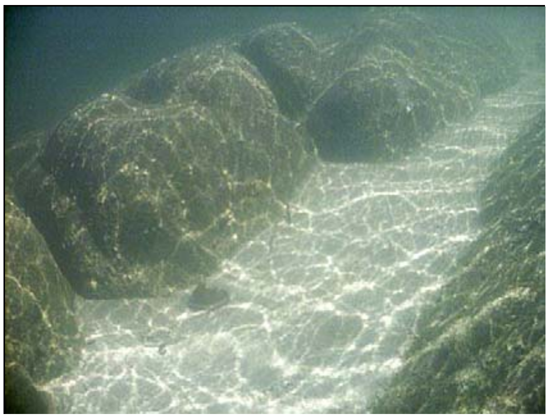

Publication No.: WI-2006-06
24 July 2006

Minor revisions 13 June 2007

The Watershed Institute

Division of Science and Environmental Policy
California State University Monterey Bay
http://watershed.csumb.edu

100 Campus Center, Seaside, CA, 93955-8001
831 582 4452 / 4431

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Carmel River Lagoon Enhancement Project: Water Quality and Aquatic Wildlife Monitoring, 2005-6

Joy Larson
Fred Watson, PhD
Joel Casagrande
Brian Pierce

All authors reside at:
Watershed Institute,
California State University Monterey Bay

Project leader contact details:
fred_watson@csumb.edu

Preface

This is a report to the California Department of Parks and Recreation. It describes water quality monitoring after the construction of the Carmel River Lagoon Enhancement Project. Included are data that have been collected for two years and preliminary assessment of the enhanced ecosystem. This report marks the completion of the first 2-years of monitoring water quality and aquatic habitat. These monitoring activities will continue for one more year as the enhancement project progresses.

Acknowledgements

The following CCoWS staff provided technical and field assistance:

Julie Casagrande
Wendi Newman
Kelleen Harris

And the following CSUMB students:

Ben Haberther
Zöe Carlson
Miles Daniels
William Perry
Jonathan Greening

We would also like to acknowledge the following agencies and people for their assistance and collaboration:

- California Department of Parks and Recreation
  - Amy Palkovic
  - Pam Armas
  - Ken Gray
  - Chris Peregrin
- NOAA Fisheries
  - John McKeon
- Monterey Peninsula Water Management District
  - Dave Dettman
  - Greg James
- California Department of Fish & Game
  - Kevin Urquhart
- Carmel River Steelhead Association
  - Frank Emerson
  - Clive Sanders
- Carmel Area Water District
  - Ray Von Dohren
- The Bug Sur Land Trust
  - Heather Brady

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Executive Summary

In summer and fall 2004, the California Department of Parks and Recreation (DPR) initiated 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 Federally 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 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.

This report summarizes monitoring results between July 2004 and June 2006 (for earlier results, see our previous reports, most recently, Larson et al., 2005). From September 2005 through December 2005, water quality in the lagoon followed seasonal patterns that were similar to those observed in previous years. A warm, saline, anox layer persisted at the bottom of the deepest parts of the lagoon. A relatively fresh surface layer gradually thickened with groundwater inputs to the lagoon, and was sharply diminished when ocean waves overtopped the sandbar in mid-October. The entire water column gradually cooled as Fall progressed. Temperatures were cooler nearer the surface, where mixing allowed free exchange of heat with the atmosphere. This mixing also entrained oxygen up to saturation levels in the surface layers. Super-saturated oxygen levels occasionally occurred deeper down at the primary halocline in association with pronounced photosythesis in this submerged layer.

The mechanical breach of the sandbar on Dec 27 2005 did not affect water quality parameters measured in the lagoon. Shortly after this breach, the sandbar had re-closed as a result of wave action, and the lagoon became highly stratified. Then on the 31st of Dec 27th members of the public breached the sandbar in the afternoon and the lagoon freshened. This began a repeating pattern of the sandbar opening and closing. The closure of the sandbar was brought on by large waves, often associated with storms. As wave action decreased, the force of the river would open the sandbar again, and the lagoon would drain rapidly. The difference in water quality parameters between high and low stages was significant. At high stages when the sandbar was closed, the lagoon was fresher and cooler with more dissolved oxygen. At low stages not only was there less habitat for fish (ie. less volume), but the lagoon was generally more saline and warmer.

On May 31 2006, the stage in the lagoon reached a record low at 1.7 ft. In June 2006, the sandbar was mechanically closed and tarps and sandbags were used to sustain a small flow of river water out to the ocean, thus maintaining a high stage in the lagoon. These efforts improved water quality in the lagoon.

Macroinvertebrates make up the majority of steelhead diet in a lagoon habitat. For this reason macroinvertebrate populations were examined for the 2-year monitoring period. Comparisons between the pre-existing lagoon and newly excavated Odello portions of the lagoon were made with a few key observations. Abundance and diversity in the water column of both the pre-existing and Odello portions of the lagoon were highest in late summer and fall. This could be due to warmer temperatures leading to more primary production in the system and/or stratification of the water column leading to greater diversity of habitats.

There are at least four taxa (peracarid crustaceans: two amphipods, an isopod, and a mysid) that are known to be steelhead prey in the Carmel Lagoon (Fields, 1984). These peracarids are the most abundant and consistent invertebrate taxa in the lagoon. Though the newly excavated lagoon has less abundant peracarid epibenthic fauna than the pre-existing lagoon, the invertebrate fauna of the newly excavated Odello portion of the lagoon has developed over the 2-year monitoring period and is expected to develop further. Ostracods were relatively abundant in the newly excavated Odello portion of the lagoon, and perhaps not previously known in the pre-existing lagoon. this suggests that the newly excavated lagoon may provide habitat that is distinct from the pre-existing lagoon – perhaps owing to its productive freshwater spring and generally more hydrologically isolated location.

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. It is separated from the ocean by a large sandbar. In the summer and fall when the sandbar is closed, the lagoon is a relatively small water body, being the surface expression of a larger aquifer and its interaction with the ocean. In the winter and spring when the sandbar is open, it is the mouth of the river as it flows into 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 at the terminus of the river 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 habitats 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). The northern backwater (North Arm) section of the lagoon is circular (*c.* 300 m in diameter) and comprises a system of channels and islands filled with aquatic vascular vegetation (Casagrande, 2002). The southern backwater (South Arm) is much more linear (*c.* 640 m; it was ~ 200 m before the enhancement project, the extension increased the length by ~ 460 m). A small hill with underlying bedrock confines the South Arm to a small channel that swells at high water into a wetland that was once used for agriculture (Casagrande, 2002). 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.

Deep-water habitat is currently found in the South Arm. In the 1996 and 1998 the South Arm was dredged and widened to increase the amount if deepwater habitat for steelhead (Alley, 1997; Entrix, 2001). In the summer of 2004, the CDPR implemented the construction phase of the Carmel River Lagoon Enhancement Project (CRLEP). This project has 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).

1.2 Purpose

In the summer of 2004, formation of new lagoon habitat began. Excavating the earth and allowing shallow groundwater to fill the resulting void achieved the creation of a new portion of the lagoon, marsh, and riparian habitat as an extension of the pre-existing South Arm (Fig. 1-1). A detailed timeline of this process is in Larson et al, 2005.

Figure 1-1. Map of Carmel River Lagoon and surrounding area (Aerial photograph courtesy MPWMD, 2004).

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. 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 for two years after excavation and establish data collection and analysis methods for future monitoring in the lagoon.

Water quality monitoring began on 20 July 2004 several weeks after excavating of the Odello arm, and has been ongoing since. In addition, invertebrate sampling and steelhead surveys have also been conducted.

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. This report addresses three main topics: hydrology, water quality, and aquatic wildlife (macro-invertebrates and steelhead habitat).

2 Hydrology

2.1 Overview

The Carmel Lagoon forms at the terminus of the Carmel River. During the dry summer months when the river is not flowing into it, the lagoon is a shallow body of water that is separated from the ocean by a sandbar. While the lagoon is isolated during the dry season, the stage fluctuates as a result of a slow flow of water back and forth through the sandbar. When the sandbar is closed and the river is not flowing into it, the lagoon stage responds to tidal fluctuations and the height of ocean waves. The salinity probably increases slightly by this exchange of water with the ocean, but this may be offset by a slight, continuous replenishment by shallow groundwater surrounding the lagoon. Beginning September and October, large waves overtop the sandbar increasing the stage and the salinity of the lagoon.

During the wet season and after the river is connected to the lagoon, the volume and stage increase as water accumulates behind the sandbar. The sandbar is mechanically breached when the stage reaches ~10 ft (A stage greater than 10 ft has the potential to inundate surrounding residential areas). After the initial breach, the main embayment of the lagoon is reduced to a wide sandy channel. At this time, the lagoon stage fluctuates with the tides and intensity of river runoff. Salinity in the lagoon is influenced primarily by both the intensity of stream flow entering the lagoon and the amount of salt water entering through the open sand bar.

Data presented in this section are from a variety of sources summarized in Table 2-1. Mean sea level, wave height, and stage data were used to calculate the Dynamic Wave Head (described below). Carmel River flow data is from the USGS gauging station immediately upstream of the lagoon (11143250 CARMEL R NR CARMEL CA). Precipitation data were average from two weather stations.

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/

2.1.1 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) and by waves overtopping the sandbar. 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. For this project, effective wave heights have been computed for closed lagoon conditions:

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

Where:

$h_{c,t}$ = effective wave height (closed sandbar) (m, NGVD)

$k_{h,c}$ = effective wave height constant (closed bar) = 0.75998 m

$c_{h,c}$ = effective wave height coefficient (closed bar) (-) = 0.350793

h_t = dominant wave height in near-shore waters

c_m = tide coefficient (-) = 0.16

m_t = tide level (m, NGVD)

Below is an overview of the hydrology of July 2004 – July 2005 (Sections 2.2 and 2.2.2, presented in Larson et al, 2005), followed by a description of the hydrology of July 2005 – June 2006.

2.2 2004 – 2006

2.2.1 June – December 2004

The relative timing of the final sandbar closure and cessation of river flow initially set summer water level and salinity in early summer. 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. 2-1). At this time, the river was no longer connected to the lagoon, and the sandbar had closed. As water slowly flows back and forth through the sandbar during the summer, the water level in the lagoon is set by the ocean – due to tidal fluctuations and the height of ocean waves (Watson & Casagrande, 2004). 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).

The lagoon stage remained low throughout August with the lowest stage, 2.36 ft, observed on 6 Aug 2004 (0.74 m, NGVD). 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. Fresh groundwater was also pumped 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.

Large wave events began in late August (Fig. 2-4), and evidence of over wash was observed on the sandbar. These large waves entering the lagoon increased the stage and salinity of the lagoon. The first significant rain event happened in the second half of October 2004, however, the river did not connect to the lagoon until 28 Dec 2004, after a large amount of precipitation on the 27th of December. By the 29th of December, the stage in the lagoon reached ~10 ft and a channel was bulldozed through to the ocean.

2.2.2 January – June 2005

Precipitation in the 2004-2005 season occurred in several distinct storm periods, with heavy rain falling over a few days in December and January, a few days in February, and a few days in March. Lagoon stages fluctuated significantly during the first of half of 2005 as flows from the river (Fig. 2-2) responded to these episodes of precipitation (Fig. 2-3).

In early January, many gullies were present on the banks of the Odello West Arm as local runoff drained over un-vegetated banks into the lagoon. Days of intense rainfall were followed by an increase in river flow, which raised the stage of the lagoon in mid February and mid March.

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.

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. 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. This has also been observed in previous years (Watson and Casagrande, 2004).

2.2.3 July – November 2005

The Carmel River flowed at the USGS gauging station upstream from the lagoon through August 25, 2005. This is the longest the river has sustained flow into the dry season in 15 years, not including El Niño years of 1995 and 1998 (Fig. 2-1). In the beginning of July the sandbar closed and the stage quickly increased (Fig. 2-2). On the 9th of July, the sandbar opened again and stayed open through the end of August.

After closure, the stage was low throughout September, though stages did not get as low as they were in July and August of 2004 (Fig. 2-2 and 2-4). To increase the volume of freshwater in the lagoon, well water was pumped into the south arm and tertiary treated wastewater from CAWD was pumped into the river channel as in 2004.

In October there was an increase in the stage from large waves washing over the sandbar. This keeps stages higher in the fall than in the late summer until the river connects to the lagoon. Figure 2-5 illustrates how the dynamic wave head changes from summer through the end of December, specifically the control that the ocean had on the lagoon water level both by pulses of over-bar flow from August through December and by slow through-bar flow.

2.2.4 December 2005

The first significant storm of the wet season was during the first week of December (Fig. 2-3), though the river did not connect to the lagoon until the end of December after more precipitation had fallen in the watershed (Fig. 2-2). As water accumulated behind the sandbar and the stage increased, mechanical breaching of the sandbar began on the 27th of December (Fig. 2-7 a.), opening the sandbar early on the 28th. Sandbar management also included spreading the sand that was dug from the channel over the sandbar (Fig. 2-7 b. and c.).

In the first few days after the breach, the channel stayed on the bedrock ledge (Fig. 2-7 e.). As storms brought large waves, sand was piled up in the breach channel, effectively closing the sandbar. This happened repeatedly throughout the storm season (Fig. 2-7 f.).

Early on the 31st of December, shortly after the initial breach, the sandbar was closed and the stage increased. A group of people dug a small channel between the lagoon and the ocean (Fig. 2-8 a. – c.). Within an hour, this small channel was a rush of standing waves to the ocean, and the lagoon drained 3.1 ft in a 24-hour period, from 7.55 ft at 5pm on the 31st to 4.48 ft on 1 January 2006 (Fig. 2-8 d. – f.).

2.2.5 January – April 2006

Precipitation in the 2005-2006 season was different from the 2004-2005 season. After a large amount of rain in late December 2005 connected the river, January 2006 was relatively dry. At the end of February long sustained periods of precipitation continued through April.

When the sandbar was initially breached, the Carmel River was flowing at 2.6 m^3/s (92 cfs). After this breach, the flow increased to 29.45 m^3/s (817 cfs) on the 3rd of January and decreased through the end of February. After a large amount of rain at the end of February, the river discharge increased again in the beginning of March. Consistent rain over many consecutive days in the saturated watershed in March and April brought the river discharge to a peak of 102.52 m^3/s (3620 cfs) on the April 5th (Fig.'s 2-2 and 2-3).

Waves washed over and through the open the sandbar (a and b in Fig. 2-9), propagating through the main lagoon when the sandbar is open (b – f in Fig. 2-9). This propagation did not influence the water quality in the main lagoon; it was just the energy of the waves that pushed the fresh river water through the main lagoon. Large waves that accompany storms would bring sand into the lagoon, and the force of the river exiting the lagoon would move the sand back out towards the ocean. This caused a buildup of sand between these two forces in the low breach channel. At times the breach channel stayed narrow and shallow along the edge of the sandbar permitting only a small flow out of the lagoon. Other times, however, this accumulation of sand would close the sandbar.

The closure of the sandbar brought on by large waves associated with storms, followed by rapid draining was a regular pattern since the initial sandbar breach; it occurred 13 times in January and February (Fig. 2-6 and Fig. 2-10). Large ripples in the sand substrate and high water marks on the banks remained after the lagoon rapidly drained (Fig. 2-11 a. and b.) (Fig. 2-11 c.). The benthic amphipod Corophium (an important source of food for steelhead – discussed in Section 5.1.1) build small tubes of mud along the substrate (Fields, 1984). In the Odello extension, these tubes were covering the bank in an area that was under water before the breach of December 31st (Fig. 2-11 d. and e.).

After the sandbar opens abruptly, the lagoon would drain to a lower stage each time (Fig. 2-6). This corresponds to the decreasing river flow from January and February. When the discharge entering the lagoon increases in March, the stage also increases.

More gullies formed along the banks of the Odello extension (Fig. 2-13 d.), even though more vegetation is present than last year. California Conservation Corps crews, Return of the Natives, and The Big Sur Land Trust have lead the efforts over the last year to eradicate weeds and propagate native plants along the banks of the Odello extension (Fig. 2-13 e. and f.). These gullies among newly planted vegetation are an indication that it will take years before this vegetation is able to stabilize the banks.

The difference in appearance of the lagoon during high and low stages was significant, as illustrated in Fig. 2-12. At low stages, the only water in the main lagoon was the river channel flowing out to the ocean; there was little, if any, standing water in the main body of the lagoon. The North Arm was only connected to the main lagoon by small channels (Fig. 2-13 a.) and the South Arm was often cut off from the main lagoon by a sandbar that formed from river deposition (Fig. 2-13 b.), as observed in previous years (Watson & Casagrande, 2004; and Larson et al, 2005). These conditions limit the amount of habitat available for steelhead.

At higher stages, the main body of the lagoon becomes inundated with water (Fig. 2-13 c.) and eventually becomes connected to the North and South Arms. The flow of the river can easily been discerned from the adjacent standing water though water quality conditions are similar.

2.2.6 May – June 2006

On May 31 2006, the stage in the lagoon reached a record low at 1.7 ft (Fig. 2-14 a.). At this stage the shallow areas of the lagoon have no water present (Fig. 2-14 b.) and the main lagoon is a small stream flowing across sand. On June 16, the sandbar was mechanically closed and the stage quickly increased. To avoid the sandbar breaching again, tarps and sandbags were used to micro-manage the flow of water out of the lagoon in order to keep the rate of outflow equal to the rate of inflow thereby maintaining a higher volume of water and more suitable habitat for rearing juvenile steelhead in the main embayment (Fig. 2-14 c. and d.).

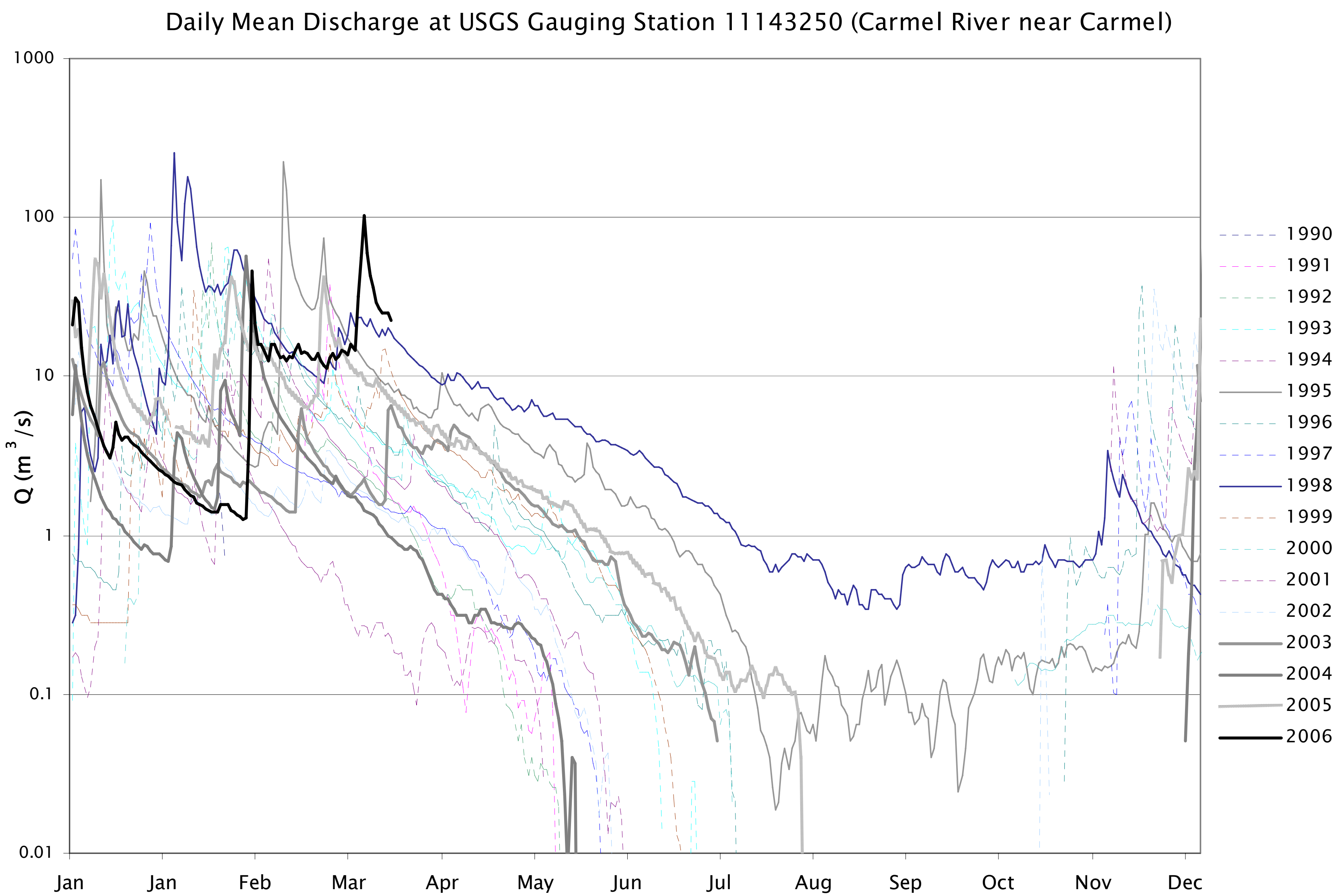


Figure 2-1. Inter-annual comparison of streamflow recession.

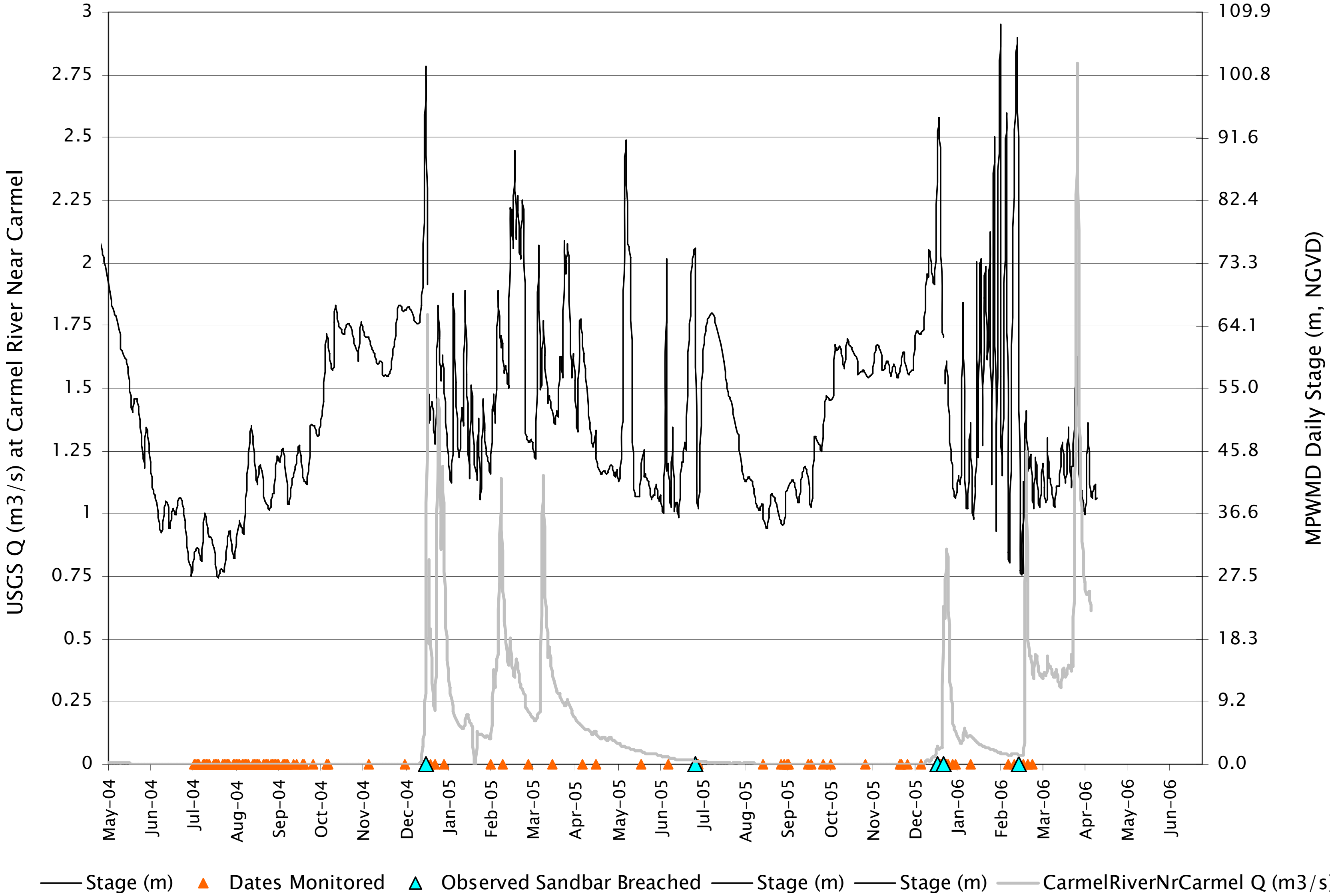


Figure 2-2. Time series of discharge from the Carmel River and lagoon stage.

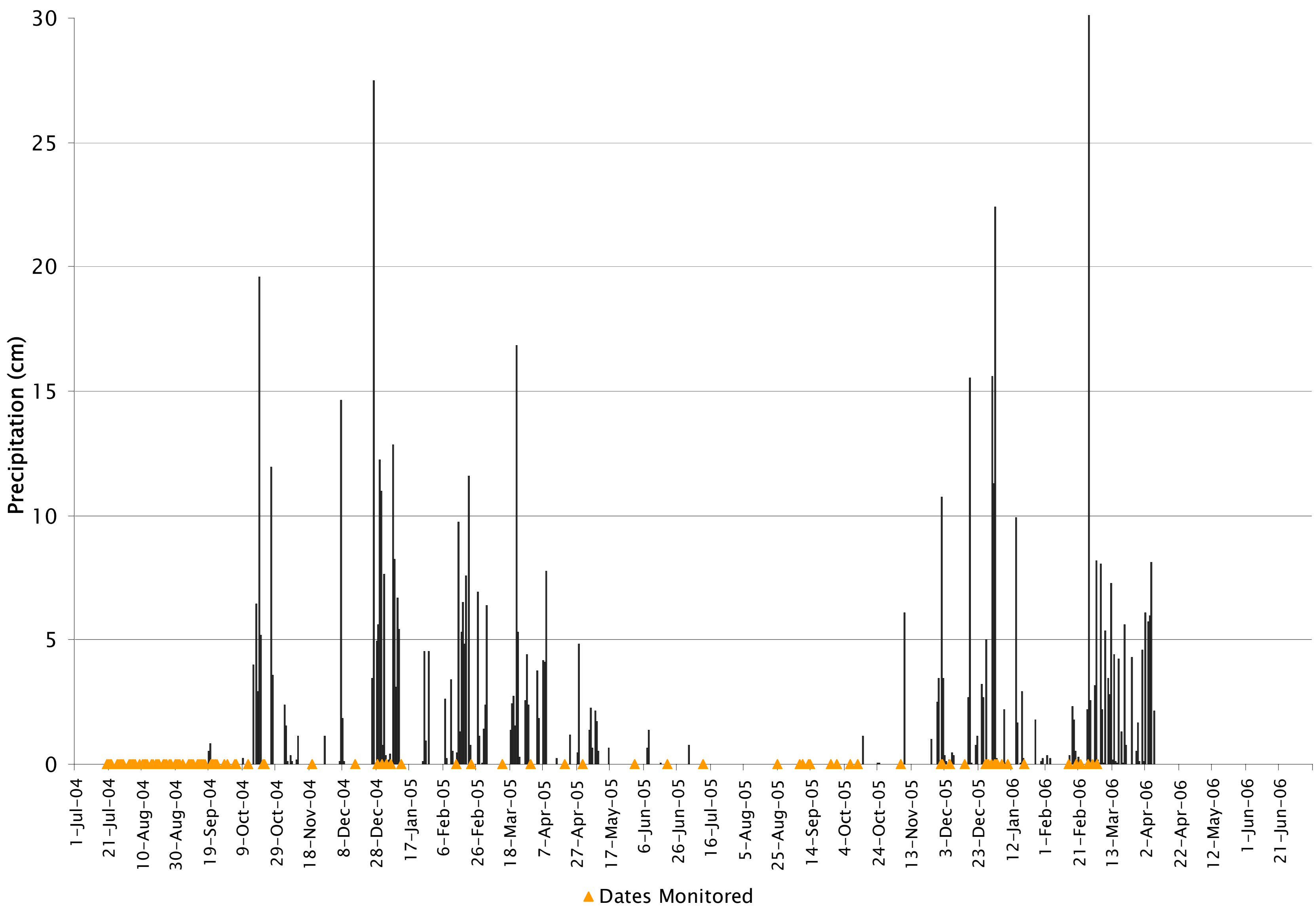


Figure 2-3. Precipitation from July 2004 – June 2006.

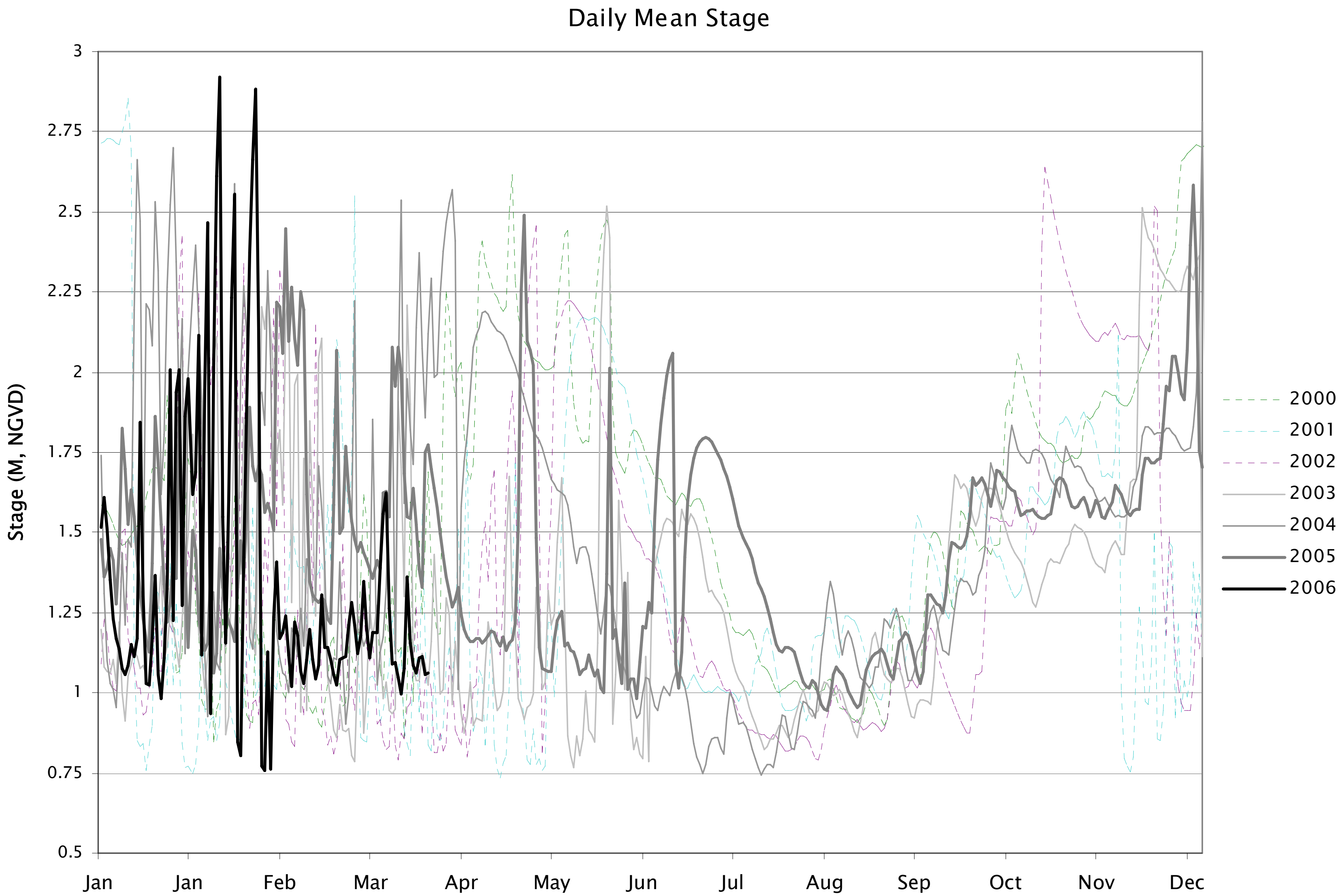


Figure 2-4. Inter-annual comparison of seasonal variations in lagoon stage.

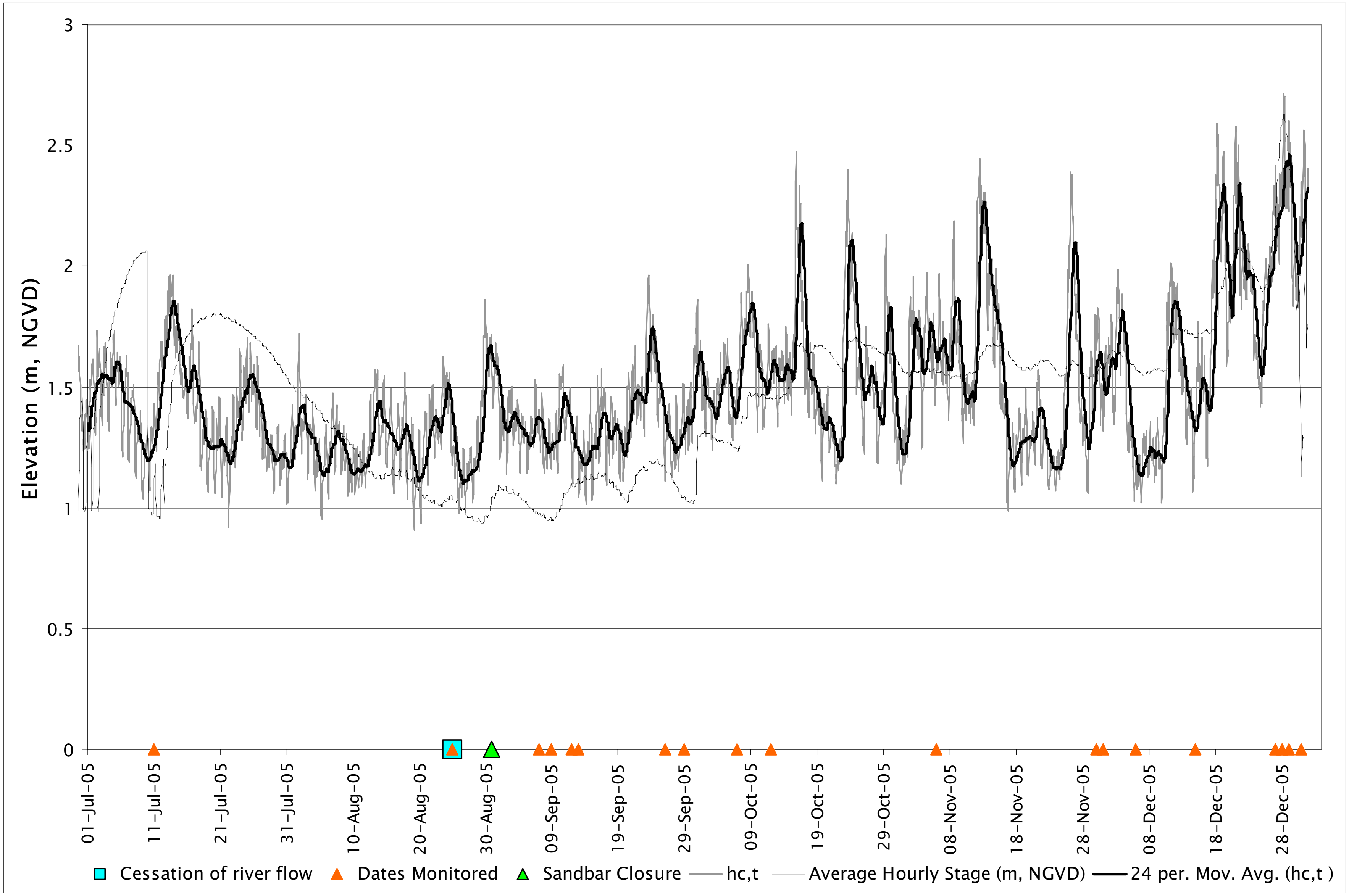


Figure 2-5. Time series of the Dynamic Wave Head and moving 24-hour average vs. Lagoon stage from Jul - Dec 2005.

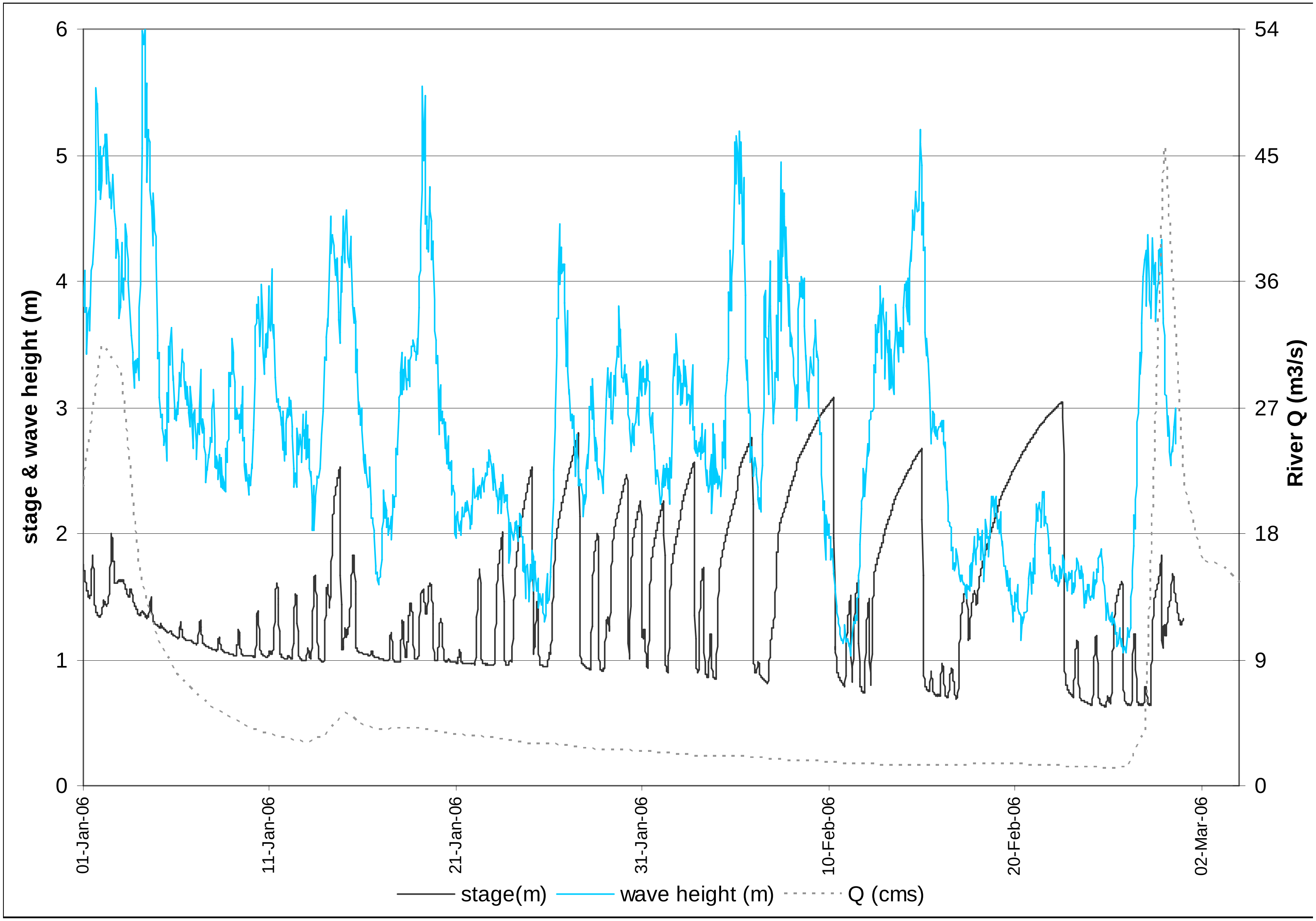


Figure 2-6 Lagoon stage, wave height, and river discharge for the first 3 months of 2006. The repeated closing and opening of lagoon are the large spikes in the stage data. This can be seen in the rise of the stage to over 2.5 m, followed by the drastic fall from a high stage to a low stage.

(a) Late on December 27, 2005 the sandbar was mechanically breached.

(b) Sandbar management continued after breaching. (29 Dec 2005)

(C) Sand that was piled up from the excavated breach channel was spread across the sandbar. (29 Dec 2005)

(d) Sandbar breach on 29 Dec 2005.

(e) Breaching plans included confining the breach channel to the bedrock ledge at the southern most corner of the lagoon. (28 Dec 2005)

(f) The breach channel filled in with sand after a large wave event. (19 Jan 2006)

Figure 2-7. Sandbar breach by Monterey County Public Works.

(a) ~3:00 pm

(b) ~3:00 pm

(C) ~3:00 pm

(d) ~4:00 pm

(e) ~4:00 pm

(f) ~4:00 pm

Figure 2-8. The lagoon drained into the ocean very quickly when the sandbar was breached by people recreating on the beach on 31 December 2005.

(a) Waves washing over the sandbar. (2 Jan 2006)


(b) Large waves entering lagoon at the north corner over the sandbar (top right of photo) and at the south corner through the breach channel (middle of photo). (2 Jan 2006)


(C) Waves washing up on the east bank of the main lagoon. (2 Jan 2006)


(d) Waves propagating through the Main Lagoon after passing the sandbar. (3 Jan 2006)


(e) Waves propagating through the Main Lagoon. (6 Jan 2006)


(f) Waves propagating through the Main Lagoon. (6 Jan 2006)

Figure 2-9. Large waves entering lagoon. From the parking lot (a), from the granite cliffs that line the south bank of the lagoon (b and c), from the North Arm (d), and from the parking lot (e and f).

(a) Open sandbar on 15 Feb 2006

(b) Closed sandbar on 19 Feb 2006

(c) Stage = 2.89 ft, 15 Feb 2006.

(d) Stage = 7.8 ft, 19 Feb 2006.

Figure 2-10. Before and after sandbar closure in Feb 2006. From the steps at the south end of the beach (a and b) and from the North Arm (c and d).

(a) Ripples in the sand in the North Arm created by water flowing quickly out of the lagoon. (1 Jan 2006)

(b) Ripples in the sand in where the North Arm meets the Main Lagoon created by water flowing quickly out of the lagoon. (1 Jan 2006)

(c) Kelp lines on the bank of the lagoon mark where the water surface was.

(d) Corophium Mud Tubes exposed out of water after the lagoon drained rapidly (site O2) (1 Jan 2006)

(e) Corophium Mud Tubes exposed out of water after the lagoon drained rapidly (site O2) (1 Jan 2006)

Figure 2-11. Rapid draining of the lagoon.

(a) Stage = 5.08 ft. (3 Jan 2006)

(b) Stage = 3.78 ft. (1 Mar 2006)

(C) Stage = 5.08 ft. (3 Jan 2006)

(d) Stage = 3.8 ft. (6 Jan 2006)

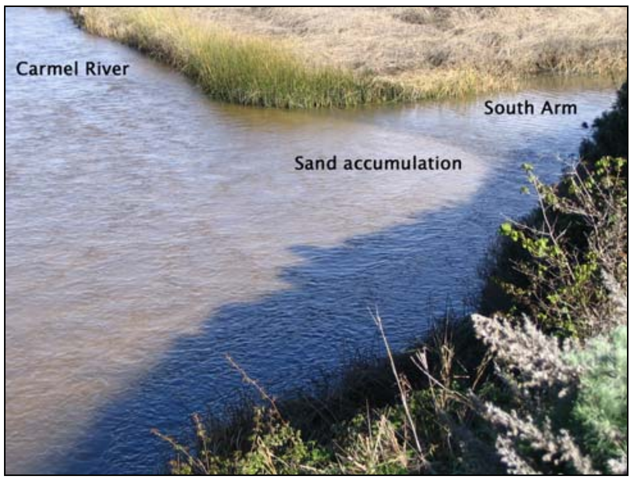
(e) Stage = 5.14 ft. (1 Jan 2006)

(f) Stage = 3.8 ft (6 Jan 2006.)

Figure 2-12. The appearance of the lagoon is different at a stage difference of less than 1.5 ft. Looking across the main lagoon at the breach channel (a & b) and at the sandbar (c & d) from the North Arm. Looking out at the main lagoon from the parking lot (e & f).

(a) Trickle from North Arm (right of photo) into the main lagoon (left). (4 Mar 2006)

(b) Seagulls in the main body of the lagoon (R2). The North Arm is connected to the main lagoon in the background behind the seagulls. (1 Jan 2006)



(c) Accumulation of sand deposited from the Carmel River at the South Arm entrance (1 Mar2006)

(d) Alejandro, Rodolfo, and Maria of the California Conservation Corps working around the Odello extension. (3 January 2006)

(e) Volunteers along the bank of the Odello extension at a planting event hosted by Return of the Natives. (21 January 2006)

Figure 2-13. The main lagoon at low and high stages (a and b), the sandbar that forms at the entrance of the South Arm (c), gullies in the new Odello extension (d), and efforts to vegetate the banks of the Odello extension (e and f)

(a) Record low stage (1.7 ft) on May 31 2006 was below the staff plate at the South Arm Pipe (photo taken at stage of 1.9 ft).

(b) At low stages there is not water in shallow areas of the lagoon. This is sampling site O3 at 1.9 ft stage (31 May 2006)

(c) The flow of the river out to the ocean was confined to the rock sill at the southern edge of the main lagoon with tarps and sandbags (19 Jun 2006).

(d) Outflow of water after it passes over the rock sill into the ocean (19 Jun 2006).

Figure 2-14. Extremely low stage on May 31 and efforts to increase the stage with management of the Sandbar.

3 Lagoon Description and Monitoring Sites

3.1 Lagoon Description

The Carmel River Lagoon area consists of a diverse assemblage of both seasonal and perennial wetland habitat types that serve as critical wildlife habitat for a wide range of species (Casagrande, 2006). Many aquatic habitat types are contingent on lagoon water volume, which is determined by river flow, sediment accumulation, wave and tide conditions, and status of the sandbar (open or closed). Larger lagoon volumes provide more available aquatic habitat. Some areas of the lagoon are permanently under water, while other areas, including the boundaries of perennial areas, are inundated only during high stages. This seasonal inundation of certain areas results in different vegetation types, invertebrate populations, and microhabitat in these areas that is distinct from perennial water habitats. This combination of seasonal and perennial wetland types at high stages provides complexity to the aquatic environment that increases available habitat for steelhead.

Areas of the lagoon that are permanently flooded include the South Arm and small portion of the North Arm. Substrate conditions in these areas consist primarily of fine sediments (silt and clay), detritus, and smaller amounts of sand. Along with steelhead (*Oncorhynchus mykiss*), western pond turtles (*Clemmys marmorata*) and California red-legged frogs (*Rana aurora draytonni*) have also been observed in the South Arm. Beds of submerged pondweed (*Potamegeton sp.*) are present in the South Arm, and the banks are lined with tule (*Scirpus sp.*), or bullrush (Casagrande, 2006). Tules were present in the pre-existing South Arm prior to excavation of the Odello extension, and are now being propagated along the new banks of the extension.

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 have been since been adjusted to include the newly excavated portions of the lagoon. Figure 3-1 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.

In general, all sites are monitored from a kayak during dry weather monitoring, and are waded during the wet weather monitoring for safety and logistical reasons. All monitoring sites are described below and photographed in Fig. 3-2).

3.2 Monitoring sites

Most of the water quality monitoring sites are in the permanent wetland habitat type of the South Arm. Another site in the main embayment of the lagoon was routinely monitored for water quality. Locations across the entire lagoon were also sampled for macroinvertebrates.

3.2.1 South Arm

The wastewater treatment plant pipe that crosses the South Arm of the lagoon is a primary historic sampling site that is over one of the deepest parts of the lagoon (S2 Fig. 3-1 and Fig. 3-2 a.). This deep section of the lagoon experiences the most stratification with respect to salinity, temperature, and dissolved oxygen.

S2 is sampled during each visit to the lagoon. It is the location of a staff plate and a stage logger maintained by the Monterey Peninsula Water Management District. Data collected from this site are taken from about the

Figure 3-1. Zones and monitored sites in all areas of the lagoon (Aerial photograph courtesy MPWMD, 2004).

middle of the pipe. Surface grab samples are collected directly into sample bottles, and an Alpha Sampling Bottle is used to obtain a sample from within 1 m of the bottom.

This section of the South Arm is bordered on the northern edge by a large seasonal mudflat. When the sandbar is closed and the stage increases, this area is inundated. When the sandbar breaches the substrate of organic material, silt, clay, and smaller amounts of sand are exposed. These mudflats provide foraging and resting habitat for Canada geese (*Branta Canadensis*) (Casagrande, 2006).

The newly excavated Odello West area of the lagoon is different from the pre-existing South Arm. The substrate in all of the Odello sites is unconsolidated, almost quicksand-like. It is unlike the North Arm which has more organic material along the bottom, and the particle sizes of the Odello extension are much smaller than those found in the main lagoon and river channel. In the spring of 2006, many portions of the bank gullied into the lagoon, adding complexity to the ground both above and beneath water.

O1 (Fig. 3-1 and Fig. 3-2 b.) is the deepest part of the newly excavated lagoon area and was routinely monitored during dry weather monitoring. During the wet season when the kayak is not used, the soft and sticky mudflats that were unsafe to walk through limited access to this site, and this site is not visited.

O2 is the northern branch of the Odello extension (Fig. 3-1 and Fig. 3-2 c.). At low stages, a freshwater spring can be seen at the top of this site. This site was monitored at all times to ascertain the effects of this slow freshwater input to the lagoon. This is the primary location of re-vegetation efforts by the California Conservation Corps, Return Of the Natives, and the Big Sur Land Trust (Fig. 2-13 *e* and f). After long periods of sustained rain, the bank of the lagoon at this site started to gully (Fig. 2-13).

The southern branch of the Odello extension, **O3** (Fig. 3-1 Fig. 3-2 d.), was rarely sampled from a kayak because it is so shallow. Monitoring at this site usually involves getting out of the kayak and wading into the water to collect measurements and samples. In February 2006, small seeps of groundwater were visible bumbling up through the substrate at O3 (Fig. 3-2 e.), and during the lowest stage on May 31 2006; there was no water at this site.

3.2.2 Main Lagoon

The main lagoon is an area of the lagoon that is wide and shallow with little to no vegetative cover or emergent vegetation. The substrate consists of coarse sands and gravels with small amounts of fine sediment (Casagrande, 2006), with very little organic material. This main embayment occupies a large surface area and is exposed to continuous wind action; it is therefore subject to more mixing than all other areas of the lagoon. This is where the river passes through the lagoon when the river and the lagoon are connected. It also the part of the lagoon that undergoes significant changes in shape from year to year, depending on where the sandbar is breached. The deepest locations are against the granite bluffs along the southern shore of the embayment (Casagrande, 2006). This is an area where steelhead have commonly been observed.

R2 is the sampling location in the main lagoon (Fig. 3-1 and Fig. 3-2 f.). Often measurements were taken from standing water, though at low stages during the spring the only water in this part of the lagoon was the flowing river channel.

3.2.3 Additional monitoring sites

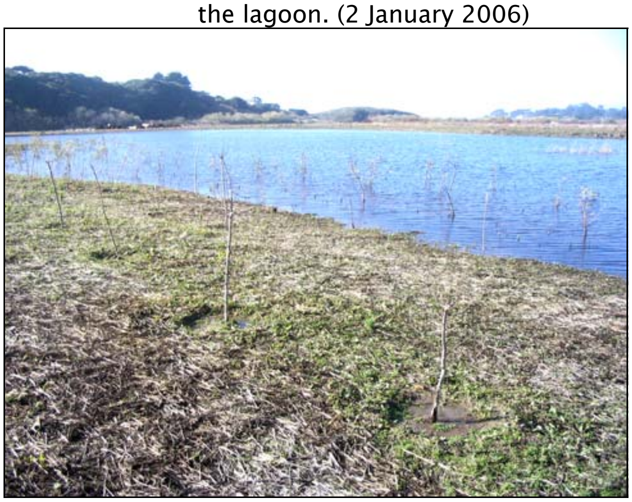
In addition to the monitoring sites described above, there are two other sites that were also sampled for invertebrates.

In the North Arm is more permanent wetland habitat. **N1** is the sampling site in the north arm and is located next to the parking lot (Fig. 3-1). This permanent estuarine habitat is surrounded by seasonal emergent tule marsh and low growing wetland hydrophytes. These surrounding areas are usually flooded when the sandbar is closed and stream flow entering the lagoon is present. The substrate in the North Arm consists of finer sediments, accumulated organic debris, and smaller amounts of sand (Casagrande, 2006).

The Carmel River channel was also sampled for invertebrates. **R5** includes the active streambed immediately upstream of the main embayment. It is not perennial; stream flows cease by early summer (See sections 2.2.1 and 2.2.3). Substrate in the channel consists of gravels, coarse sand, and smaller amounts of cobble and fine sediments. Vegetation is limited primarily to successional willow saplings and various exotic weeds that are scoured out each winter (Casagrande, 2006).

(a) South Arm pipe historic monitoring site S2. Debris on pipe is from the abrupt draining of the lagoon. (2 January 2006)

(b) Deepest part of the Odello extension O1. (22 October 2004)



(c) Newly planted willows on the bank of the Odello extension at O2. (28 December 2005)

(d) The shallow southern branch of the Odello extension O3. (1 January 2006)

(e) Seeping groundwater at the bottom of O3 at a stage of 2.98 ft (15 Feb 2006)

(f) Main Lagoon monitoring site R2. (4 March 2006)

Figure 3-2. Water quality monitoring sites.

4 Water Quality Monitoring

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. The primary objective of water quality monitoring was to track the dynamics of these parameters over time. Optimal rearing conditions are usually met 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, and the lagoon is typically highly stratified by salinity, temperature, and dissolved oxygen. 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 in the South Arm are dark and have a perennial saline lens at the bottom of the water column. 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. 2-year time series of water quality parameters are presented in Appendix A.

4.1 Sampling and analytical methods

The water quality parameters that were measured are temperature, salinity, dissolved oxygen (DO), pH, turbidity, and suspended sediment concentration (SSC). Many parameters were measured *in situ* and some were taken from samples. Often measurements and samples were taken from a kayak.

The parameters measured *in situ* were taken with an YSI Environmental 556 MPS Multiprobe System in 0.25 m interval depth profiles. These are listed in Table 4-2 with the instrument specifications for each parameter. The YSI MPS was calibrated monthly.

Surface samples were collected from each site on every visit to the lagoon. Turbidity was measured 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. SSC analysis was done on every sample by vacuum filtration. For a more extensive overview of CCoWS laboratory procedures, see Protocols for Water Quality and Stream Ecology (Watson et al, 2005).

4.2 Monitoring schedule

The timing of water quality monitoring was conducted according to the hydrologic conditions of the lagoon and can be separated into two categories: dry weather monitoring and wet weather monitoring. See Table 4-1 for a list of dates that were monitored from July 2005 – June 2006. Monitored dates are also presented in relation to precipitation, stage, and river flow in Fig.'s 2-2 and 2-3.

Routine monthly dry weather monitoring within the pre-existing lagoon and new extension of the South Arm was conducted on 6 separate dates in 2005, and 5 separate dates in 2006. Wet weather monitoring included sampling previous to, during, and after two significant storm events: one in early December before the river was connected to the lagoon and one in late December/early January as the river connected to the lagoon and the sandbar was mechanically breached.

Forecasts and radar images indicated long sustained periods of precipitation late in the season; there was not a discrete third storm isolated from other storms. These storms were not monitored in the same pre-storm, during storm, and post-storm schedule of the previous storms, but rather periodically throughout sustained precipitation, after large foreseen amounts of rain, and significant increases in river discharge.

Another important hydrologic feature of the lagoon that was closely monitored was the regular pattern of sandbar closure followed by incidental breaching and rapid draining of the lagoon. This was documented on two separate occasions. On Dec 31 2006 members of the public dug a small channel in the sandbar that connected the lagoon to the ocean. Within an hour this small channel held standing waves of lagoon and river water to the ocean. On Feb 22 2006 high flows pushed the sandbar open naturally and the stage of the lagoon dropped from 6.8 ft in 3 hours. Data were collected during or immediately after each of these events, with planned routine monitoring providing the conditions of the lagoon before these two events.

This section includes all YSI depth profiles and data from all samples that were collected from the lagoon from July 2005 through June 2006.

Table 4-2. 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

Table 4-1. Dates of water quality monitoring visits to the lagoon.

Purpose of visits	Dates	# Sites sampled
Routine monthly dry weather monitoring	Aug 25, Sep 29, Oct 25, Nov 6, 7, & 30 2005.	4
The first significant storm event of the season before the river was connected to the lagoon.	Dec 1, 6, and 15 2005	4
The second significant storm event of the season as the river connected to the lagoon, the stage increased, and the sandbar was mechanically breached.	Dec 27, 28, 29, & 1 2005, and Jan 1, 2, 3, 6, 9, & 19 2006.	4
Scattered dates throughout long periods of precipitation.	Feb 15, 19, 22, 26, Mar 1, 4, 11, 22, Apr 9, May 31, Jun 19 and 22 2006	3 - 5

4.3 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. In the late summer and fall, there is usually a layer of freshwater at the surface of the water underneath the South Arm pipe (S2). The thickness and elevation of this layer fluctuates with season and hydrological condition.

4.3.1 Results

The bottom of the freshwater layer at S2 stayed at -1 m NGVD in August and September, and the layer thickened to -2 NGVD on the 29th of Sep. In October and November when waves washed over the sandbar, the layer of freshwater became shallower (Fig. 4-1 a.). The shallower areas of the lagoon (R2, O2, and O3) also became more saline at this time, though they were generally fresher than the deepest portion of the South Arm (Fig.'s 4-2 a., 4-3 a., and 4-4 a.).

The first storm of the season in the beginning of December did not change the salinity at any site in the lagoon. It wasn't until the river connected to the lagoon at the end of December that the shallow areas of the lagoon became fresher (Fig.'s 4-2 b., 4-3 b., and 4-4 b.).

After the sandbar was mechanically breached on Dec 27, the sandbar was closed by Dec 31 and stratification with respect to salinity at S2 on this date was more pronounced than was observed from August to November. This changed when members of the public breached the sandbar in the afternoon and the lagoon freshened to an elevation of 0.5 m NGVD. As the river continued to flow into the lagoon and the sandbar temporarily stayed open, the freshwater layer became 1 m thicker by the end of January (Fig. 4-1 b.).

When the sandbar was again closed on Feb 19, the South Arm was highly stratified. On Feb 22, high river flows breached the sandbar and freshened the lagoon down to an elevation of -2 m NGVD. It was stratified again by the 26th, and the salinity in the bottom 2 m of the water column begun to gradually decrease through March 11. All of S2 stayed relatively fresh from March to late May 2006 (Fig. 4-1 c.).

When the sandbar was closed and stage increased the shallow areas in the lagoon (R2, O2, and O3) became fresher. Salinity was highest on Feb 15 when the stage was low. When the stage increased after the sandbar closed on the 19th, these sites became fresher even though S2 was more stratified. After the sandbar breach on the 22nd, salinity at the shallow sites increased again (Feb 26th), indicating that the fresh water in the South Arm was flushed out when the lagoon drained on Feb 22 (Fig. 4-2 c., 4-3 c., 4-4 c., and Tab 4-3).

Table 4-3. Salinity before and after the sandbar breached on 22 Feb 2006.

* Average of readings in the depth profile.

Date	Sandbar	Stage (ft)	R2	S2	O2	O3
Feb 15	Open	2.89	12.51	10.62 *	6.23	10.17
Feb 19	Closed	7.9	0.95 *	13.95 *	1.06 *	1.00 *
Feb 22	Open	2.7	1.28	2.28 *		
Feb 26	Open	3.06	5.12	20.09 *	4.49 *	4.63

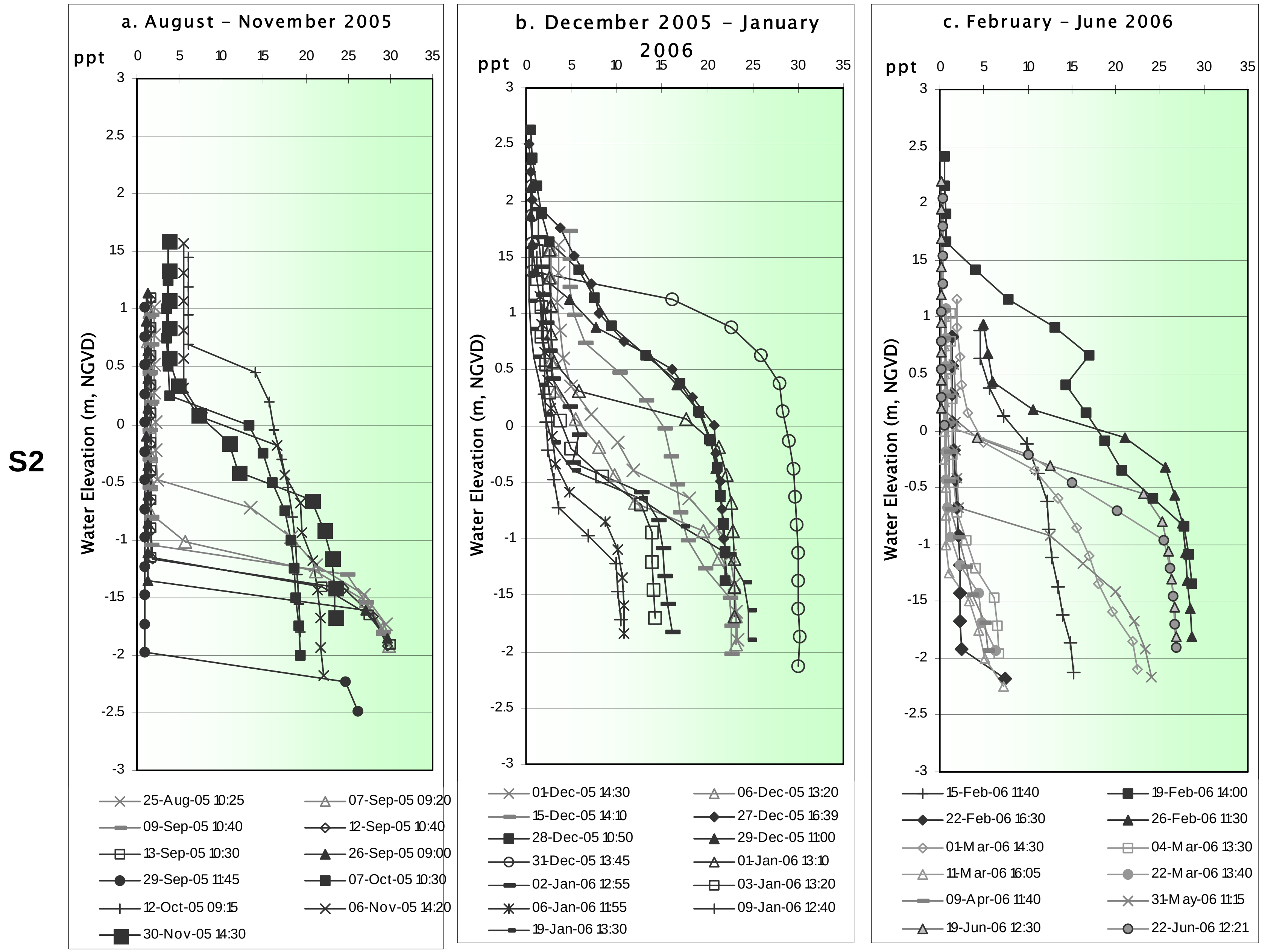


Figure 4-1. Salinity at the South Arm Pipe (S2)

R2

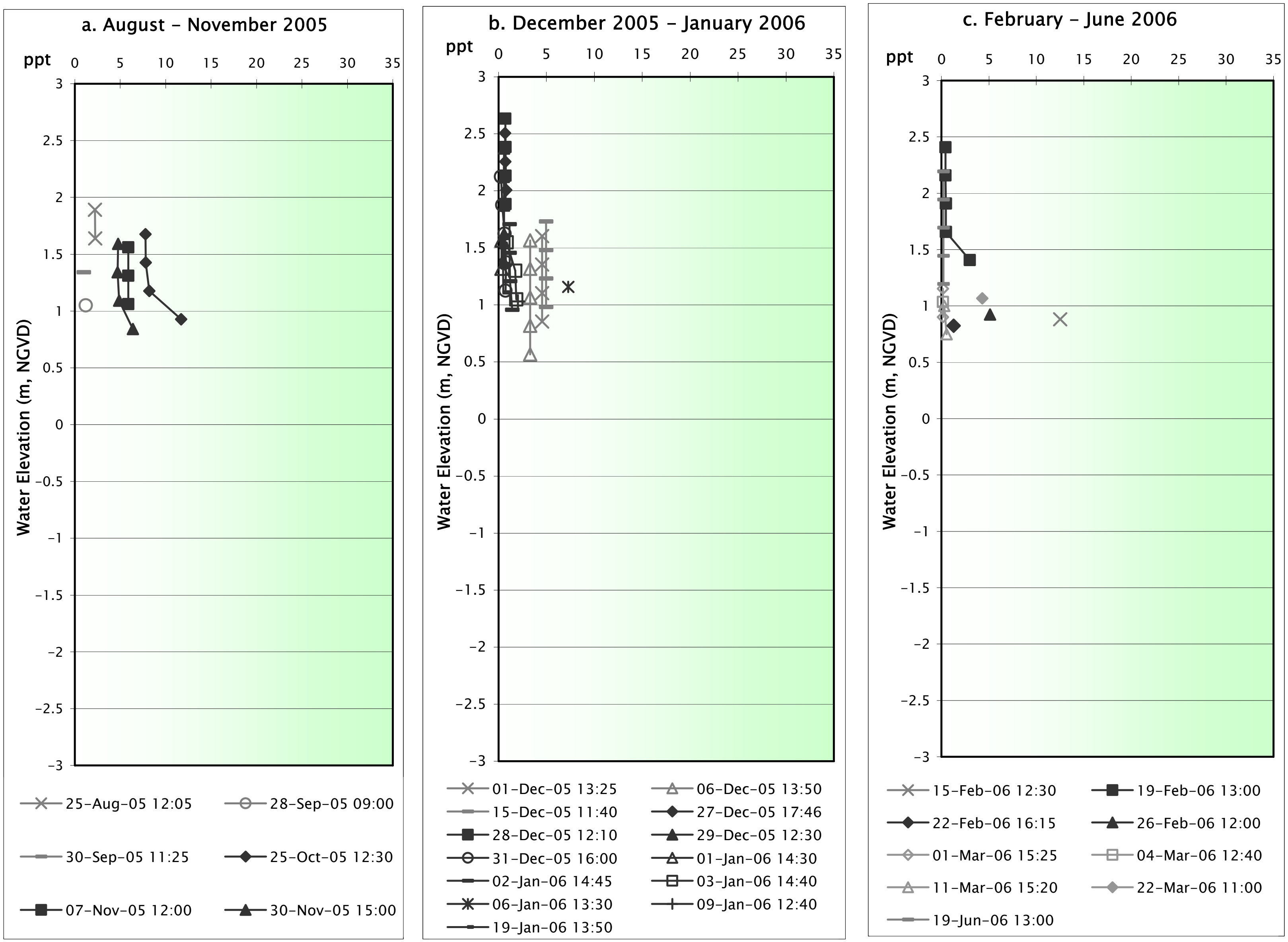


Figure 4-2. Salinity in the main body of the lagoon (R2)

O2

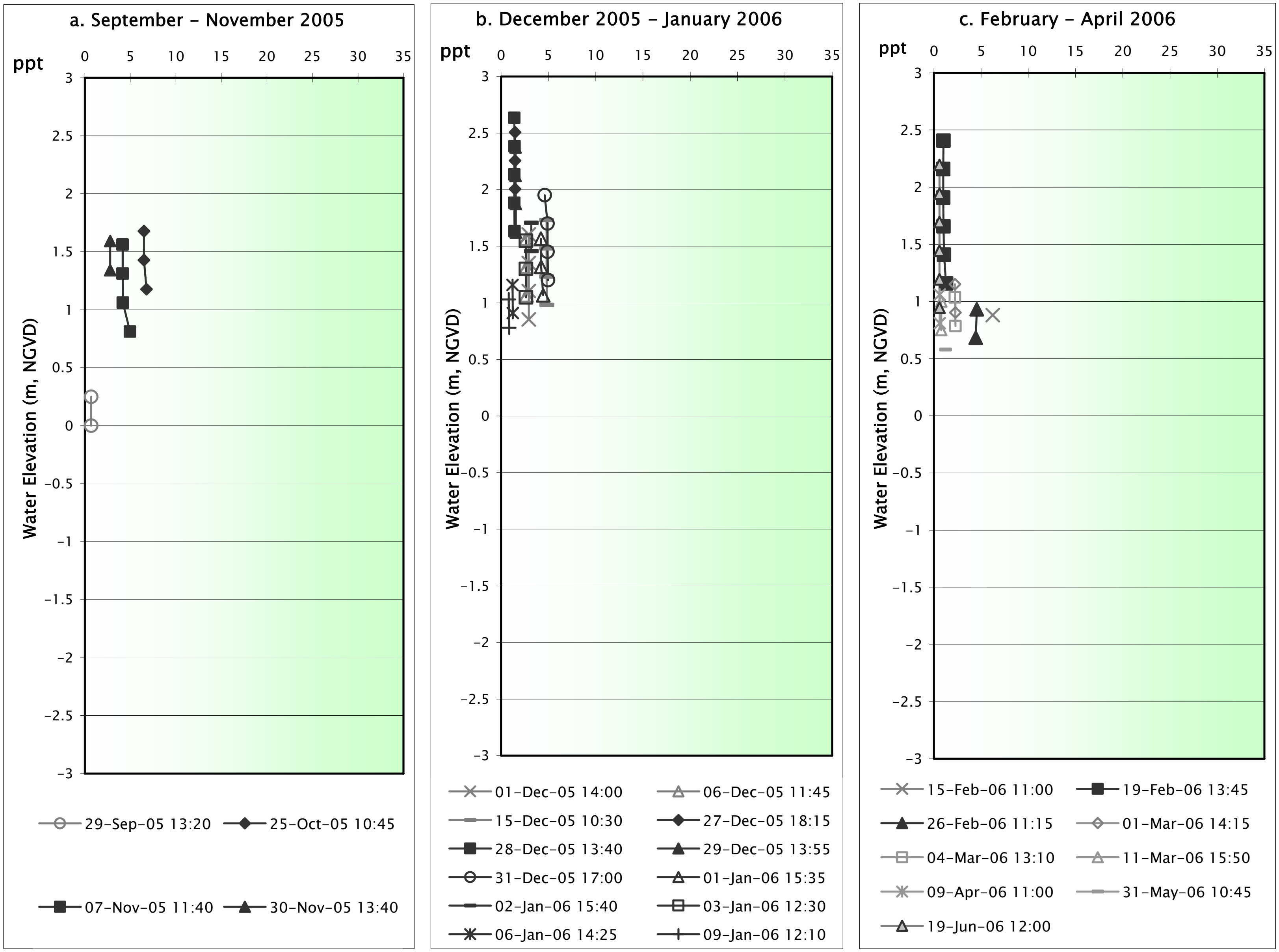


Figure 4-3. Salinity in the north finger of the Odello extension (O2)

O3

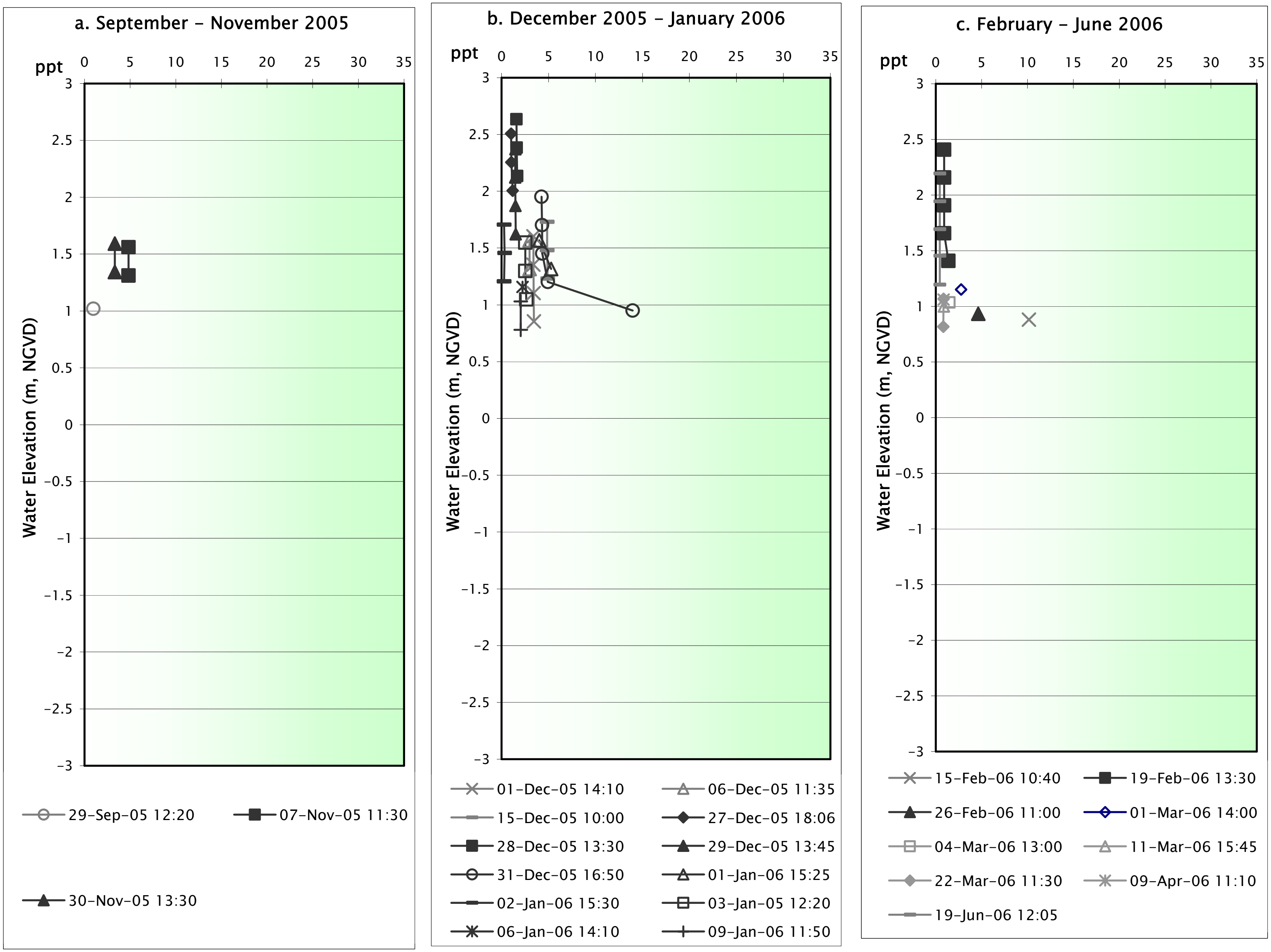


Figure 4-4. Salinity in the south finger of the Odello extension (O3)

4.3.2 Freshwater spring in O2

In June of 2005 a trickle of water was observed coming out of the mud at the top of O2 (Fig. 4-5). This section of the report examines the diluting effect that this perennial spring has on salinity in the Odello West Arm, and the range of dilution in the South Arm.

(a)

(b)

Figure 4-5. Freshwater Spring trickling into the lagoon (a) and at the top of O2 (b). Stage = 3.28 ft. 22 June 2005.

4.3.2.1 Sampling design

In the fall of 2005, on October 1, surface measurements were taken in the center of the water at equal distance intervals throughout the Odello West Arm. Three paths were paddled in a kayak, one starting at the spring source and paddling out to the confluence, one starting at the top of O3 and paddling out to the confluence, and another starting at the confluence and paddling out to the South Arm Pipe (S2). GPS points were taken with each measurement and are displayed in Fig. 4-6.

4.3.2.2 Results

There is a strong positive relationship between distance from the spring and an increase in salinity in both O2 and O3 (Fig. 4-7). The relationship is stronger in O2 (R^2 = 0.95) than O3 (R^2 = 0.85), however salinity was higher at the top of O3.

When the sandbar is closed and the river is not flowing into the lagoon, this spring could be a potential source of freshwater in the South Arm.

Figure 4-6. Map of freshwater spring sampling design.

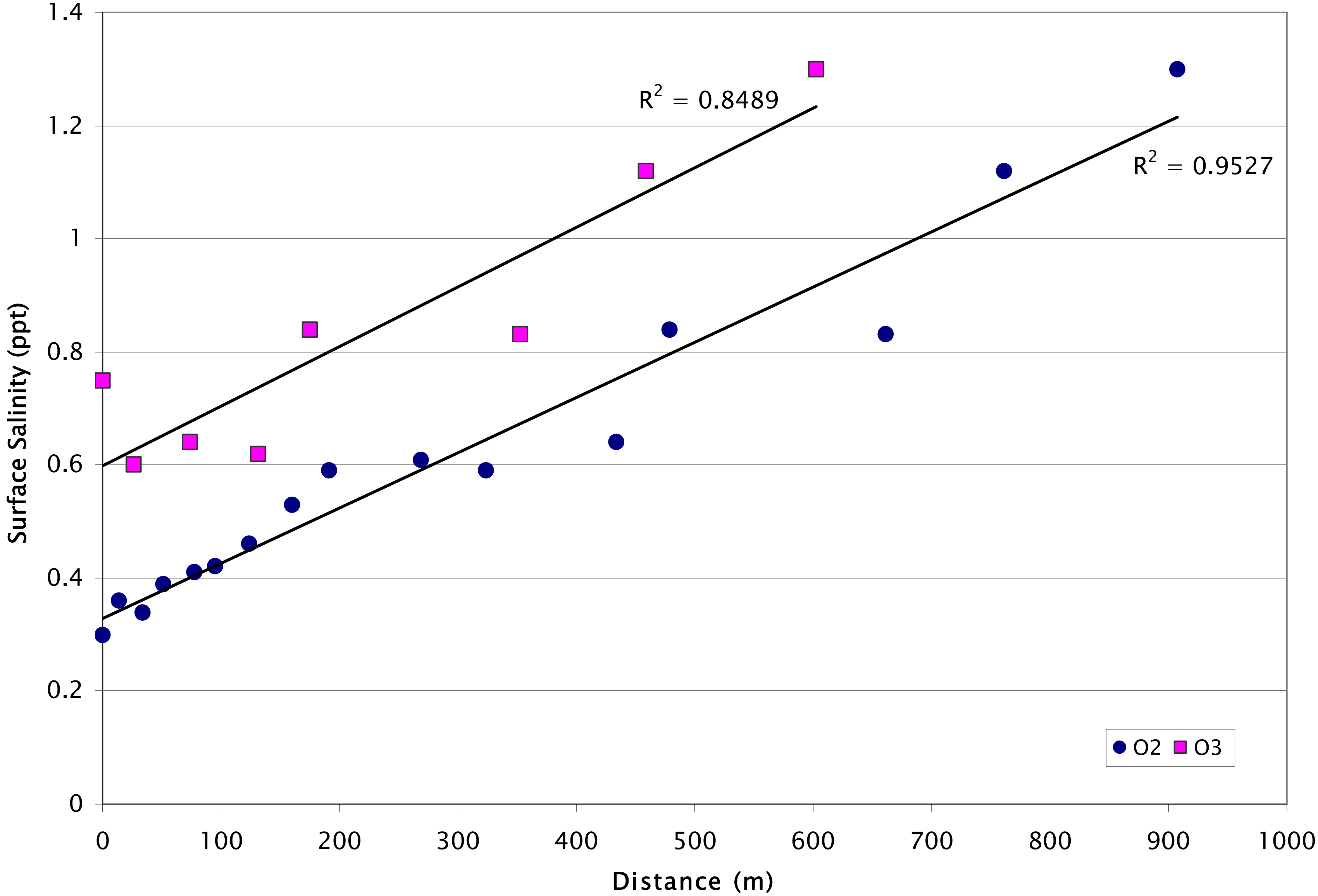


Figure 4-7 Salinity vs. distance from freshwater source.

4.4 Temperature

Temperature directly affects 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.).

4.4.1 Results

During late summer when the river stopped flowing into the lagoon, the longer warmer days of July and August increased the water temperature in the lagoon. As the days became cooler and shorter throughout autumn temperatures in the lagoon gradually decreased. All sites exhibited a gradual cooling from August through the first storm in December (Fig.'s 4-8 a., 4-9 a., 4-10 a., and 4-11 a.), after which temperatures in the lagoon increased slightly. For the most part the vertical profile was approximately isothermal, although occasionally the temperature of the deeper waters lagged 5 to 10 degrees behind the trend set by the surface waters.

During the first rain storm of the season in the beginning of December when the river had not yet connected to the lagoon, temperature in the South Arm re-stratified slightly, though the bottom 2 m did not get as warm as it was in August and September (Fig. 4-8 b.). At the end of December when the river connected to the lagoon during the second large storm system of the season, the sandbar was mechanically breached, and the river started flowing into the ocean. Temperatures stayed constant between 10ºC and 15 ºC throughout the lagoon and did not significantly change when the sandbar closed and was re-opened by members of the public on December 31st 2005 (Fig.'s 4-8 b., 4-9 b., 4-10 b., and 4-11 b.).

All though temperatures in the main lagoon (R2) stayed relatively constant from the flow of river water in the first couple weeks of January (Fig. 4-9 b.), temperatures in the Odello West Arm (O2 and O3) increased as the stage decreased (Fig.'s 4-10 b. and 4-11 b.).

On Feb 19 when the sandbar was closed and the stage was high, temperatures at all sites were cooler than when the sandbar was open and the stage was low on the 15th and also after sandbar breached on the 22nd of February (Tab. 4-4).

The shallower waters of the lagoon are more readily heated, as was observed during low stages from February through May (Fig.'s 4-8 c., 4-9 c., 4-10 c., and 4-11 c.). The lagoon gradually became warmer through the spring as stages stayed low, particularly at the shallow sites (R2, O2, and O3).

The lowest stage in the lagoon, 1.7 ft, occurred on May 31 2006. Water quality measurements were taken when the stage was 1.9 ft. The temperature range of the profile taken at the S2 at this time (Fig. 4-8 c.) was similar to profiles that have been collected from August to November, after the sandbar closed for the season and the river ceased flowing into the lagoon (Fig. 4-8 a.). It should be noted that these higher water temperatures do not exceed the water quality criterion for steelhead.

Table 4-4. Temperatures before and after the sandbar breached on 22 Feb 2006.

* Average of readings in the depth profile.

Date	Sandbar	Stage (ft)	R2	S2	O2	O3
Feb 15	Open	2.89	15.67	12.47 *	15.19	15.43
Feb 19	Closed	7.9	9.90 *	10.44 *	10.32 *	10.43 *
Feb 22	Open	2.7	11.33	11.89 *		
Feb 26	Open	3.06	12.27	11.60 *	13.73 *	13.17

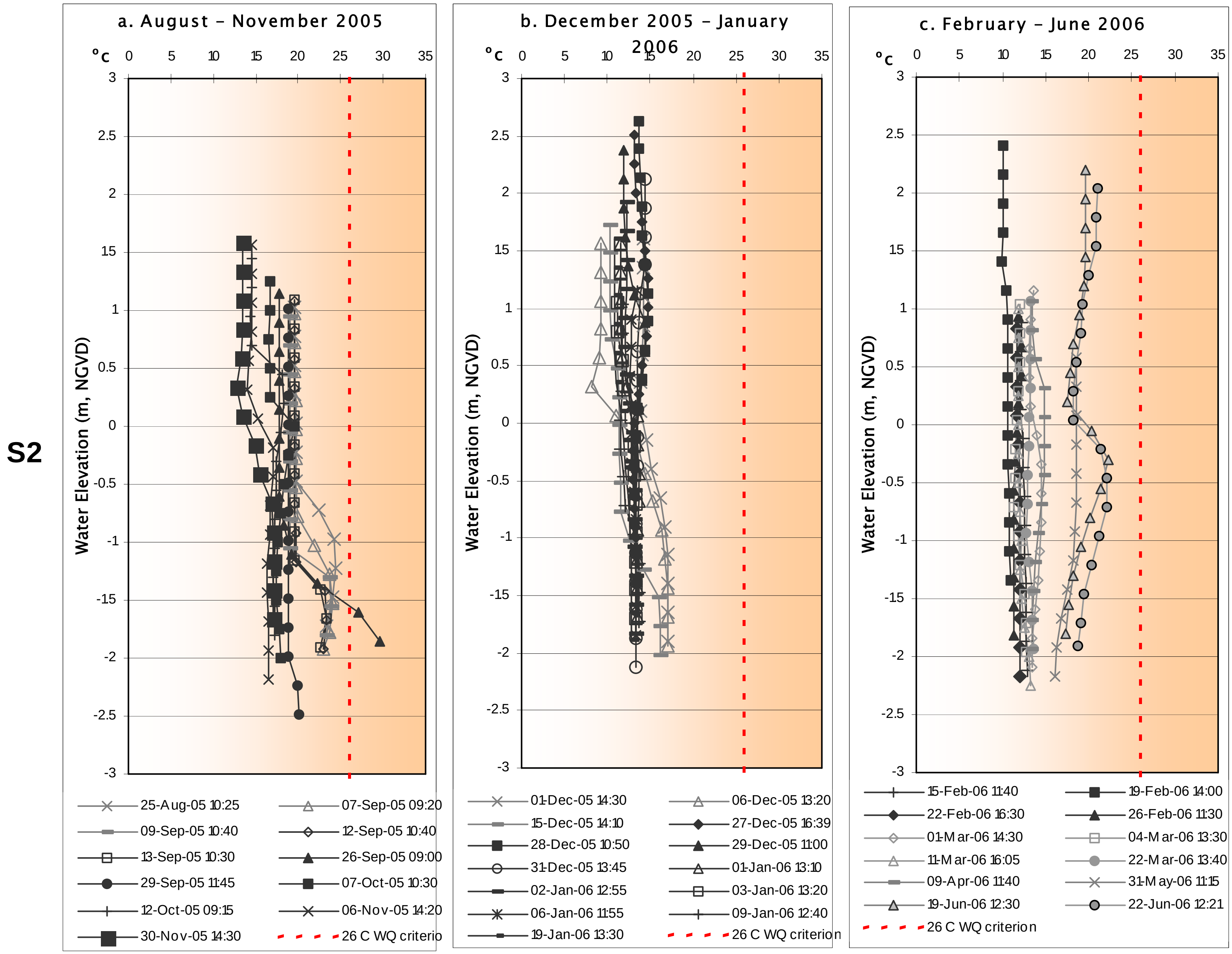


Figure 4-8. Temperature at the South Arm Pipe (S2)

R2

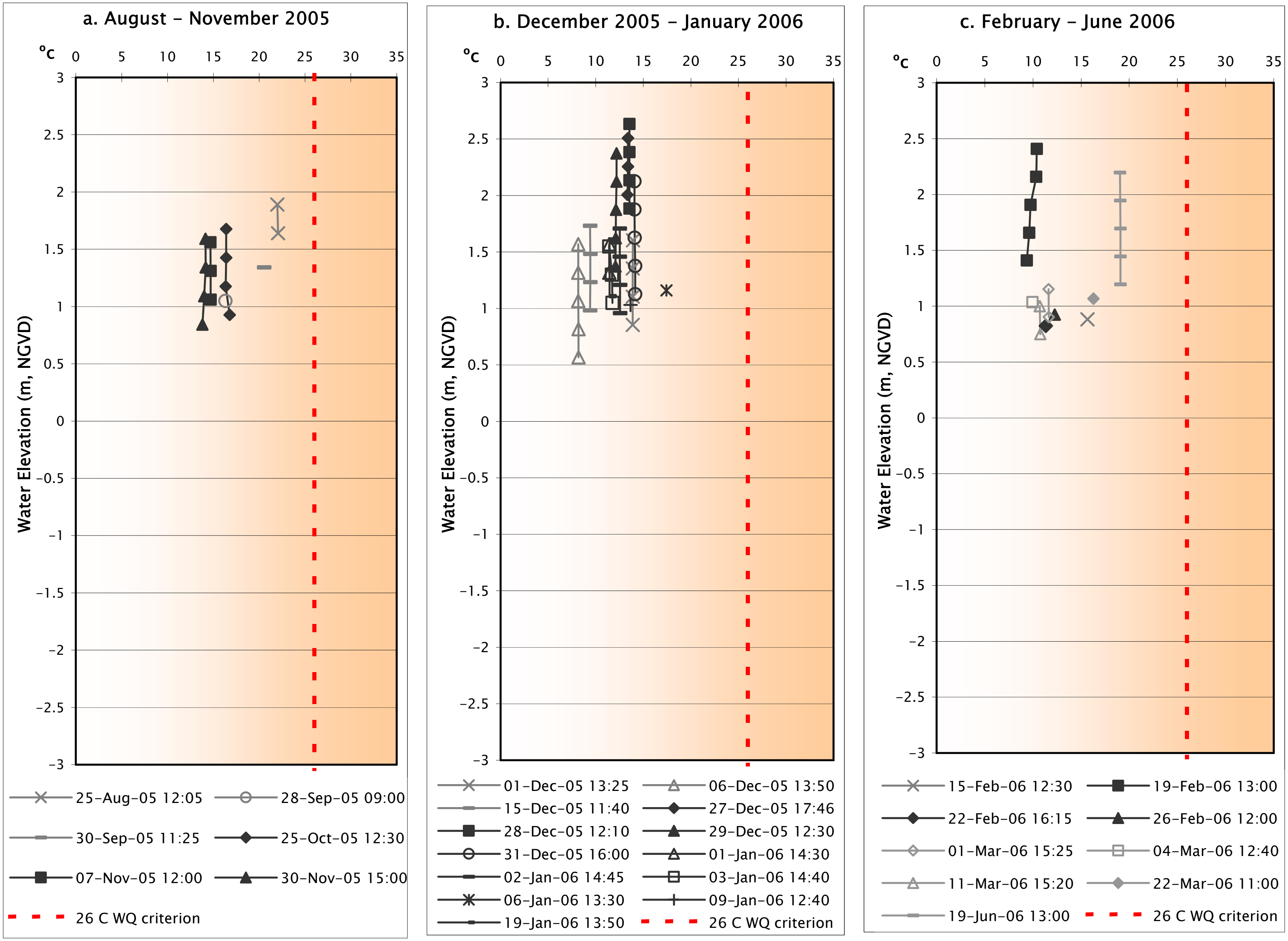


Figure 4-9. Temperature in the main body of the lagoon (R2)

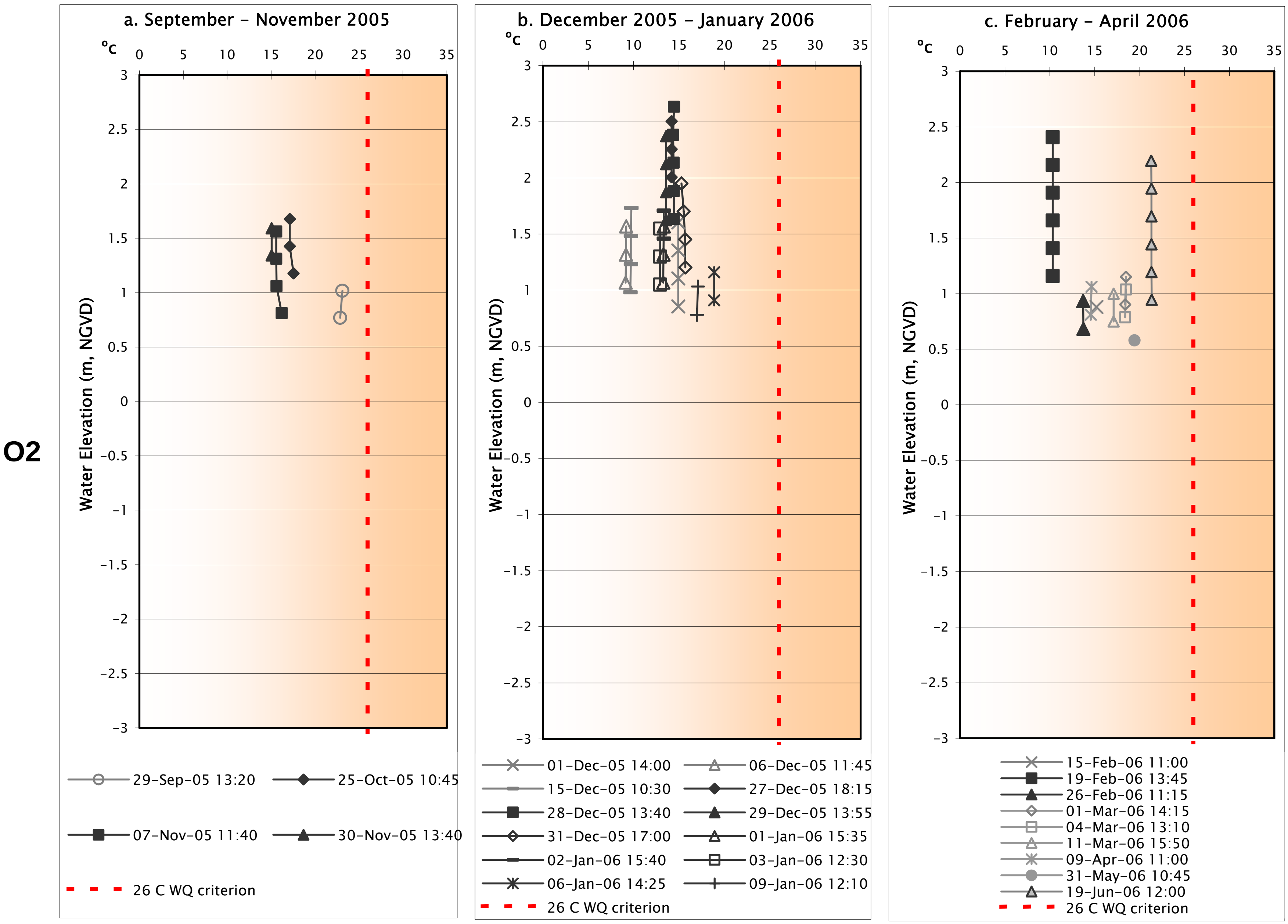


Figure 4-10. Temperature in the north finger of the Odello extension (O2)

O3

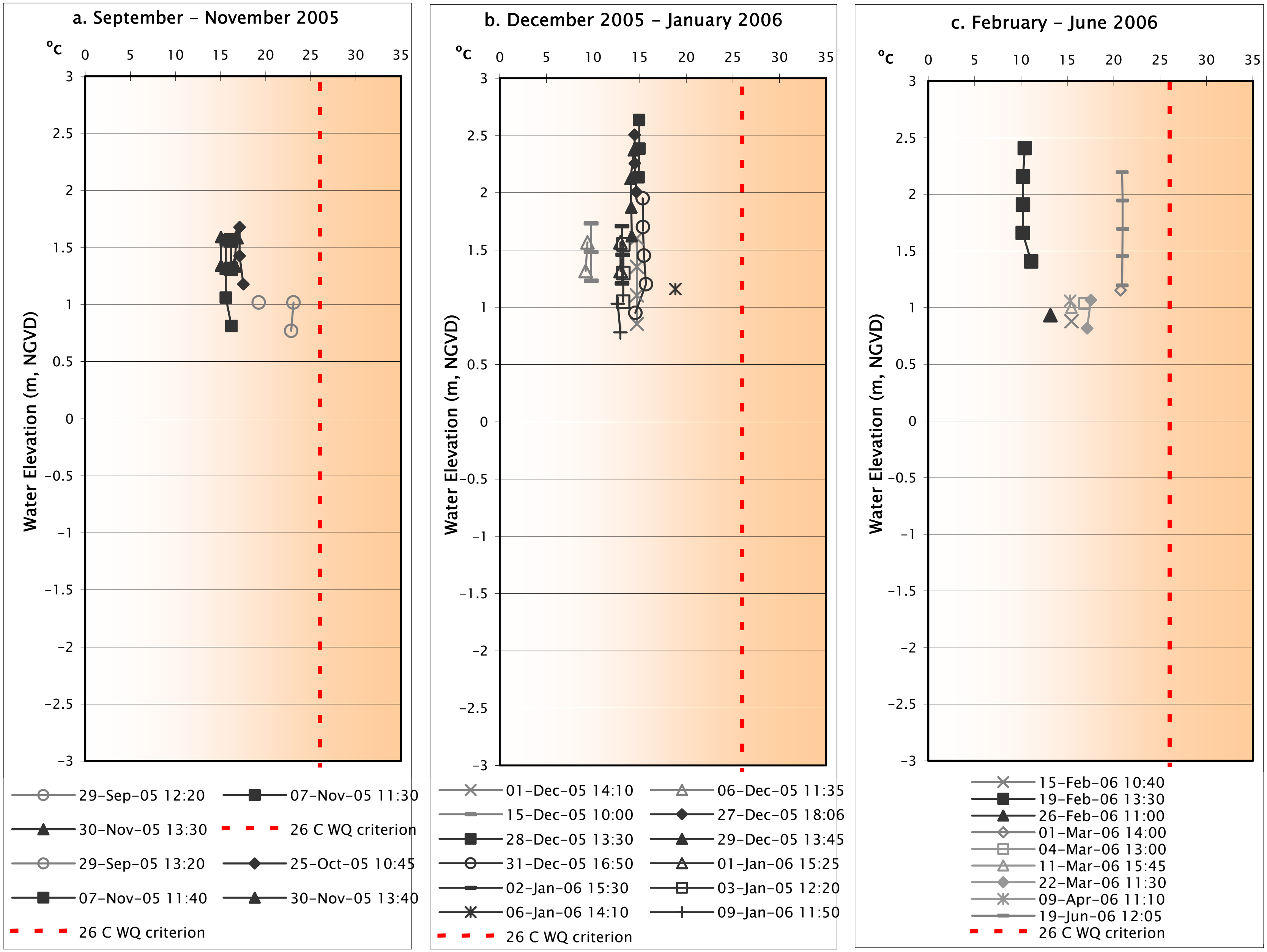


Figure 4-11. Temperature in the south finger of the Odello extension (O3)

4.5 Dissolved oxygen

Dissolved oxygen arises through two processes: 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. 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.

4.5.1 Results

There was a layer of well-oxygenated water at the surface of S2 that gradually increased from August to September and decreased in October and November, corresponding to the depth of the freshwater layer. The bottom of the layer of well-oxygenated water on Sep 29 was at -2 m NGVD, similar to the bottom elevation of freshwater on this date. In October and November there was a pocket of water between 0.5 and -0.5 NGVD with high DO concentrations, this pocket persisted until the first rain on Dec 1 (Fig. 4-12 a.).

Low DO concentrations in the main lagoon (R2) occurred at low stages (Fig. 4-13). For example, on Sep 28th when the stage was 3.44 ft, DO was 6.52 mg/L. Two days later on the 30th when the stage was 4.4 ft, the DO was 10.89 mg/L.

During the first storm of the season in early December, O3 exhibited variability not observed at any other site (Fig. 4-15 b.). On Dec 1 this portion of the Odello West Arm was anoxic; readings of the entire depth profile were below the water quality criterion of 5 mg/L for DO. This condition had improved by the 6th, and did not change significantly until the 31st, when water at this site was slightly stratified at 1m NGVD.

In late December S2 was stratified with oxygenated water occupying the top 1 - 1.5 m of the water column. On Dec 31 when the sandbar had closed, oxygen levels were the same throughout the entire water column under the pipe, possibly due to the backflow of river water into the South Arm. After the sandbar was opened on the 1st of Jan, the South Arm re-stratified with thicker layer of oxygenated water at the surface and anoxic bottom 1.5 - 2 m (Fig. 4-12 b.).

In the main lagoon (R2) and northern finger of the Odello West Arm (O2), DO concentrations were slightly higher during the first storm of December than during the second storm when the sandbar was breached. At the shallow sites, DO levels stayed constant throughout the second storm and subsequent mechanical breaching of the sandbar on December 27th.

After members of the public breached the sandbar on December 31st 2005, DO in R2 (Fig. 4-13 b.) did not change the way concentrations decreased in the Odello West Arm. After the lagoon drained quickly on the 31st of Dec 2005 and 1st of Jan 2006, DO levels dropped to just above the water quality criteria at O2 and O3 (Fig's 4-14 b. and 4-15 b.).

The same drop in DO concentrations was observed at O2 and O3 from the high stage of Feb 19 and after the lagoon drained rapidly on the 22nd. At low stages (15th and 22nd), DO was much lower (just above the 5 mg/L water quality criterion) than it was at high stages (19th) (Tab. 4-5).

In the spring at S2, the top 2 m of the water column was well oxygenated, while the bottom of the water column gradually became more anoxic at -1.5 m NGVD, and the water was beginning to stratify again (Fig.4-12 c.). The relationship between DO and salinity at the bottom of the water column at S2 that was present in the fall (low DO, high salinity) was not present in the spring. The water column at bottom depths of −0.5 to −1.5 m NGVD had plenty of oxygen at both high and low salinity concentrations (compare Fig's 4-12 a. and c. with 4-1 a. and c.).

DO concentrations were very low at O2 during the low stage of 1.9 ft on May 31st. As with temperature, the difference in DO concentrations between high and low stages in the main lagoon and Odello West Arm can be easily seen in the February - May 2006 graphs (Fig's 4-13 c., 4-14 c., and 4-15 c.).

Table 4-5. Dissolved oxygen concentrations before and after the sandbar breached on 22 Feb 2006. * Average of readings in the depth profile.

Date	Sandbar	Stage (ft)	R2	S2	O2	O3
Feb 15	Open	2.89	6.14	6.14 *	5.35	6.62
Feb 19	Closed	7.9	11.67 *	9.74 *	11.88 *	11.62 *
Feb 22	Open	2.7	7.80	10.15 *		
Feb 26	Open	3.06	9.93	8.02 *	6.54 *	7.28

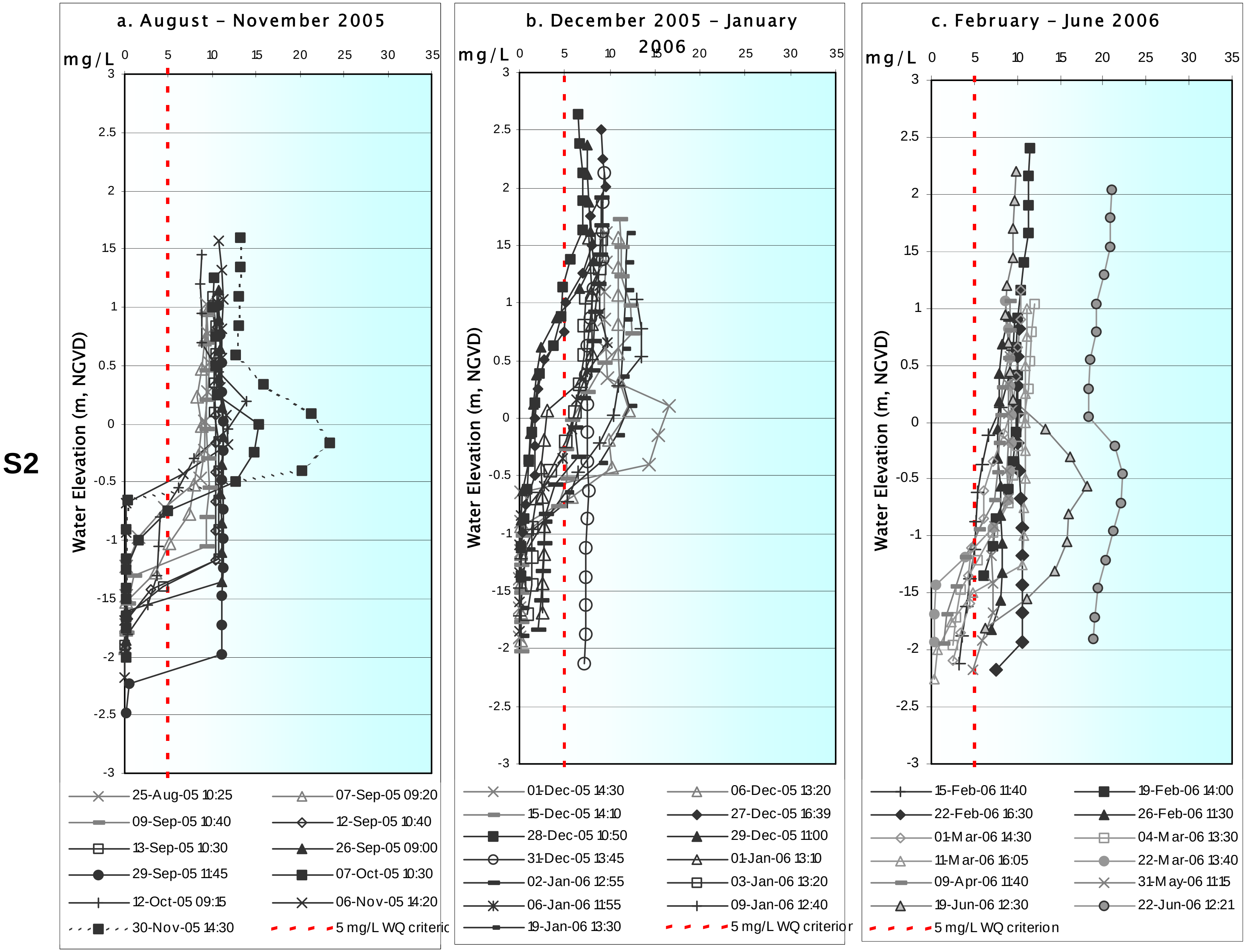


Figure 4-12. Dissolved oxygen at the South Arm Pipe (S2)

R2

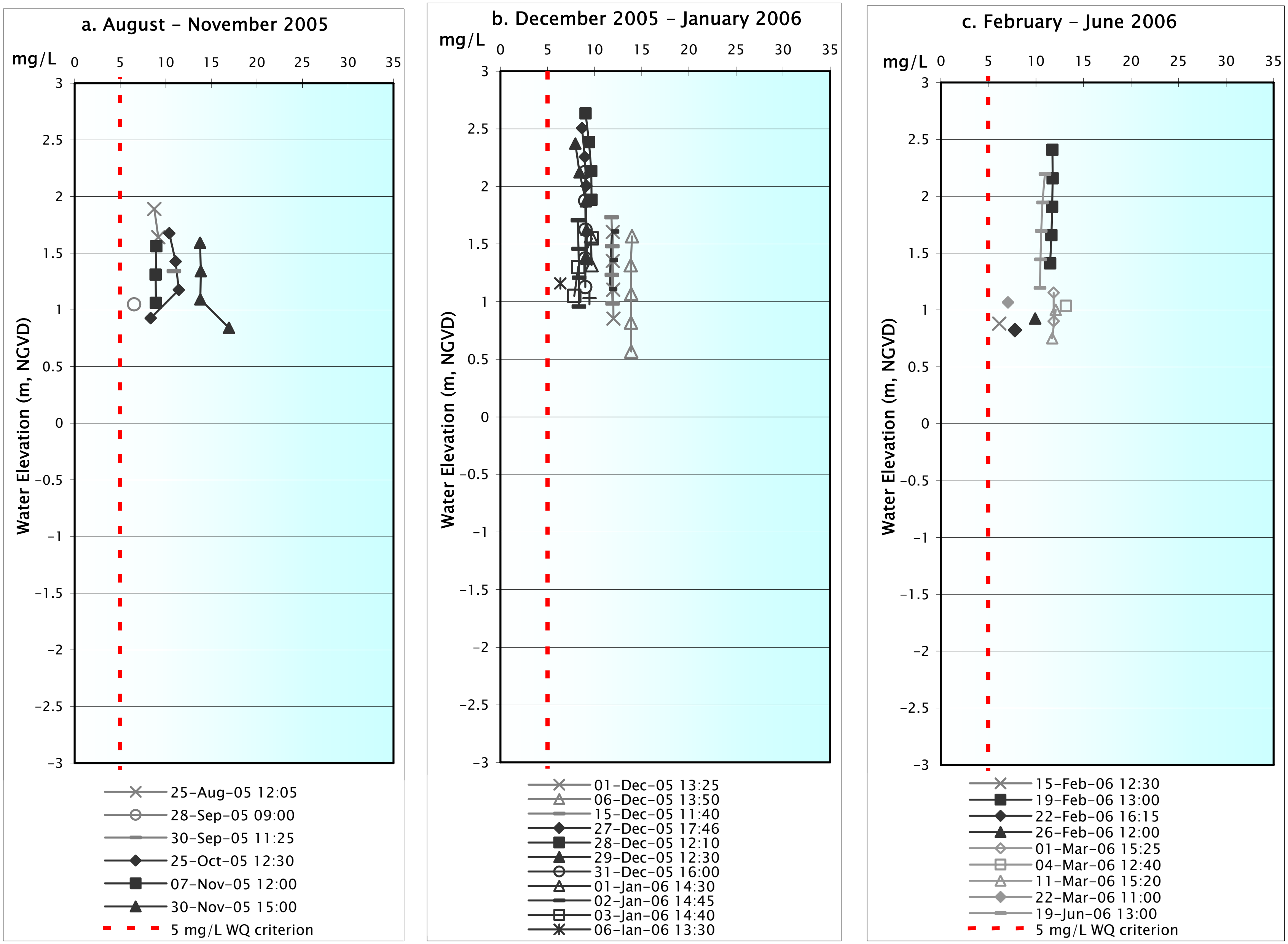


Figure 4-13. Dissolved Oxygen in the main body of the lagoon (R2)

O2

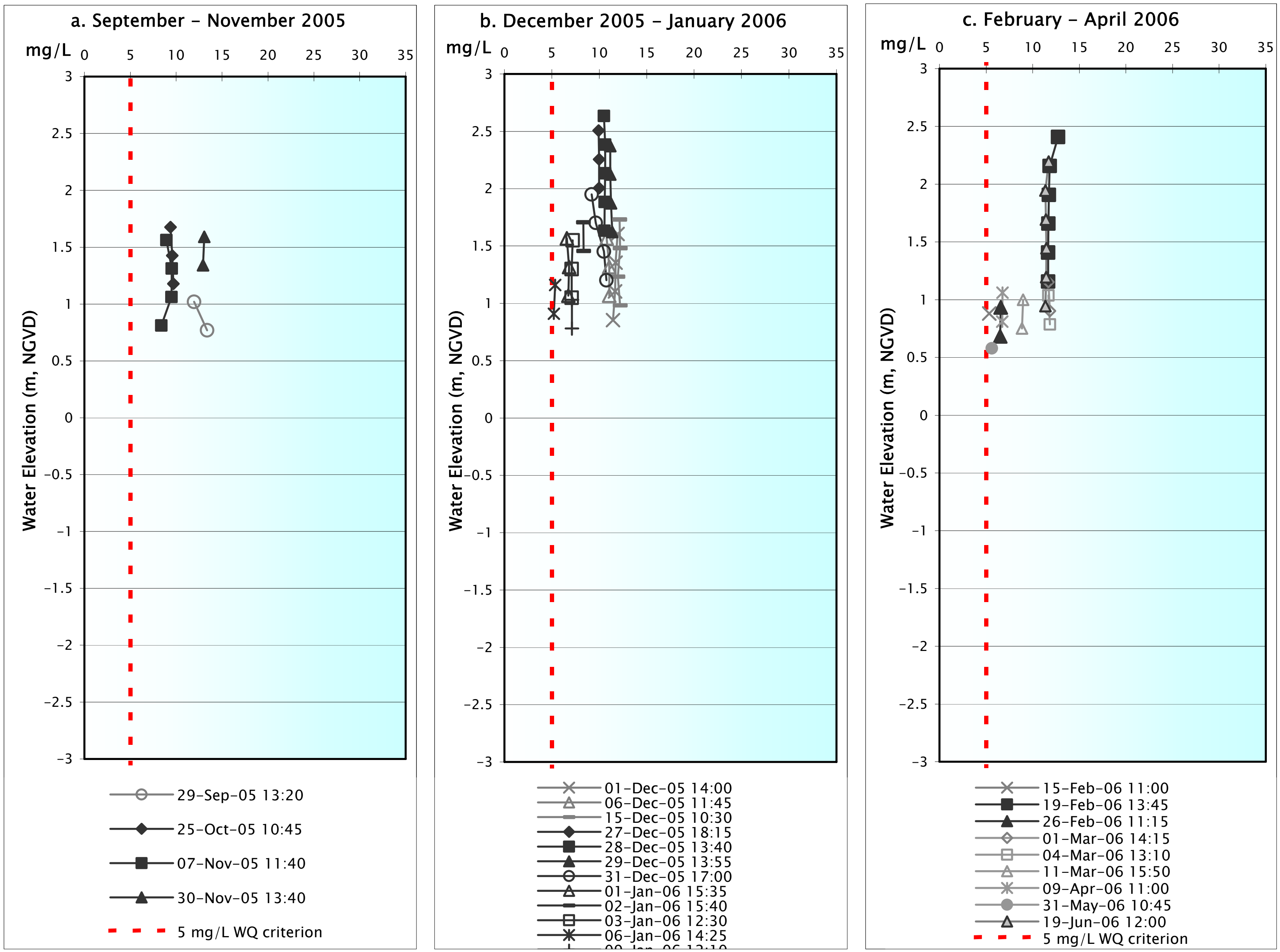


Figure 4-14. Dissolved Oxygen in the north finger of the Odello extension (O2)

O3

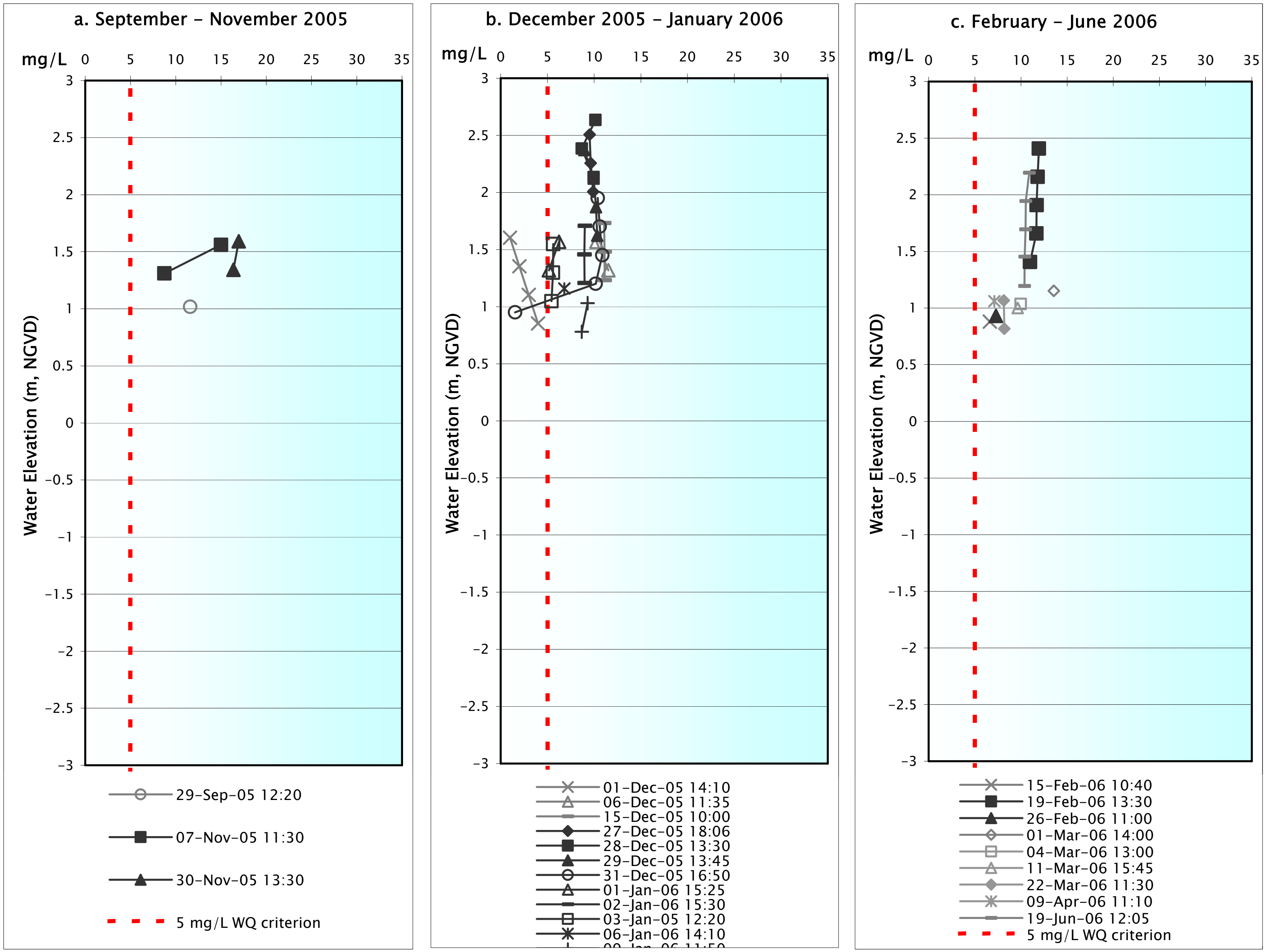


Figure 4-15. Dissolved Oxygen in the south finger of the Odello extension (O3)

4.6 Suspended sediment concentration and turbidity

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

Measurement of SSC and turbidity is intended to monitor for localized erosion as rainwater from the banks can carry fine sediment particles into the lagoon.

4.6.1 Results

Fig.'s 4-17 and 4-18 display a 1-year time series of suspended sediment concentration (SSC) and turbidity. A 2-year time series is in Appendix B.

Spikes in SSC and turbidity were never isolated to one site, but were present at multiple sites at the same times. The largest SSC and turbidity measurements in the lagoon were observed during periods of high precipitation at the end of December, in February and March (compare Fig.'s 2-3 with 4-17 and 4-18).

Almost all spikes that exceeded the water quality criterion during storms occurred in the Odello West Arm. SSC and Turbidity were highest at O3 with more fluctuation here than all the other sites (Fig.'s 4-17 and 4-18). At low stages this site has the least amount of water in it, allowing the bottom sediment to be easily disturbed and liberate fine particles of sediment into the shallow water column. Care was taken not to disturb the substrate during sample collection, but currents in the water from wind visibly stirred up fine sediment particles into the water column. Thus, high SSC and turbidity values may not be a result of localized erosion. Other spikes occurred in O2, which is not as shallow and small sediment plumes were never observed as a result of strong water currents, as at O3. This is also the site of various new gullies (Fig. 4-16), a strong indication of localized erosion.

Figure 4-16. Gullies in the banks of O2 (31 May 2006).

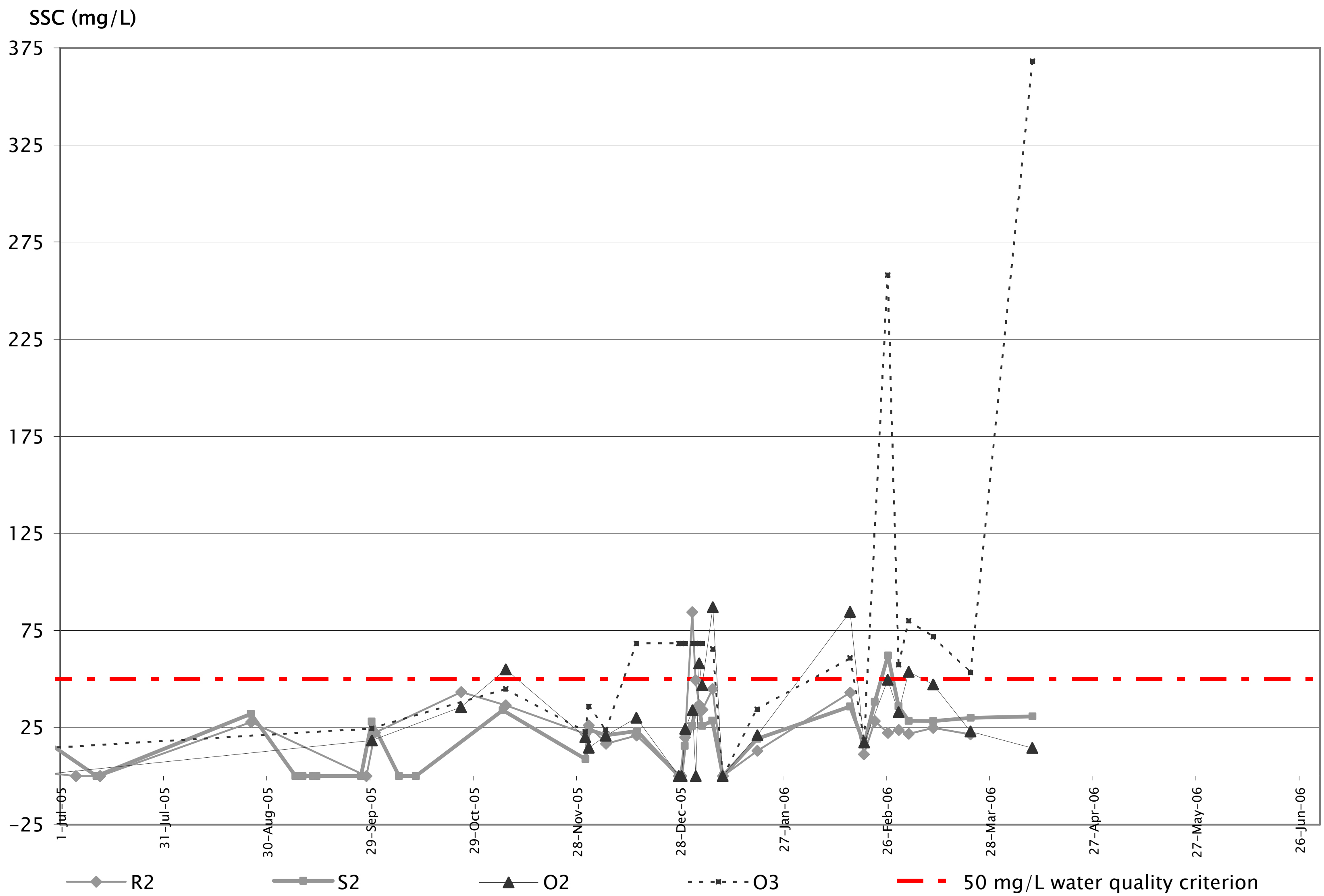


Figure 4-17. Suspended sediment concentrations July 2005 through June 2006.

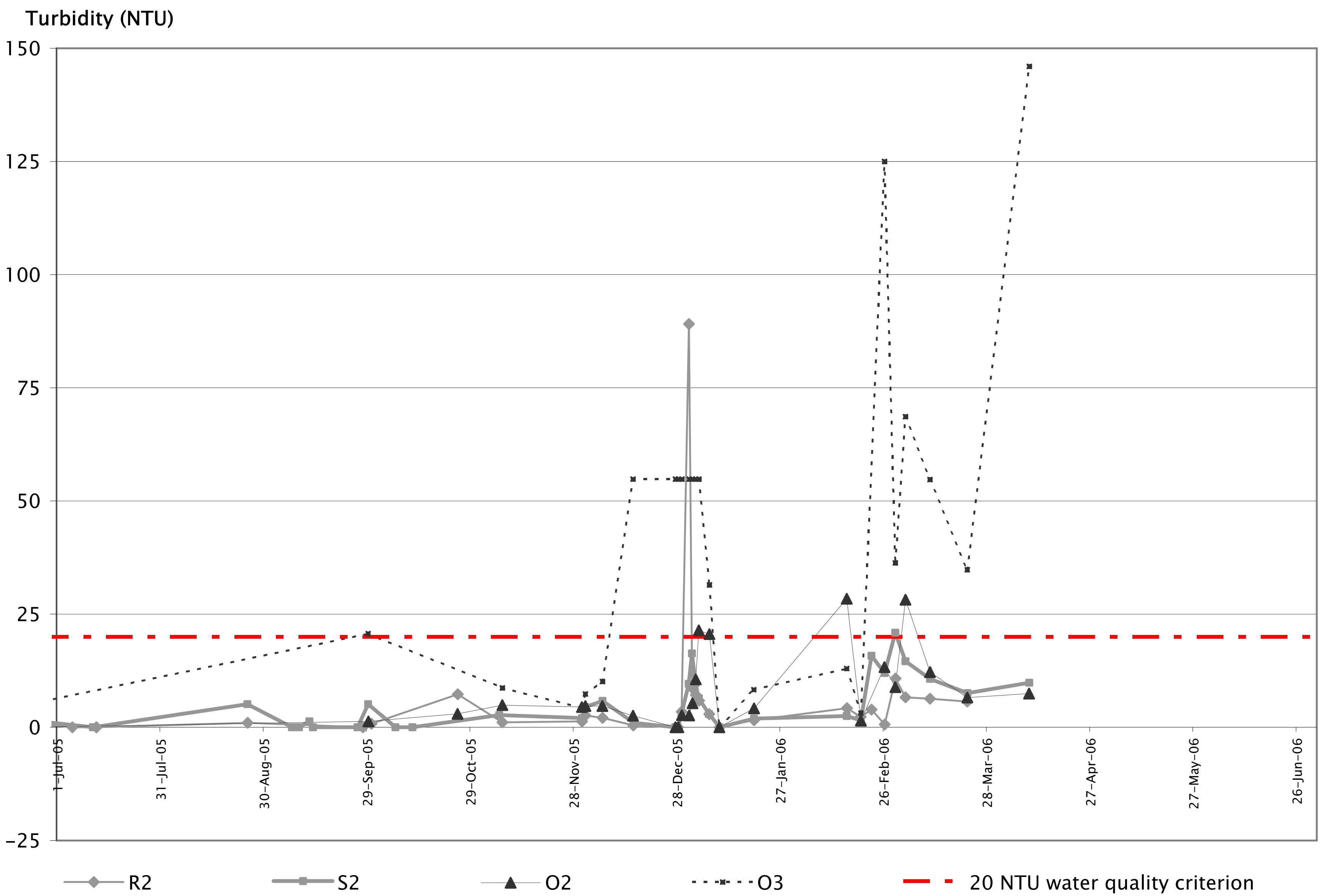


Figure 4−18. Turbidity from July 2005 through June 2006.

4.7 Wave propagation

When the sandbar was open in January, waves entered through the breach channel and crossed the lagoon. They also washed over the sandbar at the northern corner of the lagoon next to the parking lot (see Fig. 2-9). Water quality measurements were taken across the main lagoon to determine how these waves were affecting the lagoon on 3 and 6 Jan. Fig.'s 4-19 and 4-20 are diagrams created in Photoshop and are not to scale, but they display the data that were collected and demonstrate how ocean waves affected the water quality of the main lagoon.

Areas where water was flowing near the river mouth were well mixed with respect to temperature, salinity, and DO. In the northern end where there was standing water there was more variation in these parameters on the 3rd, but on the 6th when the stage was 1 ft lower, there were not as many places to sample.

On 3 Jan the temperature of the entire main lagoon was between 11°C and 12°C. On the 6th, however, the shallower northern portion of the lagoon was 5°C warmer than where the river was flowing in. Noticeably, the salinity was higher in the northern end where the waves washed over the sandbar than it was near the river mouth where the waves flowed directly into the lagoon. Waves propagating through the open sandbar near the river mouth had little effect on salinity; even right next to the ocean and sandbar in the path of the waves where high salinity levels might be expected, the salinity was only 1.23 ppt. Waves washing over the sandbar in the north increased the salinity (at depth on the 3rd). Dissolved oxygen was also slightly higher near the river mouth where the river was flowing through than in the standing water in the northern end.

These data indicate that ocean water was not actually entering the lagoon through the breach channel, but rather the energy of the waves propagated through the fresh water that was exiting the lagoon from the river.

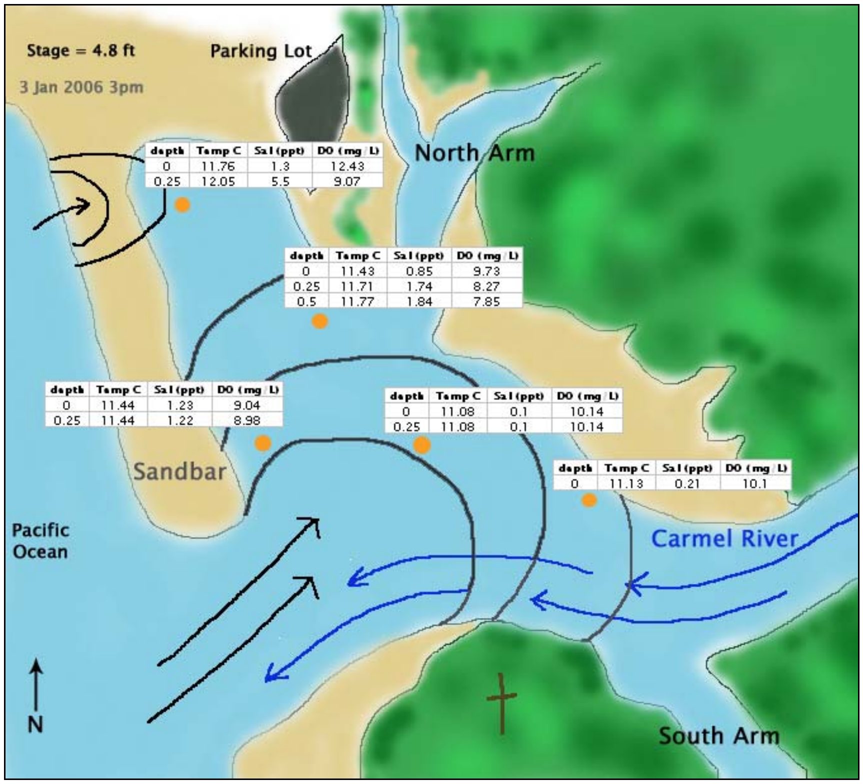


Figure 4-19. Diagram of water quality measurements taken in the main lagoon as ocean waves are propagating through it. 3 Jan 2006

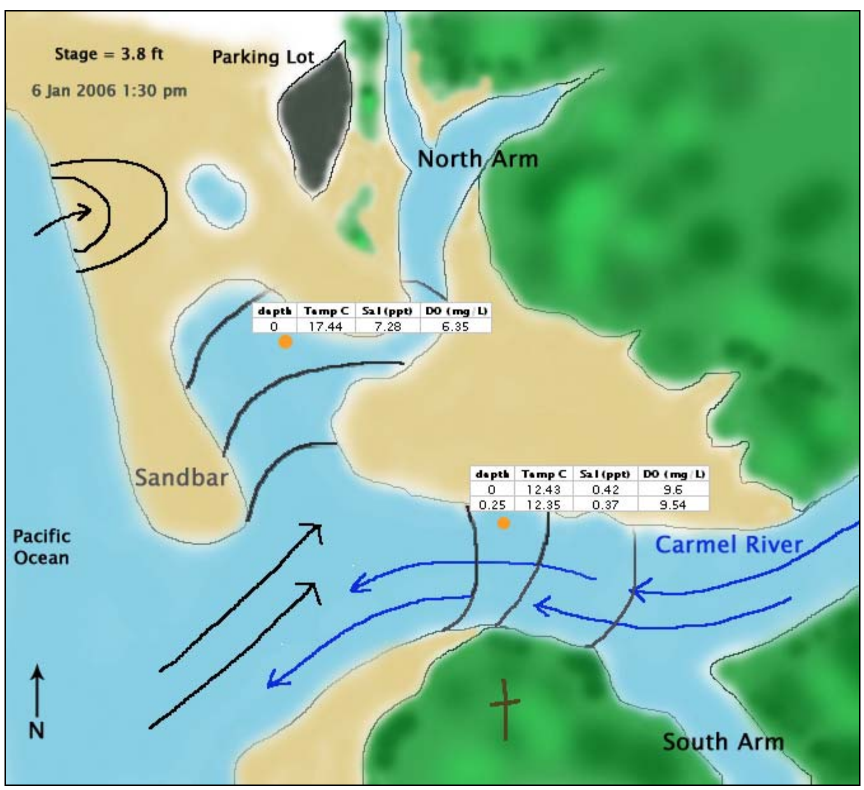


Figure 4-20. Diagram of water quality measurements taken in the main lagoon as ocean waves are propagating through it. 6 Jan 2006

5 Macroinvertebrates

5.1 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 2-year period at 3 sites within the Odello portion of the lagoon, as well as 4 within the original lagoon (see Section 3.2). 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.

5.1.1 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 layer or those open to tidal mixing result in steelhead with quicker growth rates as opposed to closed and heavily stratified lagoons (Smith, 1990). 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 for fish.

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 from the Carmel River Lagoon were the amphipods *Anisogammarus (Eogammarus)* and *Corophium*, the isopod *Gnorimosphaeroma*, and the mysid *Neomysis* (Fields, 1984).

5.2 Sampling Methods

7 sites were sampled on 9 occasions over a 2-year period. In the first year sampling occurred before and after the removal of the earth barrier, as well as before and after the initial sandbar breach. Sampling during the second year occurred at 3-month intervals. Water quality measurements were also taken with invertebrate samples.

Macro-invertebrates were collected using a D-net (opening ~0.043 m^2, mesh size 500 μm) on a 1.5 m pole (Fig. 5-1). 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, then moving 2 meters along the bank (or out of the area disturbed by the previous sweep) and sweeping again, then moving 2 meters more (or out of the area disturbed by the previous sweep) for a final sweep. Each of these three sweeps represent one sample.

Figure 5-1 D-net used for sampling macroinvertebrates

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 because of the depth of the water.

The water column collection method consists of an 180° arc sweep of the net with the top of the net below the surface of the water. The end of the pole was held against the sampler's body, ensuring precision in the arc sweeps. Figure 5-2 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 the total number of sweeps per sample (usually 3 sweeps per sample). The volume of water per sample is calculated to be 0.84 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 their escape. Figure 5-3 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 the total number of sweeps per sample (usually 3 sweeps per sample). The area of eipbenthos per sample is calculated to be 1.46 m^2.

In 2004 through March 2005 a total of 3 sweeps was done per stance; the net was moved back and forth 3 times before it was removed from the water and the contents cleaned into the sample jar. This method was modified in 2005 – 2006 to include one sweep per stance; the net was swept once before it was removed from the water and its contents cleaned into the sample jar. The volume of water and area of epibenthos was multiplied by the total number of sweeps per sample to obtain the total volume of water and area of epibenthos sampled.

5.2.1 Lab analysis

After invertebrates were sorted from dirt and plant debris in the sample, they were 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.

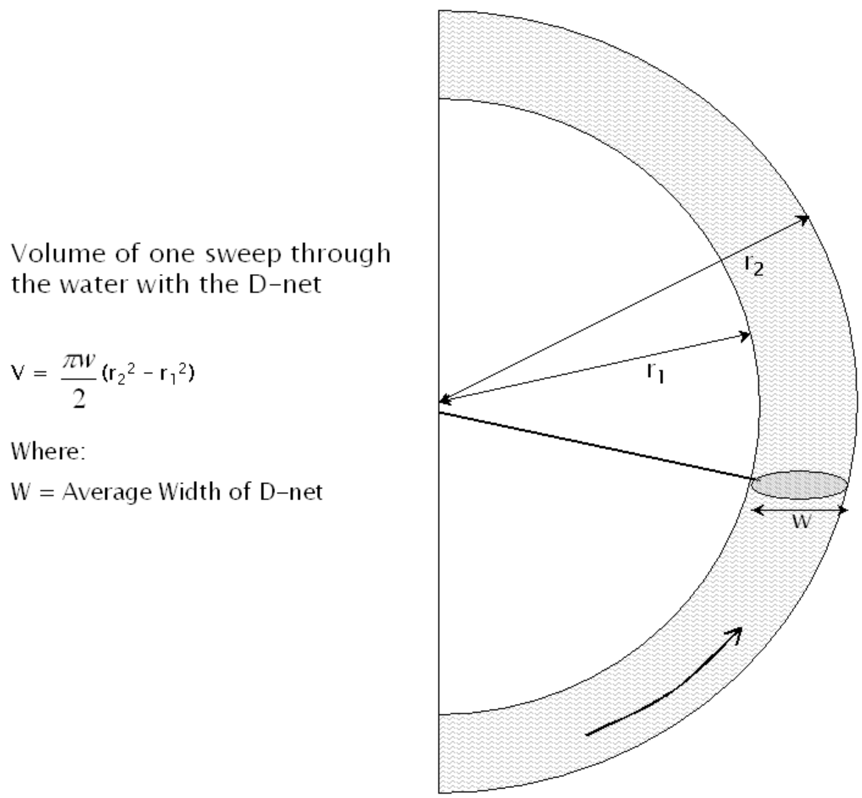


Figure 5-2 Geometry of sampling method for water column invertebrates.

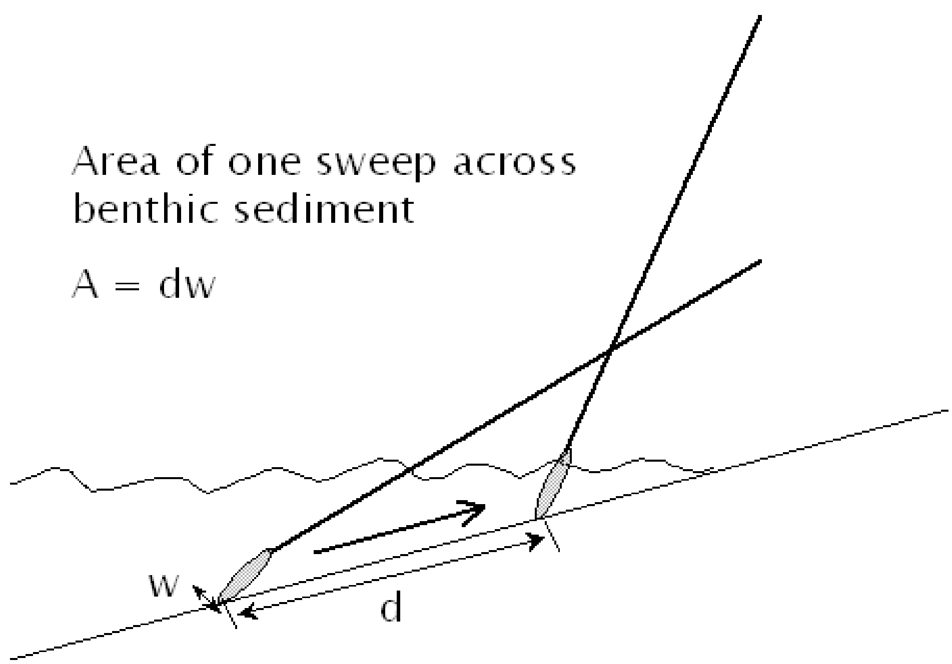


Figure 5-3 Geometry of sampling for epibenthic invertebrates.

5.3 Results

5.3.1 Taxa Present

Table 5-1 is a list of all observed taxa in the lagoon. Photographs of each taxa are in Appendix C. All taxa in the graphs and text are referred to by the lowest classification identified, which can be found in **bold** in Table 5-1.

A few taxa were only present once or twice, or only occurred in specific samples. Hirudinea and Polychaeta were only present once in the epibenthos of the river mouth (March 22 2006). Libellulidae was only present once, at the South Arm pipe on March 22 2006. The dragonfly larva Aeshnidae was the only taxa to occur exclusively in the Odello sites. It was present on 3 separate occasions: October 2004 and June & September 2005. Ceratopogonidae was only found in the river mouth in June and September of 2005. Empididae was only present at the South Arm Pipe in October 2004 and September 2005. Spinicaudata was present in the river mouth and in the North arm on Dec 15 2005. A few taxa were only present in the pre-existing lagoon sites and never found in any sample from the Odello sites: Ceratopogonidae, Empididae Ephydridae, Spinicaudata, and Nematoda.

5.3.1.1 General characteristics

Of all the taxa present in the lagoon, the 4 key taxa *Eogammarus, Corophium*, *Gnorimosphaeroma*, and *Neomysis*) that were found in the stomachs of steelhead smolts by Fields (1984), were present in the lagoon during our sampling. General characteristics for each of these 4 taxa are below. General characteristics for all taxa present in the lagoon can be found in Larson et al, 2005.

All four taxa that Fields found in steelhead stomachs are Peracarids (a superorder of crustaceans) that share some common features. They are typically restricted to permanent bodies of water that are cool, clean, and well oxygenated; they have distinct patterns of vertical migration; they have relatively limited ability to move upstream or drift downstream, they obtain much of their energy while feeding on bottom substrates; and all serve as important prey to a large number of predatory fishes (Covich and Thorp, 2001).

They are also similar in similar in the range of foraging behaviors used in obtaining food resources. Juveniles are typically dependant on microbial foods such as algae and bacteria, but adults feed on larger food items and are predatory (Covich & Thorp, 2001; and Gooderham & Tsyrlin, 2002). Because they obtain energy from a wide variety of sources, they can reach high population densities (Covich and Thorp, 2001).

5.3.1.1.1 Amphipoda

Corophia and Gammarids (scuds) are found in abundance in estuarine environments. 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). As adults Amphipods become opportunistic scavengers, predators, and omnivores depending on food availability (as cited in Covich and Thorp, 2001). Corophidae are typically found in more saline environments than other amphipods (Gooderham & Tsyrlin, 2002).

5.3.1.1.2 Isopoda

Gnorimosphaeroma is the genus of Isopod that is the Carmel River Lagoon. Isopods (sow bugs) are flattened peracarid crustaceans. They are detritovorous and primarily epibenthic. 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). They are common in lowland, slightly saline systems (Gooderham & Tsyrlin, 2002).

5.3.1.1.3 Neomysis

Mysids are small opossum shrimps, peracarid crustaceans found in oligotrophic lakes and estuaries. They are coldwater organisms that reproduce in summer. The mysid life cycle is thought to last approximately 3-4 years (Smith, 2001). Mysids are known to tolerate high temperatures and low DO for short time periods (Covich and Thorp, 2001).

Table 5-1 List of all observed taxa.

Names in bold are the names each taxa is referred to as in the text and in graphs. Shaded boxes indicate a documented food source for steelhead in the Carmel River Lagoon (Fields, 1984).

Phylum	Class	Order	Family	Genus	Common Name
Annelida	Clitellata (Subclass **Hirudinea**)				Leech
Annelida	**Polychaeta**				Bristle worms
Arthropoda	Insecta	Coleoptera	**Dytiscidae**		Predaceous diving beetle
Arthropoda	Insecta	Diptera	**Ceratopogonidae**		Biting midge larvae
Arthropoda	Insecta	Diptera	**Chironomidae**		Midge larvae
Arthropoda	Insecta	Diptera	**Chironomidae (pupa)**		Midge larvae
Arthropoda	Insecta	Diptera	**Empididae**		Dance fly larvae, Dagger fly larvae
Arthropoda	Insecta	Diptera	**Ephydridae**		Brine fly larvae
Arthropoda	Insecta	Ephemeroptera	**Baetidae**		Mayfly larvae
Arthropoda	Insecta	Hemiptera	**Corixidae**		Water Boatman
Arthropoda	Insecta	Hemiptera	**Notonectidae**		Backswimmer
Arthropoda	Insecta	Odonata	**Libellulidae**		Dragonfly larvae
Arthropoda	Insecta	Odonata	**Aeshnidae**		Dragonfly larvae
Arthropoda (Subphylum Crustacea)	Branchiopoda	Diplostraca (Suborder Cladocera)	**Daphnidae**		Water Flea
Arthropoda (Subphylum Crustacea)	Branchiopoda	Diplostraca (Suborder **Spinicaudata**)			Clam shrimp
Arthropoda (Subphylum Crustacea)	Malacostraca (Subclass Eumalacostraca)	(Superorder Peracarida) Amphipoda	(Suborder Gammaridae) Corophiidae	**Corophium**	Scud
Arthropoda (Subphylum Crustacea)	Malacostraca (Subclass Eumalacostraca)	(Superorder Peracarida) Amphipoda	(Suborder Gammaridae) Anisogammaridae	**Eogammarus**	Scud
Arthropoda (Subphylum Crustacea)	Malacostraca (Subclass Eumalacostraca)	(Superorder Peracarida) Isopoda	Sphaeromatidae	**Gnorimosphaeroma**	Isopod
Arthropoda (Subphylum Crustacea)	Malacostraca (Subclass Eumalacostraca)	(Superorder Peracarida) Mysidacea	Mysidae	**Neomysis**	Opossum shrimp
Arthropoda (Subphylum Crustacea)	**Ostracoda**				Seed Shrimp
Mollusca	Gastropoda	Pulmonata	**Physidae**		Aquatic snail
Nematoda					Round worm

5.3.2 Abundance and Diversity

Taxa abundance was calculated by dividing the total number of individual per taxa per sample by the total volume of water column (m^{-3}) or area of epibenthos (m^{-2}) sampled. Abundances for samples collected from the pre-existing lagoon sites (R2, N1, and R4) and the Odello sites (O1, O2, and O3) were summed and graphed in relation to time in Fig.'s 5-2 and 5-5).

The following observations are based on Figures 5-2 and 5-5:

- Peracarids (Corophium, Eogammarus, Gnorimosphaeroma, and Neomysis) were the most abundant and consistent groups of taxa present.
- Abundance and diversity were highest in late summer and fall. This seasonal variation was less pronounced in the epibenthos. We suggest that the pattern is driven by:
    - o Warmer temperatures leading to more primary production in the system
    - o Stratification leading to greater diversity of habitats
    - o Breeding phenology
    - o Closed-bar conditions, with no advective losses of invertebrates to the ocean
- The fauna of the newly excavated lagoon has developed over the monitoring period. Insects have tended to decline, particularly after the initial disconnected freshwater period. Ostracods and epibenthic peracarids have tended to increase over the 2-year period.
- To date, the newly excavated lagoon has less abundant peracarid epibenthic fauna than the pre-existing lagoon.
- The newly excavated lagoon had more abundant ostracods than the pre-existing lagoon.

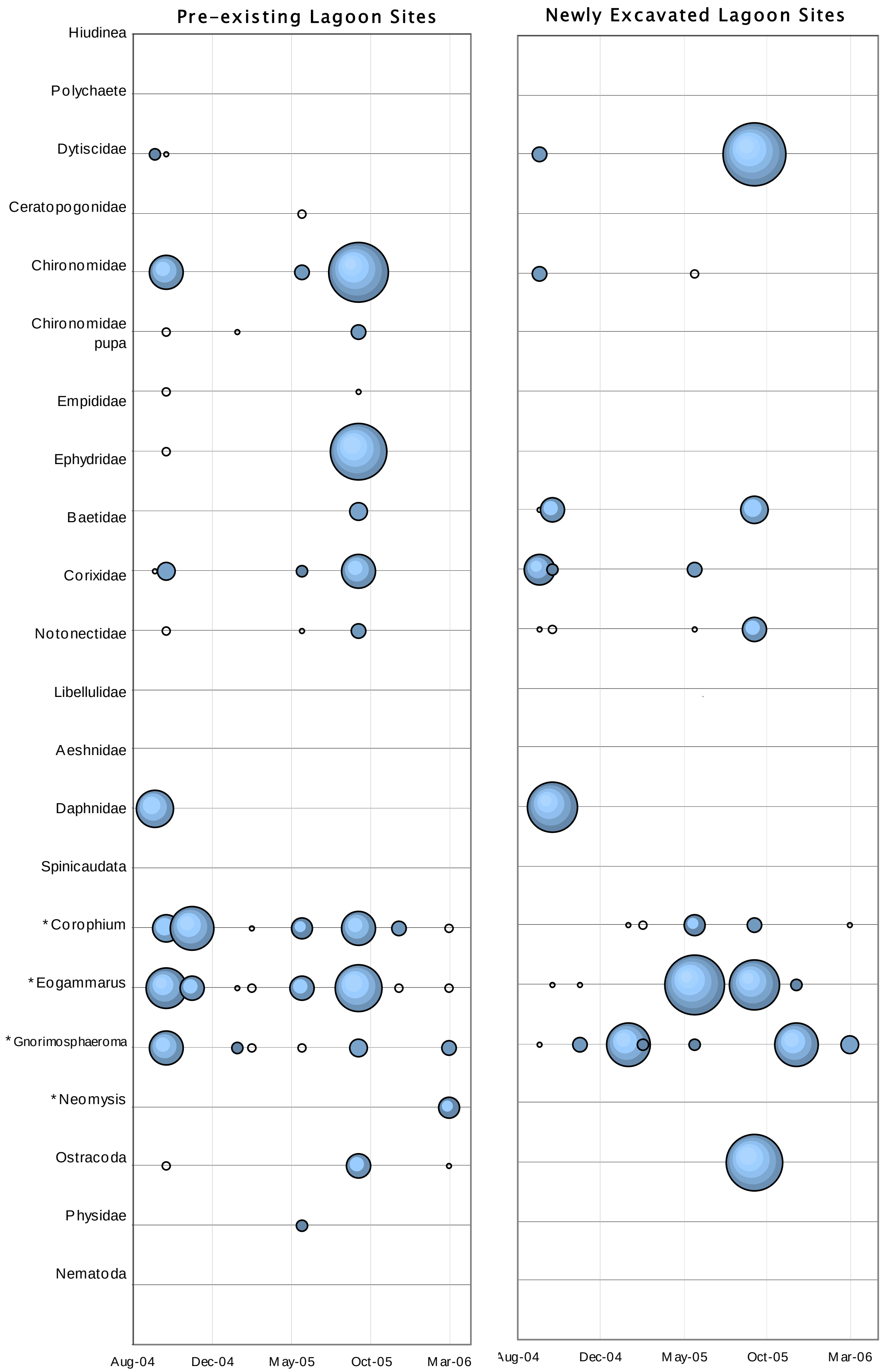


Figure 5-2 Invertebrate abundance in water column samples in the pre-existing and newly excavated lagoon areas. Sizes of bubbles represent relative abundance (m^{-3}). * Found in Steelhead stomachs (Fields, 1984)

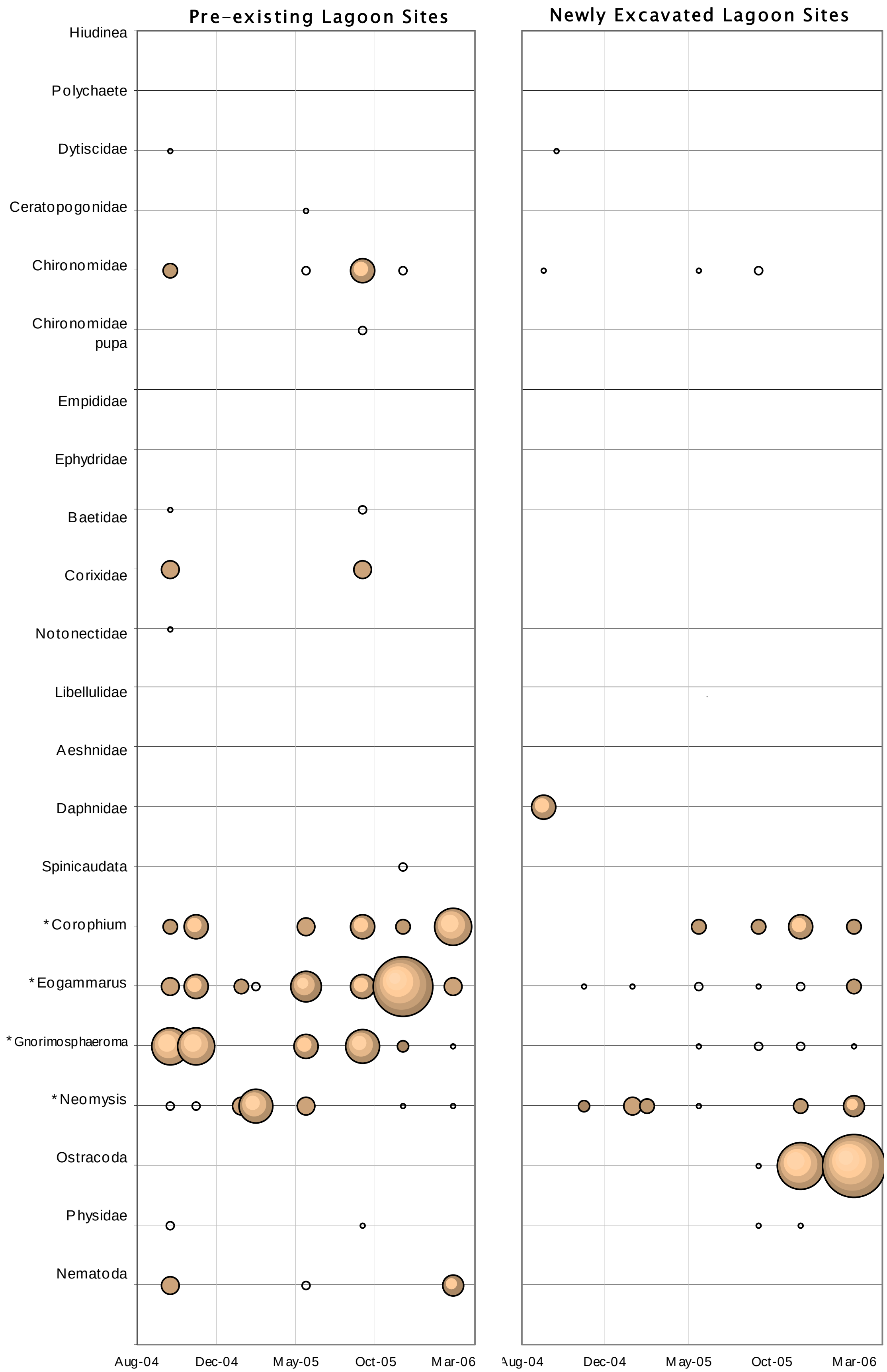


Figure 5-5 Invertebrate abundance in epibenthic samples in the pre-existing and newly excavated lagoon areas. Sizes of bubbles represent relative abundance (m^{-2}). * Found in Steelhead stomachs (Fields, 1984)

5.3.2.1 Shannon-Wiener Index

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.

In general, diversity in the water column was slightly higher in the pre-existing lagoon (Fig 5-6). Diversity throughout the lagoon peaked during summer and late fall, for reasons suggested earlier. Epibenthic diversity was higher in the pre-existing lagoon, until 2006, where it was higher in the newly excavated lagoon during the last two sampling events. This is perhaps due to the gradual development of the ecosystem in the newly excavated lagoon, and the refuge that the newly excavated lagoon provides from the disturbances of river flow and ocean influx. The sandbar breach and the pattern of opening and closing in Mar 2006 had little effect on macroinvertebrate diversity in the Odello portion of the lagoon; though in the spring of 2006, diversity in the epibenthos of the pre-existing lagoon was the lowest in the two-year sampling period.

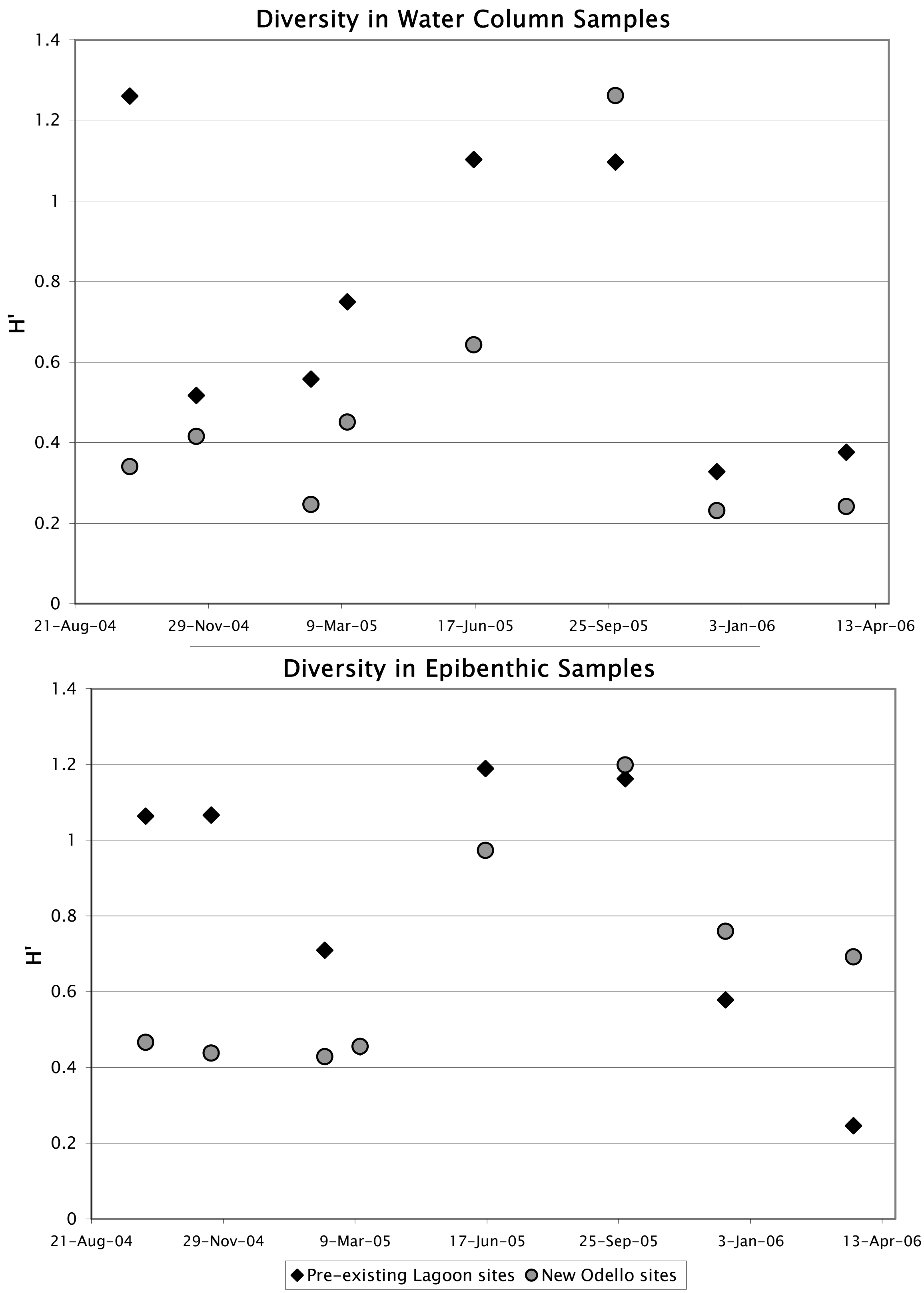


Figure 5-6 Changes in taxa diversity through time.

5.3.3 Functional Feeding Groups

The functional feeding groups to which all taxa belong are summarized in Table 5-1. Functional feeding groups serve as descriptors of trophic interactions (Harrington and Born, 2000). In very general terms, collectors and gatherers collect or gather fine particulate matter, filterers filter fine particulate matter, and predators feed on other living animals. Some taxa fit into more than one of these designations. The percentages of the different functional feeding groups presented in Fig 5-7 are based on published functional feeding group designations, as cited in the caption of Tab 5-1. Most of the taxa present in the lagoon are collectors.

The percentage of predators in the pre-existing lagoon was roughly the same amount (<10%) over two years with the exception of the period of time from November 2004 through March 2005 when there was none. Collectors, most of which are collectors/gatherers, dominate the pre-existing lagoon.

Overall the complexity of trophic interactions in the new Odello portion of the lagoon increased by means of more variation from sample to sample. This is the most obvious trend in these data. Most invertebrates in the Odello portion of the South Arm were collectors from Nov 2004 through Mar 2005. In the second half of 2005 and in 2006, there was more variety as the percentage of collector/gatherers and predators increased (Fig. 5-7).

Table 5-1 Functional Feeding Group of each taxon (Harrington and Born, 2000; Gooderman and Tsyrlin, 2002; Chigbu, 2004; Merrit and Cummins, 1996)

Taxon	Functional Feeding Group
Hirudinea	Predator
Dytiscidae	Predator
Ceratopogonidae	Collector/Gatherer
Chironomidae	Collector/Gatherer
Chironomidae pupa	Collector/Gatherer
Empididae	Predator
Ephydridae	Collector/Gatherer
Baetidae	Collector/Gatherer
Corixidae	Collector/Gatherer
Notonectidae	Predator
Libellulidae	Predator
Aeshnidae	Predator
Daphnidae	Collector/Filterer
Spinicaudata	Predator
* Corophium	Collector/Gatherer
* Eogammarus	Collector/Gatherer
* Gnorimosphaeroma	Collector/Gatherer
* Neomysis	Collector
Ostracoda	Collector/Gatherer
Physidae	Collector
Nematoda	Collector/Gatherer

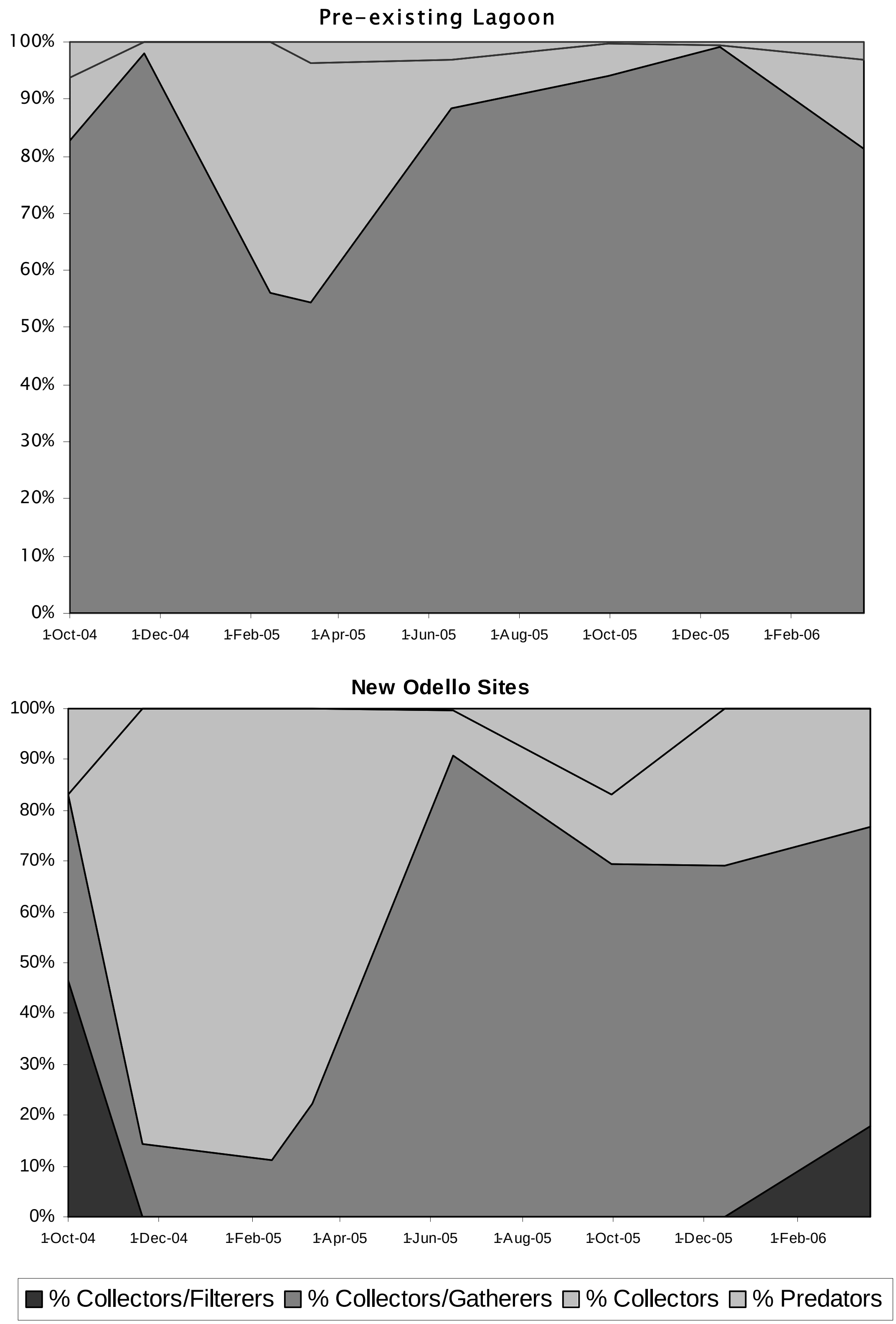


Figure 5-7 Comparison of changes in community structure between pre-existing and newly excavated portions of the lagoon. Data presented are a combination of water column and epibenthic samples.

5.3.4 Salinity Relations

The range of salinity values that each taxa occured in are summarized using Box & Whisker plots in Fig. 5-9. An explanation of the descriptive statistics that are displayed in this plot is in Fig. 5-8. This examination of salinity ranges for invertebrates in the lagoon is based on limited data from water column samples, this analysis will continue as more data becomes availible. It should be noted that just because taxa were observed in a specified salinity it is not an indication of preference or tolerance, but is largely dependant on availible habitat in the lagoon. Note also that this analysis only includes surface salinity measurements and data from water column samples.

The taxa present in the widest ranges of salinity concentrations were the peracarids. These salinity ranges have many outliers, which could account for their abundance throughout the lagoon. Insects are generally intolerant of salinity, as confirmed by our rough analysis of the correspondence between taxa occurrence and salinity in the uppermost layer of the water column. We would thus expect them to exhibit limited abundance in a lagoon that is prone to saline conditions, even at the surface at times. Peracarid crustaceans, on the other hand appear to thrive over a range of salinity levels, including freshwater. So they are expected to be found throughout the diverse habitats of the lagoon, wherever their food is abundant (i.e. areas of high algal photosynthesis, or sufficient supply of fine particulate organic matter).

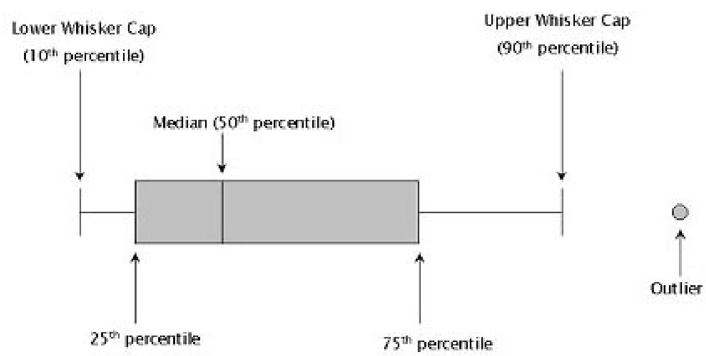


Figure 5-8 Explanation of display of descriptive statistics in Box and Whisker plots.

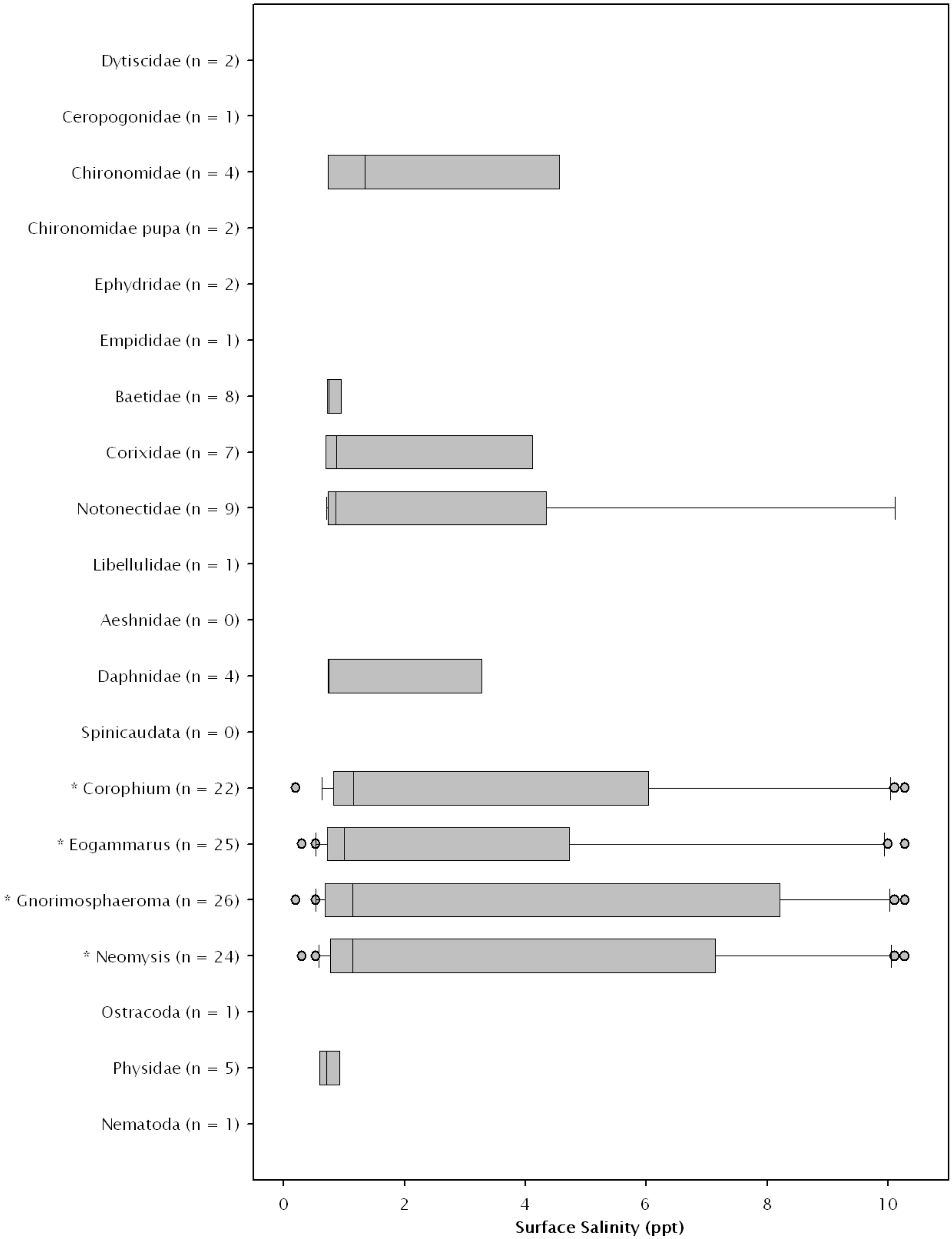


Figure 5-9 Range of salinity that each taxa occurred in the water column of the Carmel River Lagoon.

n represents the number of samples the taxon occurred in.

6 Video Monitoring for Steelhead

6.1 Introduction

Monitoring of special status species such as steelhead should be done in such a way as to minimize impacts to the species themselves. Current practices for monitoring steelhead in habitats such as the Carmel Lagoon include seining, snorkeling, or operating cameras from human-powered boats. These are all relatively intrusive and may both impact the organisms and bias the data. We have previously deployed underwater video cameras from fixed locations in the lagoon, both manually and in a remotely triggered fashion. This has met with limited success, since the fish were not usually where the cameras were, and the visibility is very poor (Larson et al., 2005).

Here, we describe a new approach to monitoring steelhead presence in shallow lagoon habitats, using an underwater camera mounted to a small remotely operated untethered boat.

This section of our report is excerpted from an early draft of a CSUMB Capstone thesis by B. Pierce (in prep. 2006) under the supervision of F. Watson and the technical advice of S. Moore.

6.1.1 Background

The idea of mounting a camera onto a pre-built remote-controlled hobby boat was considered as an appropriate approach to developing this design. However, it was quickly discovered that such craft are wholly unsuitable to this purpose. The reasons for this include extremely limited battery capacity, averaging about 20 minutes runtime, on/off throttle control on most models, disallowing the slow trolling necessary for survey work, limited controller range, and limited space for equipment. Given these limitations, a craft was constructed to meet the specific demands.

The goal was to design a stable craft that would be capable of operating on the surface of Carmel Lagoon, slowly trolling the waters for a number of hours, using a video camera that would broadcast digital video back to a computer on shore. Also, it was necessary to create the craft to be as small as practicable and to create as little disturbance as possible.

6.2 Design

The basic frame of design is a sheet of pressure-treated plywood (for water resistance) resting on two pontoons constructed from standard 4” PVC pipe. This allows for a simple, cheap, spacious, and nearly unsinkable platform. The craft was originally constructed with standard weight "schedule 40" piping, but was later changed to thinner-walled pipe for lighter weight. This reduced the draft of the pontoons and significantly increased efficiency. Figure 6-1 shows the early concept design for this specialized craft.

6.2.1 Power

The vessel is entirely battery powered. The system has been demonstrated to continue operating to 2.5 hours and beyond. There are two separate battery systems in the design, one at 7.2V for the propulsion hardware (motor, rudder, and radio control electronics), and another at 4.8V for the camera and wireless router (video/communications system).

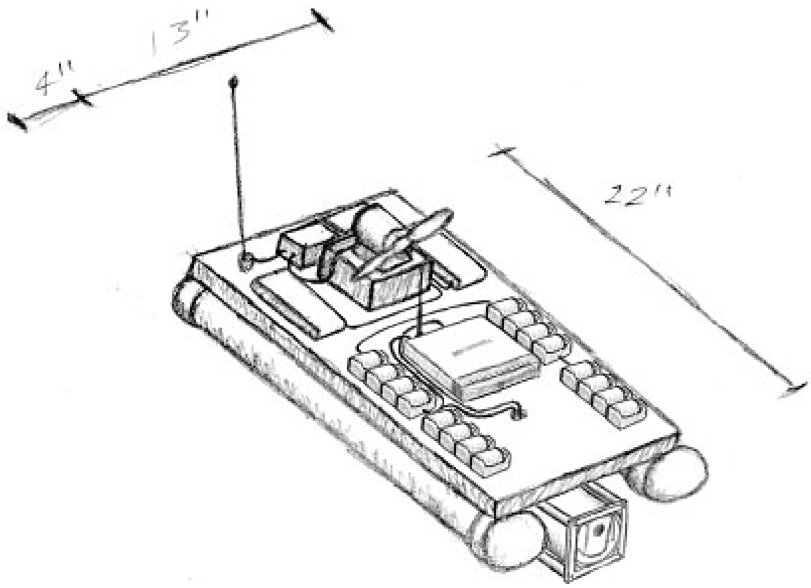


Figure 6-1 Early concept sketch of vessel (Brian Pierce, 2006)

6.2.2 Propulsion and Control

In conceiving of a propulsion system, it was apparent that stealth is paramount, due to known issues with juvenile steelhead spooking easily. Because of this, an in-air propulsion system using off-the-shelf hobby airplane parts was used with a propeller mounted to an airframe near the rear of the craft.

It quickly became apparent the craft is much heavier than the typical airplane, and experiences dramatically higher drag, due to having to move through water. Because of this, the largest propeller blade available with the smallest available amount of pitch (10", XX pitch) was used to maximize propeller efficiency, and therefore, overall electrical efficiency of the propulsion system. Furthermore, it proved necessary to provide a propeller airframe design that allowed for maximum airflow over the motor to prevent overheating, and in addition, a rear-mounted fan for auxiliary motor cooling.

Control is via a four-channel analog hobby controller; analog control of the vessel was chosen for reasons of reliability and range. This controller, in conjunction with a reversible, variable speed electronic speed controller, allows for variable-speed propulsion, and reversing of the propeller to back out when it has run into objects in front of it. Two other channels are used for rudder control, and control of camera tilt. The camera armature is designed to allow approximately 40° of tilt, using a secondary control stick. Steering is provided by an additional channel on the controller linked to a servo that controls a rudder affixed to the rear of the craft.

6.2.3 Camera and Communications

The camera is mounted underneath the vessel in a custom-built housing constructed of PVC piping and 1/2" plexiglass. The camera is an AXIS 205 uses a 4mm lens and is capable of transmitting 640x480 pixel video at 30 frames per second. The camera's tilt functionality allows it move from horizontal to approximately 45 degrees downward. The focal length of the camera is manually adjusted to approximately six feet.

It transmits this signal via Ethernet to an on-board router using commonly available Category 5 twisted-pair wiring. Wireless ethernet data transmission from the boat to the shore is achieved using a D-Link WBR-1310 802.11g router with an added 7dBi gain antenna. In testing, this results in a useful signal range of approximately 100-120 meters.

6.2.4 Revisions and Final Assembly

During initial testing of the craft, the need for some revisions became apparent. Due to lack of sufficient airflow over the motor, a result both of an original motor mount design that provided insufficient airflow, and a slow craft velocity that did not allow for sufficient airflow over the airplane motor, the propeller motor would overheat during extended use. A redesign of the propeller motor, along with an overall lightening of the craft, became necessary to reduce weight and hydrodynamic drag. Lightening was accomplished by replacing the schedule 40 4” PVC pipe with "schedule 200 4” PVC pipe for a dramatic weight reduction. This allows for greater performance and battery life while allowing the motor to run much cooler.

6.3 Results

The propulsion system works as designed and maneuverability is excellent. Effective techniques for finding steelhead include slow trolling, and allowing the craft to drift without the motor running but with the video system running, to totally eliminate motor noise as a factor. However, the craft has recorded steelhead even while running at full speed (walking pace), further demonstrating the ability of this vehicle to film juvenile steelhead in the lagoon with minimal disturbance.

Initial footage gathered from the craft to date includes a large school of juvenile steelhead in the North Arm of the lagoon and in the South Arm. Footage of stickleback was also taken in the initial recordings. Though this is still in a testing phase, compared to snorkel surveying, this tool allows for easier, more repeatable and objective research with less disturbance than current practices. Therefore, this new method shows considerable potential for future studies in the Carmel Lagoon.

6.3.1 Limitations

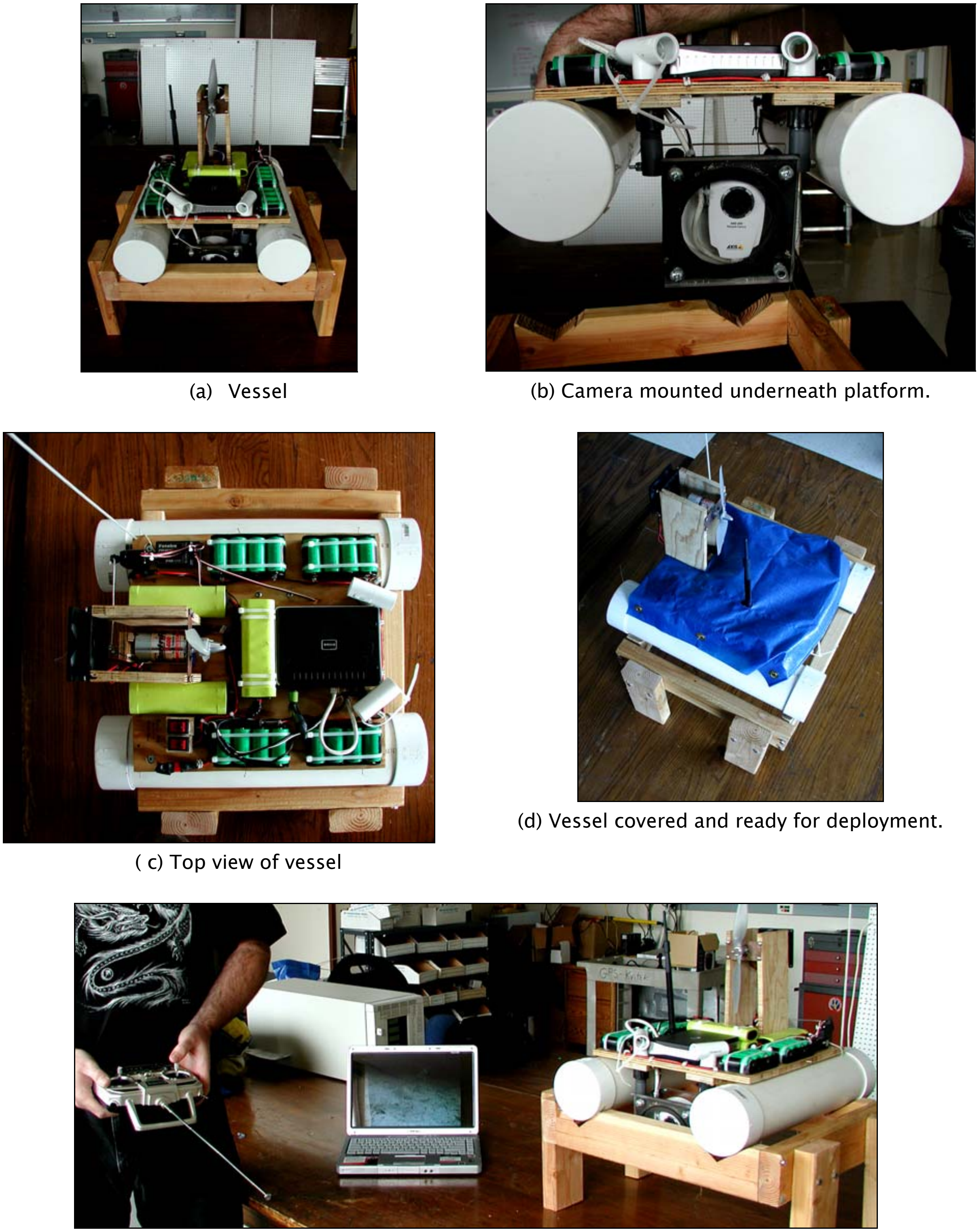
Probably the chief limitation is that the system still relies on visual monitoring, and the lagoon is fairly turbid. By using the system just prior to seining events, we hope to get some idea of the relative delectability of fish using the video system.

An important technical limitation in the current design is video signal range. Signal range averages about 100-120 meters. While the receiving laptop computer can be easily relocated, it is not always practical at the lagoon to get well within this range (especially at high stages). Also, it is important to note that at the outer limits of this range, video frame rate does suffer due to poor signal strength, so the usable range is somewhat less. This is expected to be corrected soon, as part of a revision to the design.

6.4 Future work

Increasing useful video range is high on the list of important improvements to make. GPS integration is expected to be added, to allow for recording of locations where video is taken, and for facilitate standardized, repeatable video surveys. Further reducing weight and drag is a priority, as is adding panning capability to the camera. Providing an eye-mounted ‘heads up’ display for the operator to use is being considered, to facilitate easier operation of the craft, especially by a single operator, instead of having one person drive the craft while the other monitors the video. Finally, adding a camera atop the craft is desired, to allow for easier remote control when the craft is out of visual range from the operator. The addition of these features in the near future will create a robust research platform for *O. mykiss* and other species in lagoon environments.

Though there are some additional technical improvements that can be made, with this operational, non-intrusive vessel it is now possible to sample the locations of steelhead within the lagoon and minimize the possible biases that have limited this technology in the past.



(a) Vessel

(b) Camera mounted underneath platform.

(c) Top view of vessel

(d) Vessel covered and ready for deployment.

(e) All pieces of the surveillance system: remote control, laptop, and vessel.

Figure 6-2 Platform vessel that was created specifically for the lagoon.

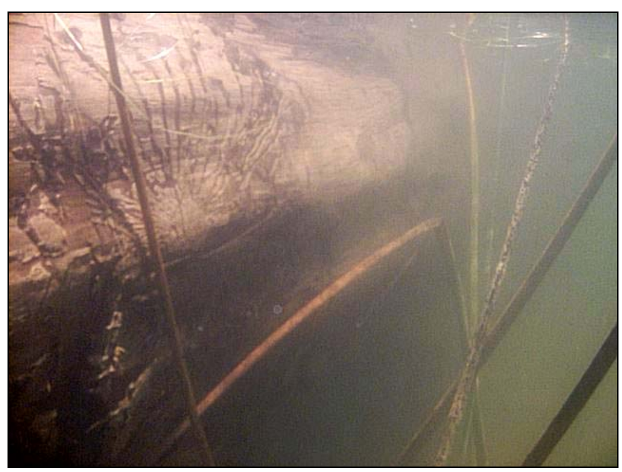
(a) Remote controlled boat with Operator in the North Arm.

(b) Fish in the North Arm.

(c) Substrate of the main lagoon next to the granite cliffs.

(d) Fish under the South Arm Pipe (S2) in some reeds.

(e) Bottom view of an aerator in the South Arm.



(f) Large woody debris in the new Odello portion of the lagoon.

Figure 6-3 Still images from the underwater camera platform. (6 July 2006, Brian Pierce)

Figure 6-4 A school of fish observed in the North Arm with the underwater camera platform. (6 July 2006, Brian Pierce)

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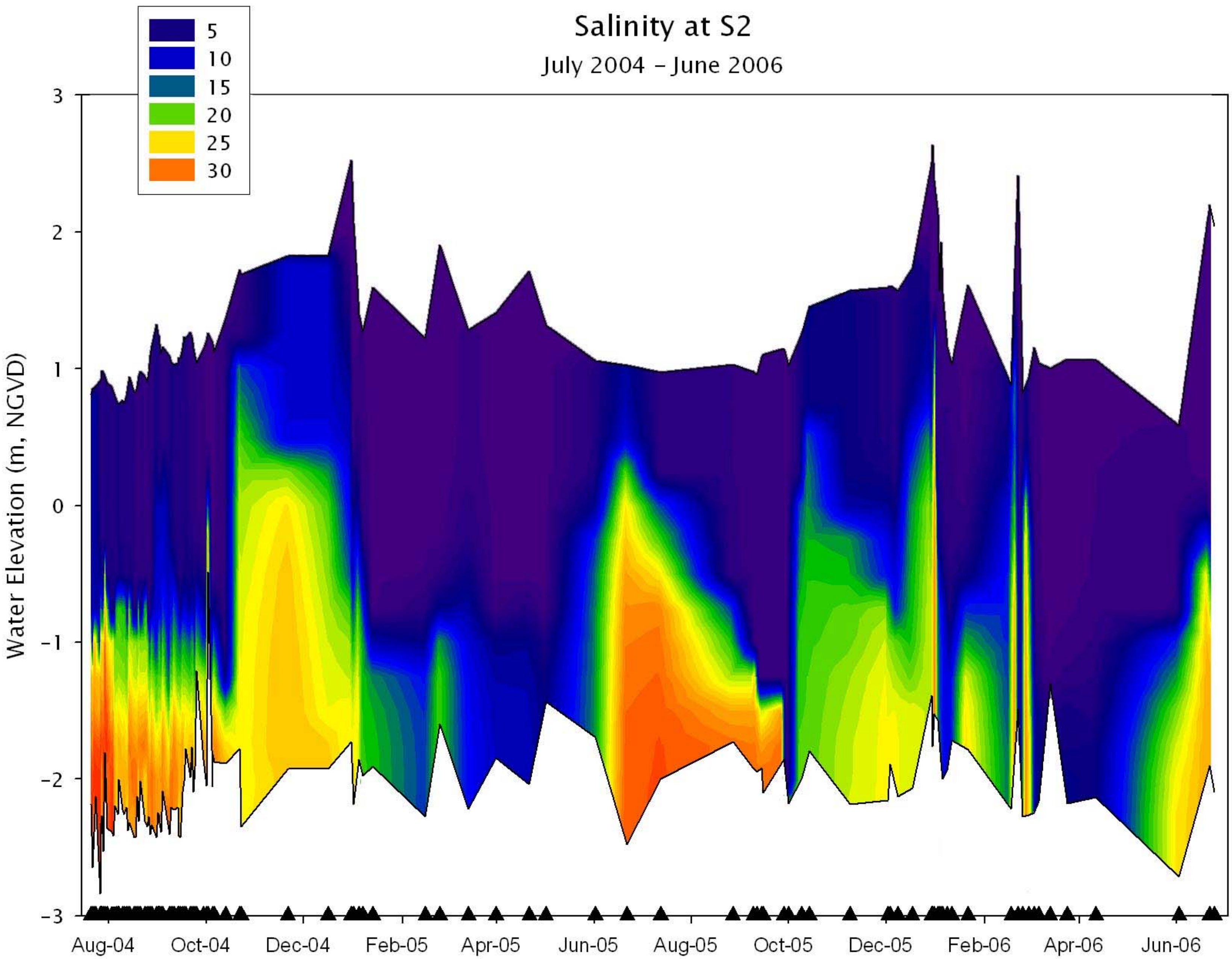
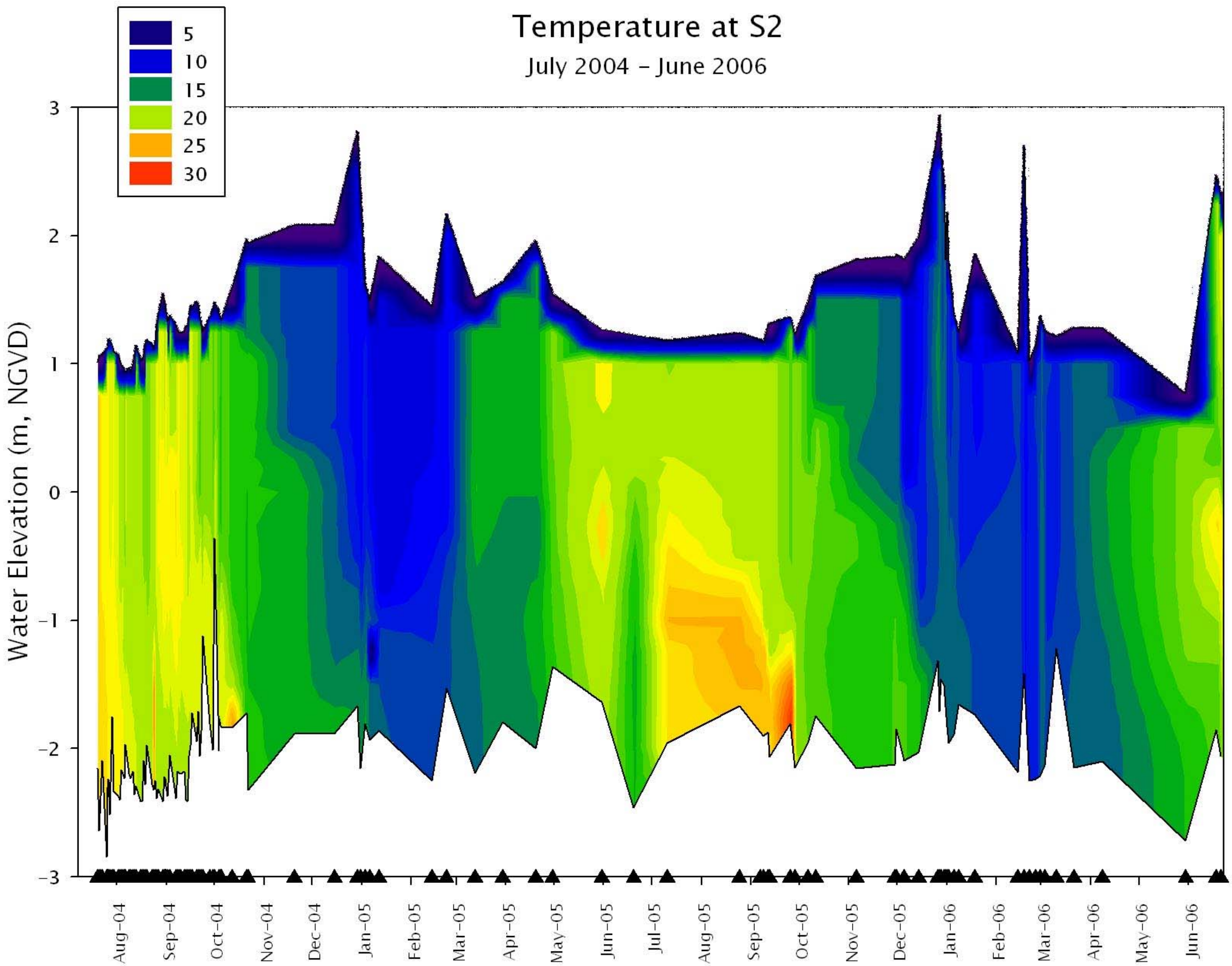
8 Appendices

Included in these appendices are:

- Appendix A: 2-year time series of depth profiles at S2
- Appendix B: 2- year time series of SSC and Turbidity data
- Appendix C: Macroinvertebrate taxa

Appendix A: 2-year time series of depth profiles at S2





Temperature at S2
July 2004 - June 2006
5
10
15
20
25
30
Water Elevation (m, NGVD)
3
2
1
0
-1
-2
-3
Aug-04
Sep-04
Oct-04
Nov-04
Dec-04
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
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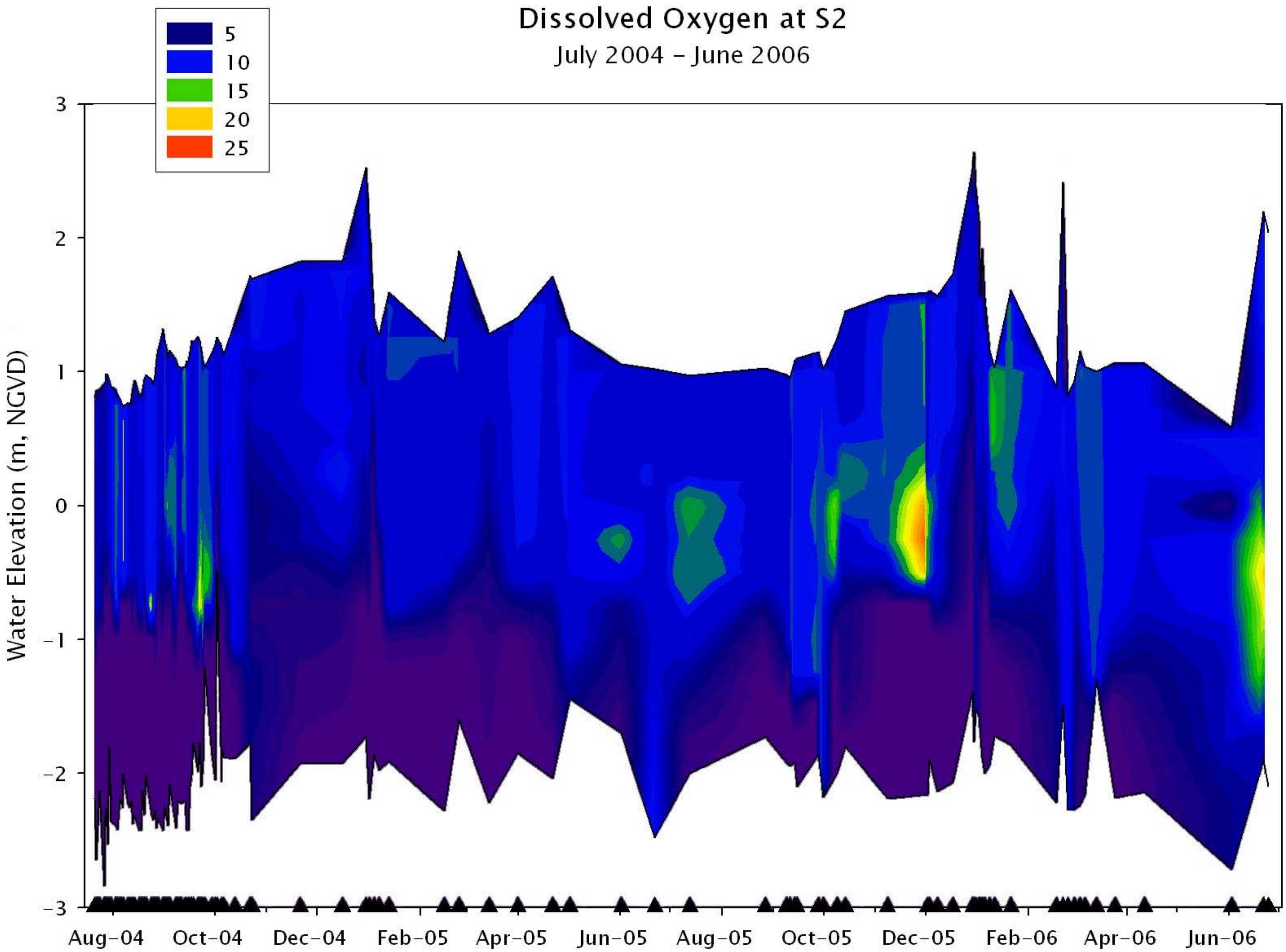
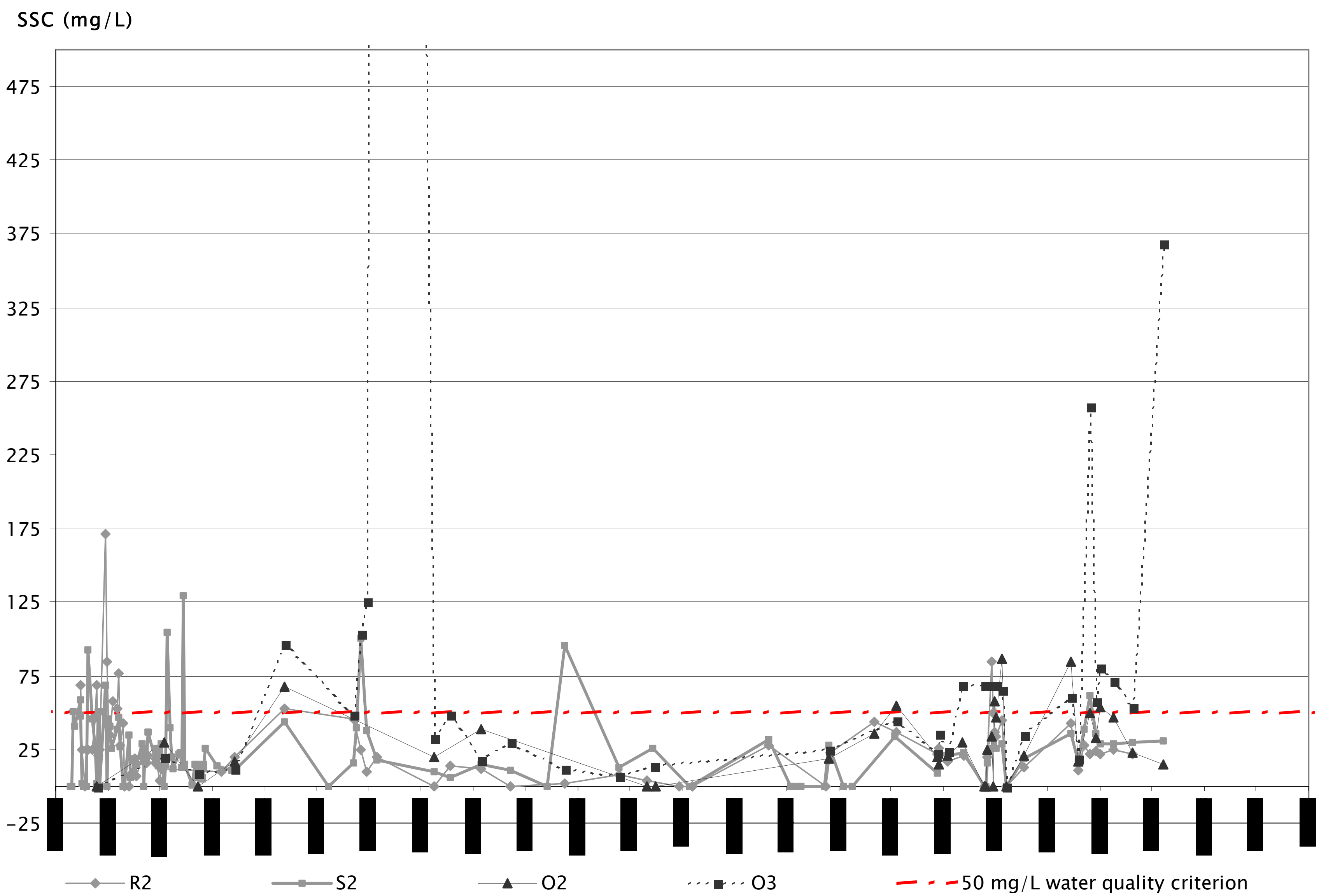
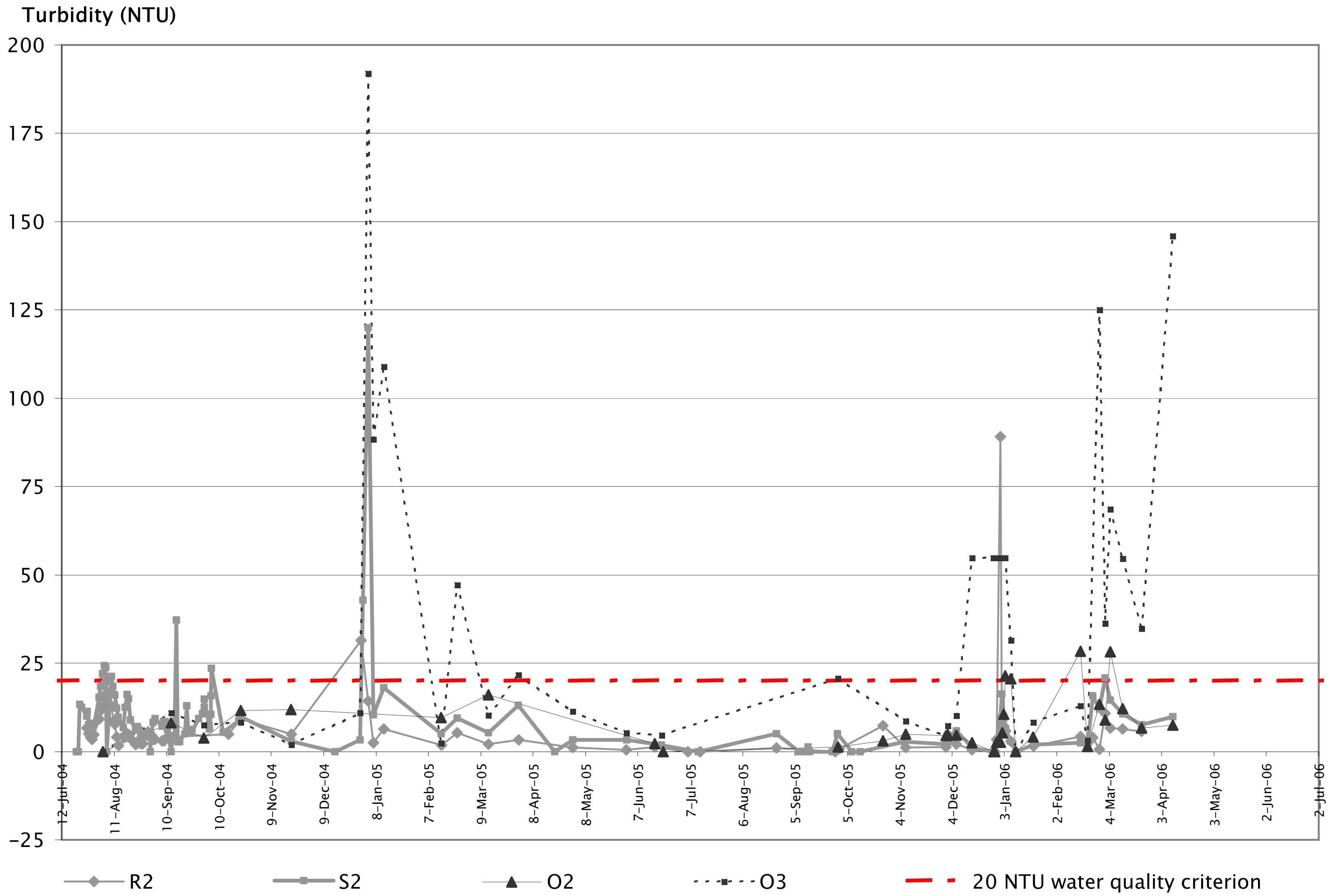
Apr-06
May-06
Jun-06


Dissolved Oxygen at S2
July 2004 - June 2006
5
10
15
20
25
Water Elevation (m, NGVD)
3
2
1
0
-1
-2
-3
Aug-04
Oct-04
Dec-04
Feb-05
Apr-05
Jun-05
Aug-05
Oct-05
Dec-05
Feb-06
Apr-06
Jun-06

Appendix B: 2- year time series of SSC and Turbidity data





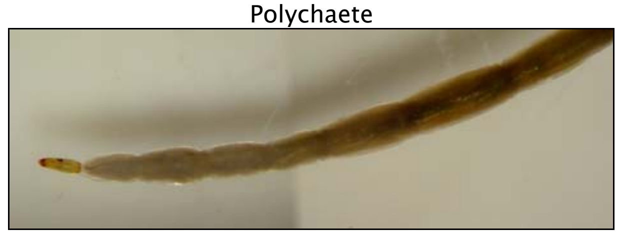
Turbidity (NTU)
200
175
150
125
100
75
50
25
0
-25
12-Jul-04
11-Aug-04
10-Sep-04
10-Oct-04
9-Nov-04
9-Dec-04
8-Jan-05
7-Feb-05
9-Mar-05
8-Apr-05
8-May-05
7-Jun-05
7-Jul-05
6-Aug-05
5-Sep-05
5-Oct-05
4-Nov-05
4-Dec-05
3-Jan-06
2-Feb-06
4-Mar-06
3-Apr-06
3-May-06
2-Jun-06
2-Jul-06
R2
S2
O2
O3
20 NTU water quality criterion

Appendix C: Macroinvertebrate taxa

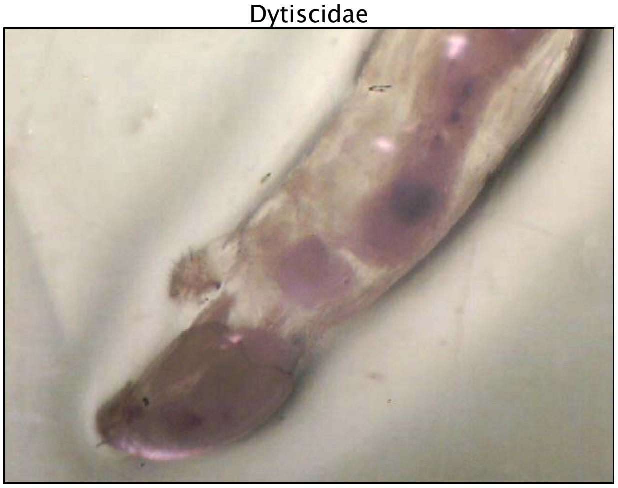
Hirudinae

Polychaete

Dytiscidae



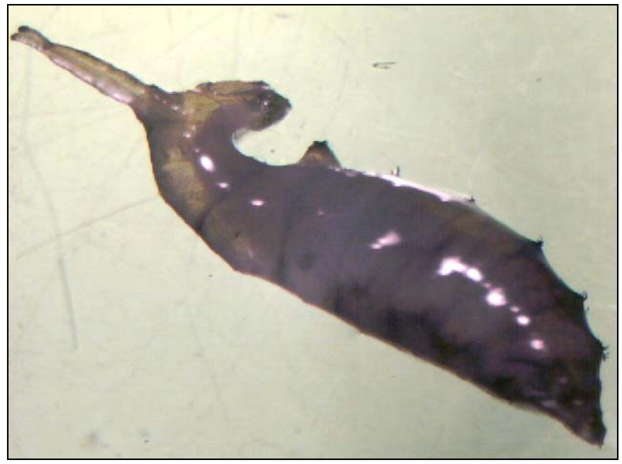
Ceratopogonidae



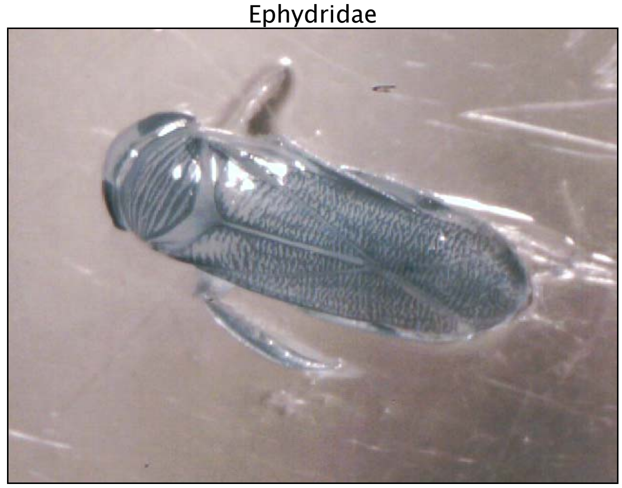
Chironomidae

Chironomidae pupa


Empididae

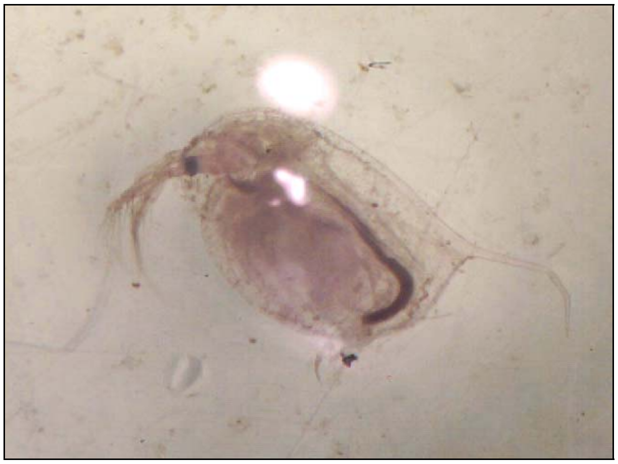

Ephydridae


Baetidae


Corixidae


Notonectidae

Aeshnidae

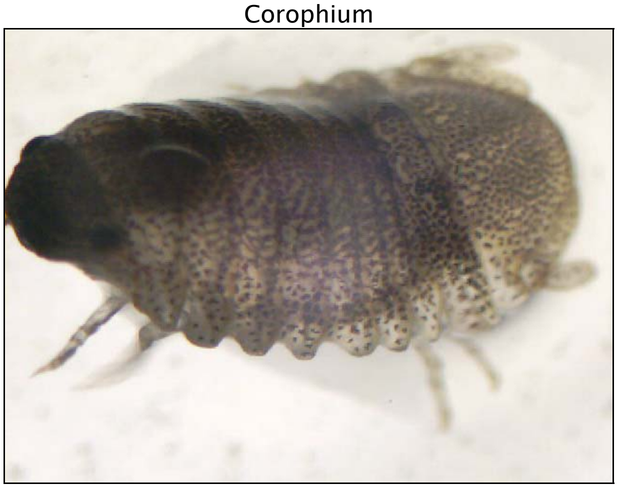


Dapnidae

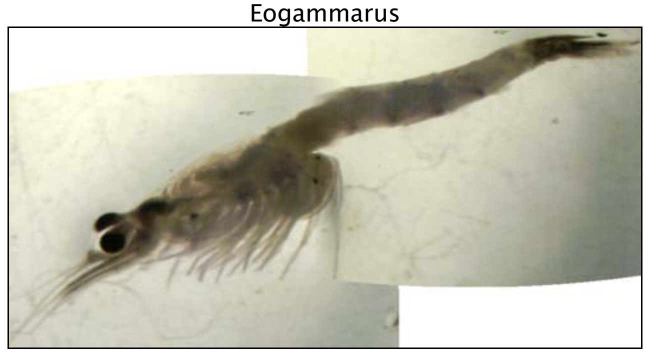
Spinicaudata

Corophium

Eogammarus



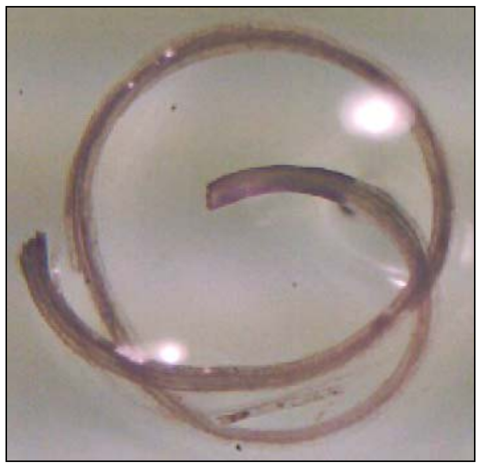
Gnorimosphaeroma



Neomysis

Ostracoda

Physidae



Nematoda