the new lagoon could be because of greater separation from the fast-flowing river, which would have a sink effect on adjacent invertebrate populations. This idea is supported by the fact that the new lagoon only supported higher densities after the sand bar was breached. There are also other possibilities. The difference could be because of reduced predation from steelhead, because the steelhead were either avoiding the open areas of the new lagoon, or were attracted to the lotic feeding opportunities of the river. It is unlikely to be due to a difference in water characteristics, since the surface layers of the entire lagoon were essentially fresh at this time. Any adverse sediment levels were apparently more prevalent in the new lagoon due to erosion from the newly excavated banks. Continued decline in densities by the March sampling date may simply be an indication of the declining phase of an annual cycle in invertebrate densities, ultimately driven by changes in water temperature. Whether or not such a cycle occurs will become clearer as we sample invertebrates during the next two winters. A final factor to consider in all these analyses is the possibility that short-term weather-driven changes on time scales of a few days may occur, manifesting as random variation in samples taken only once per month. Daily sampling for a few days would reveal the extent of any short-term variability.



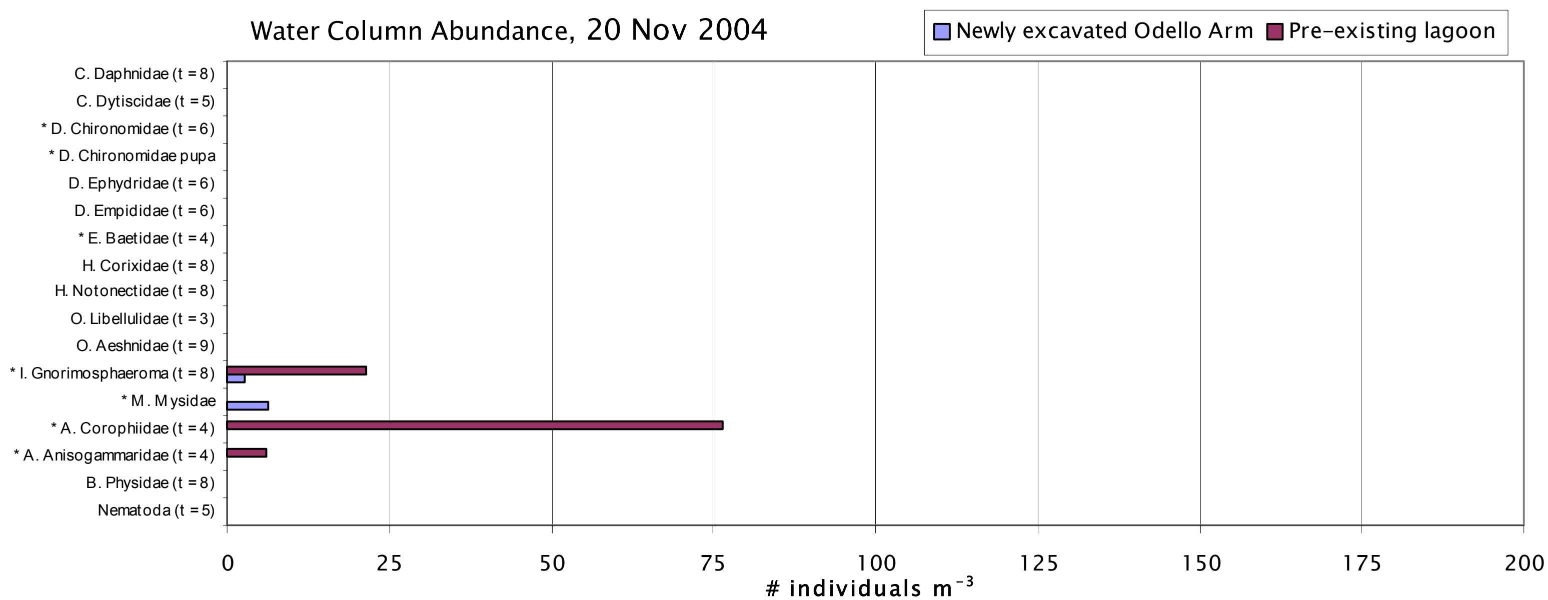
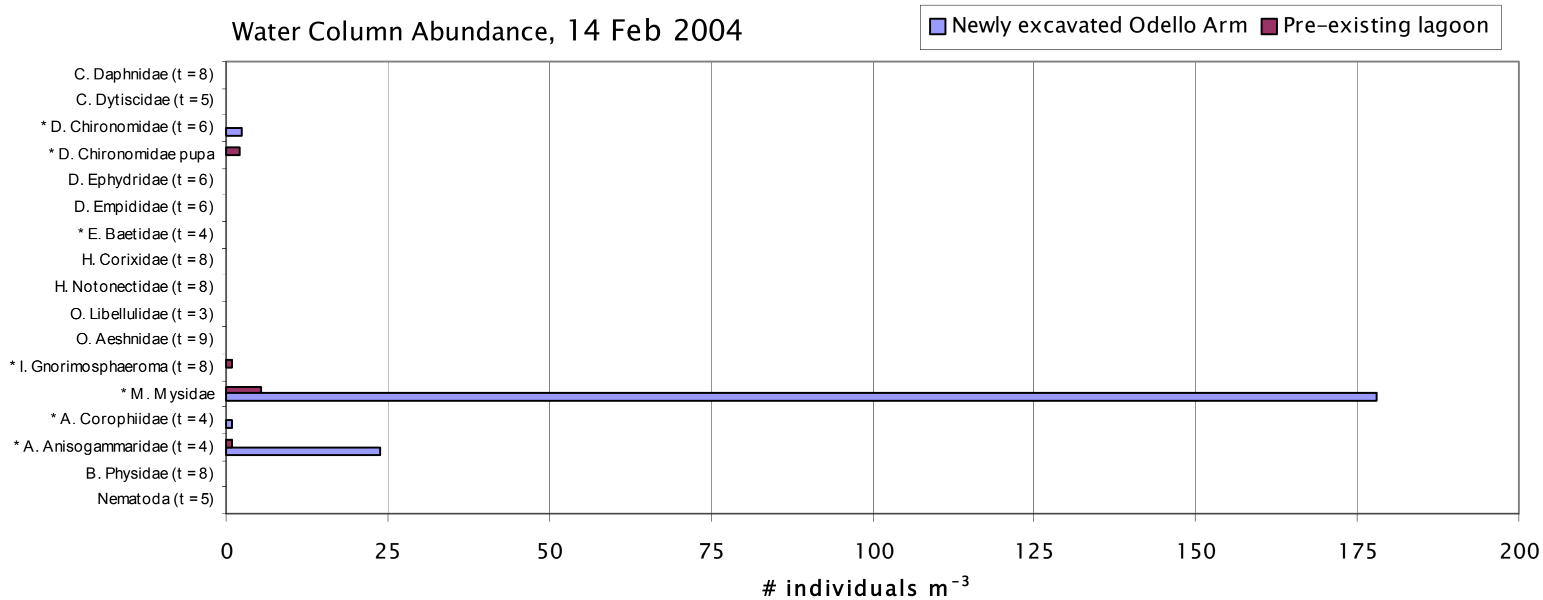


Figure 7.7. Taxa abundance in water column samples from before and after removal of the earth barrier. * Major food invertebrate for juvenile steelhead or found in stomachs of steelhead smolts.



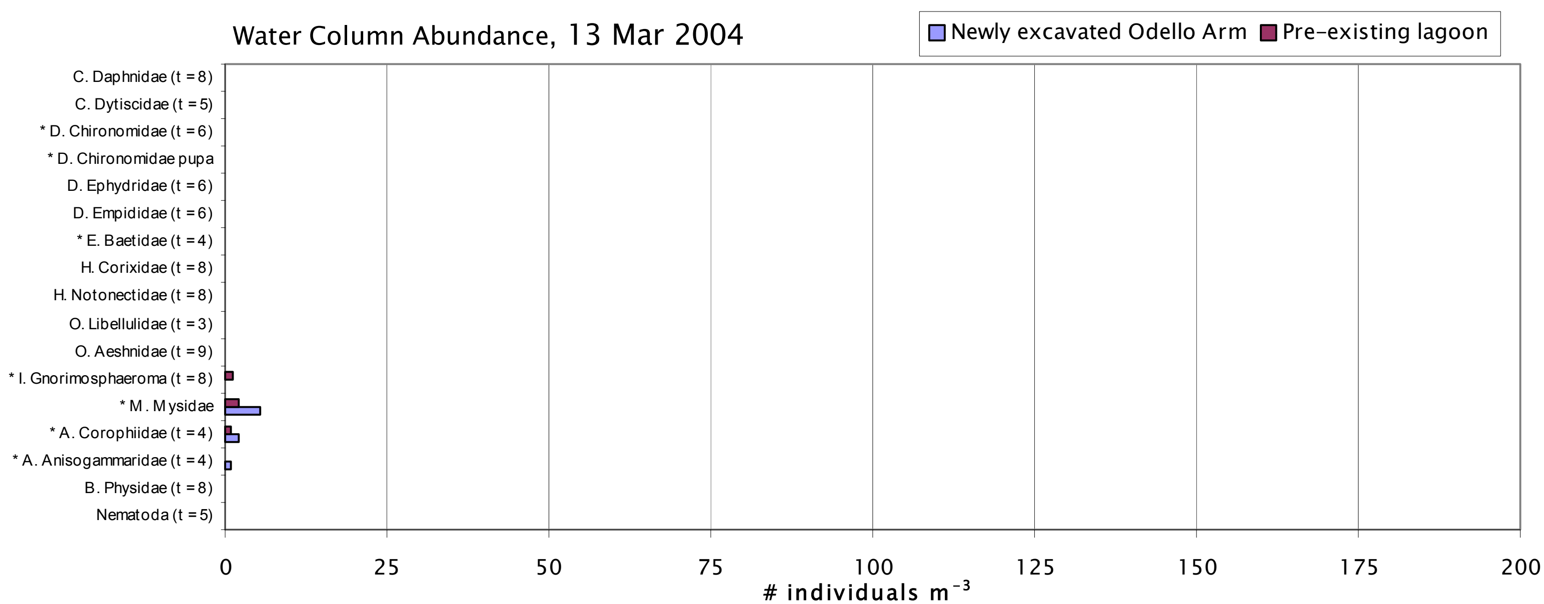
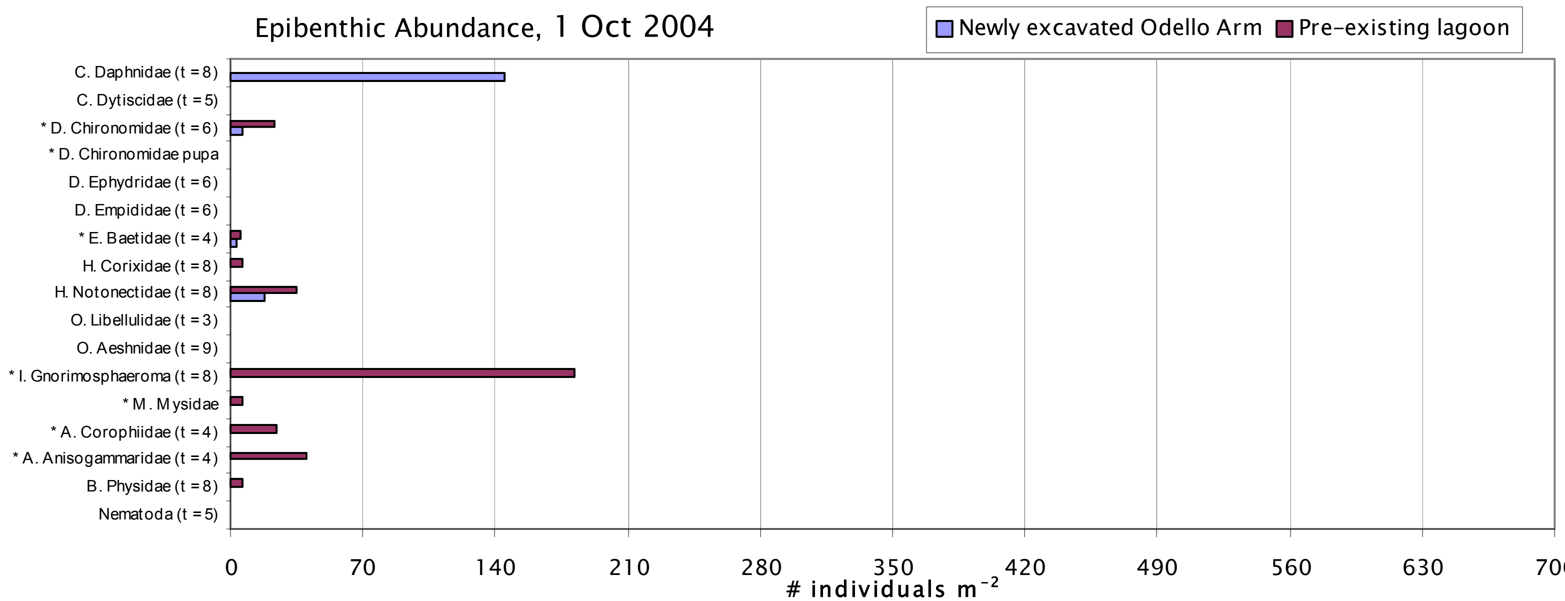


Figure 7.8. Taxa abundance in water column samples during the storm season while the sandbar was open. * Major food invertebrate for juvenile steelhead or found in stomachs of steelhead smolts.

7.3.4.2 Abundance in Epibenthic Samples

Epibenthic densities mirrored water column densities, in that the non-crustacea effectively disappeared after connection of the two lagoons, and mysids peaked to very high densities the new lagoon in February. But the pattern of seasonal decline differed. Firstly, epibentic crustacean densities increased from October to November. This tends to detract from the dilution hypothesis suggested for the water column data, and support a hypothesis based on inherent advantages of the new lagoon over the original lagoon. One such hypothesis is that invertebrates were initially more dense in the newly connected new lagoon due to lack of fish cover leading to absence of predation by fish. But the water column and epibenthic data disagree in their support for this. An alternate hypothesis is that the bottom of the newly connected new lagoon was inherently better habitat for epibenthos, perhaps because it had almost never been foraged by aquatic organisms. Most freshwater taxa that had foraged there in previous months might now be dead, lying on the bottom, and available to be foraged upon.

Evidence of preferable habitat in the new lagoon persisted through November, and February, into March. In general the colonization of the new lagoon was extremely rapid, due to apparent advantages of the newly formed habitat over the pre-existing habitat of the original lagoon. Future sampling should reveal whether this advantage prevails in the long-term, or whether a homogeneous equilibrium is eventually reached after the initial peak that we have already observed.



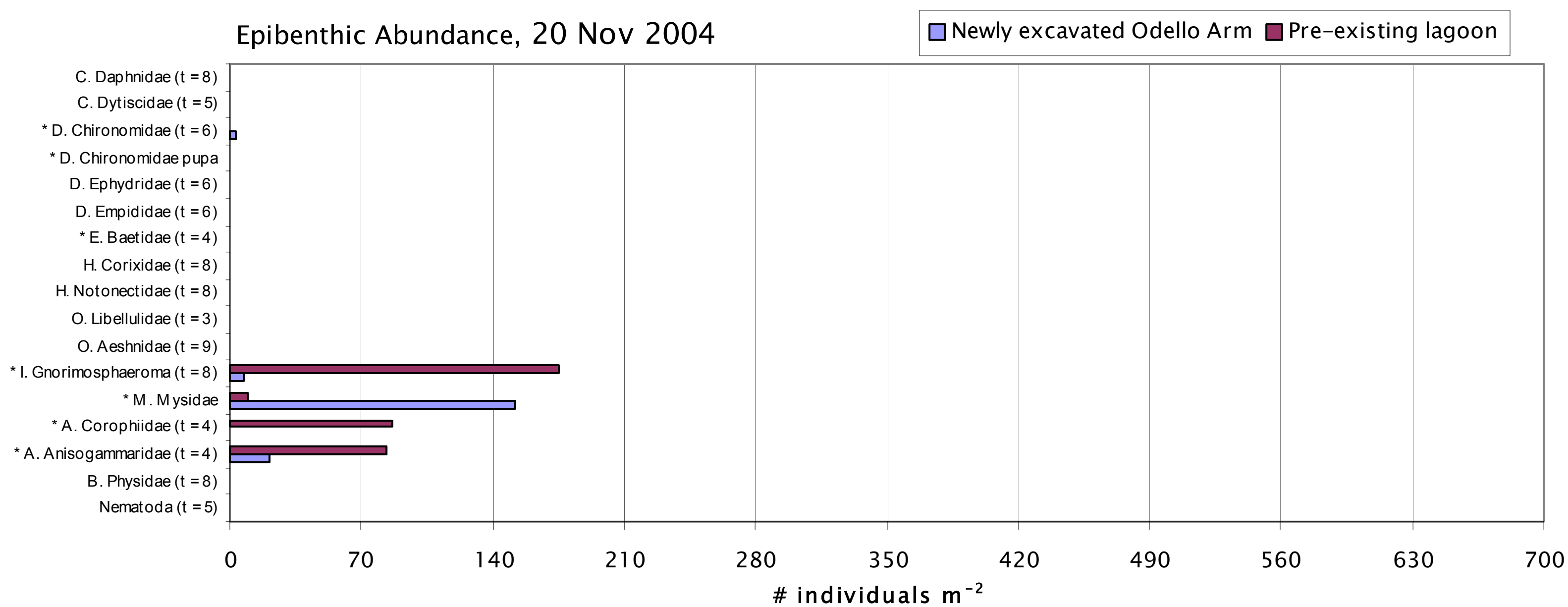
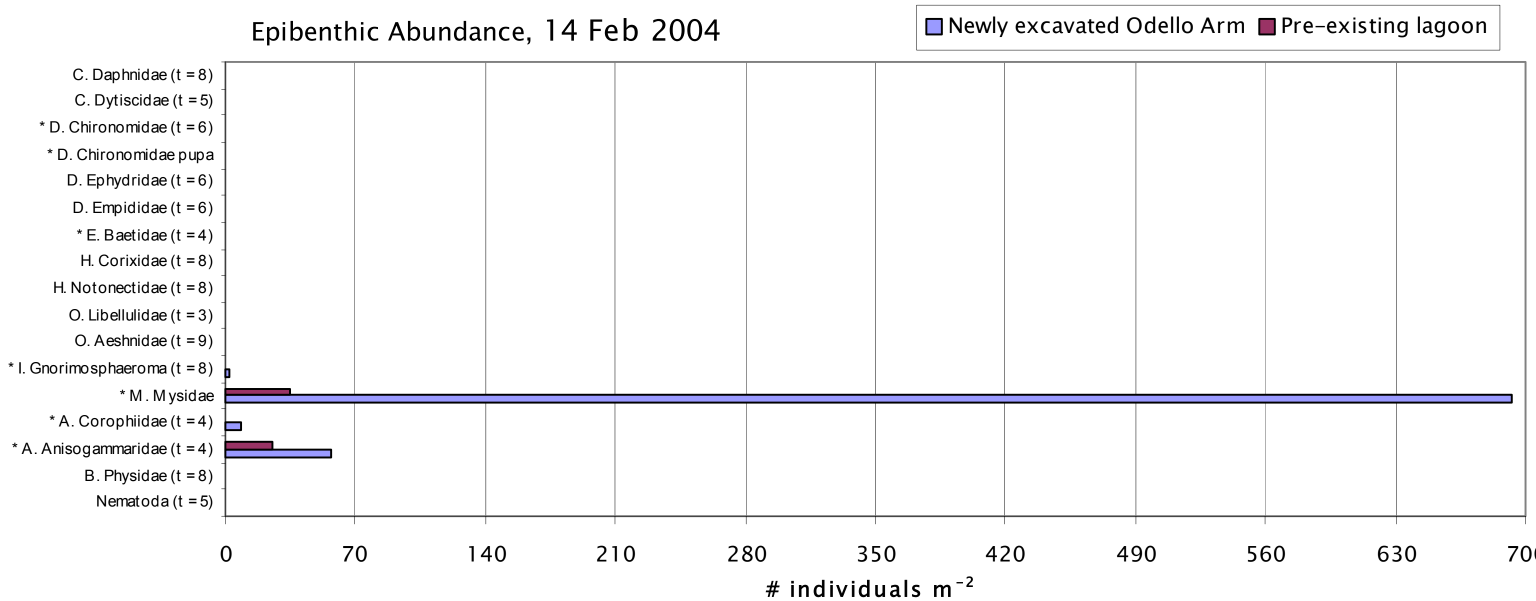


Figure 7.9. Taxa abundance in epibenthic samples from before and after removal of the earth barrier. * Major food invertebrate for juvenile steelhead or found in stomachs of steelhead smolts.



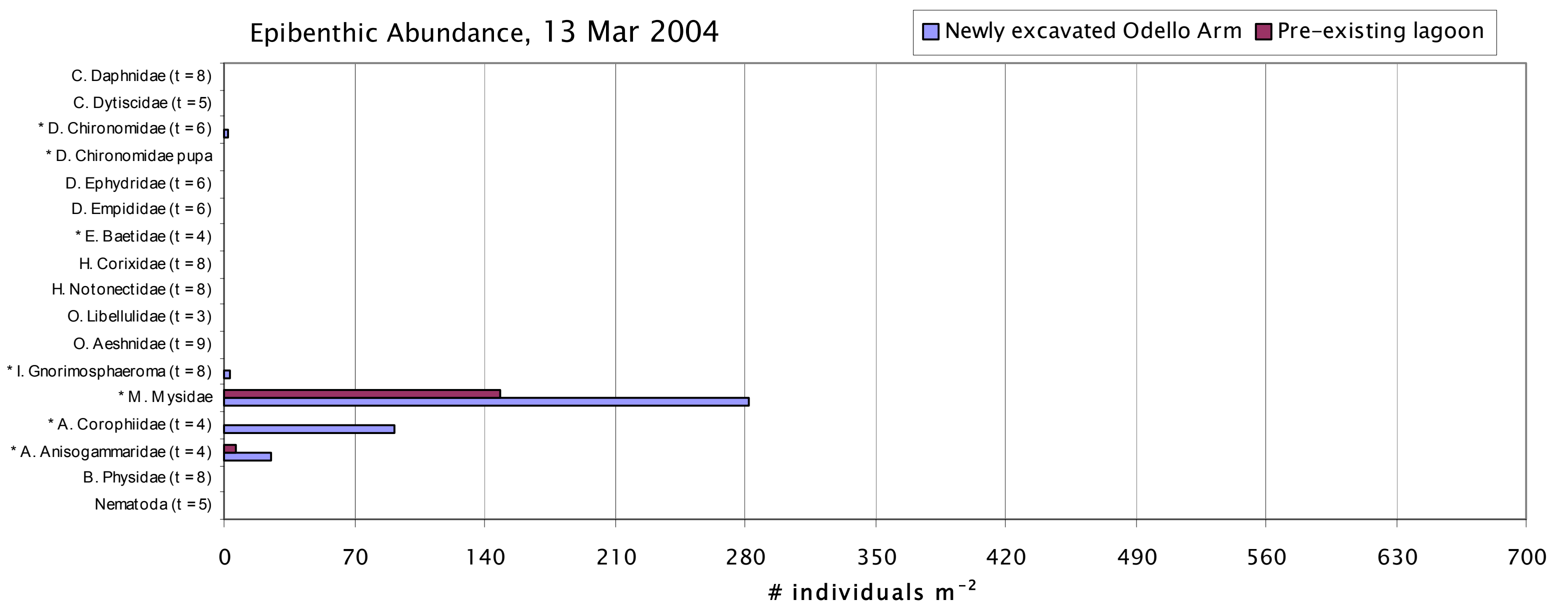


Figure 7.10. Taxa abundance in epibenthic samples during the storm season while the sandbar was open. * Major food invertebrate for juvenile steelhead or found in stomachs of steelhead smolts.

7.3.5 Diversity

Trends in Shannon-Weiner diversity are illustrated in Figure 7.11. Two key observations can be made. Firstly, the original lagoon was almost always more diverse than the new lagoon – which is perhaps a reflection of the wider variety of habitat characteristics (particularly vegetation, depth, salinity, and substrate). Secondly, diversity decreased in the original lagoon over time. This may be a seasonal effect driven by temperature. In summer months, higher temperatures lead to more algal production, perhaps supporting a wider variety of grazing organisms that depend on this production. Stratification is also much more pronounced in summer, leading to a wide range of salinity-based and light-based habitats extending vertically throughout the water column.

7.3.6 Functional Feeding Groups

The functional feeding groups to which all taxa belong are summarized in Tab. 7.3. Figure 7.12 illustrates how percentages of these groups change with respect to time in the pre-existing lagoon sites and the newly excavated sites.

The most obvious pattern that the only occurrences of filterers were in the newly excavated lagoon before connection with the original lagoon. The only filterers were daphnids, and they were eliminated immediately upon connection with the original lagoon probably because of a combination of intolerance to saltwater, and predation by Neomysis.

Table 7.3. Functional feeding group of each taxon (Harrington and Born, 2000; Gooderham and Tsyrlin, 2002; Chigbu, 2004).

Taxon	Functional Feeding Group
Cladocera Daphnidae	Filterer
Coleoptera Dytiscidae	Predator
Diptera Chironomidae	Collector
Diptera Chironomidae pupa	Collector
Diptera Ephydridae	Collector
Diptera Empididae	Collector
Ephemeroptera Baetidae	Collector
Hemiptera Corixidae	Collector
Hemiptera Notonectidae	Predator
Odonata Libellulidae	Predator
Odonata Aeshnidae	Predator
Isopoda Gnorimosphaeroma	Shredder
Mysidacea Mysidae	Predator / collector
Amphipoda Corophiidae	Collector
Amphipoda Anisogammaridae	Collector
Basommatophora Physidae	Shredder
Nematoda	Collector

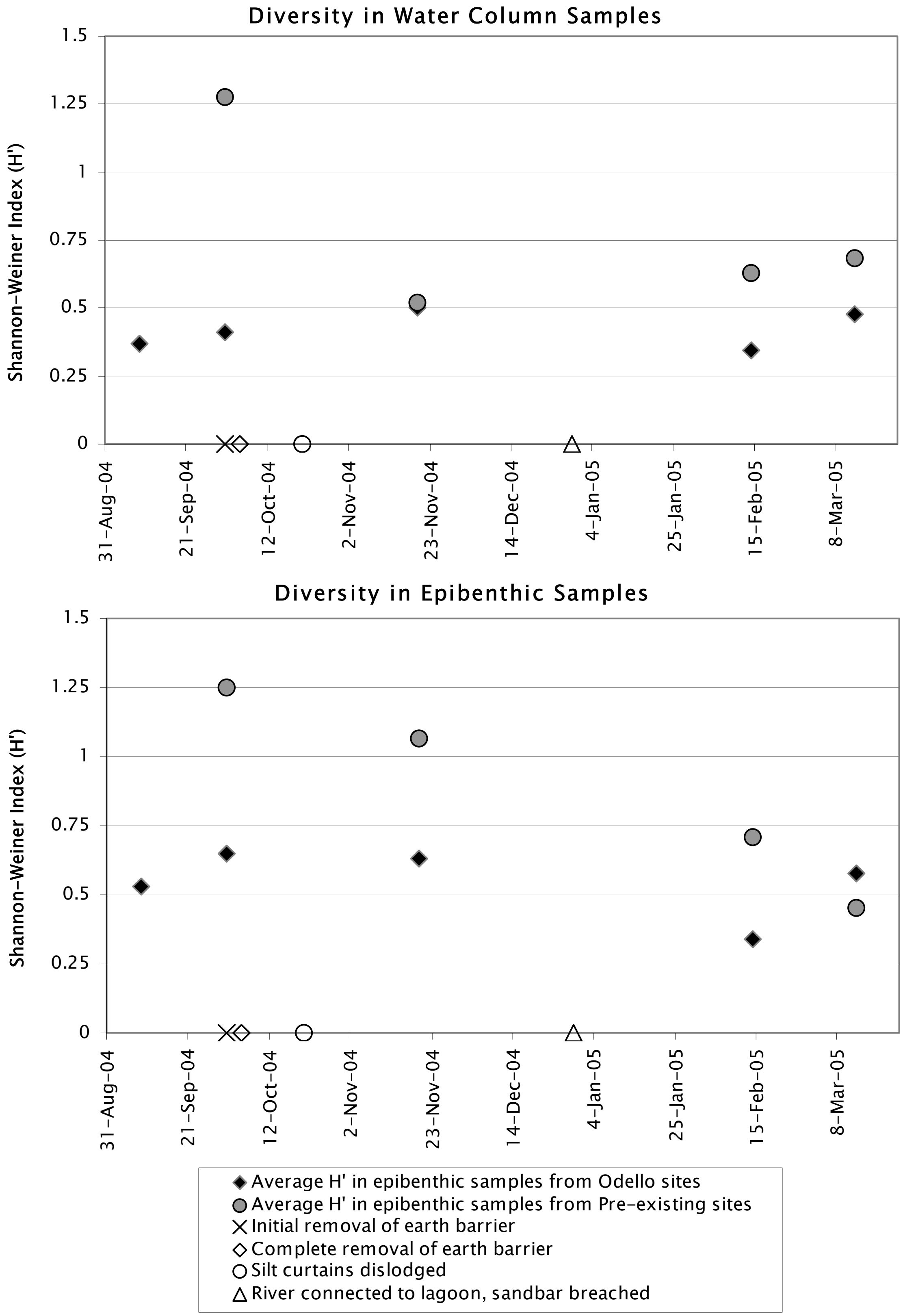


Figure 7.11. Changes in taxa diversity through time.

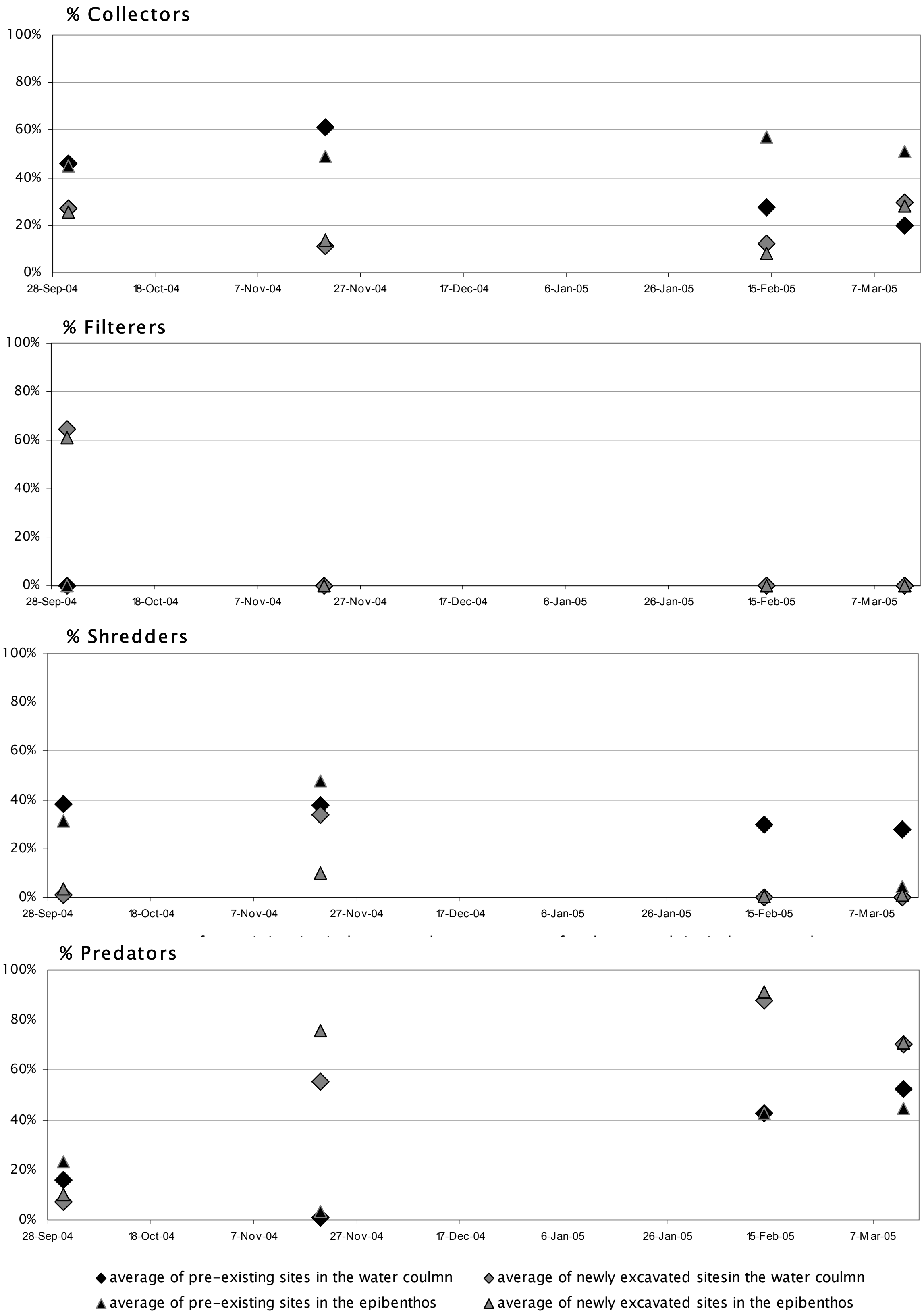


Figure 7.12. Comparison of changes in community structure between pre-existing and newly excavated portions of the lagoon.

Overall, there were more collectors and shredders in samples collected from the pre-existing lagoon sites, and more predator/collectors in samples collected from the newly excavated Odello sites. The latter group is dominated by mysids, which opportunistically switch between collecting phytoplankton and preying upon other zooplankton (Covich & Thorp, 2001). Examination of the contents of their feeding apparatus may yield clues as to their ecological context in the lagoon- either top invertebrate predator, or just another collector.

7.4 Discussion and future work

The data and analyses presented here are necessarily coarse. Carmel Lagoon varies in many dimensions, and only a few of these dimensions were able to be intersected by our brief sampling design. The lagoon varied between the original and newly excavated areas, and our sampling covered this variation. The lagoon varied between water column and bottom habitats, and our sampling addressed this. However many of the aquatic fauna are vertical migrators, and our sampling did not address this other than to standardize sampling times to generally occur in the morning. The lagoon varied seasonally, which we addressed; but it also rose and fell with period of high ocean wave energy, tidal cycles, and pulses of river flow – none of which were specifically addressed in our invertebrate sampling design.

Notwithstanding these limitations, the data reveal some clear patterns that are of use in evaluating the success of the restoration. Most importantly, the restoration now supports the same important taxa as the original lagoon, at densities that generally equal or exceed those of the original lagoon.

Some specific notes for future sampling are:

- Take water quality measurements with every sample. Consistent water quality measurements were not made with each sample collected. In the future, measurements of temperature, salinity, DO, and pH shall be taken every time an invertebrate sample is collected to establish the range of water quality parameters that each taxa is found in the Carmel River Lagoon.
- Include sampling site/s in the small creek entering to the south of the Odello Arm – in order to explore whether the freshwater input from this stream influences the water quality, aquatic invertebrate community, and ultimately the fish distribution in the lagoon.
- Conduct some detailed sampling campaigns over approximately 48-hour periods in order to better understand how the current sampling data are subject to diurnal vertical migration influences.

8 Steelhead

The Carmel River supports a successfully restored run of steelhead trout (MPWMD). Adult steelhead migrate in from the ocean, through the lagoon, and up to their natal spawning tributaries. Most adults return to the ocean after spawning to repeat the cycle the following year. In spring, juvenile steelhead migrate down the river, to the lagoon to rear prior to life in the ocean. Most juvenile steelhead over-summer in the lagoon and some may stay up to two years.

Many factors determine steelhead habitat in lagoons, and the optimal configuration is not precisely known. Fresh, oxygenated water is important, and is usually available in the surface layers. Cover from avian predators is also important, since predation by birds is not uncommonly observed when juvenile steelhead are known to be in the lagoon (observations by present authors, and others). Steelhead may avoid this predation by seeking either deeper water, or vegetative cover. However, deeper water is more saline, and may be dark enough to inhibit visual predation on zooplankton. In streams, trout species are well known to prefer cooler waters, with upper temperature limits of approximately 20 °C. However, steelhead are able to thrive in streams with warmer temperatures (up to 25°C), but this requires a shift to habitats with faster water velocities where invertebrate drift is higher (Smith & Li, 1983). Likewise, in lagoons, because of the typical abundance of invertebrates, steelhead can tolerate higher temperatures and actually grow rapidly (Smith, 1990). At some point, this enhanced growth may become limited by food supply. Self-regulation may occur, whereby steelhead reduce their own food supply. Or abiotic factors may come into play, such as reduction in lagoon volume after periods of reduced ocean wave energy, or oxygen crashes caused by pulse of enhanced decomposition following in-wash of kelp, or die off of phytoplankton following periods of hot weather. The outcomes of these processes may explain observed deaths of steelhead in the lagoon, such as the adult found dead in mid-2004, as well as 5 young of the year and 1 yearling found in the North Arm after it had been cut off from the main lagoon in the summer 2005.

Monitoring steelhead presence and distribution within lagoon aids in the understanding of these processes. It provides a basis for evaluating the success of the current restoration, and helps guide planning for future restorations in this or other lagoons.

One of the primary purposes of this enhancement project is to create more steelhead refuge in the lagoon. After excavation was completed and re-vegetation initiated, the primary questions became:

- Are steelhead using the newly excavated Odello portion of the South Arm?
- What portions of the lagoon are suitable for and commonly used by steelhead?

The intent of monitoring was initially to determine steelhead presence in the new lagoon. As the project moves forward, the intent will expand to examine stronger links between elements of the habitat: how water quality, food resources, and protection from predators interact to provide suitable habitat. This section describes progress in the development of an automated underwater steelhead surveillance system, and reports monitoring results from this system as well as from hand-held camera and seining techniques used later in the study period.

8.1 Underwater Surveillance System

Existing techniques for monitoring steelhead in lagoons are sub-optimal. We make the following observations based on our own previous experience in the lagoon. Seining provides perhaps the most complete survey, but it is labor intensive when used in complex lagoon settings, and has limited permissibility due to the fact that it constitutes harassment under the Endangered Species Act (ESA). Hand-held videoing from a boat seems to deter the fish. Snorkeling with hand-held video is subjective, can be extremely cold, and has potential risks to human safety due to hypothermia and bacterial water quality. Both hand-held techniques can provide occasionally excellent results, but cannot be relied upon for an objective survey at any time of year.

Remote underwater video cameras provide a potential alternative. We tested this in exploratory work and found that steelhead could be observed using these cameras, but that reviewing hours of footage might be a time-consuming and ultimately limiting factor. Thus, in the work described below, we tested a system that used video motion detection software to automatically record fish movement in front of remote underwater video cameras.

Figure 8.1. Underwater surveillance equipment. (Watts, 2005)

8.1.1 Equipment

The underwater surveillance system is made up of the following equipment:

- Underwater video camera – one of two units tested:
    - Aqua-vu brand – monochrome infra-red
    - SplashCam Delta Vision brand - color
    - 12V sealed-lead-acid battery (marketed by jump-starting cars)]
    - ADVC video converter
    - Powermate 200 watt power inverter
    - firewire digital video cable
    - laptop computer
    - motion detection software (SupervisonCam, marketed primarily for home security)

The motion-detection software allows the surveyor to both view camera footage in real time and have it automatically record short video segments after being triggered by motion in the video. The operator can leave the system unattended for several hours and then return to quickly review only the potentially interesting footage.

At most sites, the camera was placed in a rig that was attached to a stake that was installed at a site by hammering the stake into the substrate. The rig was installed at the survey site usually on the evening prior to surveying to minimize the amount of same-day disturbance to the site to be surveyed.

8.1.2 Sites Surveyed

Surveying sites were selected to cover a wide range of habitat types within the lagoon. At times, surveying occurred in areas that were already known to have steelhead in them. A description of surveyed sites is in Table 8.1 and some are shown in Figure 8.3. Diagrams of how the camera was set up under water at some of the sites are given in Figure 8.2.

An attempt was made to monitor mainly just after dawn and just before dusk. Steelhead in the lagoon are thought to be most active at dawn and dusk, but camera visibility is reduced at these times. So some compromise was required.

Visibility was documented for each visit, separately for human observations through the camera, and for the motion detection software. Video visibility was measured by attaching a hookless fishing lure to a fishing pole and dragging it through the water in front of the lens at a range of distances. The distance from the lens at which the lure could still be seen was recorded, as was the distance at which the camera detected its motion. During this process, the triggering threshold of the software was adjusted for best performance. The threshold is the percent of change in the view of the lens that starts the recording process. Its optimal value depended on the amount of sunlight, sun angle, direction of camera view, water movement, presence of vegetation at the site, etc. A standard secchi disk reading was also taken at a majority of visits to directly measure visibility.

Table 8.1. Description of surveillance locations.

Site code	Site description
R2A	Bottom substrate of the main lagoon at the entrance to North Arm.
R2B	Immediately next to granite outcrop on the southern bank of the main lagoon.
R5	River mouth where the vegetation is dominated by tules.
R5B	In the river between the tules (R5) & willows (R6).
R6	River channel where the vegetation is dominated by willows (upstream of R5).
R7	Left bank of the river channel ~300ft upstream of mouth.
S0	Entrance to South Arm.
S2A	South Arm pipe.
S2B	Immediately next to granite outcrop close to the pipe in the South Arm.
S4	Right bank of south arm that is a mudflat at low stages, camera installed in between clusters of tules.
O0	Border of pre-existing South Arm and new Odello extension.
O1	Deep part of new Odello extension.

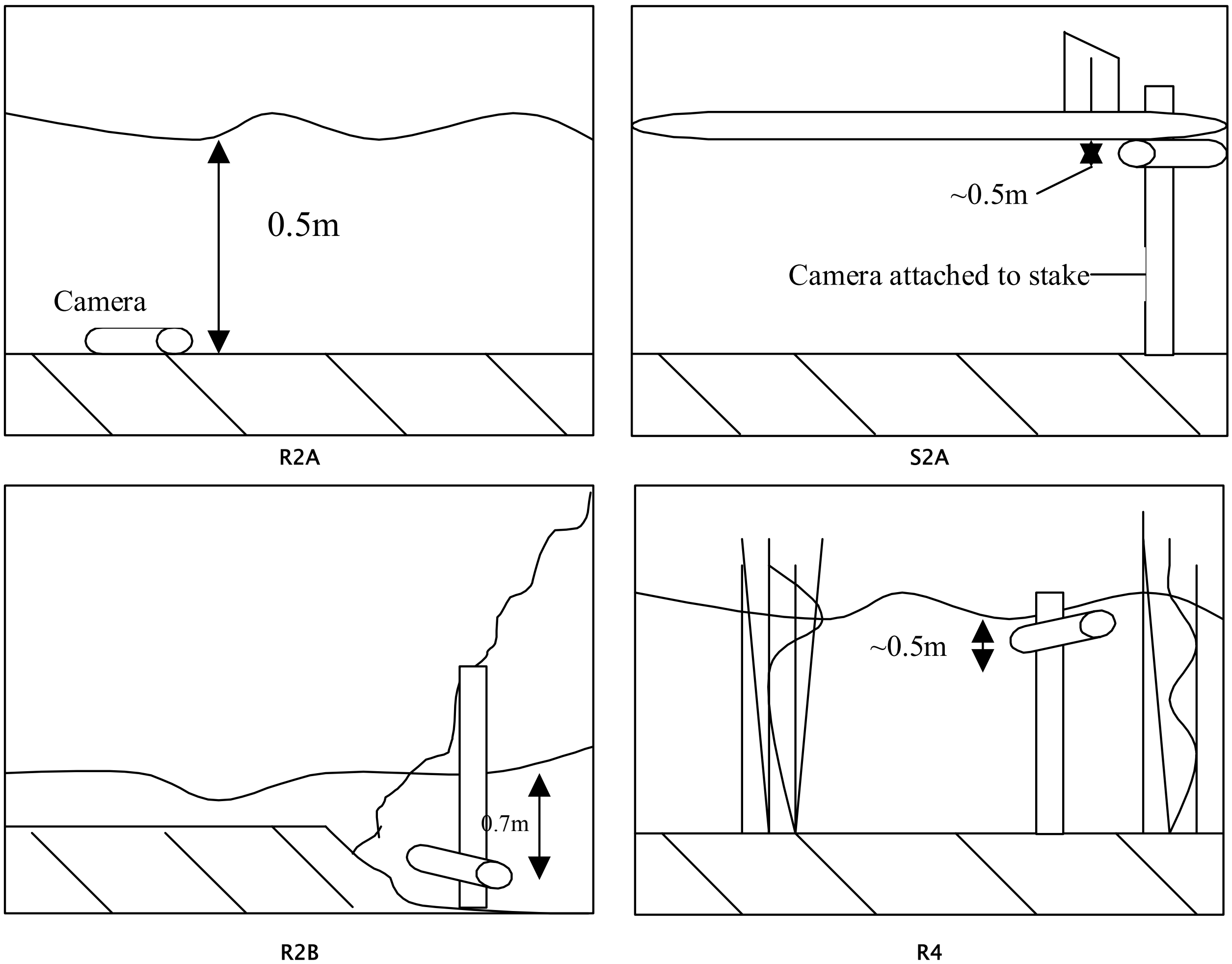


Figure 8.2. Diagrams illustrating the camera set up at sites R2A, R2B, S2A, & R4 (from Watts, 2005).

(a) R2B

(b) S2A

(c) S2B

(d) S4

(e) O1

Figure 8.3. Underwater camera surveillance sites R2B, S2A, S2B, S4, O1 (from Watts, 2005).

8.1.3 Surveillance effort

A summary of observations is in Table 8.2. A total of 40 hours have been spent at the lagoon with the operational camera surveillance system. The majority of these hours could be considered 'tests' because numerous technical challenges continually presented themselves during the development of the system. During only a minority of these testing hours did we feel that the camera setup was such that there was a reasonable chance of recording a steelhead should any be in the lagoon. Of the 40 hours, 77 minutes were captured by the motion detector. For most of the time the trigger threshold was set to 10% or 20%, but ranged from 5% to 50%.

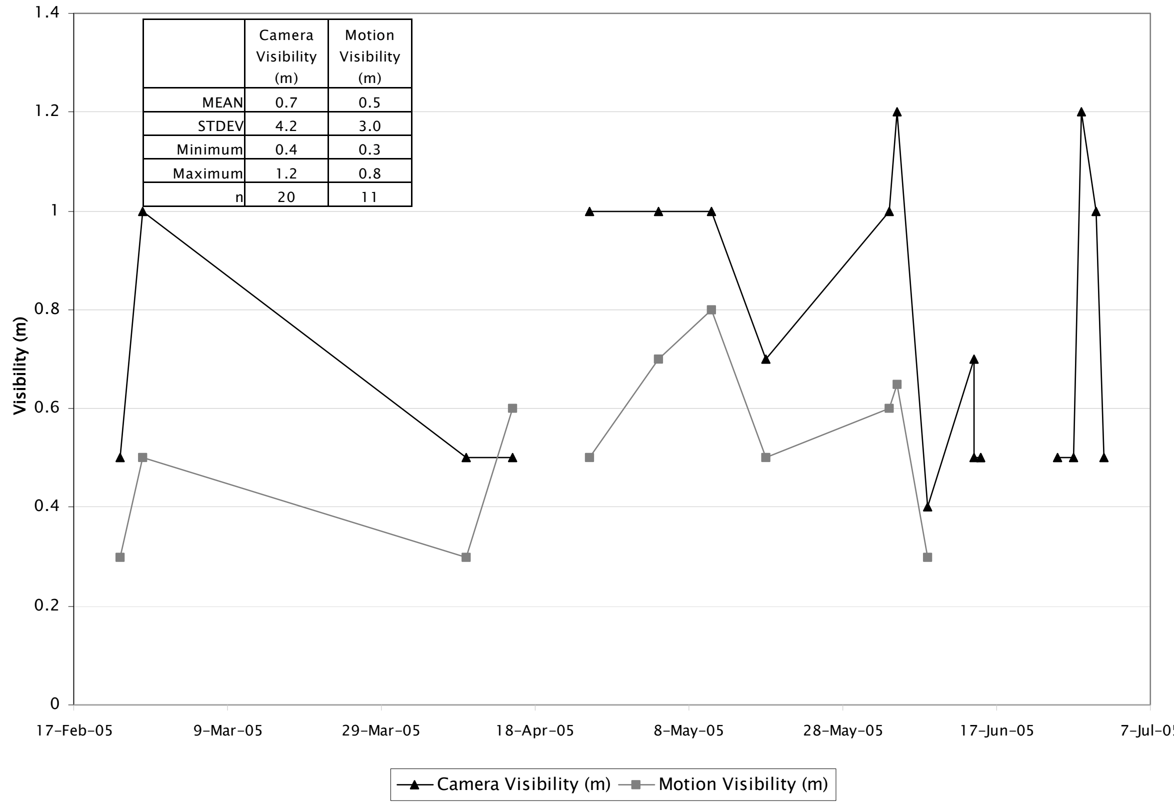
Table 8.2. List of underwater surveillance activity and site notes.

Date	Site	Camera Time	Total camera time (min)	"Good" Camera Time	Visit Comments
19-Nov-04	R2A	10:30am/11am	30	ok for seeing fish	Sunny, slight breeze
15-Dec-04	S2A	3pm/3:30pm	30	Poor	Cloudy
9-Feb-05	R2A	11:35am/12:20pm	50	Poor	Too much water and light detection w/50%, observed fish jumping, 20% better movement recording than 40 and 30%
23-Feb-05	R2B	9:20am/9:36am	15		High water movement
26-Feb-05	R2B	9:14am/10:10am	70	Good	
26-Mar-05	R2B	5:20am/7am	60	Poor	High turbidity, water flow, no system set-up
9-Apr-05	S2A	8:58am/9:58am	60	Good	Near reeds, little surface disturbance, slight breeze, high clouds
13-Apr-05	S2A	7:55am/9:07am	80	Good	Sunny, some clouds, slight breeze picked up ~9:30am, calm waters
20-Apr-05	S2A	6:50am/8:10am	60	Good	Over cast, cloudy, sun came out around 9am, turbidity depth 0.9m, breezy at times
25-Apr-05	S2A	6:30pm/7:30pm	150	Good	Low tide exposed camera, disturbance of sediments from trying to push further down, moved new location
4-May-05	S2A	6:50am/9:20am	100	Good	Overcast, slight breeze
11-May-05	S2A	7:40am/9:20am	170	ok	Sunny, no clouds
3-Jun-05	R2B	7:00am/9:15	135		Foggy and overcast
4-Jun-05	R2B	6:56am/8:15am	75		Foggy, cloudy, slight breeze
8-Jun-05	O1	6:35am/9:05am	150		Cloudy
14-Jun-05	O0	6:45am/8:45am	120	Good	Heavy marine layer with onshore breeze and geese around area
14-Jun-05	O0	6:28pm/8:05pm	97	Good	Sunny with slight onshore breeze
15-Jun-05	R2B	7:32am/9:41am	129	Good	Sunny and high clouds
15-Jun-05	R2B	6:55pm/7:55pm	60	Good	Slightly cloudy
16-Jun-05	O0	7:40am/9:52am	135	Good	Sunny with high clouds
17-Jun-05	O0	8:42am/10:39am	117	Good	Sunny and offshore breeze
20-Jun-05	S0	7:20am/8:45am	85	Good	Slightly overcast
25-Jun-05	R5B	3:23pm/4:37pm	74	Good	Sunny with high winds and no clouds
27-Jun-05	R5	7:24am/8:45am	80	Good	Morning clouds with sight breeze
28-Jun-05	R5B	9:45am/11:00am	75	Good	Cloudy with slight breeze
30-Jun-05	R6	6:00pm/7:00pm	60	Good	Cloudy with slight breeze
1-Jul-05	R7	3:40pm/5:14pm	94	Good	Cloudy with wind

8.1.4 Visibility

The main limitation to the effectiveness of the automated underwater video system was low visibility. On many occasions, fish were observed in the lagoon by the human surveyor standing on the bank of the lagoon, but not by the camera system underwater. An example of poor visibility is shown in Figure 8.4. Maximum visibility averaged around 0.8 m for human interpretation of features, and 0.5 m for software-detectable motion (Fig. 8.5). There were no apparent trends in visibility between February and July 2005.

Figure 8.4. Poor visibility at O1 with visibility test lure in the frame. Note that O1 is a site that was more turbid than other sites surveyed for fish. (8 June 2005)



	Camera Visibility (m)	Motion Visibility (m)
MEAN	0.7	0.5
STDEV	4.2	3.0
Minimum	0.4	0.3
Maximum	1.2	0.8
n	20	11

Figure 8.5. Visibility range of underwater camera and motion detector.

8.1.5 Other Limitations

Technical challenges and other limitations of the automated underwater video system included:

- Changes in lagoon depth between camera deployment and use. For dawn surveillance, the camera was often deployed the night before, so that surveillance was not immediately preceded by the disturbance of deployment.
- Supplying enough battery power to operate the system remotely for several hours of use.
- Water movement causing camera wobble and displacement (for deployments without stake-mounted housings).
- False triggering of the motion detection software, caused by: floating debris, moving vegetation, and shifting rays of sunlight.
- Theft of the camera while not attended

8.1.6 Stickleback

Many stickleback were recorded with the under water surveillance system (Fig. 8.6). Table 8.3 lists the locations and dates of stickleback sightings.

Table 8.3. Stickleback sightings.

Location	Date
R2B	26-Feb-05
R2B	3-Jun-05
R2B	15-Jun-05
R5	27-Jun-05
R5B	25-Jun-05
R5B	25-Jun-05
R6	30-Jun-05
S2	11-May-05
S2	18-May-05
S2A	15-Dec-04
O0	14-Jun-05

Figure 8.6. Captured image of stickleback at R5, 27 June 2005

8.1.7 Steelhead

Steelhead were observed with the underwater surveillance system on only one occasion, at R7 on 1 July 2005 (Fig. 8.7.), and this was only after the fish had been located by snorkeling. Steelhead footage comprised 1.41 minutes of the total 77 minutes captured by the motion sensor. At the time of image capture, low stages coupled with the shallow depths in the main lagoon, and no connection between the North Arm and the main lagoon limited the amount of available habitat. Only the river area appeared to offer fresh, marginally deep water under cover from predators. Other places in the lagoon appeared to be unsuitable for prolonged usage by fish.

Figure 8.7. Juvenile steelhead captured on automated underwater video system. (Miles Daniels, 01 Jul 05)

8.2 Handheld underwater camera

Low stages limit the amount of habitat for all fish, restricting them to a few places in the lagoon. Once these places were identified (initially by J. McKeon, NMFS), a digital camera with an underwater casing was used to record their activity (Figs 8.8 & 8.9) in the following locations: R2B, R4, and R5 on 16, 20, and 21 June 2005. The quality of images from the handheld digital camera was superior to the quality of images from the SplashCam, since the latter was a standard analog video camera with about half a mega-pixel of effective resolution, and the former had several mega-pixels. The handheld camera also has the clear advantage of mobility, at the expense of possible disturbance. The successful handheld images were collected at a time when the steelhead had few options for taking refuge away from human invasion of their habitat.

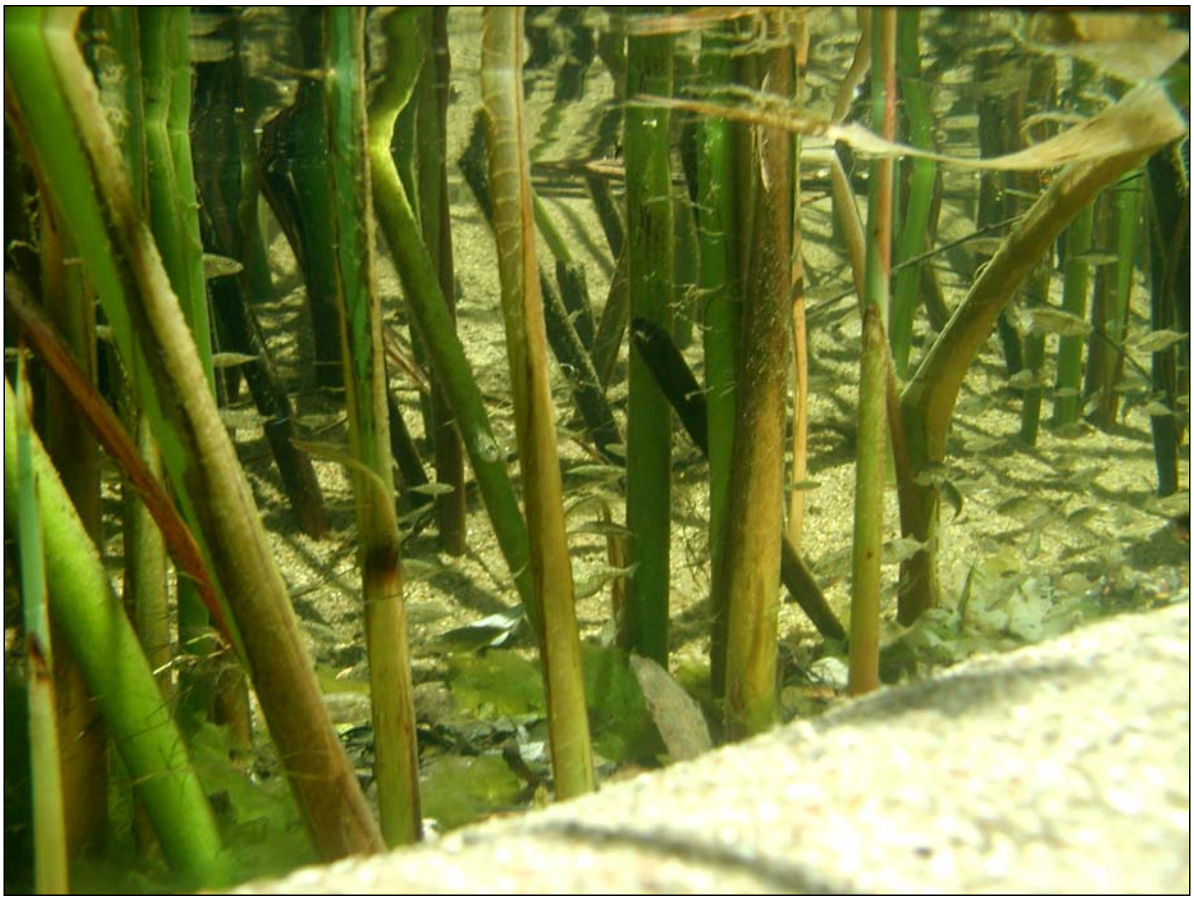


Figure 8.8. Image of stickleback taken with a hand-held digital camera in the tules at R4. (Joel Casagrande, 21 June 2005)

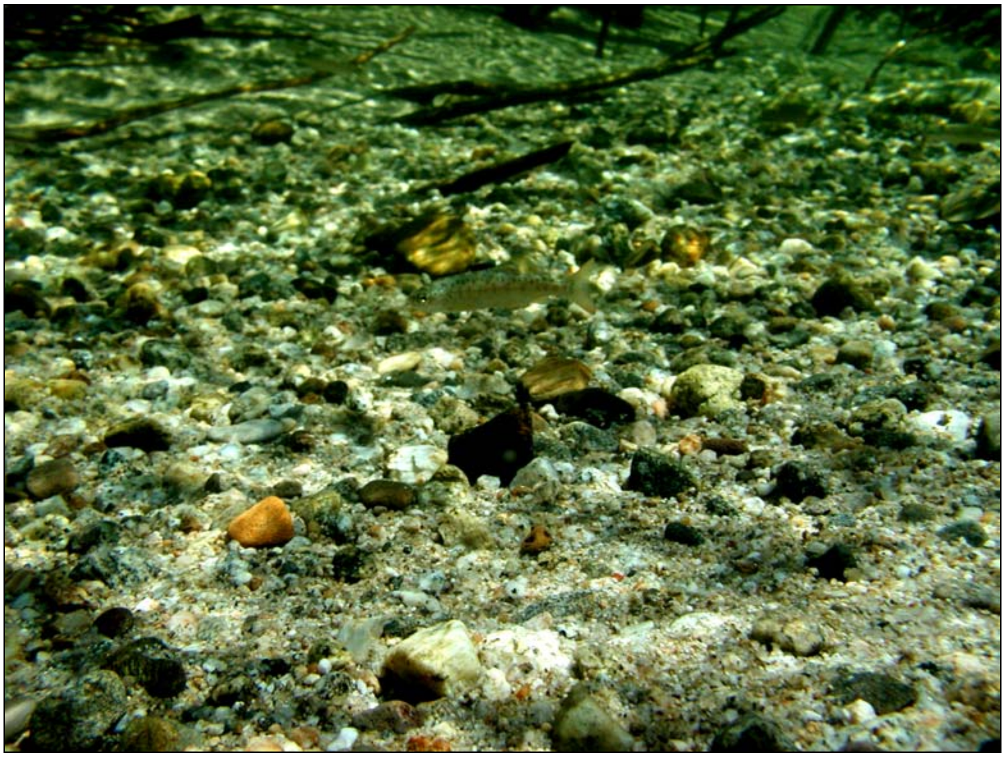


Figure 8.9. Close up image of steelhead taken with a hand-held digital camera at R4. (Joel Casagrande, 21 June 2005)

Figure 8.10. Image of steelhead taken with a hand-held digital camera at R4. (Joel Casagrande, 20 June 2005)

8.3 Seining

Seining was conducted by State Parks in the Odello Arm on June 21st 2005, confirming the presence of numerous steelhead in the new restoration.

Figure 8.11. Seining in the Odello arm. 21 June 2005

Figure 8.12. Seining in the Odello arm. 21 June 2005

8.4 Discussion

The key result of the various steelhead survey efforts is that in early summer, while the river was still flowing, steelhead were present in both the original lagoon and the newly restored Odello Arm. Given that the habitat volume in the original lagoon was minimal at this time, the fact that the restoration provided additional habitat means that the restoration is thus far a success, and is likely to have a positive impact on the viability of the Federally Threatened South Central-Coastal California Steelhead Evolutionary Significant Unit. Further, the new Odello portion of the South Arm also adds critical refuge during periods of high stream flow and immediately following a breach.

Thus far, the automated underwater system has not proved useful. Its benefits are that it is less intrusive and has the potential to be more objective than other techniques because it conducted remotely and does not involve human presence at the sampling location. Its disadvantage is that it has not yet recorded any fish whose presence was not already known. This may be an inherent limitation of the system, primarily due to lack of visibility. Or it may be because the best sampling sites are yet to be located, or not enough hours have been spent at the existing sampling locations given the low density of steelhead in the lagoon. One would presume that if steelhead were in the lagoon, and they were to some degree faithful to certain core habitat areas, that hidden cameras could be pre-deployed in these areas to provide continuous monitoring of steelhead densities in core areas.

Handheld video has worked very well on a few occasions where fresh, clear, spring river water was flowing through a shallow lagoon. But on other occasions when the lagoon was deep and closed, no steelhead were seen after several hours of snorkeling – just prior to a seining event that yielded many steelhead.

In the past few years, most seining days have yielded steelhead. These included State Parks seines in fall 2004 and early summer 2005, fall 2004 surveys by the Carmel River Steelhead Association, as well as fall surveys in 2003 and earlier years by J. Hagar and others.

While laborious and restrained by permit limitations under the ESA, seining remains the only reliable method for determining presence/absence and estimating abundance. Further development of automated video may be worthwhile, particularly if it is possible to determine long-term core use areas beforehand by snorkeling. Use of acoustic cameras would also be worth investigating.

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10 Appendices

Included in these appendices are:

Appendices A – D: Depth profiles of temperature, salinity, dissolved oxygen, and pH.

Appendix E: Invertebrate data of each sample.

10.1 Appendix A: Temperature profiles

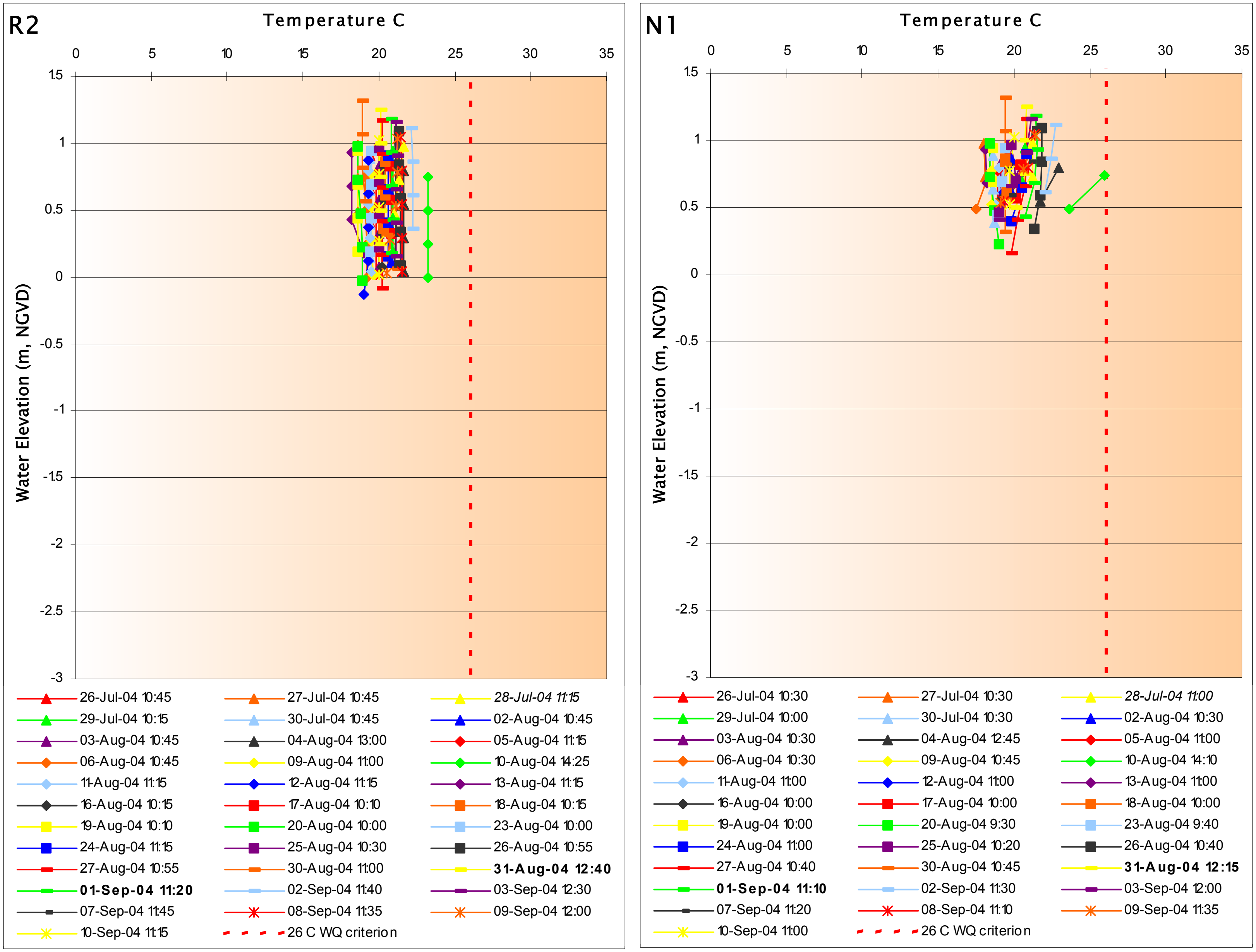


Figure 10.1. Temperature profiles at R2 and N1 during Phase 1.

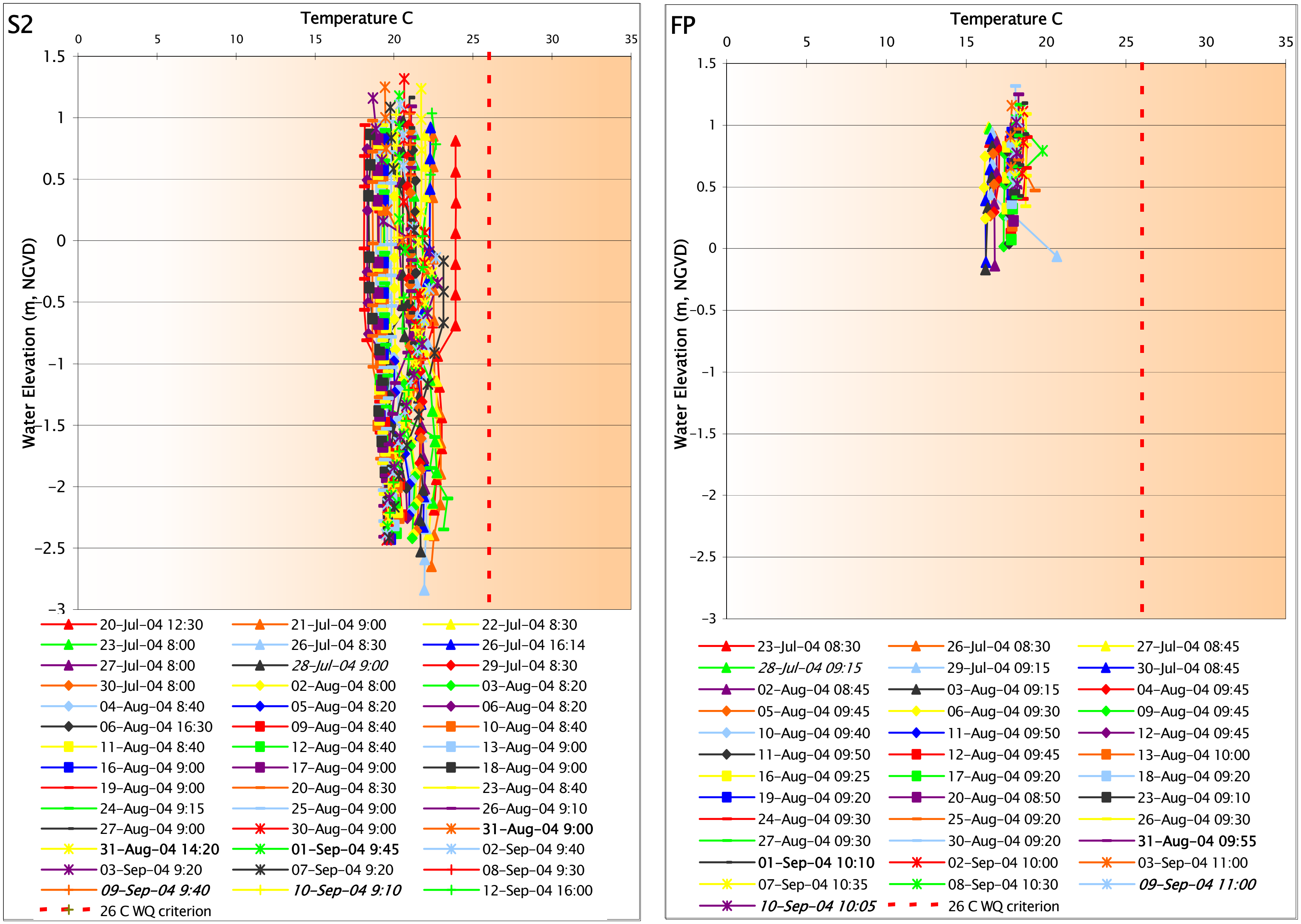


Figure 10.2. Temperature profiles at S2 and FP during Phase 1.

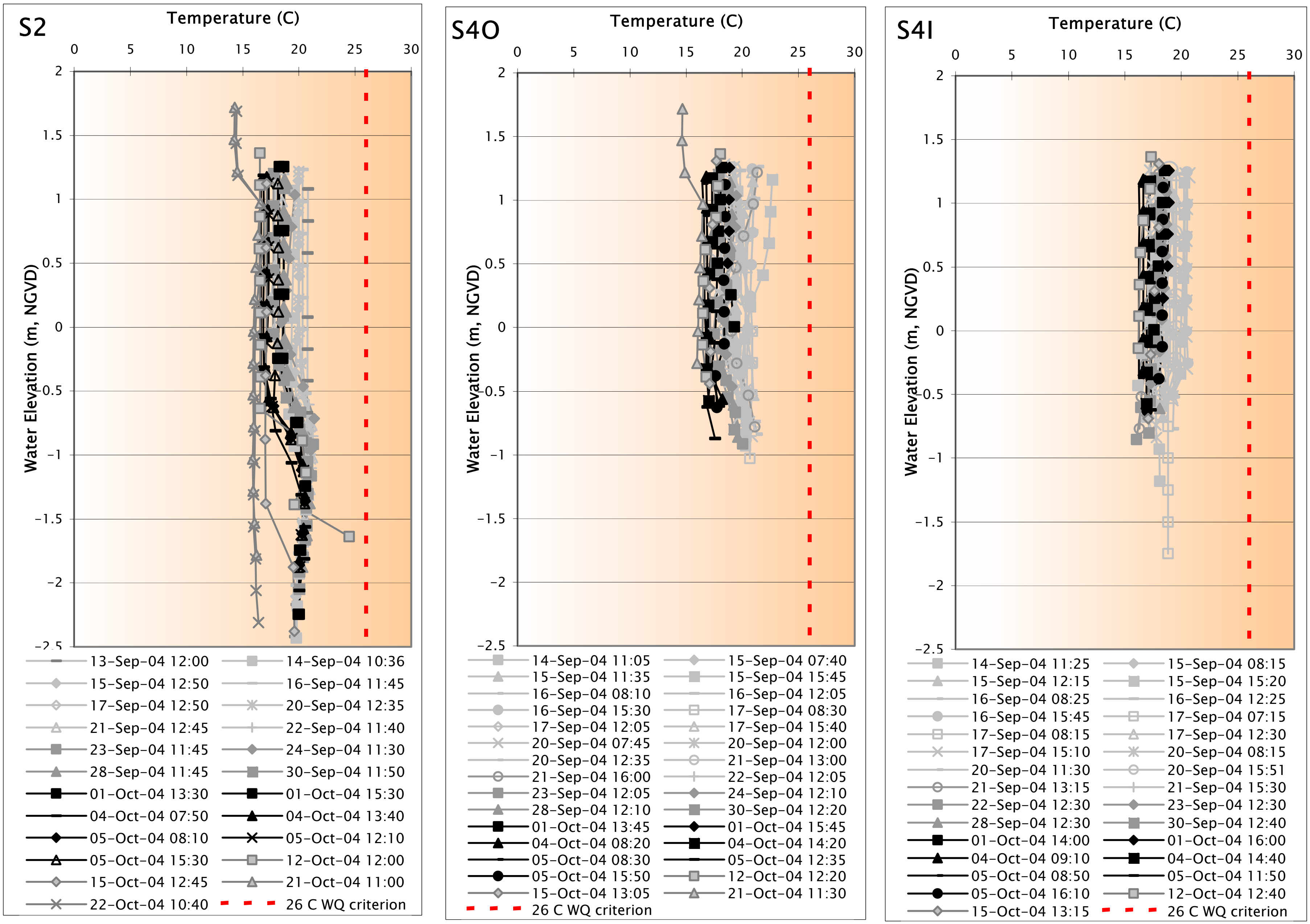


Figure 10.3. Temperature depth profiles at S2, S4), and S4I during Phase 2.

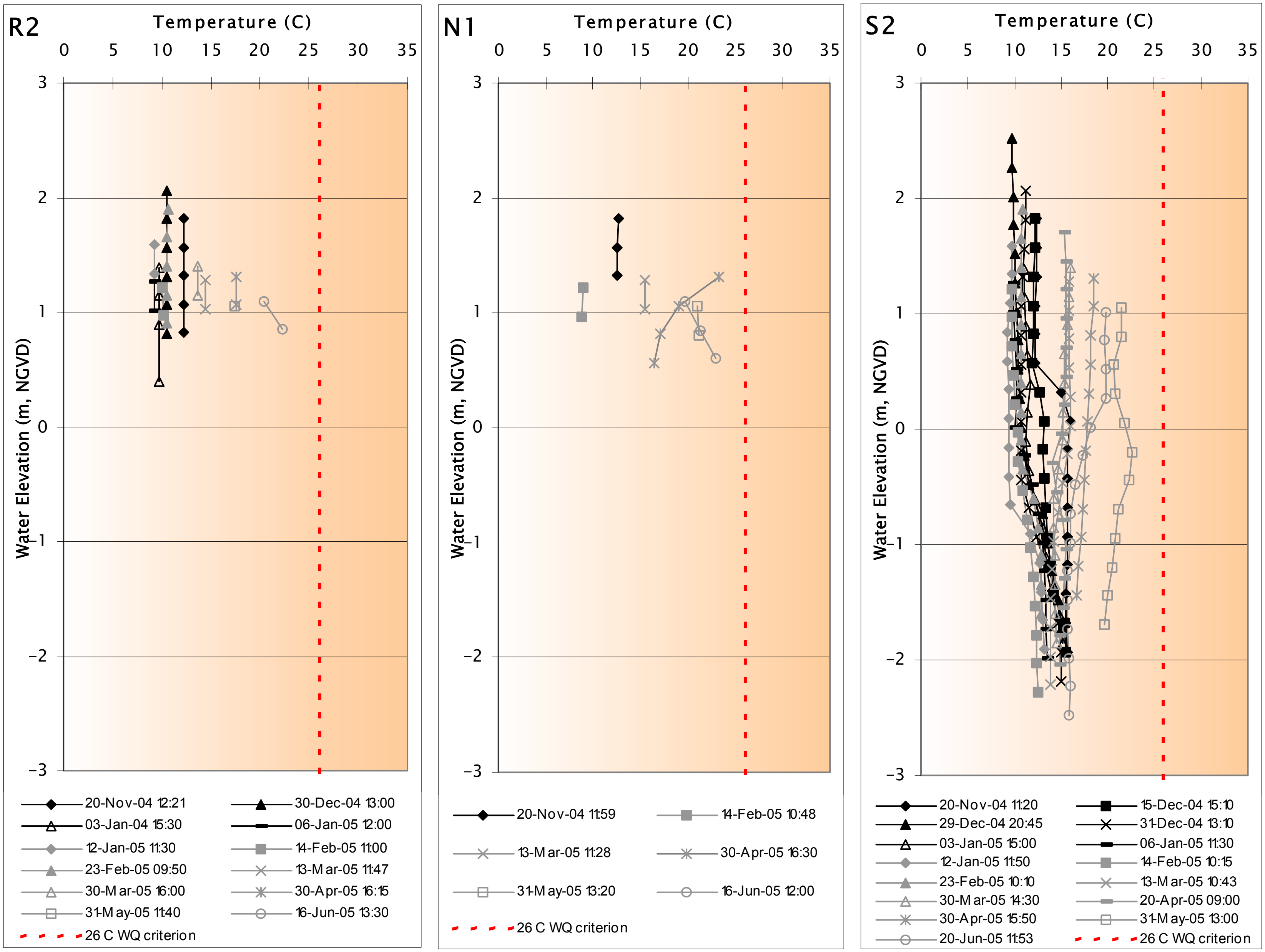


Figure 10.4. Temperature profiles at R2, N1,and S2 during Phases 3 and 4.

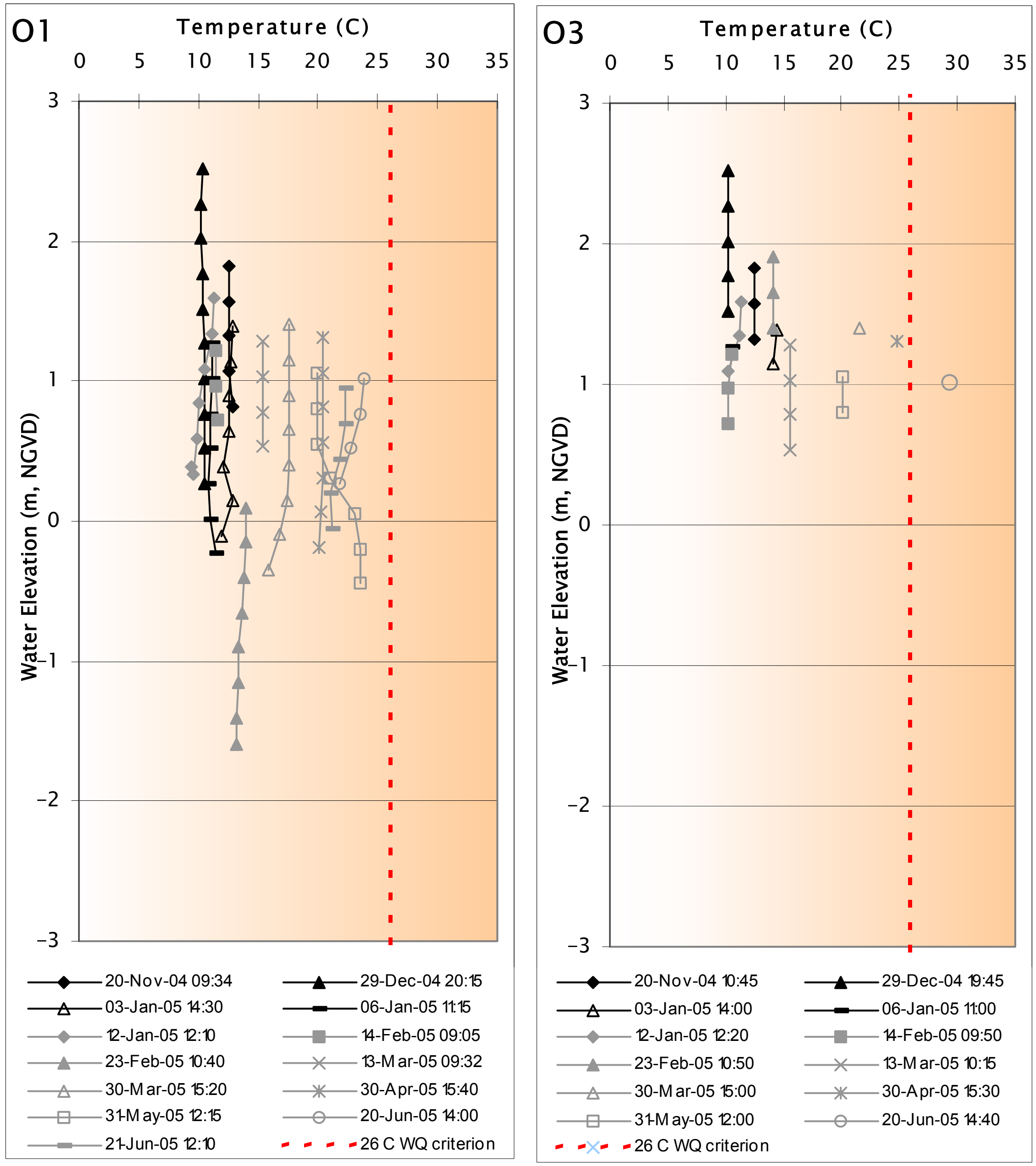


Figure 10.5. Temperature profiles at O1 and O3 during Phases 3 and 4.

10.2 Appendix B: Salinity Profiles

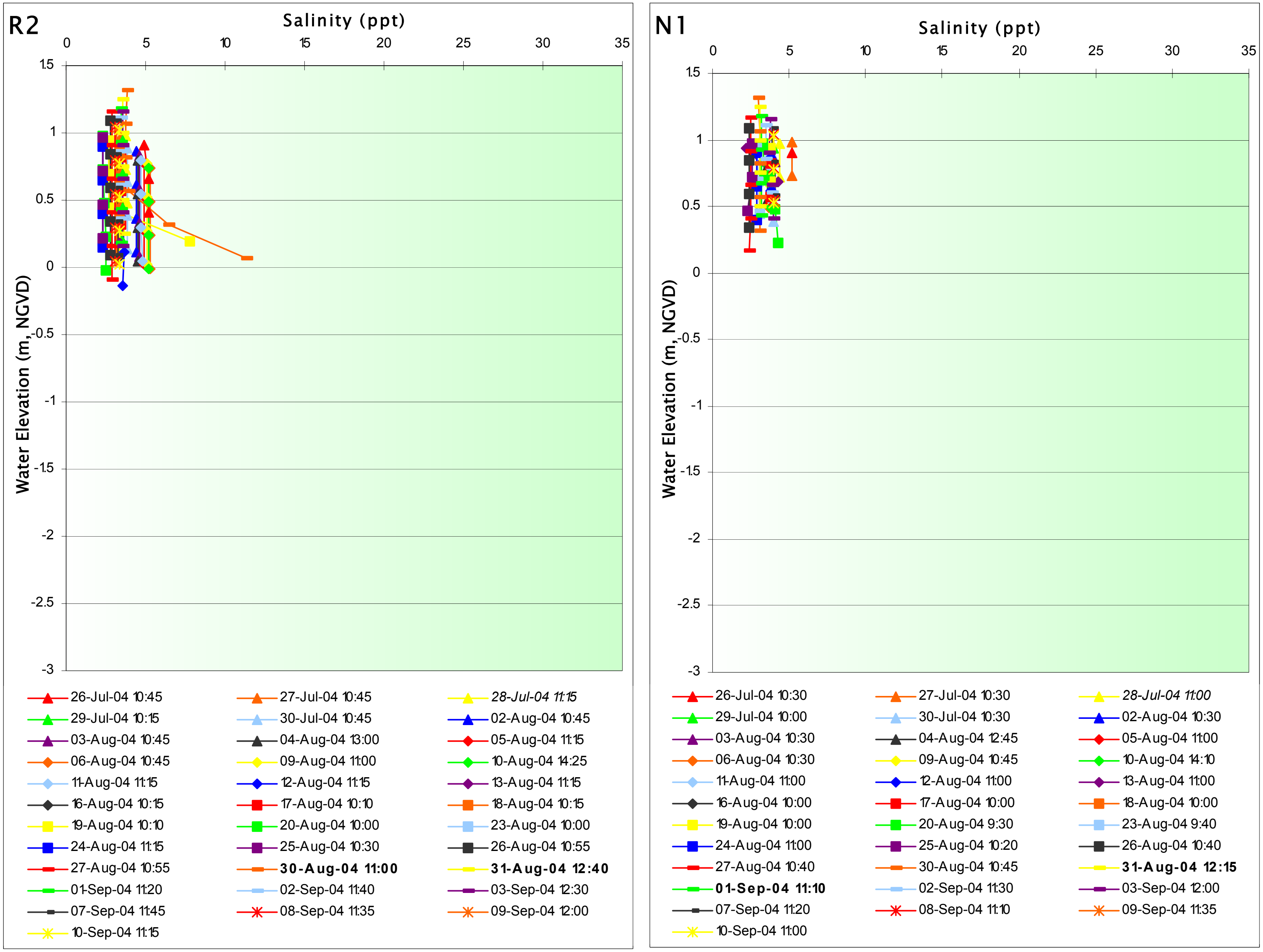


Figure 10.6. Salinity profiles at R2 and N1 during Phase 1.

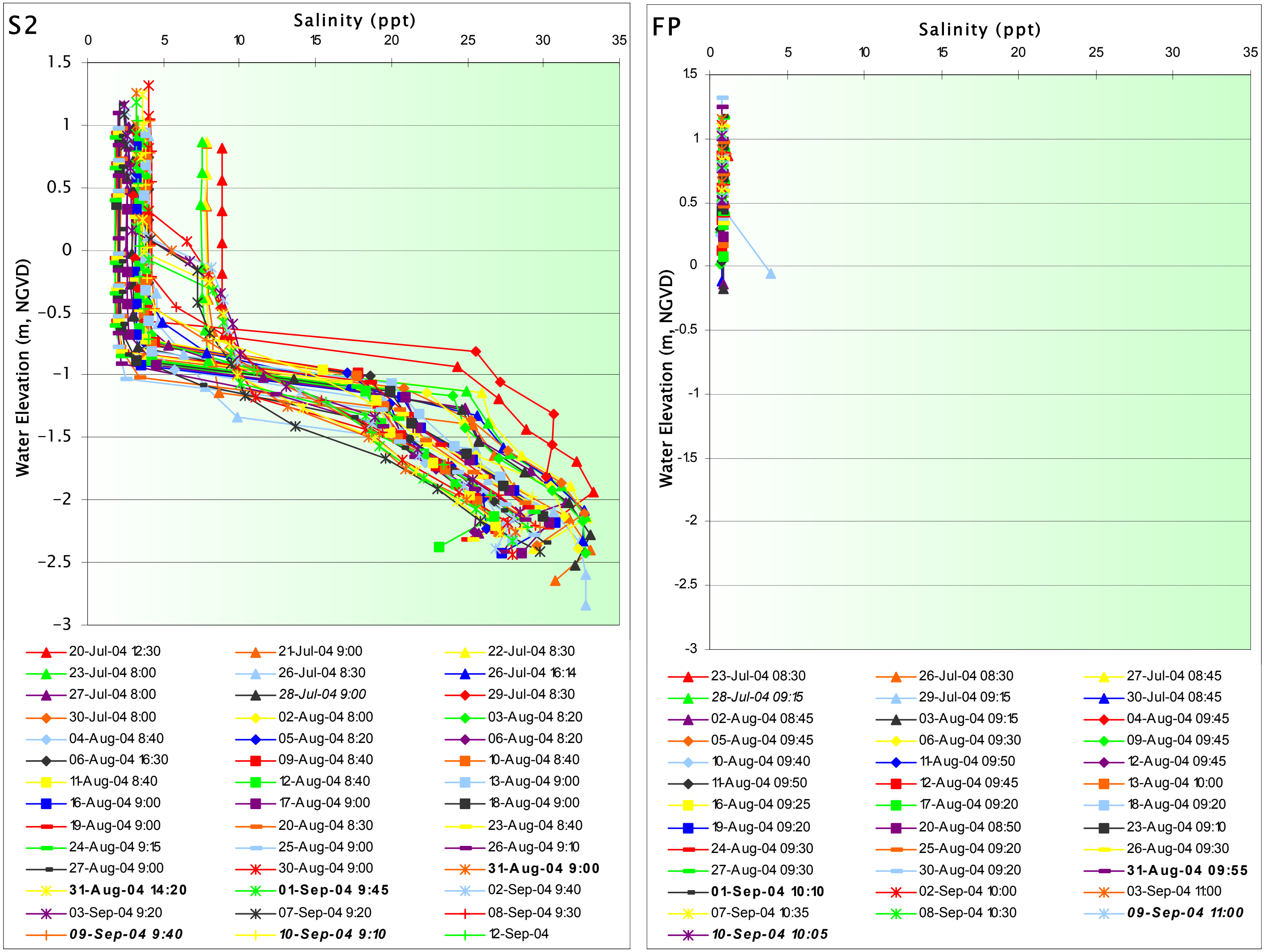


Figure 10.7. Salinity profiles at S2 and FP during Phase 1.

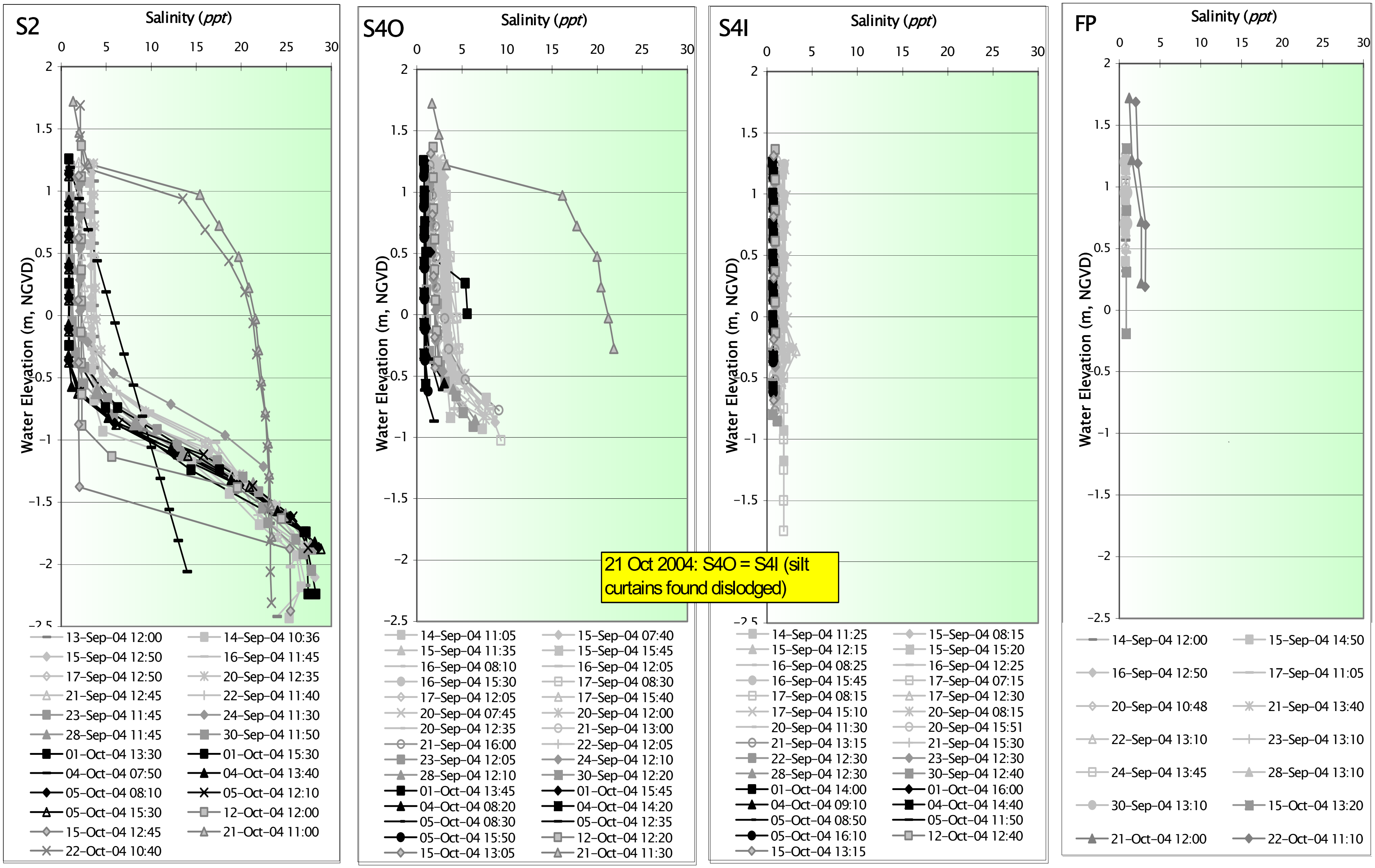


Figure 10.8. Salinity depth profiles at S2, S4O, S4I, and FP during Phase 2.

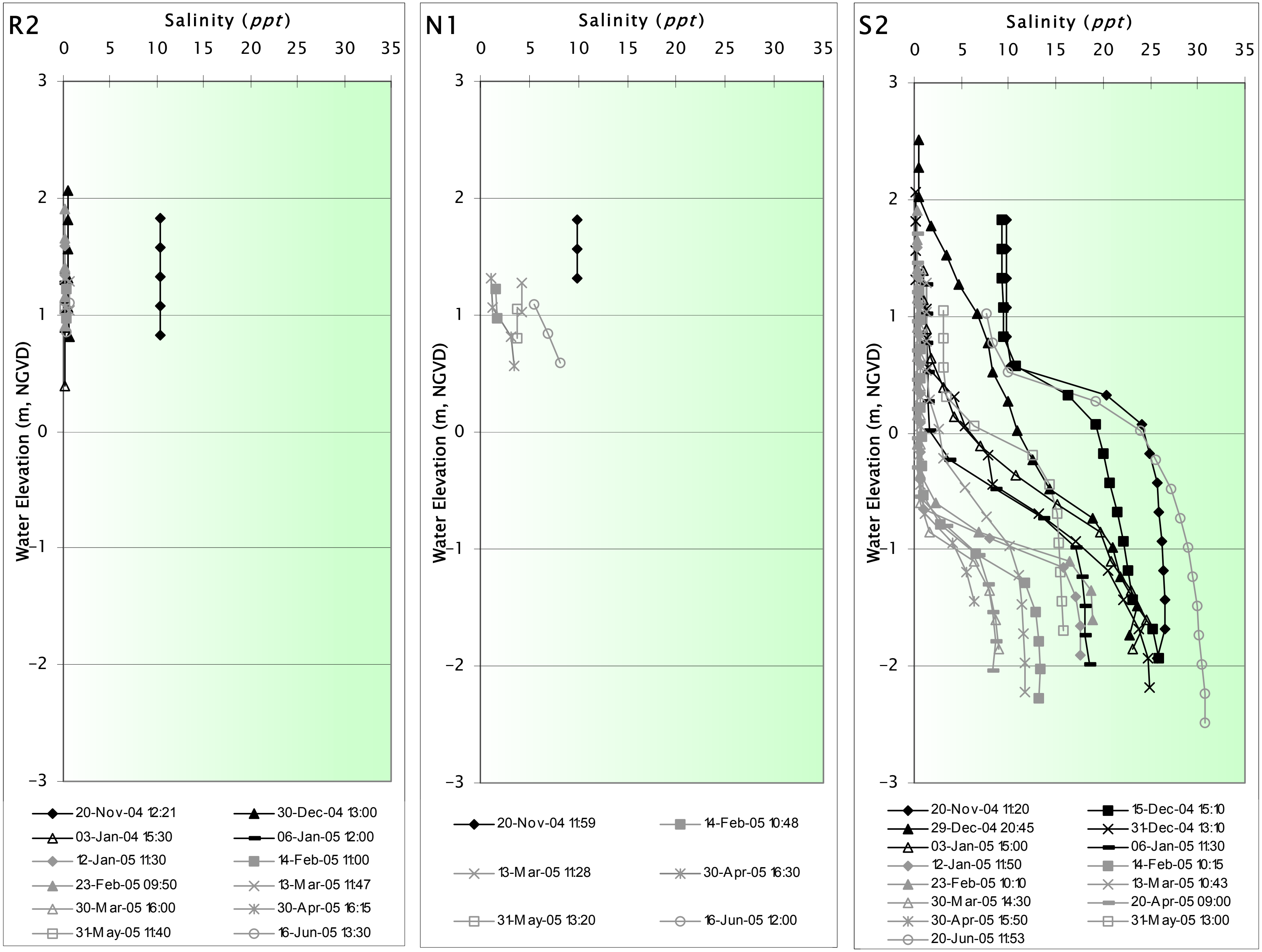


Figure 10.9. Salinity profiles at R2, N1, and S2 during Phases 3 and 4.

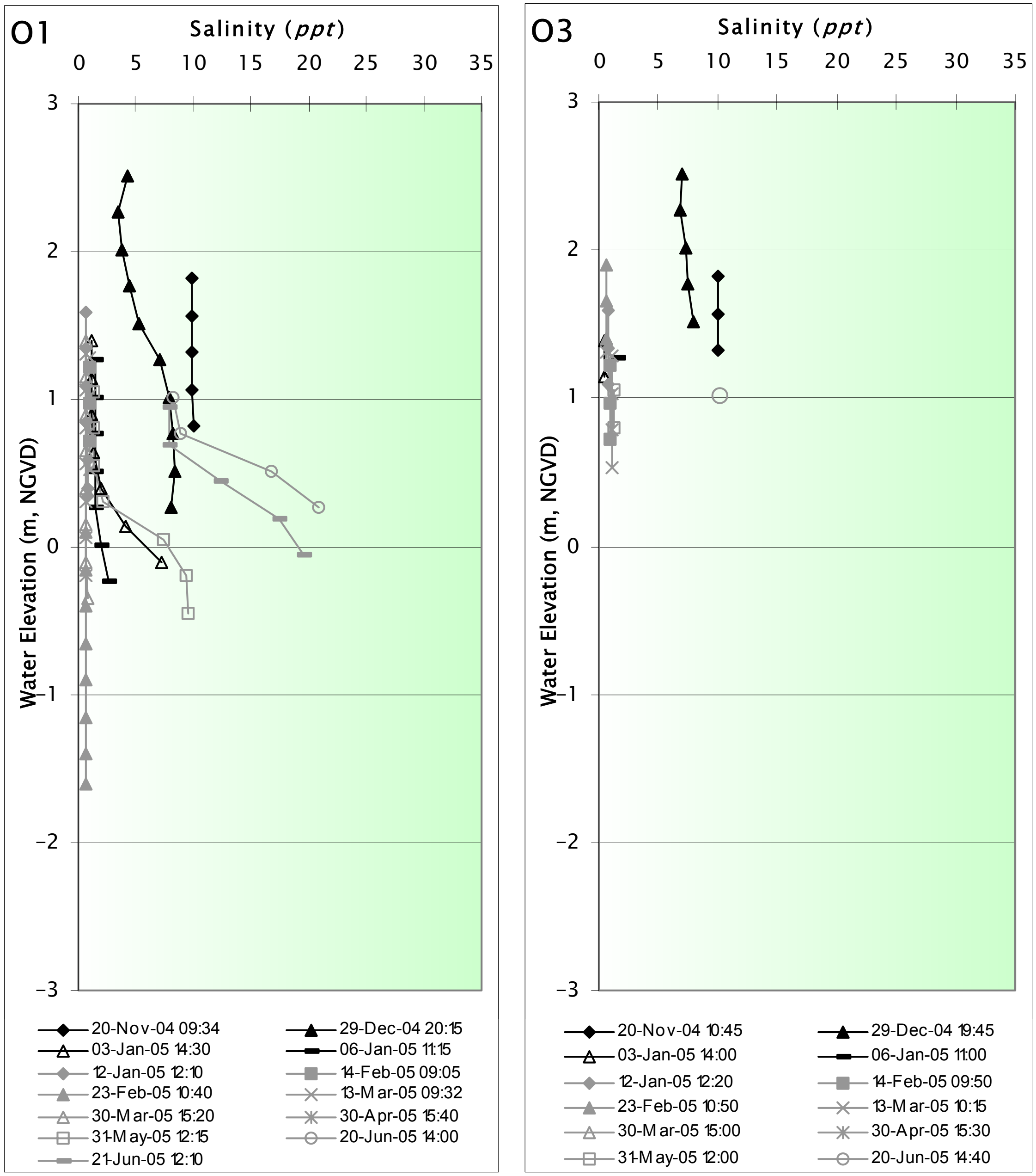


Figure 10.10. Salinity depth profiles at O1 and O3 during Phases 3 and 4.

10.3 Appendix C: Dissolved oxygen profiles

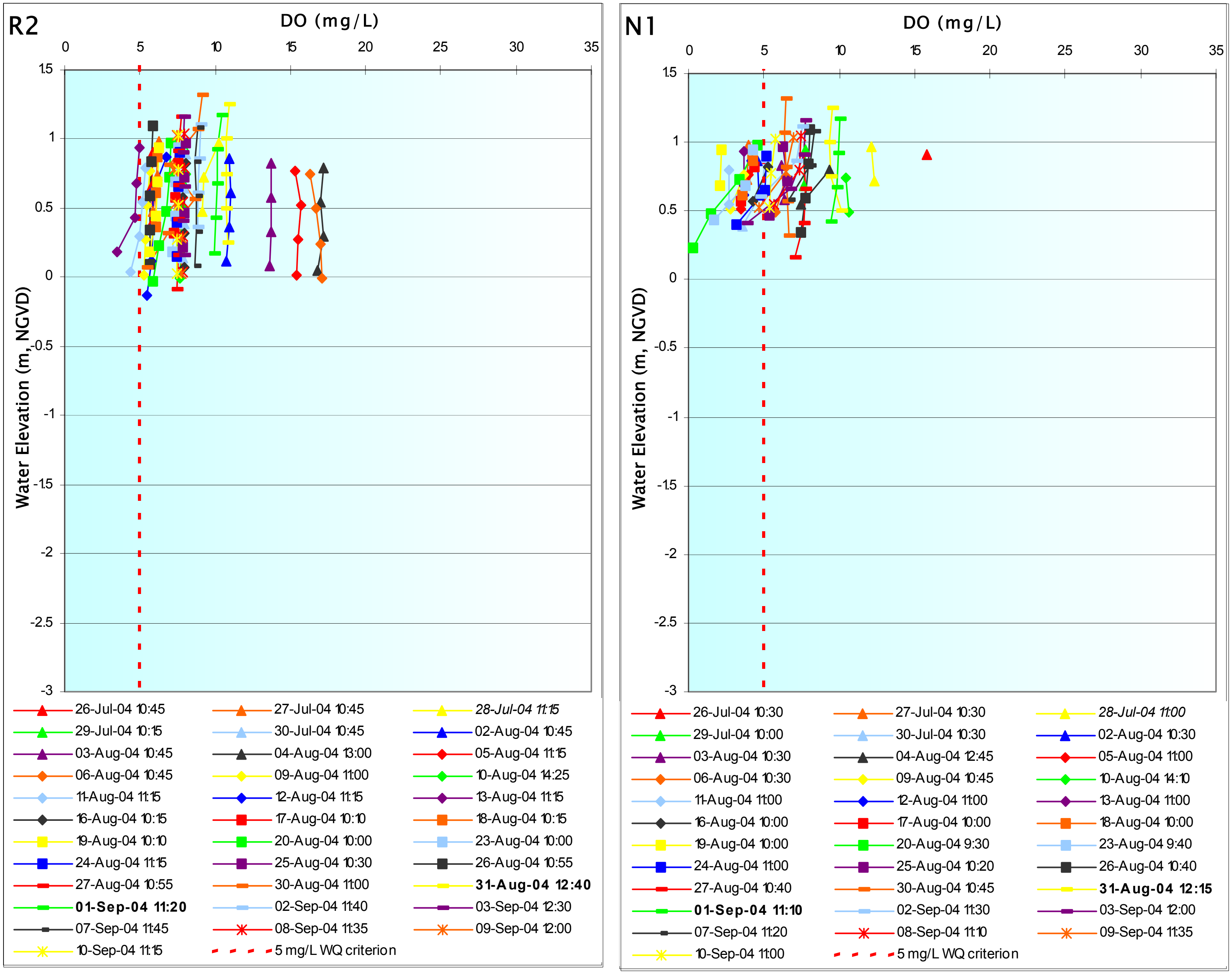


Figure 10.11. Dissolved oxygen profiles at R2 and N1 during Phase 1.

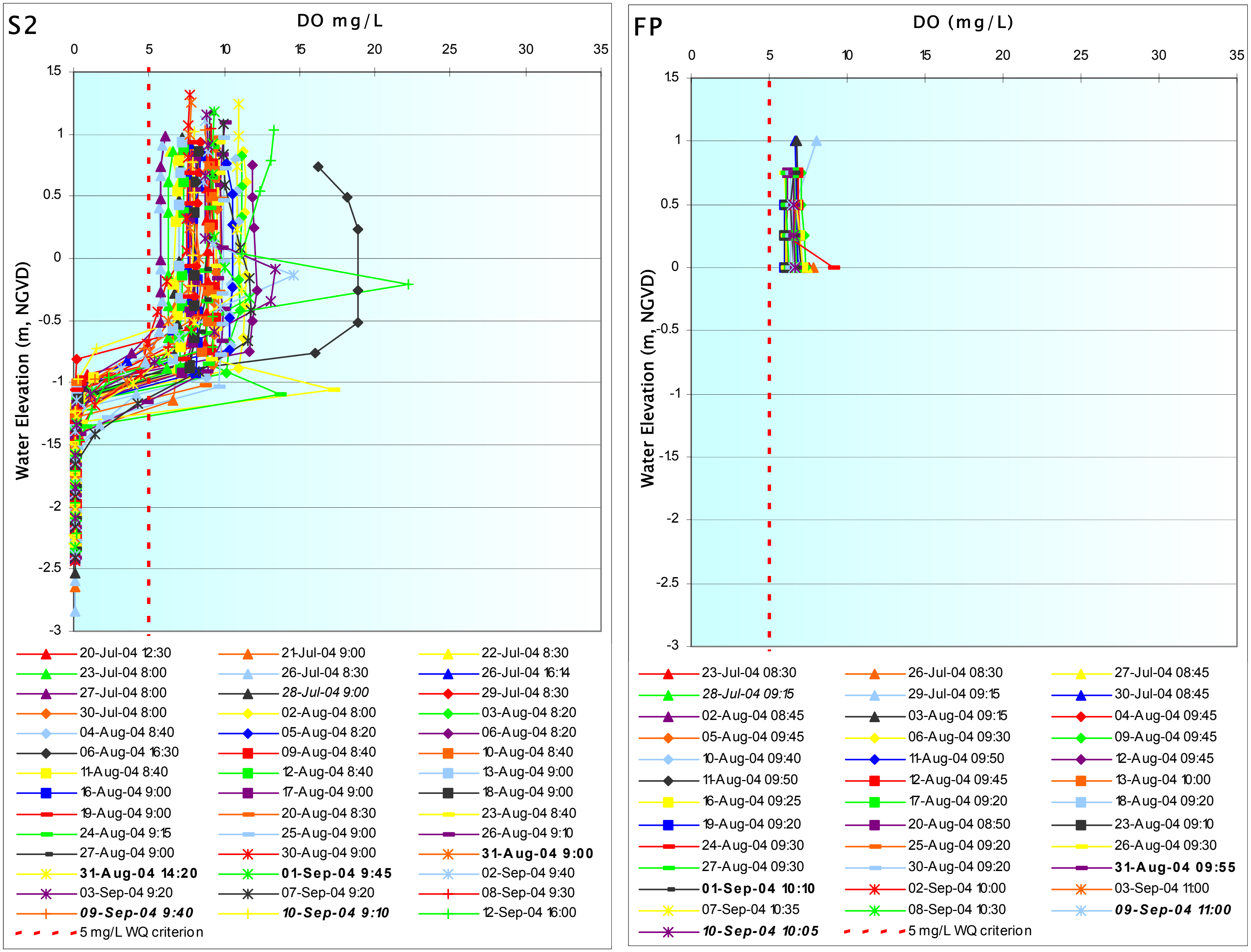


Figure 10.12. Dissolved oxygen profiles at S2 and FP during Phase 1.

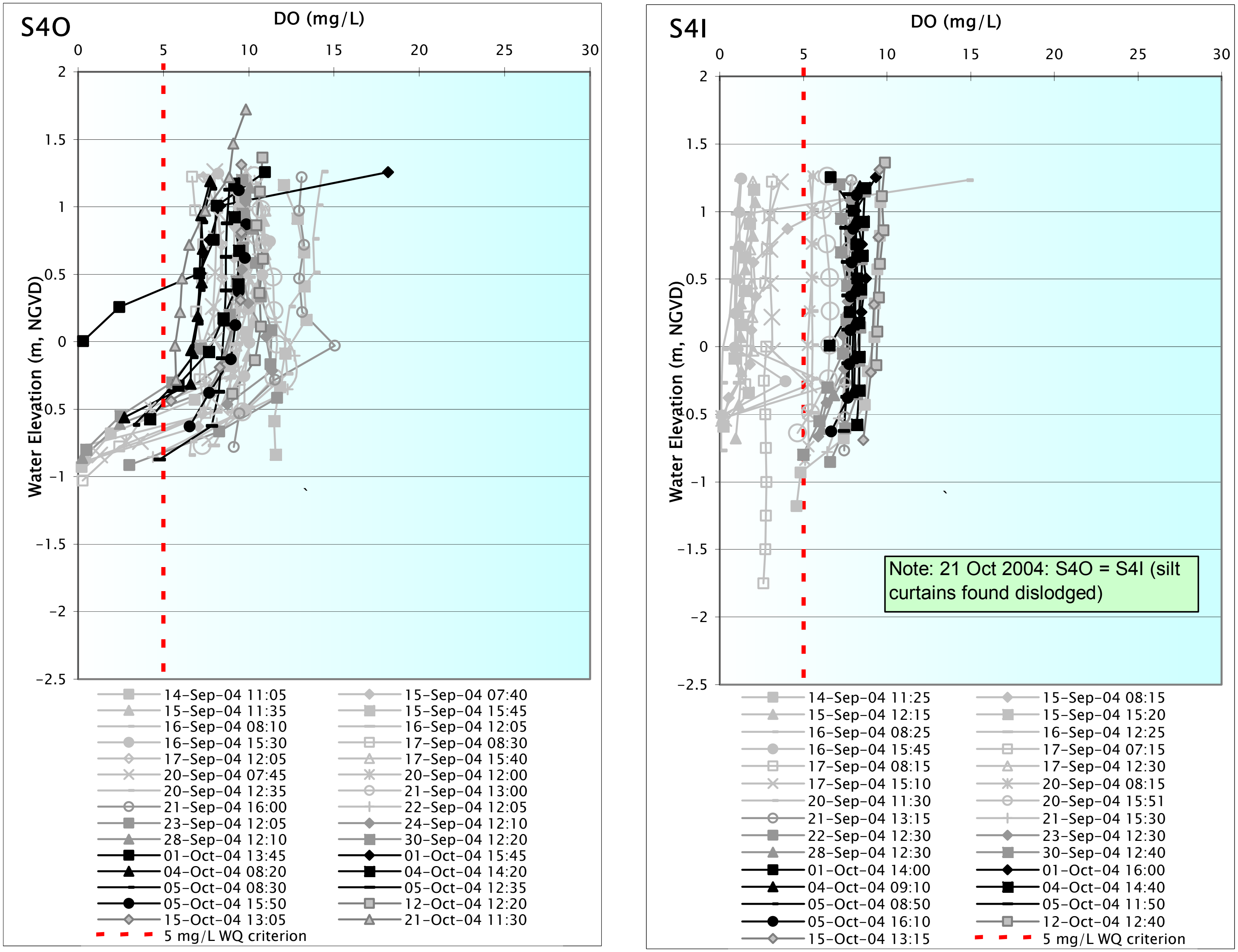
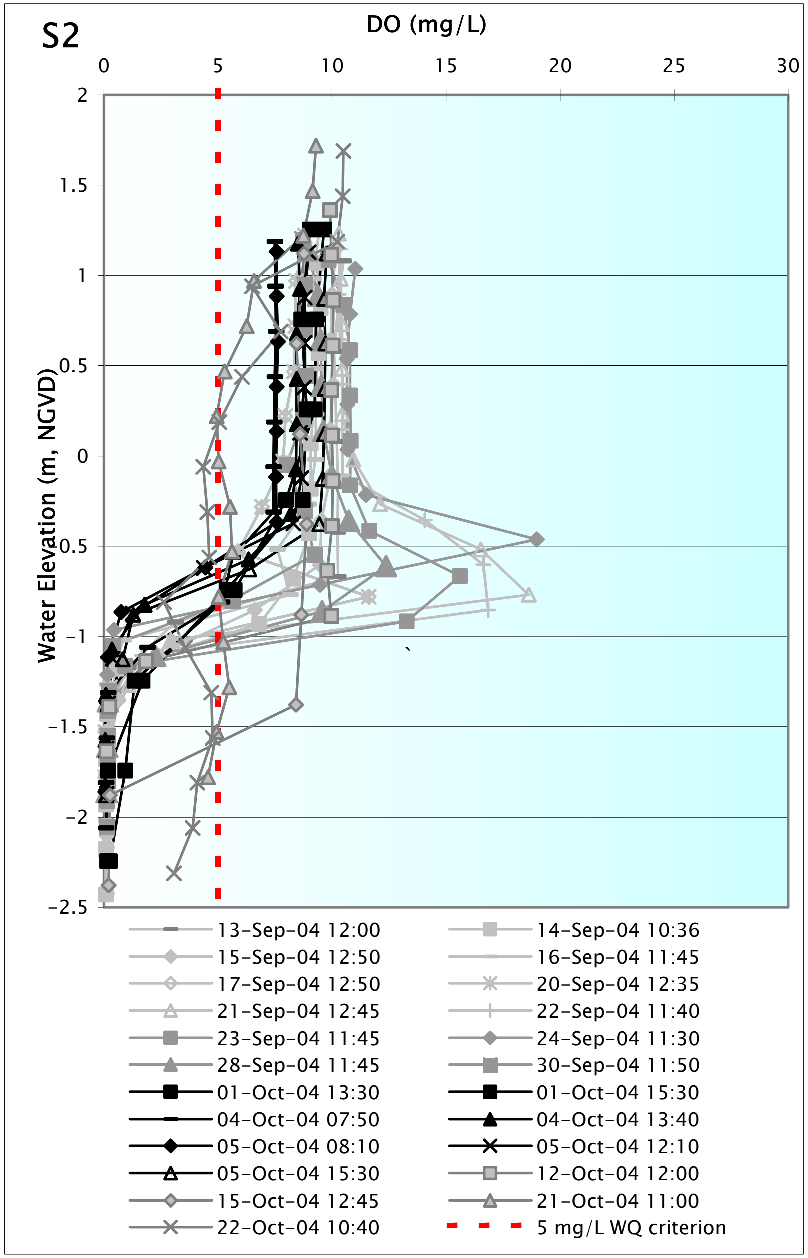


Figure 10.13. Dissolved oxygen depth profiles at S4O and S4I during Phase 2.



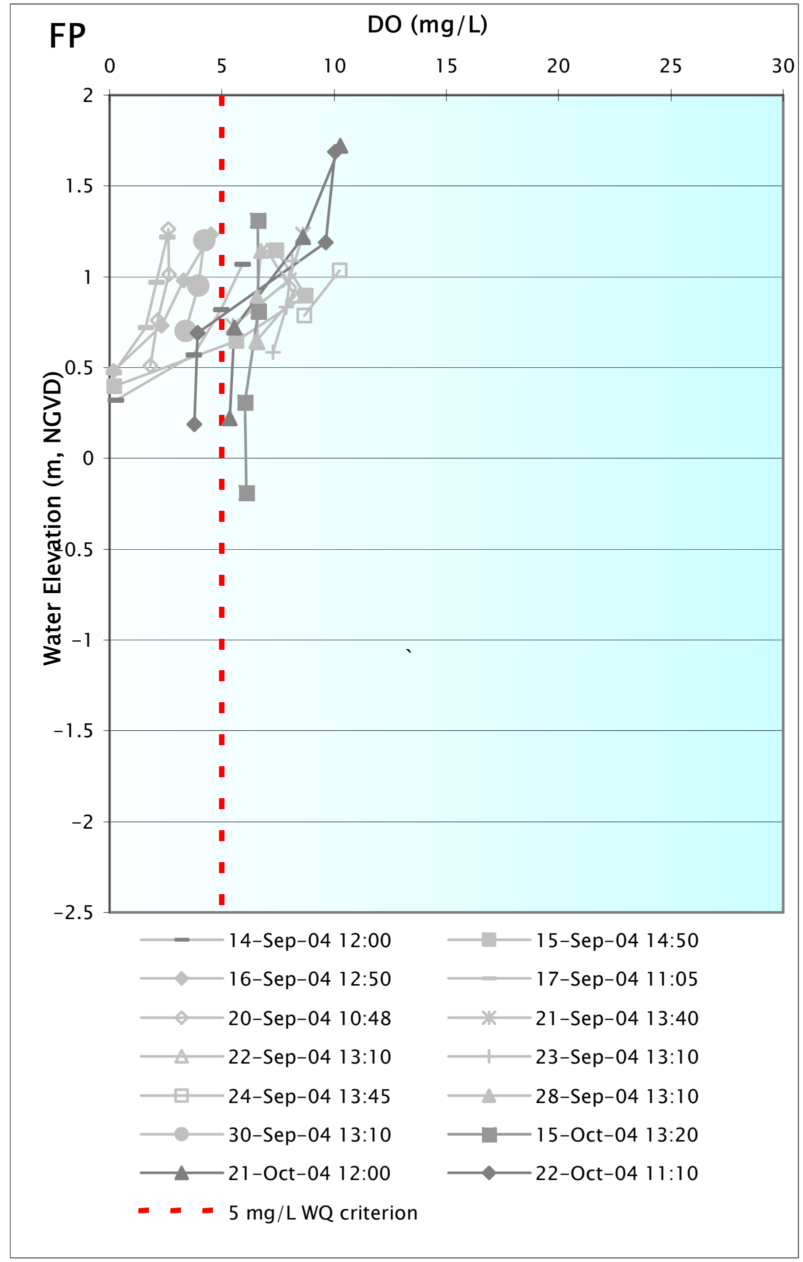


Figure 10.14. Dissolved oxygen depth profiles at S2 and FP during Phase 2.

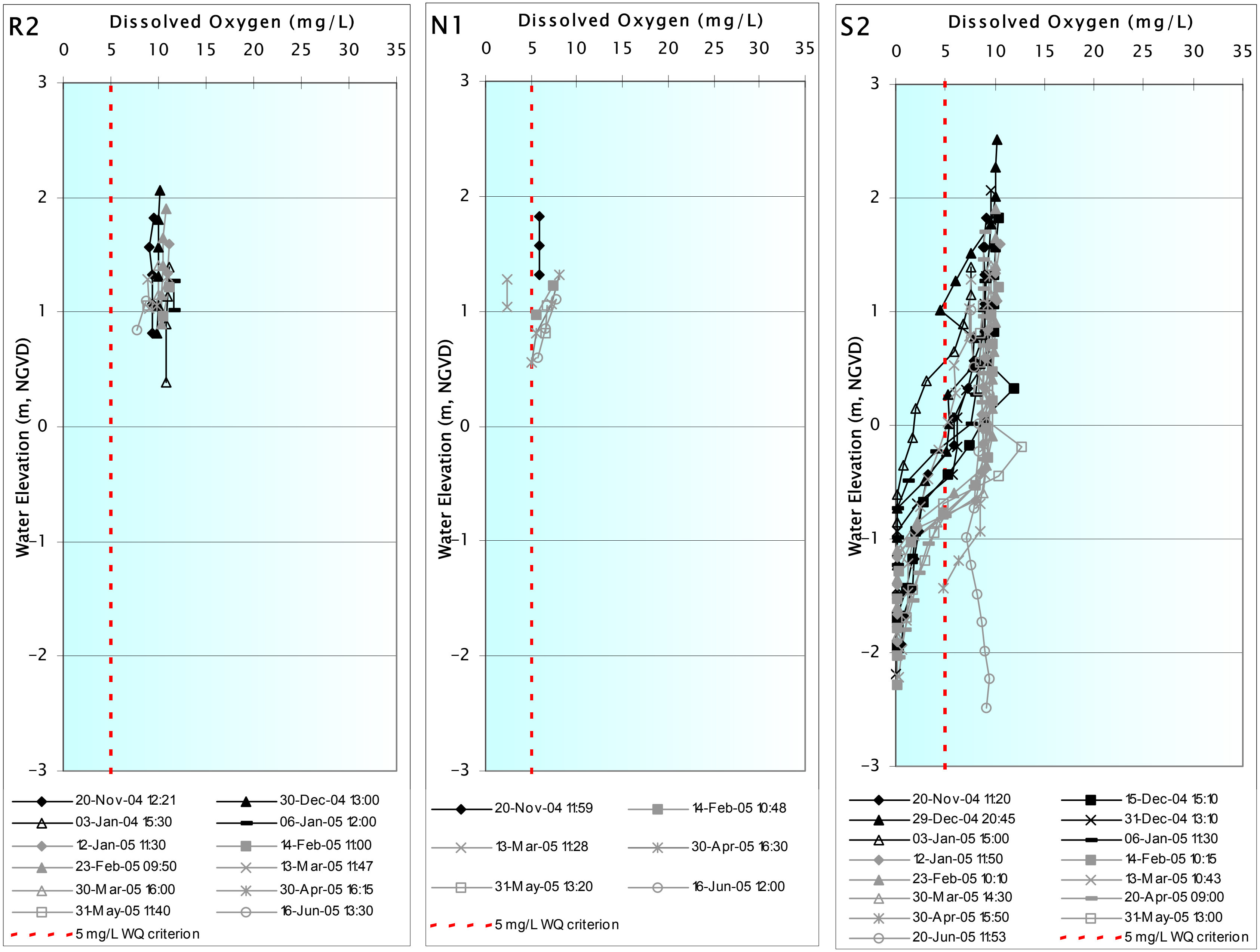


Figure 10.15. DO depth profiles at R2, N1, and S2 during Phases 3 and 4.

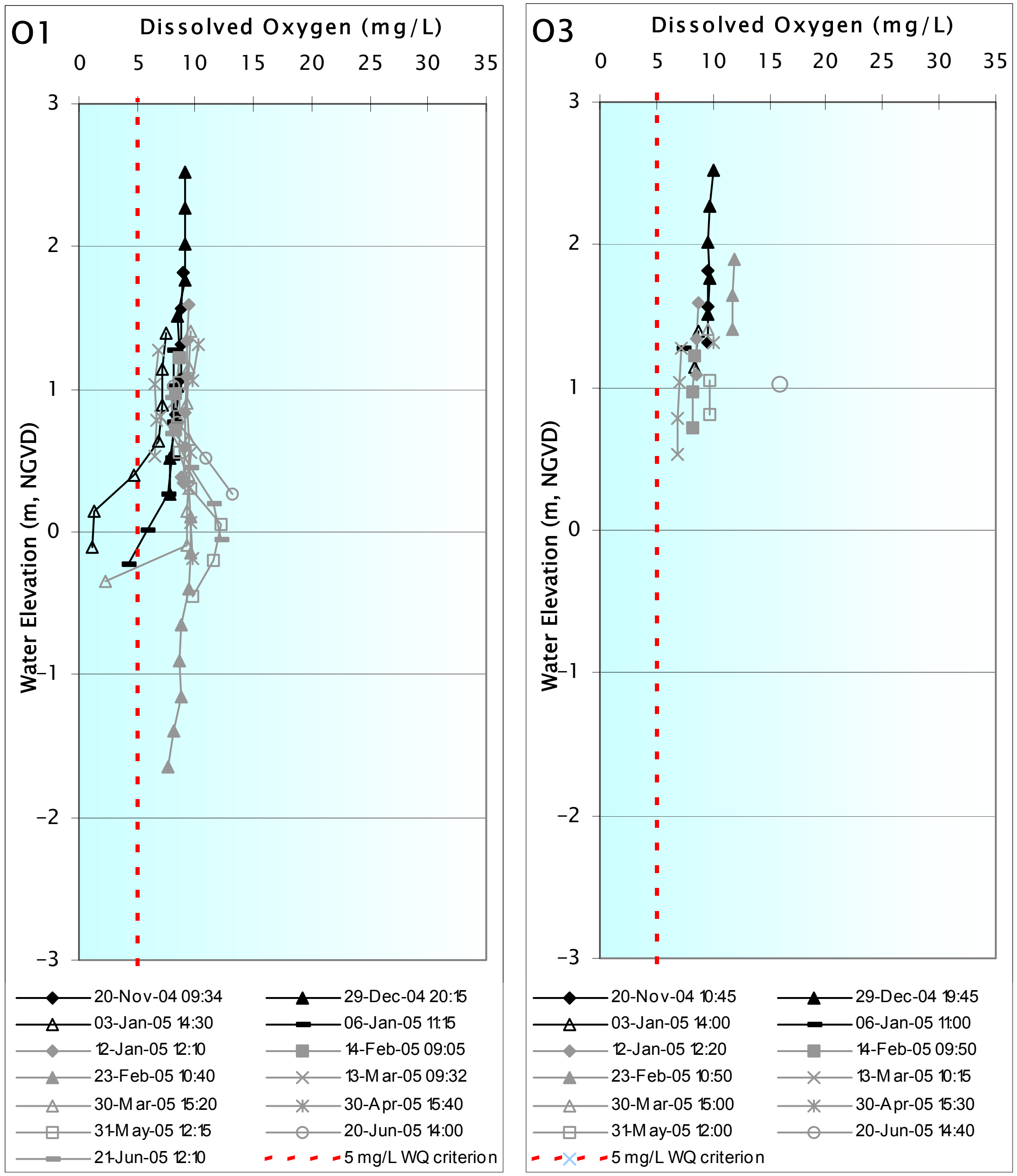


Figure 10.16. DO depth profiles at O1 and O3 during Phases 3 and 4.

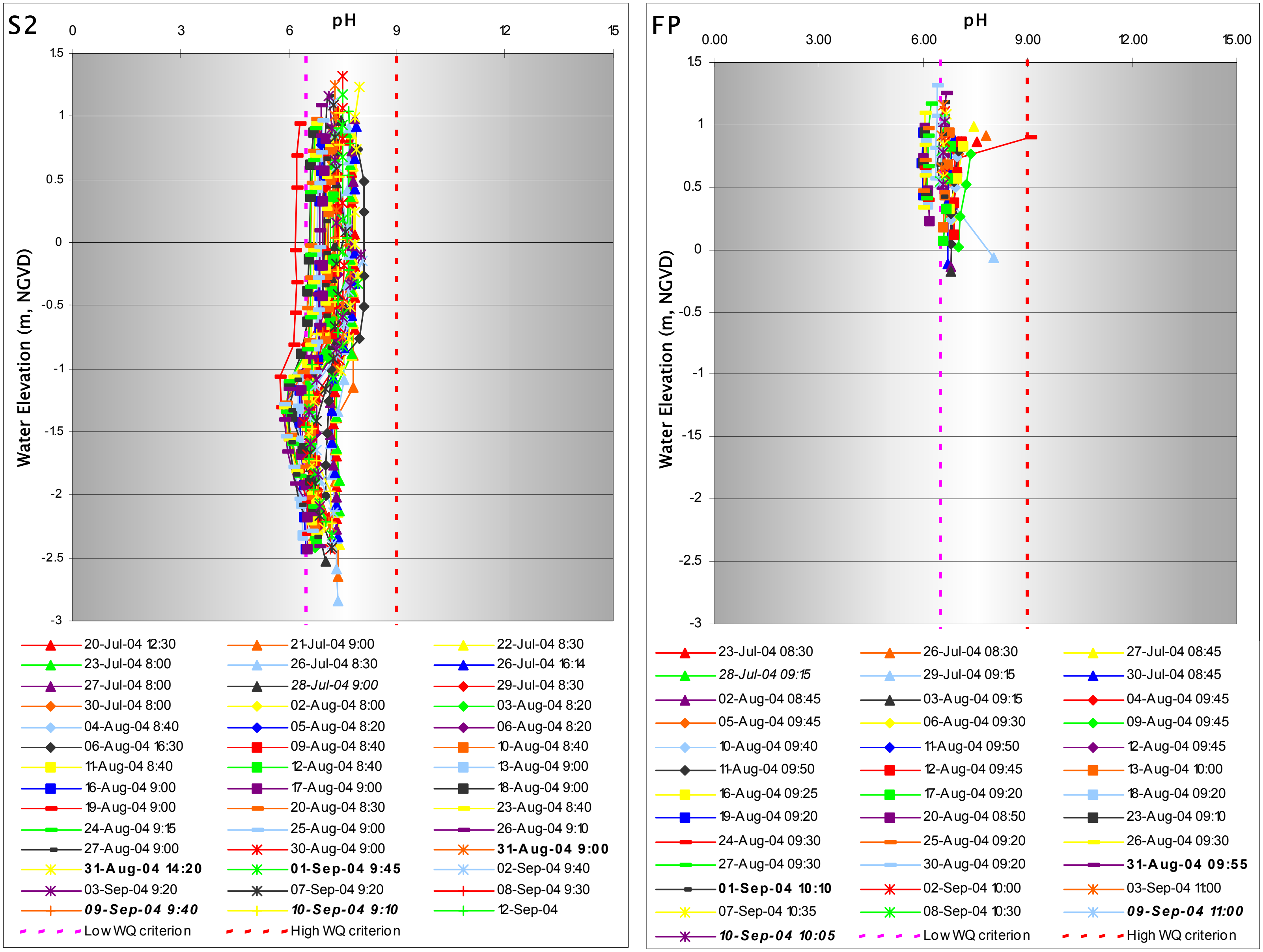


Figure 10.17. pH profiles at S2 and FP during Phase 1.

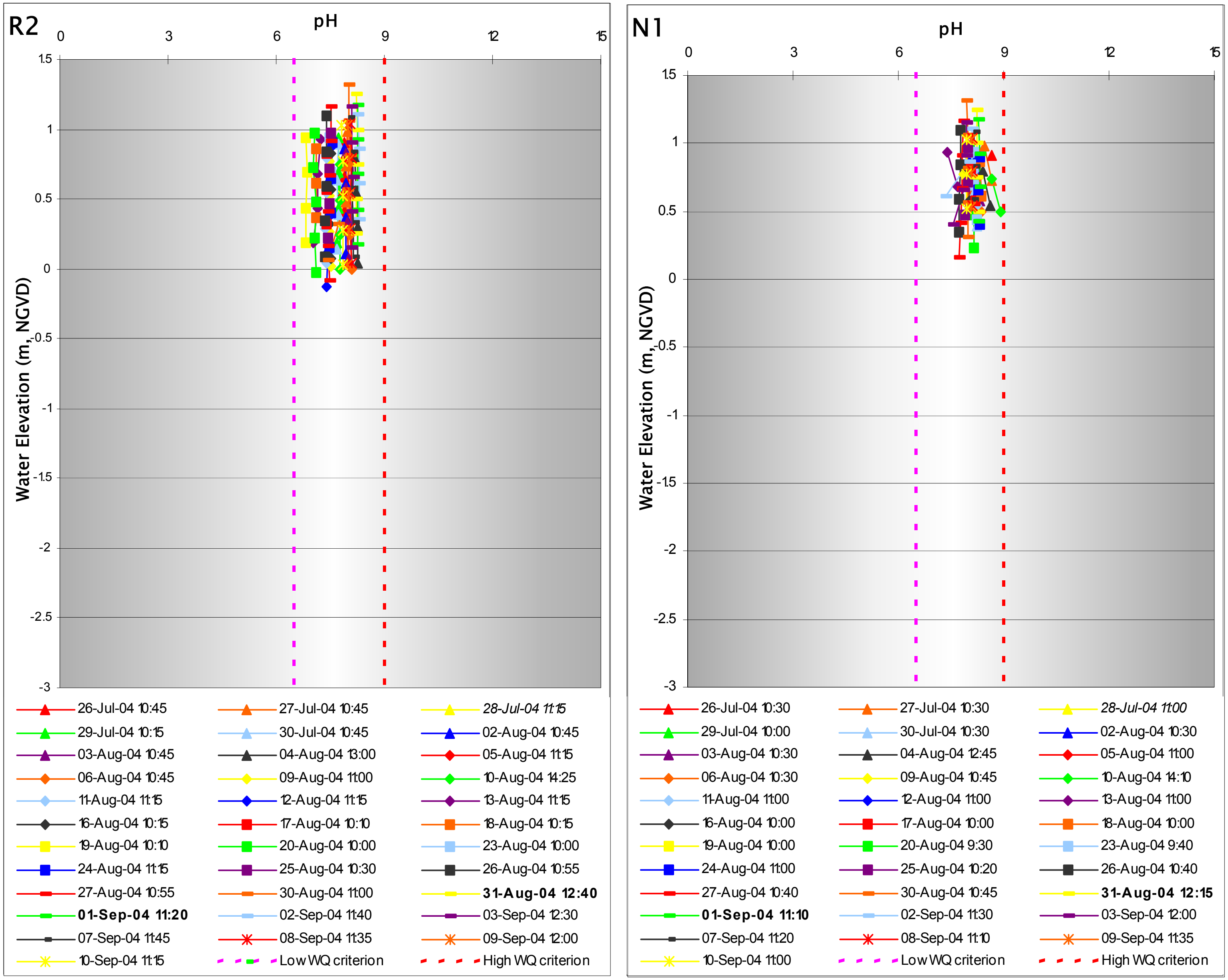


Figure 10.18. pH profiles at R2 and N1 during Phase 1.

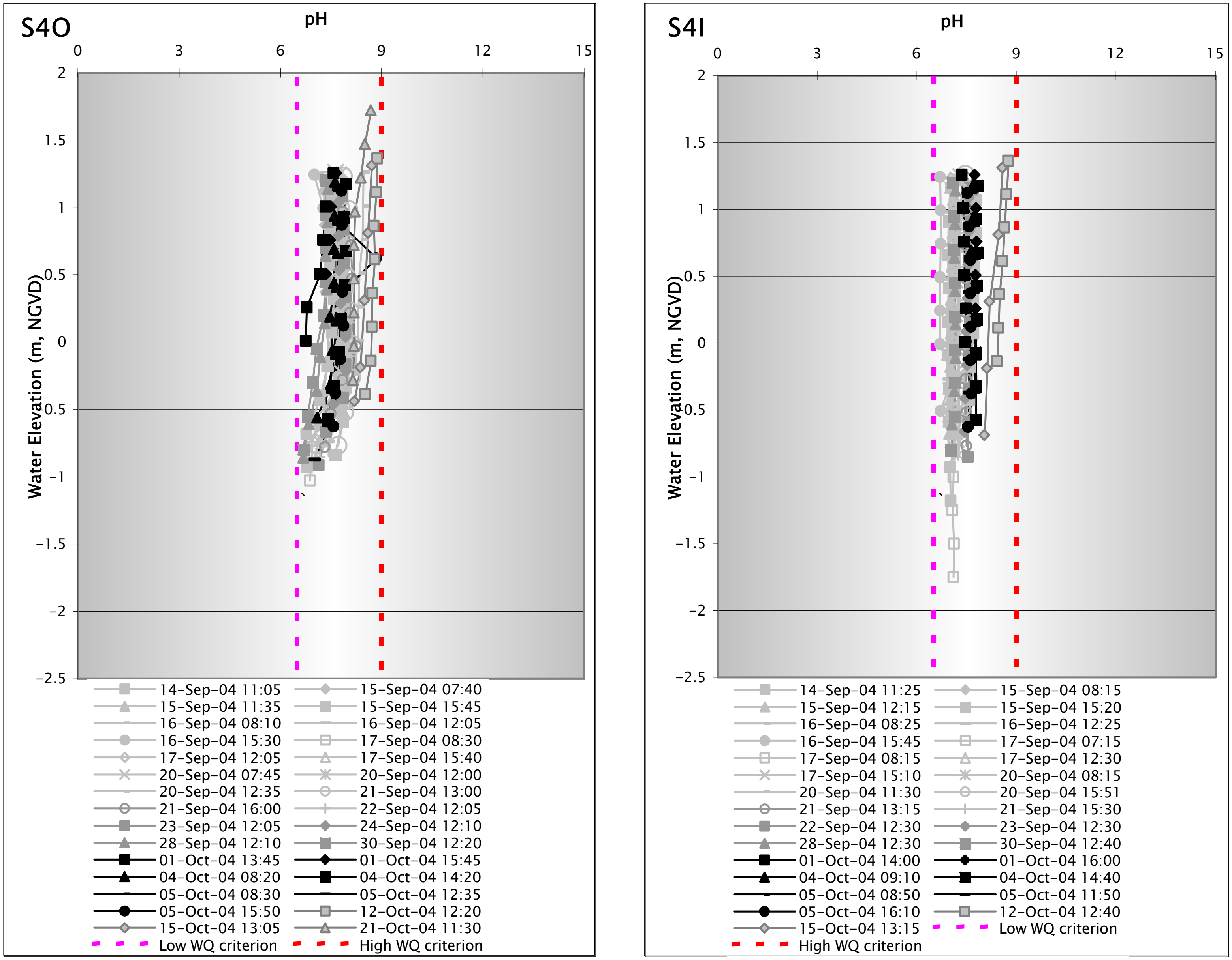


Figure 10.19. ph depth profiles at S4O and S4I during Phase 2.

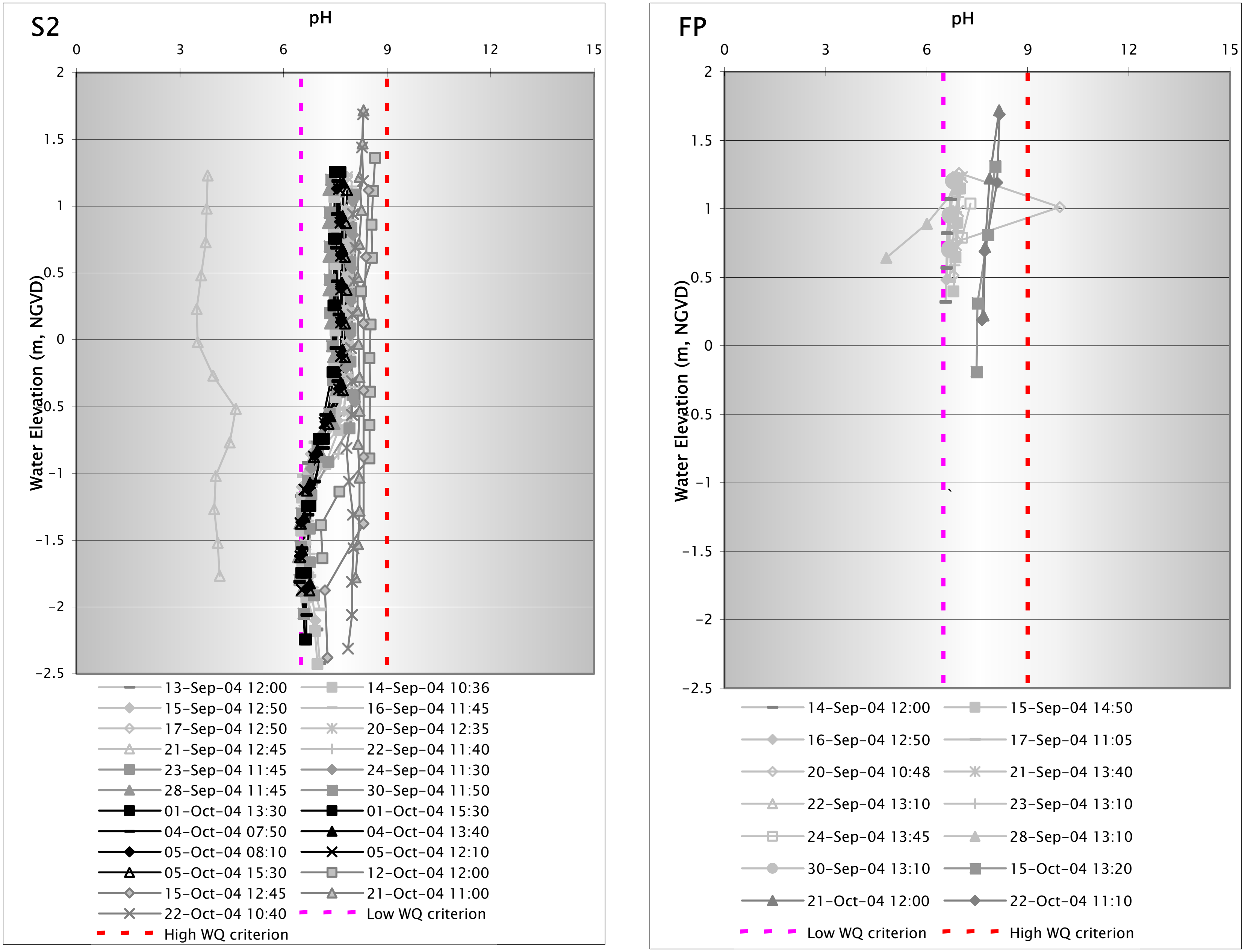


Figure 10.20. ph depth profiles at S2 and FP during Phase 2.

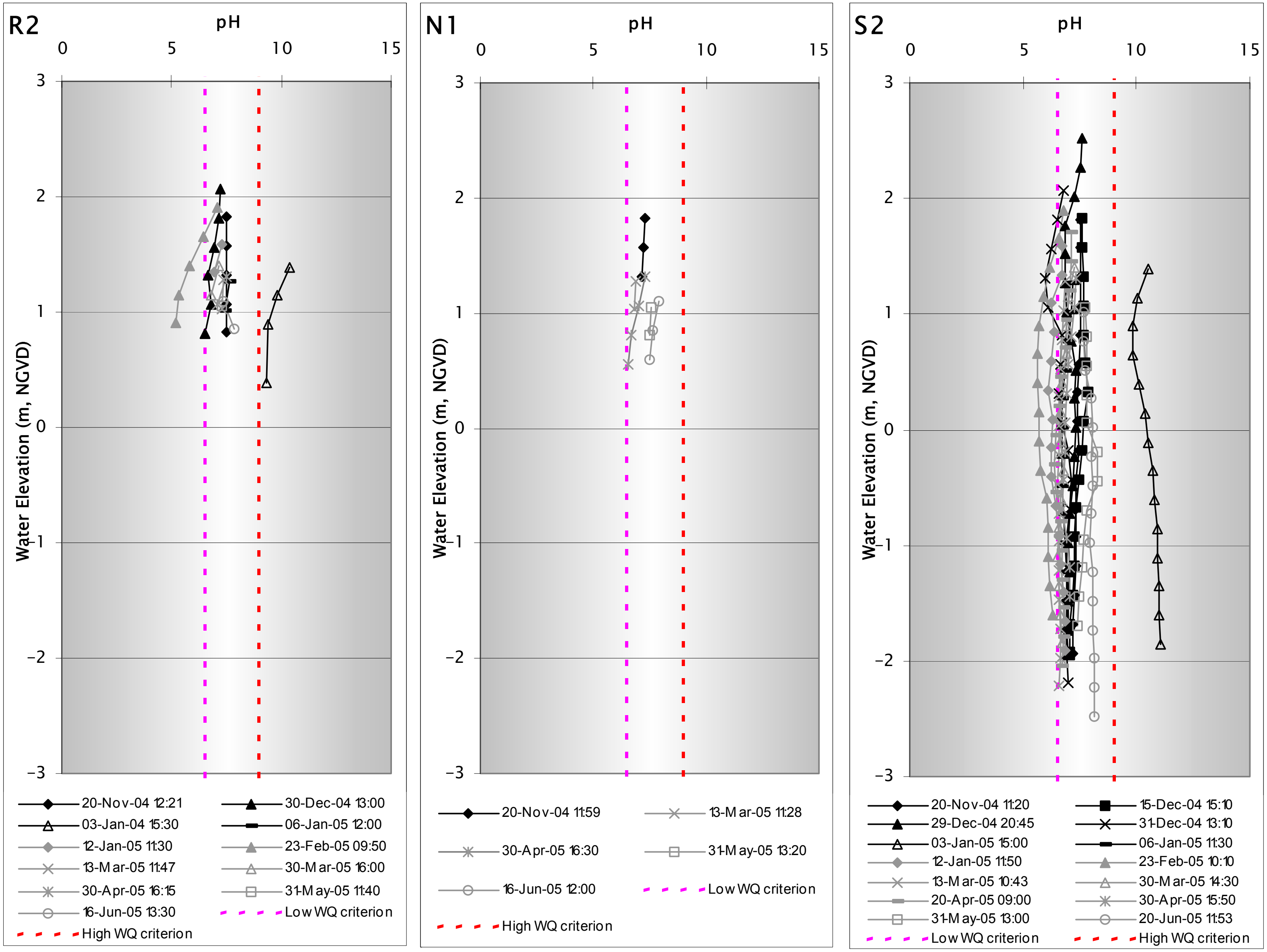


Figure 10.21. pH depth profiles at R2, N1, and S2 during Phases 3 and 4.

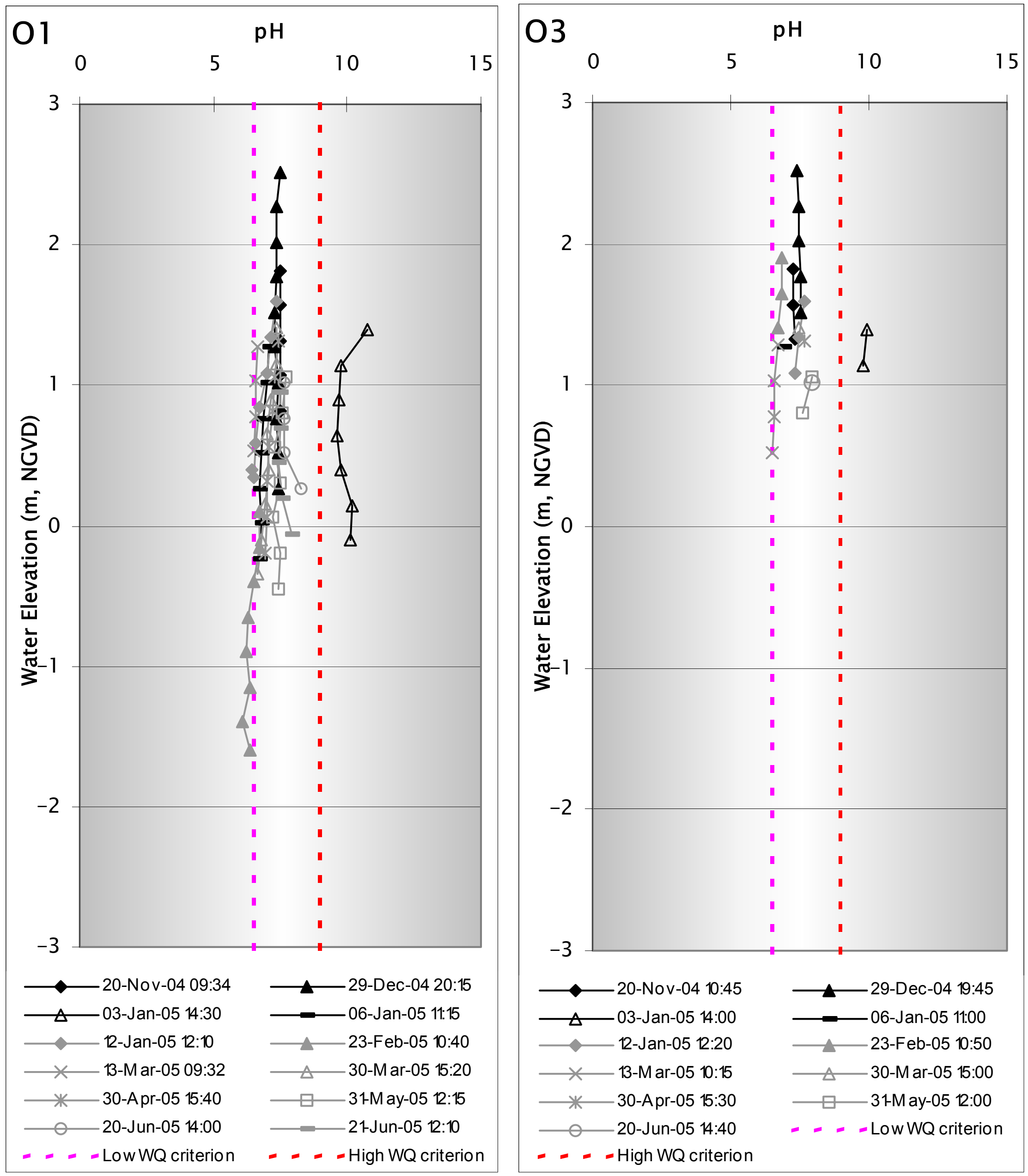


Figure 10.22. pH depth profiles at O1 and O3 during Phases 3 and 4.

10.4 Appendix E: Macroinvertebrate Data

Table 10.1. Macroinvertebrate taxa of the Carmel Lagoon.

site	wc = water column eb = epibenthic	date	G. Corophium	G. Eogammarus	I. Gnorimosphaeroma	M. Mysidae	B. Physidae	E. Baetidae	D. Chironomidae	D. Chironomidae pupa	D. Ephydridae	D. Empididae	H. Corixidae	C. Daphnidae	C. Dytiscidae	O. Libellulidae	O. Aeshnidae	H. Notonectidae	Nematoda
O3	eb	9-Sep-04	0	0	0	0	0	4	18	0	0	0	14	2112	18	0	0	0	0
O3	wc	9-Sep-04	0	0	0	0	0	3	9	0	0	0	15	2239	16	0	0	2	0
O3	eb	1-Oct-04	0	0	0	0	0	5	11	0	0	0	0	139	1	0	0	8	0
O3	eb	20-Nov-04	1	69	9	255	0	0	2	0	0	0	0	0	0	0	0	0	0
O3	eb	14-Feb-05	9	118	2	1082	0	0	0	0	0	0	0	0	0	0	0	0	0
O3	eb	13-Mar-05	10	6	1	371	0	0	0	0	0	0	0	0	0	0	0	0	0
O3	wc	1-Oct-04	0	0	0	0	0	0	0	0	0	0	0	171	0	0	0	9	0
O3	wc	20-Nov-04	0	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0
O3	wc	14-Feb-05	1	2	0	97	0	0	0	0	0	0	0	0	0	0	0	0	0
O3	wc	13-Mar-05	4	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
R2	eb	1-Oct-04	86	97	789	4	0	0	0	1	0	0	1	0	0	0	0	0	0
R2	eb	20-Nov-04	312	100	466	1	0	0	0	0	0	0	0	0	0	0	0	0	0
R2	eb	14-Feb-05	1	2	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0
R2	eb	13-Mar-05	2	9	3	8	0	0	0	0	0	0	0	0	0	0	0	0	0
R2	wc	1-Oct-04	25	0	99	0	0	0	2	5	0	0	0	0	0	0	0	0	0
R2	wc	20-Nov-04	143	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R2	wc	14-Feb-05	0	1	0	2	0	0	0	4	0	0	0	0	0	0	0	0	0
R2	wc	13-Mar-05	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
N1	eb	1-Oct-04	0	0	1	9	28	23	20	1	0	0	21	0	4	0	0	152	0
N1	eb	20-Nov-04	39	215	233	37	0	0	0	0	0	0	0	0	0	0	0	0	0
N1	eb	14-Feb-05	3	109	2	149	0	0	0	0	0	0	0	0	0	0	0	0	0
N1	eb	13-Mar-05	2	17	0	639	0	0	0	0	0	0	0	0	0	0	0	0	0
N1	wc	1-Oct-04	41	7	9	74	5	0	44	4	0	0	30	0	1	0	0	18	0
N1	wc	20-Nov-04	28	13	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N1	wc	14-Feb-05	1	0	0	9	0	0	0	1	0	0	0	0	0	0	0	0	0
N1	wc	13-Mar-05	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
found in stomachs of steelhead smolts (Fields, 1984)																			
major food invertebrates for juvinille steelhead (Kitting, 1990)																			
estuarine or freshwater																			
estuarine																			
freshwater																			

Table 10.1. Continued.

site	wc = water column eb = epibenthic	date	G. Corophium	G. Eogammarus	I. Gnorimosphaeroma	M. Mysidae	B. Physidae	E. Baetidae	D. Chironomidae	D. Chironomidae pupa	D. Ephydridae	D. Empididae	H. Corixidae	C. Daphnidae	C. Dytiscidae	O. Libellulidae	O. Aeshnidae	H. Notonectidae	Nematoda
R4	eb	1-Oct-04	21	77	5	13	0	0	81	3	0	0	6	0	0	0	0	0	0
R4	eb	20-Nov-04	26	49	66	4	0	0	0	0	0	0	0	0	0	0	0	0	0
R4	eb	14-Feb-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R4	eb	13-Mar-05	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R4	wc	1-Oct-04	9	20	23	48	0	0	66	2	5	0	5	0	0	0	0	3	162
R4	wc	20-Nov-04	23	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R4	wc	14-Feb-05	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R4	wc	13-Mar-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S2	wc	9-Sep-04	1	4	139	0	0	0	0	0	0	0	3	0	14	0	0	0	0
S2	wc	1-Oct-04	0	1	20	0	0	0	0	0	0	7	0	0	0	0	0	3	0
S2	wc	20-Nov-04	0	1	27	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S2	wc	14-Feb-05	0	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
S2	wc	13-Mar-05	0	0	2	1	0	0	0	0	0	0	0	0	0	1	0	0	0

found in stomachs of steelhead smolts (Fields, 1984)

major food invertebrates for juvinille steelhead (Kitting, 1990)

estuarine or freshwater

estuarine