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Carmel River Lagoon Enhancement Project: Water Quality and Aquatic Wildlife Monitoring, 2006-7

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Preface

This is a report to the California Department of Parks and Recreation. It describes water quality and aquatic invertebrate 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 3-years of monitoring water quality and aquatic habitat. The report adopts the same format and certain background text from previous years' reporting by the same research group (e.g. Larson et al., 2005).

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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 (CCoWS), 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 through Spring 2007, with an emphasis on the most recent year from mid-2006 onwards (for earlier results, see our previous reports, most recently, Larson et al., 2005, 2006).

During 2006-7, the lagoon reached a typical dry-season low stage of 3.5 ft in September 2006. Thereafter, typical ocean wave action periodically raised the stage and the salinity at depth through fall and early December. The 2006-7 winter yield one of the lowest stream flow totals on record for the Carmel River. So the initial mechanical sandbar breach was not necessary until February 11th, whereas in most years it occurs in December. The lower river stopped flowing on May 22nd, one of the earliest dates on record.

Water quality in the lagoon followed seasonal patterns during 2006-7 that were similar to those observed in previous years. A warm, saline, anoxic 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 fall. At times, even the surface water was mildly saline (circa 5 ppt). The entire water column gradually cooled as fall progressed into winter, warming slightly after breaching in mid-February, and then warming significantly after sandbar closure in early spring 2007. 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. Higher oxygen levels occasionally occurred deeper down at the primary halocline, possibly due to warming and photosynthesis in this submerged layer.

Breaching activities significantly lowered the overall habitat volume of the lagoon – but did not precipitate abnormal water quality dynamics relative to other years with respect to salinity, temperature, suspended sediment, or dissolved oxygen.

Temperatures only exceeded 26° (an upper threshold for steelhead) at one site (the inland extent of the newly excavated lagoon) on one sampling date. Surface dissolved oxygen levels only went below 5 mg/L (a lower threshold for steelhead) at one site (the north arm) on one sampling date (in March 2007). Suspended sediment concentration only exceeded 50 mg/L and 20 NTU at one site on one sampling date.

The macroinvertebrate community in the lagoon was diverse, and largely similar between the pre-existing and newly excavated sections. Community composition was dominated by peracarid crustaceans (amphipods, isopods, and oppossum shrimps), along with lesser numbers of chironomids (insects). A key difference between the new and old sections was that, starting in late 2005, the newly excavated section developed a near-dominant population of ostracods, while this taxon remained almost absent from the pre-existing lagoon. Also in the new section, there were positive trends in a few epibenthic taxa throughout the project

(Corophium, Eogamarus, and Ostracoda) and a slight negative trend in one taxon (Neomysis). In the water column, many taxa declined from mid-2005 onwards (perhaps due to increased steelhead predation pressure; pending further investigation).

The remotely operated underwater video boat was successfully developed as a technological product. A remote operator can wirelessly pilot the small boat (about 80 cm long) to most locations in the lagoon while simultaneously recording up to three hours of wireless digital video showing about half as much as can be seen by a snorkeler. A simple ‘fish-finder’ sonar attachment can also be deployed. The boat’s scientific utility is still being tested. The major limiting factor is underwater visibility. The boat may only be useful during times of year when the water is clear (e.g. Spring). An ongoing student thesis is comparing hypotheses relating to steelhead presence and absence as influenced my micro-habitat factors such as depth, distance from shore, and substrate size.

1 Introduction

The Carmel Lagoon forms the mouth of the Carmel River, near the town of Carmel at the northern end of the Santa Lucia Range along the Central Coast of California. In the summer 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) involved the excavation and planting of new lagoon, marsh, and riparian habitats. One of the primary purposes of this project was to create more habitat for two Federally Threatened species: steelhead trout and California red-legged frog (CRLF, *Rana Aurora draytonii*). Additional indirect benefits include increased habitat for migratory avifauna and western pond turtles (*Clemmys marmorata*) both a Federal and State Species of Special Concern.

The Carmel River Lagoon lies at the end of the Carmel River between two residential areas: Carmel By The Sea to the north and Carmel Meadows to the south (Fig. 1-1). 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 et al., 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 outcropping bedrock confines the South Arm to a small channel that swells at high water into a wetland that was once used for agriculture (Casagrande et al., 2002). A remnant channel on the southern border of the lagoonal plain suggests that at some point in the past, the south arm of the lagoon extended hundred meters to the south of the main river channel, running alongside the steep granite bluffs to the south of the lagoon. Prior to CRLEP, this channel was a willow-dominated muddy habitat, only submerged during the highest lagoon stages, and during the largest floods. 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).

Deep-water habitat is currently found in the South Arm, the result of dredging activities in the late 1990’s. 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 area 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

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

riparian habitat as an extension of the pre-existing South Arm (Fig. 1-1). A detailed timeline of this process was given by Larson et al. (2005).

Initially, water quality and biological monitoring were conducted to assess what effects implementing the construction phase of the Carmel River Lagoon Enhancement Plan had on habitat conditions for steelhead and California red-legged frog. For the past two years, CCoWS continued monitoring in order to document changes in the newly enhanced portions of the lagoon. 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 three years after excavation.

Monitoring began on 20 July 2004 several weeks after excavation of the Odello arm, and continued through Spring 2007. The main parameters that were measured by the CCoWS team were salinity, temperature, dissolved oxygen, and macroinvertebrate abundance. Other groups coordinated various steelhead seining efforts during the project period. To augment the seining effort by providing more detailed habitat-usage information, the CCoWS team also developed a limited capability to observe steelhead using a remotely operated boat mounted with an underwater video camera and sonar unit.

2 Hydrology

2.1 Overview

The Carmel Lagoon forms at the terminus of the Carmel River once a sandbar has formed at the river's mouth. Throughout the year, the lagoon's volume and depth fluctuate in response to changes in several hydrologic forces including stream flow, ocean wave height, and ocean tides (Watson and Casagrande, 2004).

In summer when stream flow entering the lagoon has ceased, the lagoon volume and depth begin to recede. After the sandbar has formed, the initial depth, volume, and salinity of the lagoon depends on the timing of the closure and the amount of stream flow entering the lagoon at this time. Water begins to slowly exit the lagoon at the base of the sandbar due to a greater upstream hydrologic head. The rate lagoon waters flow through the sandbar is determined by the water elevation in the lagoon and ocean wave height (Watson and Casagrande, 2004). In fall, the lagoon's volume, depth and salinity all increase due to an increase in waves overtopping the sandbar.

During the rainy season, stream flow entering the lagoon usually resumes, following the first few significant storms. The incoming stream flow accumulates behind the sandbar and therefore raises the water elevation in the lagoon. Once the lagoon's water elevation reaches approximately 9-10 ft. in elevation the sand bar is mechanically breached by county staff to alleviate flood risk to neighboring properties. Typically, after an opening in the sandbar has been made much of the main embayment and north arm areas of the lagoon are drained within hours. Standing waters are retained in the South Arm and some of the Odello Arm areas due to greater depths that exist there.

While the sandbar is open the Carmel River flows through the main embayment area directly to the ocean. The lagoon's water elevation then fluctuates with the tides on a diurnal basis.

2.2 Dynamic Wave Height

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 process that is determined principally by the ocean and is largely independent of 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 (NOAA, online data from moored buoy several miles offshore)
c_m = tide coefficient (-) = 0.16
m_t = tide level (m, NGVD) (NOAA, online data)

The following sections present an overview of the hydrologic conditions throughout the project. For a more detailed review of the hydrologic conditions for the 2004-2006 period, see Larson et al. (2005, 2006).

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/

Data presented in this chapter were retrieved from a variety of sources summarized in Table 2-1.

2.3 2004 – 2007

2.3.1 June- December 2004

By June 13th 2004, the sandbar had closed and the lower Carmel River stopped flowing into the lagoon (Fig. 2-2). This was the earliest cessation since 1994 (see Fig. 2-1). The lagoon stage remained low throughout July and August reaching its lowest level of 2.36 ft on August 6th (0.74 m, NGVD). On July 25th 2004, treated water from the nearby water treatment facility (CAWD) was released into the lagoon to raise the water level due to concerns of unsuitable water quality conditions for rearing steelhead. Fresh groundwater was also pumped from an old well on the Odello property directly into the South Arm of the lagoon. The volume of water this added to the lagoon could not be quantified, due to inconsistent pumping rates. Beginning in late August, large waves began topping the sandbar (Fig. 2-5). Evidence of over wash (e.g. kelp debris and displacement of beach sands) were observed on the sandbar. The wave overwash increased the stage and salinity of the lagoon (Figs 2-2 & 2-5).

The first significant rain event occurred in late October (Fig. 2-3), however, the lower river did not connect to the lagoon until December 28th 2004, following a significant rain event that began on the December 27th. By the 29th of December, the stage in the lagoon reached ~10 ft and the lagoon was mechanically breached by county staff.

2.3.2 January – November 2005

Heavy rainfall occurred at times throughout January 2005 and periods of intense rainfall were followed by an increase in river flow and lagoon stage in mid February and mid March (Figs 2-2 & 2-3). These storms provided adequate stream flow in the lower river (Fig.2-2).

By mid April and May, stream flow in the lower river began to decline but remained high enough for flow to persist through June. Between April and June the sandbar closed and reopened multiple times due to sufficient river flow and a lowered sandbar height.

Flow in the lower Carmel River continued through August 25th. This was the longest the river had sustained flow into the dry season in 15 years, not including El Niño years of 1995 and 1998 (Figs. 2-1 & 2-2). The sandbar closed in early July, filled rapidly, and breached again on July 9th and remained open through the end of August.

After closure, the lagoon stage remained low through September, though stages did not get as low as they were in July and August of 2004 (Figs 2-1 and 2-2). Again, well water was pumped into the south arm and tertiary treated wastewater was added from the CAWD treatment plant to increase the lagoon volume and the amount of freshwater.

In October, large waves began washing over the sandbar increasing the lagoon water elevation and salinity.

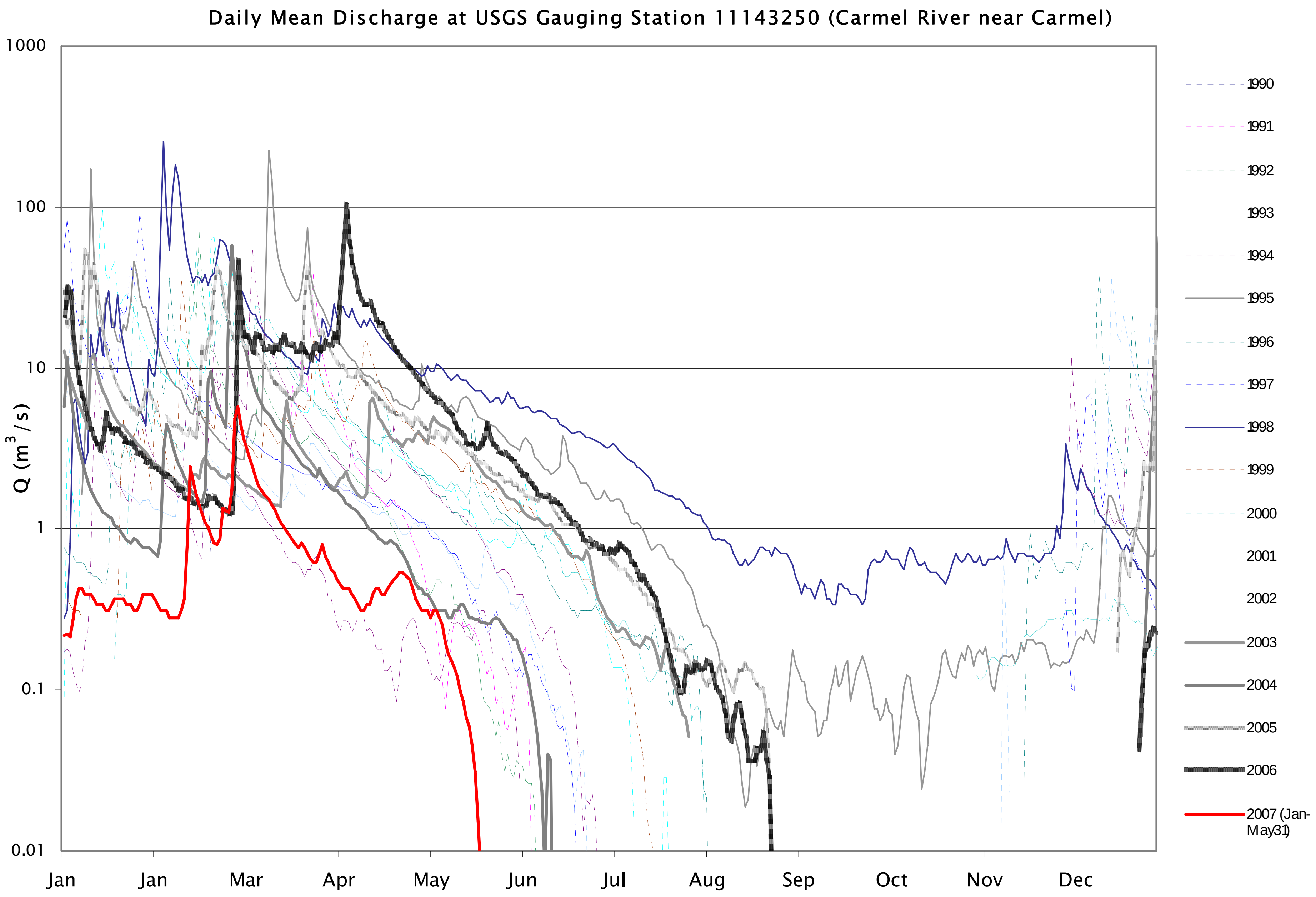


Fig 2-1. Inter-annual comparison of seasonal variations in lagoon stage. Data for 2007 is through May 31st.

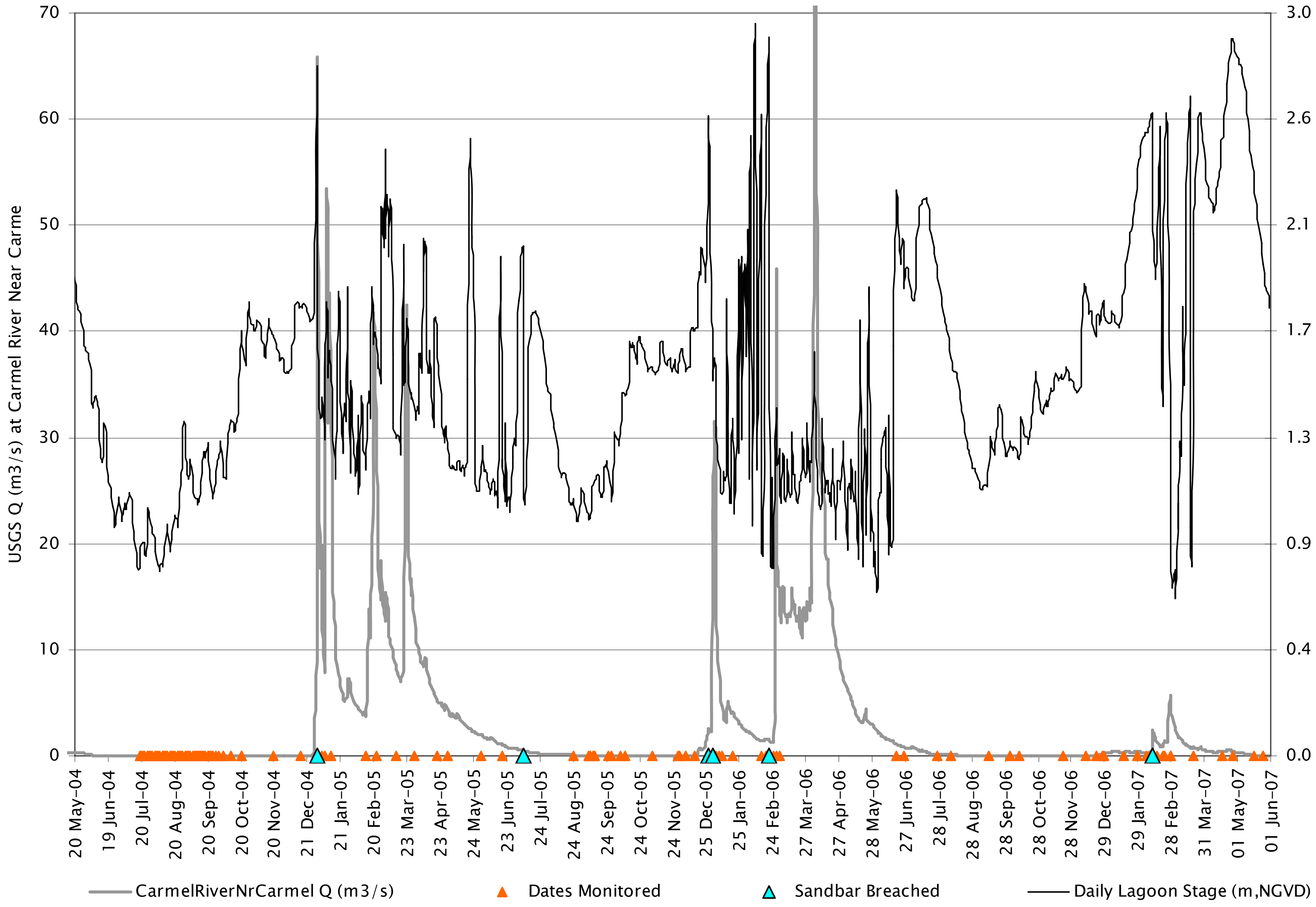


Fig 2-2. Time series of discharge and lagoon stage throughout the project.

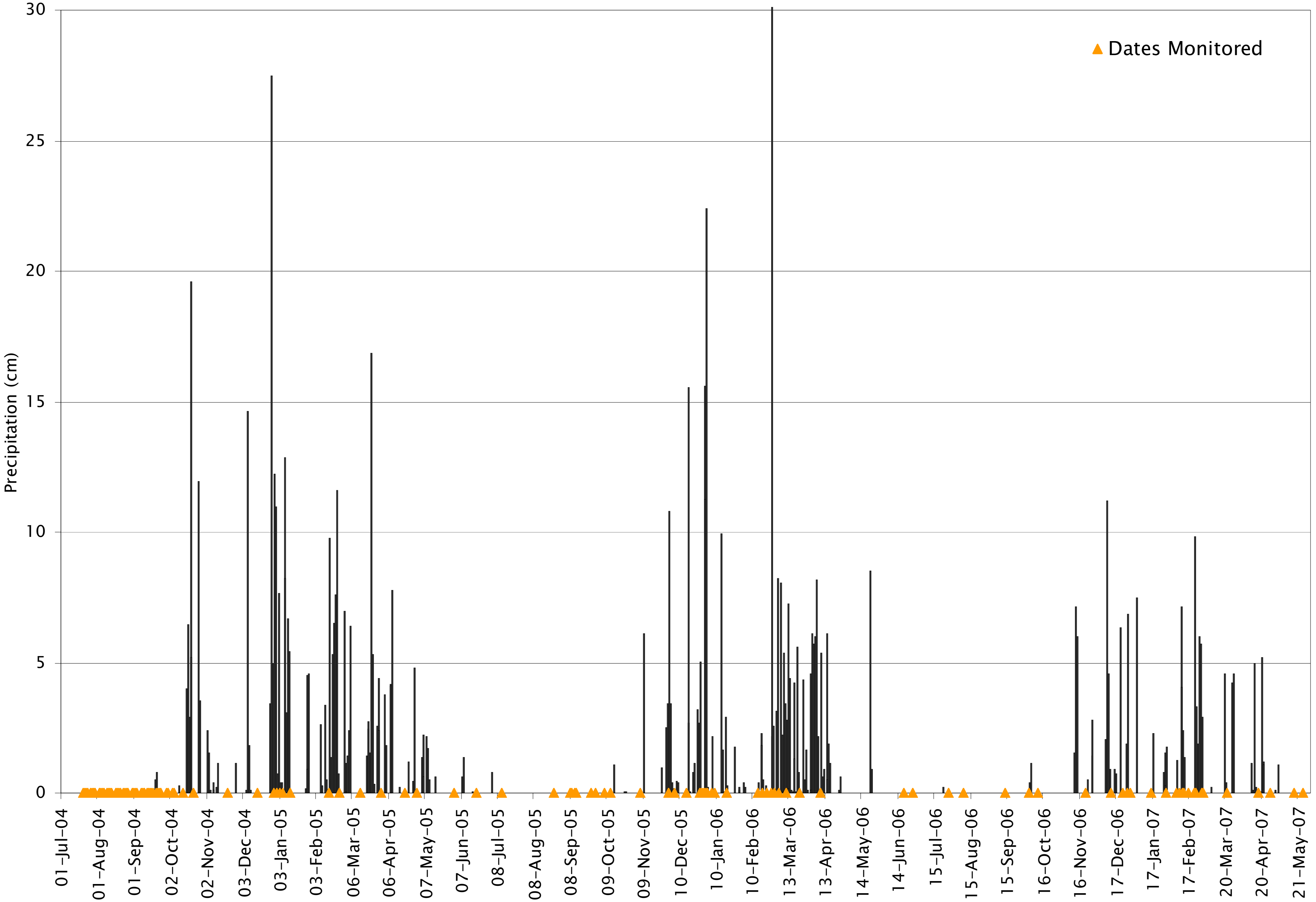


Fig 2-3. Daily precipitation totals from July 1, 2004 – May 31, 2007.

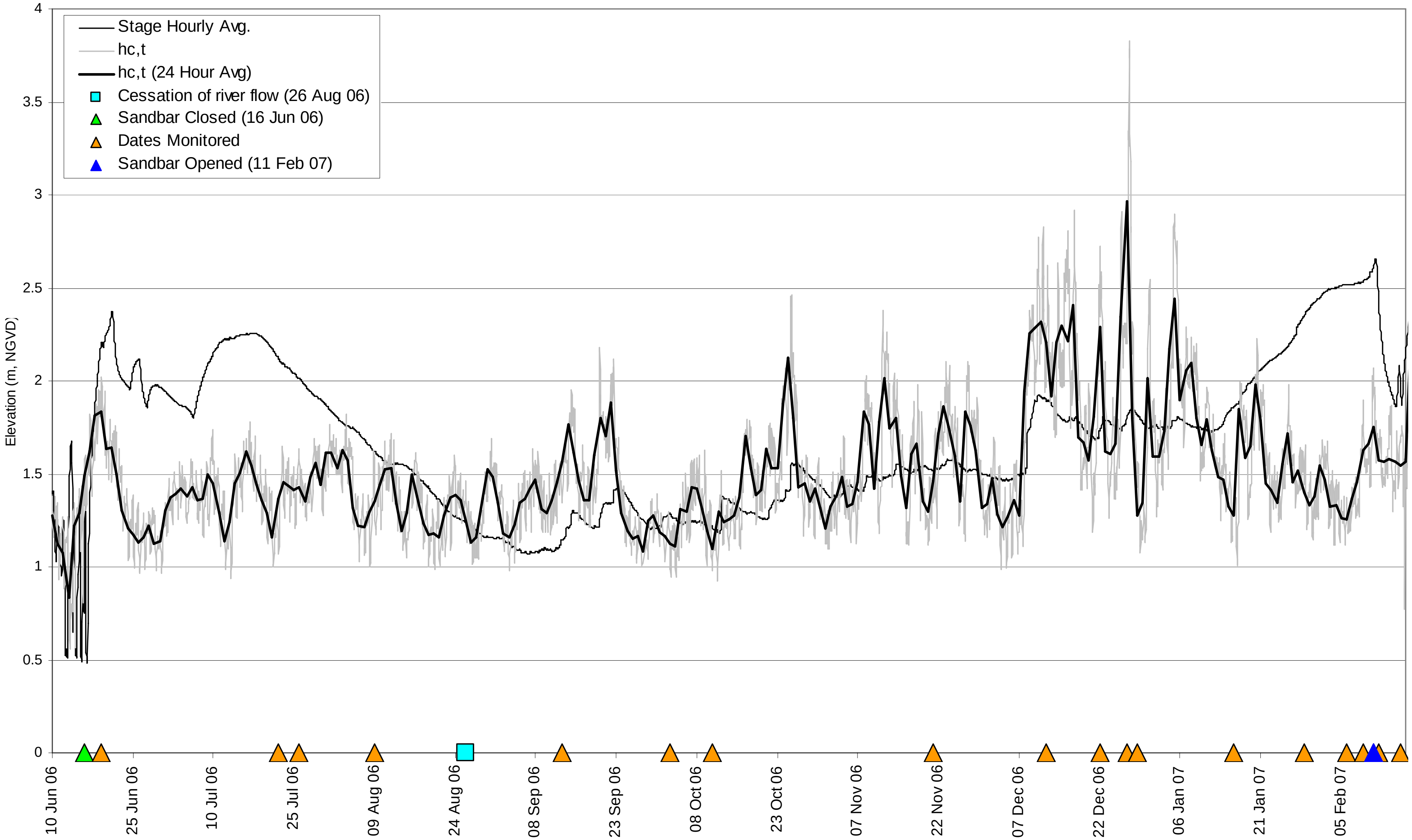


Fig 2-5. Dynamic wave height.

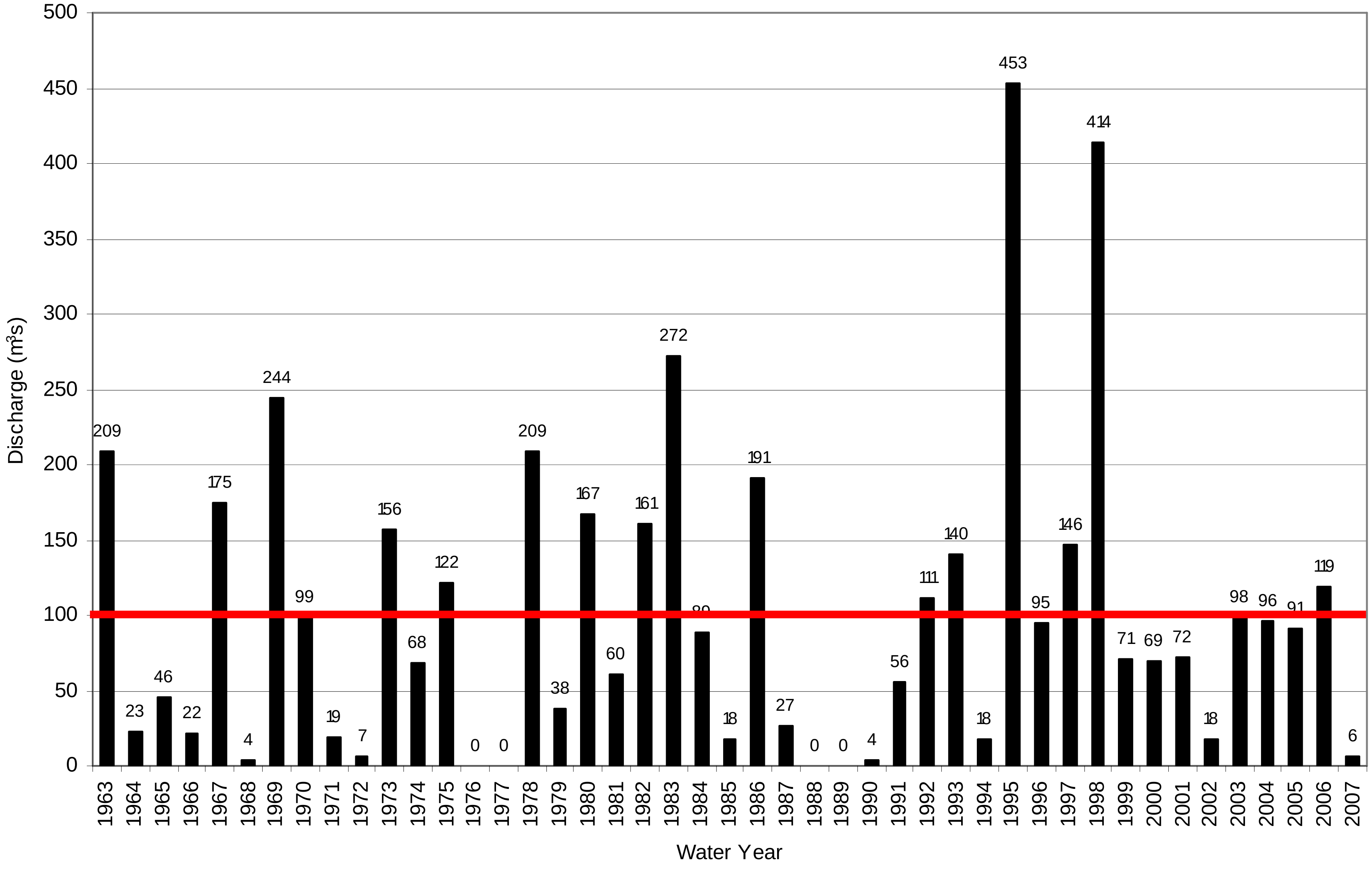


Fig 2-6. Comparison of peak stream flow values for all water years on record for the lower Carmel River USGS Gage 11143250. The red line represents the average annual peak flow (100 m³s) for this site.

2.3.3 December 2005

The winter's first significant storm occurred in early December (Fig. 2-3); however stream flow entering the lagoon did not resume until the end of December (Fig. 2-2). On the 27th of December county crews began to breach the sandbar, which was eventually opened early on the 28th. In an effort to slowly drain the lagoon (more optimal for juvenile steelhead) attempts were made to keep the breach corridor over a rocky sill that is usually buried by sand along the south end of the beach. The top of the sill sits at approximately 7-8 ft above mean sea level and would therefore allow the lagoon to drain down to that level while still maintaining a suitable volume for juvenile steelhead. The first few days following the breach, the channel stayed atop the bedrock sill. Shortly after, large waves closed the sandbar opening. However, on December 31st a group of park visitors illegally breached the sandbar to the north of the bedrock sill causing a rapid and significant reduction in lagoon volume.

2.3.4 January – June 2006

January 2006 was relatively dry. Reduced stream flow and sand accumulation from larger waves caused the sandbar to close and re-breach at least 13 times in January and February (Figs. 2-2 & 2-1).

Throughout the end of February and April long periods of intense rainfall occurred (Fig. 2-3) which increased stream flow in the lower Carmel River (Fig. 2-2). By March lands throughout the watershed were saturated. The continued precipitation throughout March and April resulted in a peak river discharge of 103 m^3/s (3,620 cfs) on April 5th (Figs. 2-2 & 2-6).

On May 31st 2006, the lagoon stage reached a record low of 1.7 ft (Fig 2-2). At these levels, rearing habitat for juvenile steelhead in the main embayment and north arm areas was substantially limited. On June 16th the sandbar was mechanically closed and with stream flow still entering the lagoon, the stage quickly increased. To avoid another mid summer breach, a wall of sandbags underlined with tarps was used to maintain exit flows over the bedrock sill, thus keeping the water elevation in the lagoon's main embayment at a higher level (more suitable for rearing juvenile steelhead) (Figs. 2-2 & 2-7).

2.3.5 July – December 2006

Periods of rainfall continued through April and May, which maintained stream flows in the lower Carmel River well into August. After the lagoon closed on June 16th, the water elevation rose to a maximum of 7.75 ft which slowly subsided to 6.0 ft by July 6th. The lagoon elevation rose again to 7.3 ft by July 18th. From here, the lagoon volume slowly declined until reaching a summer minimum of 3.5 ft on September 6th. By September, ocean wave heights had increased as did the occurrence of wave overwash into the lagoon. During periods of greater dynamic wave height, water elevations in the lagoon were maintained at higher levels, as is shown in Figure 2-5.

Although the first significant rainfall occurred in mid November (Fig. 2-3), stream flow in the lower Carmel River did not resume until December 25th (Fig. 2-2).

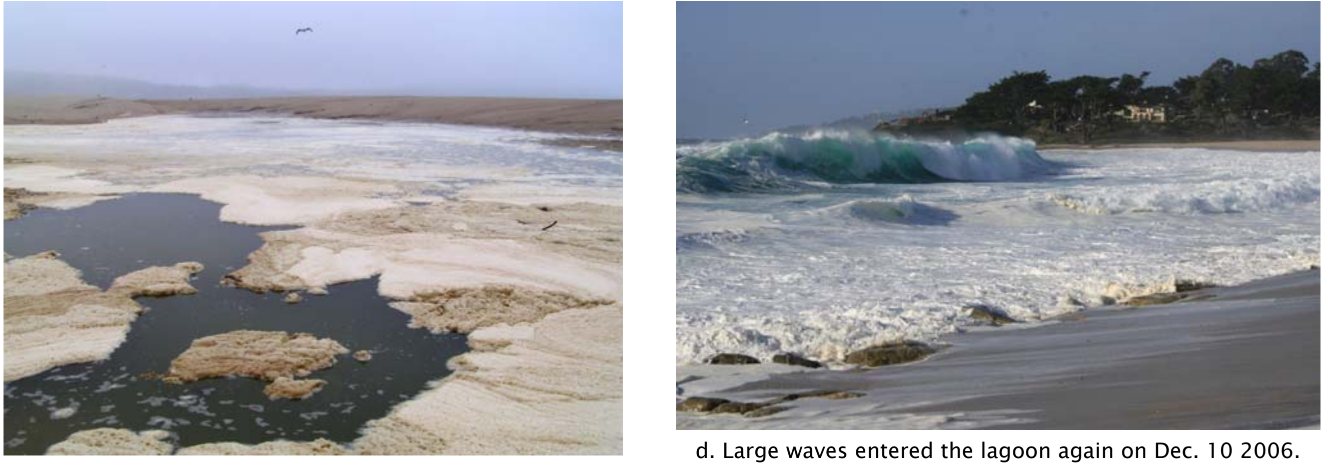
2.3.6 January – June 2007

Precipitation totals for January were low thus producing low stream flows in the lower Carmel River. By early February, storms had produced enough runoff to fill the lagoon thereby necessitating a mechanical breach on February 11th. Following the initial breach, the lagoon filled and breached itself on three occasions over the next 14 days. On February 28th stream flow in the lower Carmel River peaked at 202 cfs (5.7 m^3s); well below the annual peak average and the seventh lowest annual peak since records began in 1963 (Fig. 2-6).

After being open for only 37 days, the sandbar closed on March 20th due to declining stream flow and sand replenishment on the beach. The lagoon filled to an elevation of 9.5 ft (2.9 m) on April 27th and then began its gradual summer decline (Fig. 2-1). Stream flow volumes in the Carmel River continued to decline throughout March and April and on May 22nd flow in the lower river ceased. This is the earliest the lower river has dried since 1991 (Fig 2-2), which was at the end of a four year drought. By May 31st the water elevation in the lagoon was at 5.9 ft (1.8 m).

a. Lagoon outflow was restricted at the 2005 breach site with the help of a dozer and sandbags.
(17 Jul. 2006)

b. Sand was gradually replenished during the summer (8 Aug. 2006).



c. Large surf on Sept. 13, 2006 filled the sandbar en-catchments with sea water and copious amounts of foam.

d. Large waves entered the lagoon again on Dec. 10 2006.

f. Winter surf lowered the sandbar's elevation and broadened its width (29 Jan. 2007)

Figure 2-7. Seasonal sandbar morphology

a. Sandbar management began early morning on Feb. 11, 2007 but had to be postponed for safety concerns, stage: 2.6 m.

b. Sandbar management resumed at 9:00 and by 9:30 the sandbar was breached.

c. Sandbar management continued throughout the morning.

d. Early morning walkers found themselves stranded by the mid morning breach.

f. The lagoon drained slowly but the breach channel continued to grow.

g. At 11:00, flows increased and small rapids formed but the stage remained at 2.6 m.

Figure 2-8. Sandbar breach by Monterey County Public Works (11Feb. 2007).

a. On Feb. 12, 2007, the breach flows scoured the sandbar and exposed the granite sill, stage: 2.2 m.

b. The breach site was popular with beachgoers. (15 Feb. 2007)

c. By Feb. 16, 2007, sand had filled the breach channel, stopping outflow.

d. Five days after the initial breach, the lagoon stage dropped 1.2m, which was evident in the debris lines, stage: 1.4 m. (16 Feb. 2007)

e. After a few pseudo-natural breaches, the breach channel scoured the sandbar even more and migrated north off of the granite sill. (27 Feb. 2007)

f. At least one juvenile steelhead became stranded following a pseudo-natural breach of the lagoon on February 27th. (27 Feb. 2007)

Figure 2-9. Morphology of the breach channel.

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 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 and wet weather monitoring, and are only waded during foul weather for safety and logistical reasons. All monitoring sites are described below and photographed in Figures 3-1 and 3-2.

3.2 Monitoring sites

Most of the water quality monitoring sites are in the permanent wetland habitat type of the South Arm and newly created Odello Arm. Other sites include some in the main embayment and the North Arm. 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 (Figs 3-1 3-2a.). 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. Temperature loggers were distributed vertically through the water column and recorded hourly temperature data at this site from Aug 2006 though May 2007. S2 is also the location of a staff plate and a stage logger maintained by the Monterey Peninsula Water Management District.

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).

3.2.2 Odello Arm

Three sites are monitored for water quality and macroinvertebrates in the Odello Arm. The newly excavated Odello Arm is different from the pre-existing South Arm. The substrate in all of the new Odello sites was initially loose like quicksand and appears to be gradually consolidating. It is unlike the North Arm which has more organic material along the bottom. 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, gullies formed along the banks of the Odello Arm, adding complexity to the shoreline and altering the original bathymetry of the Odello Arm.

O1 (Fig.'s 3-1 & 3-2b), is the deepest part of the newly excavated lagoon area and was routinely monitored during dry and wet weather monitoring.

O2 is the northern branch of the Odello extension (Fig.'s 3-1 & 3-2c). 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.

The southern branch of the Odello extension, **O3** (Fig.'s 3-1 & 3-2d), was sampled from a kayak during high stages and waded during low stages. During the lowest stages there is no water at this site.

3.2.3 Main Embayment

The main embayment of the 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 bathymetry 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 frequently been observed.

R2 is the sampling location in the main embayment (Fig.'s 3-1 & 3-2f). 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.

R4 includes the active streambed immediately upstream of the main embayment (Fig.'s 3-1 & 3-2g). It is not perennial as stream flows typically cease by early summer (see section 2). Substrate in the channel consists of gravels, coarse sand, and smaller amounts of cobble and fine sediments. The banks are lined with emergent tules with willows increasing upstream (Casagrande, 2006).

3.2.4 North Arm

The North Arm is largely an emergent wetland dominated by tule marsh located next to the main parking lot at the lagoons northern edge. **N1** is the sampling site in the north arm and is located east of the parking lot (Fig.'s 3-1 & 3-2e). The surrounding wetland 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). When flooded steelhead use can be substantial.

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

(a) South Arm pipe historic monitoring site S2. Deepest section of the entire lagoon. (22 February 2007)

(b) Looking east towards the deepest part of the Odello extension O1 from Carmel Meadows. (15 February 2007)

(c) Tule (*Scirpus sp.*), Odello extension at O2. (22 February 2007)

(d) The southern most branch of the Odello extension O3. (3 October 2006)

(e) North arm of the main lagoon at N1 (6 December 2006)

(f) Main Lagoon monitoring site R2. (8 August 2006)

(g) The river channel swelling with river and lagoon water, R4 (15 February 2007)

4 Water Quality Monitoring

In broad terms, desirable water quality parameters for steelhead in lagoons include sufficient volume and depth, 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. The best conditions for steelhead typically occur in late spring and early summer just after the sand bar has closed (May-July). At this time, there is usually sufficient volume, mild temperatures, high DO, and low salinity.

During the dry season there is reduced volume, and the lagoon is typically highly stratified with respect to salinity, temperature, and dissolved oxygen. A layer of relatively fresh water is normally maintained at the surface of the lagoon down to the halocline, or the boundary between fresh and salt water. This fresh layer originates from the residual flows during 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 (Watson & Casagrande, 2004).

The deepest parts of the South Arm are dark and usually contain saline waters near 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 density stratification and relatively minor surface wind energy, these deeper waters rarely mix and become completely isolated from the atmosphere. The halocline acts as a solar collector, where incoming solar energy is trapped at depths where the water becomes more opaque. The lack of mixing limits the ability for these warmed layers at depth to dissipate heat to the atmosphere. This often results in pronounced algal production, super-saturated afternoon oxygen levels at the halocline, and oxygen minima beneath the halocline. However, during open sandbar conditions and sufficient river flows, the bottom water column occasionally becomes fresh and well mixed. A five-year time series of water quality parameters is presented in Appendix A.

4.3 Sampling and analytical methods

The water quality parameters that were measured are temperature, salinity, dissolved oxygen (DO), pH, turbidity, and suspended sediment concentration (SSC). All parameters were measured *in situ,* except for suspended sediment and turbidity. 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 parameters 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 and at S2, a Alpha Sampling Bottle was used to obtain a additional sample from within 1 m of the bottom. Turbidity was measured using a HACH Portable Turbidimeter (Model 2100P). Measurements made with this instrument have an accuracy of ± 2% 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).

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 (since last reporting by Larson et al., 2006).

Purpose of visits	Dates	# Sites sampled
Routine monthly dry weather monitoring	Jul 26, Aug 10, Sep 13, Oct 3, & 11, 2006	7
Wet weather monitoring	Nov 21,Dec 12, 22, 27, & 29, 2006 and Jan 16, 29, Feb 6, 9, & 11, 2007	7
Lagoon breach monitoring	Feb. 11, 12, and 16, 2007	7
Post lagoon breach and routine monitoring	Feb 21, 22, 23, 28, Mar 1, 22, 28, Apr 17, 27, May 17 & 25, 2007	7

4.4 Monitoring schedule

The timing of water quality monitoring was conducted according to the hydrologic conditions of the lagoon and can be separated into three categories: dry weather monitoring, wet weather monitoring and breach monitoring. See Table 4-1 for a list of dates that were monitored from July 2006 – May 2007. Monitored dates are also presented in relation to precipitation, stage, and river flow in Fig.'s 2-3 and 2-2.

Routine monthly dry weather monitoring within the pre-existing lagoon and new extension of the South Arm was conducted on eleven separate dates in 2006, and nine separate dates in 2007 (Table 4-1). Wet weather monitoring included sampling previous to, during, and after three significant storm events, with greater than 1.3 cm of precipitation. Storm weather monitoring was conducted on ten separate dates throughout the 2006/2007 storm season (Table 4-1). The first storm monitoring was performed in late December when the river just began entering the lagoon, the second in early February, and a third storm in late February.

Monitoring was also conducted during the initial mechanical breaching of the sandbar along with incidental pseudo-natural breaches.

4.5 Salinity

Coastal lagoons are often stratified, containing saltwater at depth, and fresher water at the surface. A stratified water column can often lead to adverse water quality conditions because it reduces mixing which leads to anoxic conditions in deeper waters. At certain times of year, the saline layers at depth provide a saltwater transitional environment that helps to facilitate smoltification, the physiological 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 throughout the lagoon. The thickness and elevation of this layer fluctuates with season and hydrological condition.

4.5.1 Results

Figure 4-2 displays a one-year time series of Salinity in Carmel River Lagoon, a 5-year time series is available in appendix A.

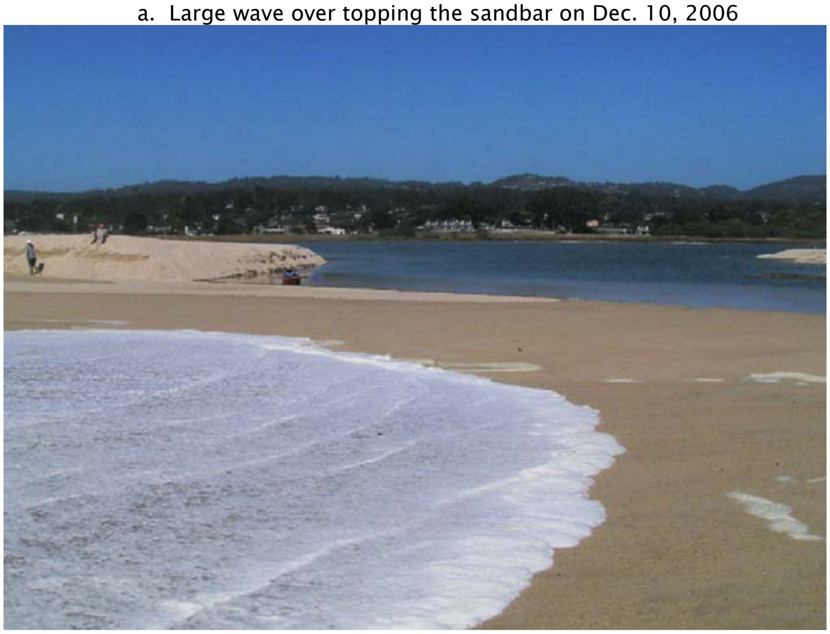
In late July, the water column in the South Arm was stratified with a halocline at approximately -0.5 m NGVD. Throughout August and September, the lagoon stage gradually declined and the South Arm began to freshen at depth (8ppt). All the other shallow monitoring sites remained unstratified at 8 ppt salinity throughout the remainder of summer and fall of 2006. In early October, large waves over topped the sandbar increasing salinity at depth. The lack of river flow through November, combined with large winter surf, raised the surface salinity to 6 ppt throughout the lagoon, and raising the bottom salinity in the South Arm to 20 ppt (Figs 4-2 & 4-3a through 4-9a).

By December, the river had yet to connect to the lagoon and numerous waves over topping the sandbar were observed (Fig 4-1a). This led to elevated salinity levels throughout December, with a brackish layer ranging from the surface to 0.5 m NGVD. It was not until mid February that significant river flows reached the lagoon and lowered the salinity in shallow areas to concentrations < 5 ppt. By mid February the freshwater lenses had expanded from -0.5 m to 2.0 m NGVD (Fig.'s 4-2 & 4-3b through 4-9b).

After the sandbar was mechanically breached on February 11th, large surf and the lack of strong river flows caused the sandbar to rebuild and close off the lagoon by February 16th. After the initial closure, three pseudo-natural breaches occurred which scoured the sandbar even more and allowed surf to enter the lagoon more frequently. This caused a steep spike in salinity throughout lagoon, limiting freshwater to shallow areas above 1.0 m NGVD (Fig 4-2). Then on February 28th, due to increased river flows and the open sandbar, the lagoon became completely fresh (Figs 4-2 & 4-3b through 4-9b).

With the continued river flow and repeated pseudo-natural breaches, the lagoon remained fresh until late March. Then by 28 March, the river flowed declined and a large 6.0 m surf event inundated the lagoon with ocean water. On March 22 at S2, the freshest layers (< 5ppt) were above 1.5 m NGVD and salinities > 30 ppt were observed at 0.25 m NGVD and below (Figs 4-1b, 4-1 c, 4-2). With the exception of the upper river arm site (R4) which maintained a 1-meter thick freshwater lens, all other lagoon sites showed similar but less pronounced spikes in salinity nearing 25 ppt at 1.0 m NGVD (Figs 4-3c through 4-9c). By mid April the sandbar closed for the summer and river flow declined to 0.39 m^3/s, however, this low flow continued through early May, allowing the freshwater lens to thicken to 1.5m (Fig.'s 4-2 & 4-3c through 4-9c).

a. Large wave over topping the sandbar on Dec. 10, 2006



b. Waves entering the breach channel on Mar. 22, 2007

c. Seawater filled the lagoon and increased clarity (22 Mar. 2007).

Figure 4-1 Wave overtop increases lagoon salinity.

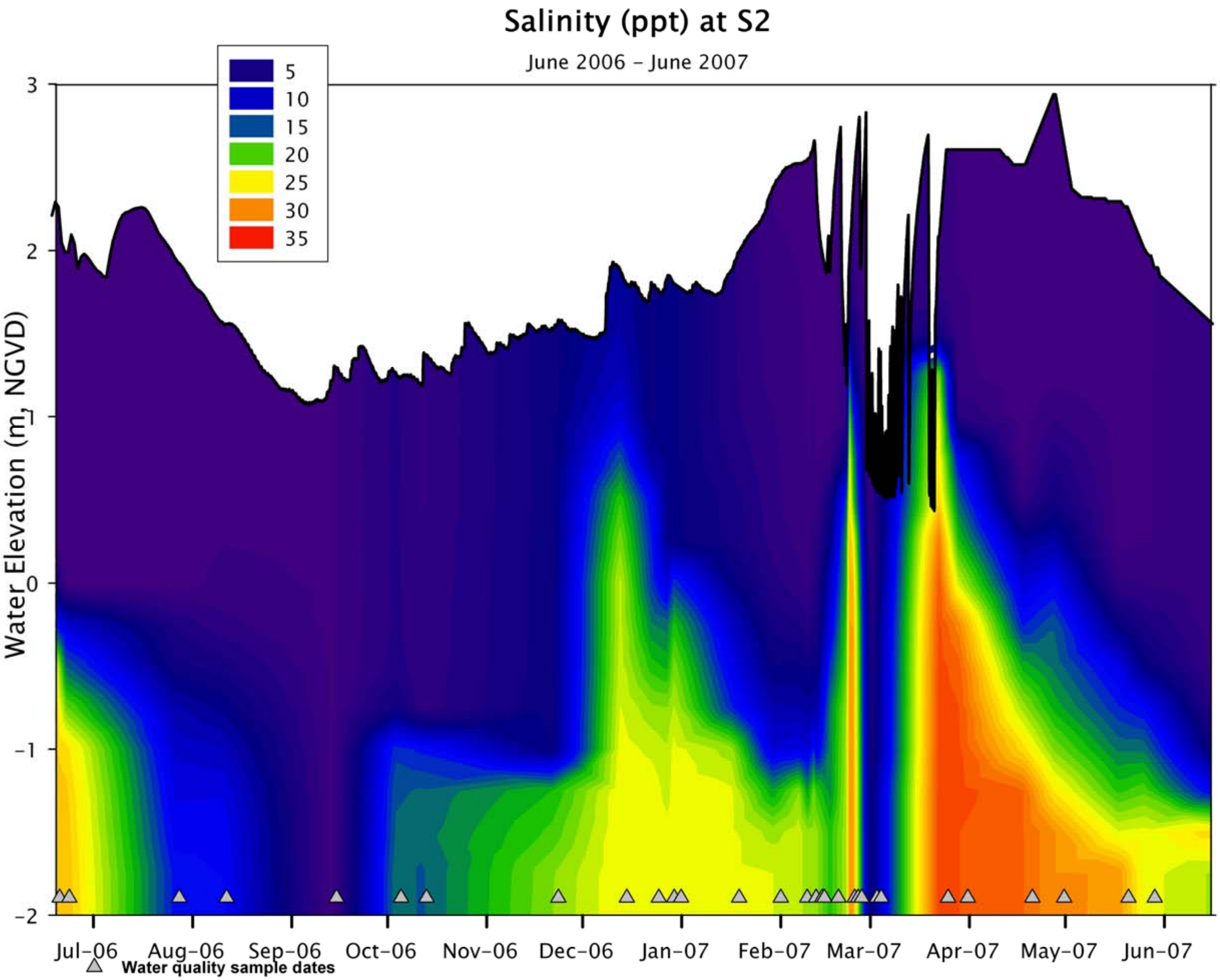


Figure 4-2. Salinity profile time series at S2

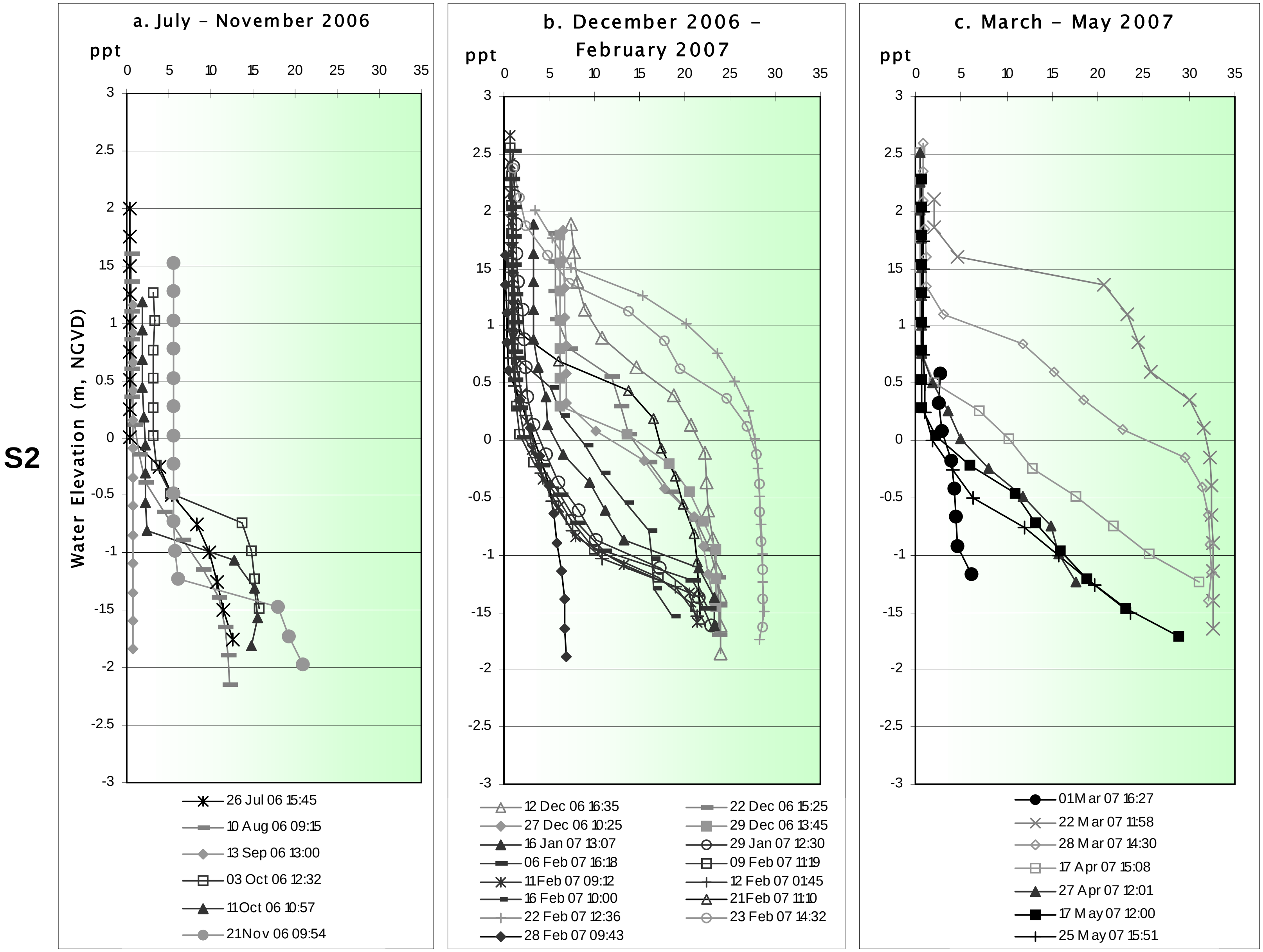


Figure 4-3. Salinity at the South Arm Pipe (S2)

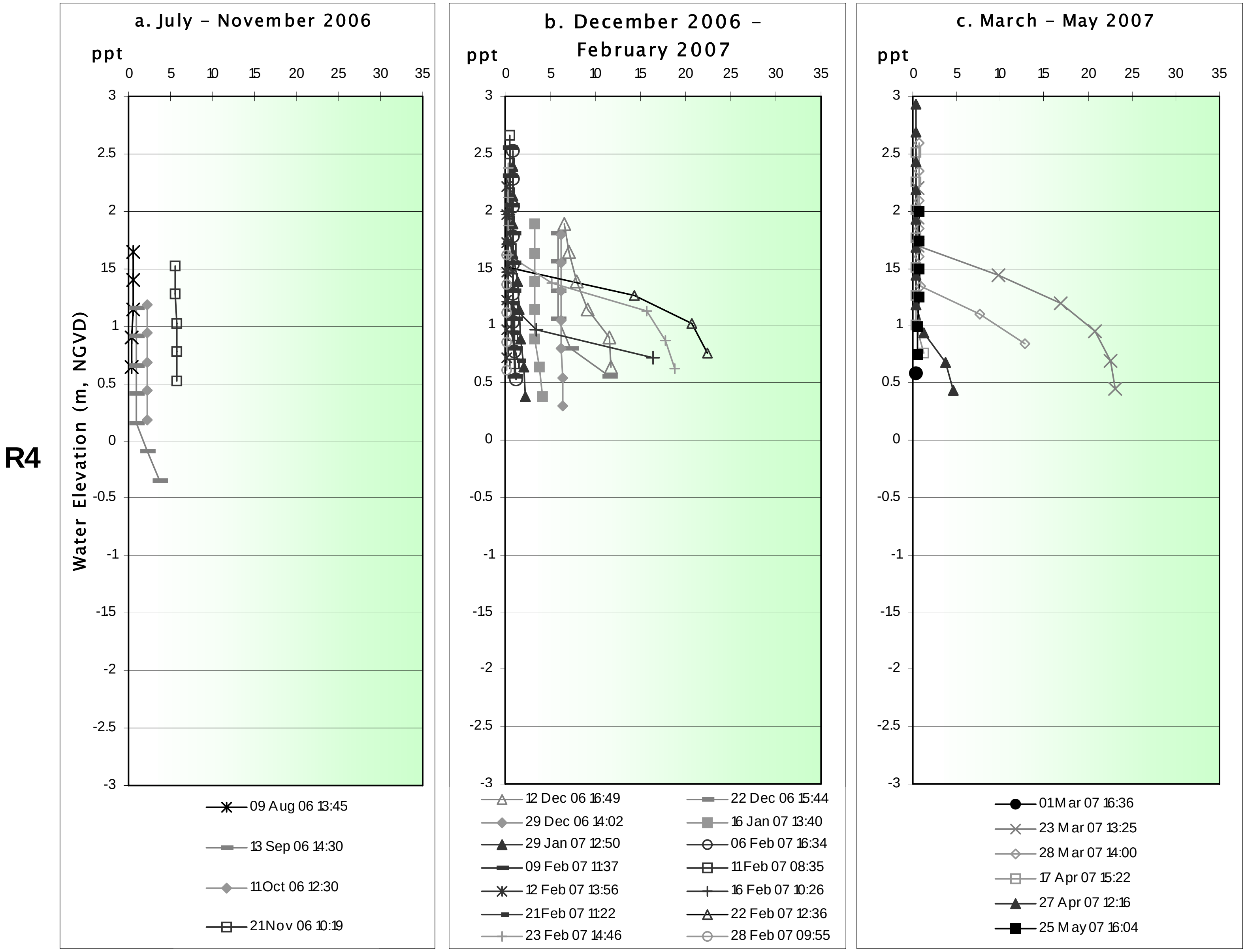


Figure 4-4. Salinity at the river mouth near the main lagoon (R4)

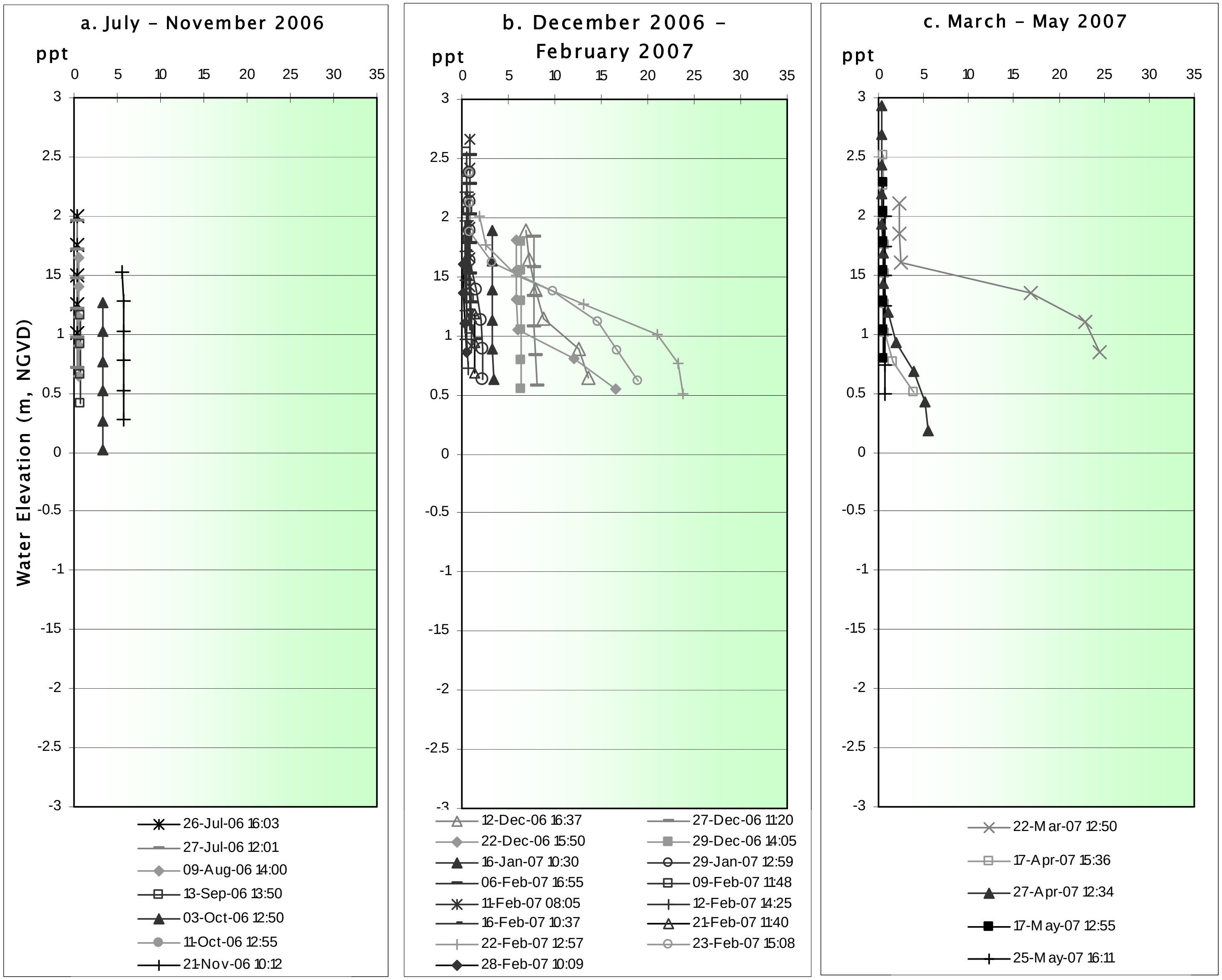


Figure 4-5. Salinity in the main body of the lagoon (R2)

N1

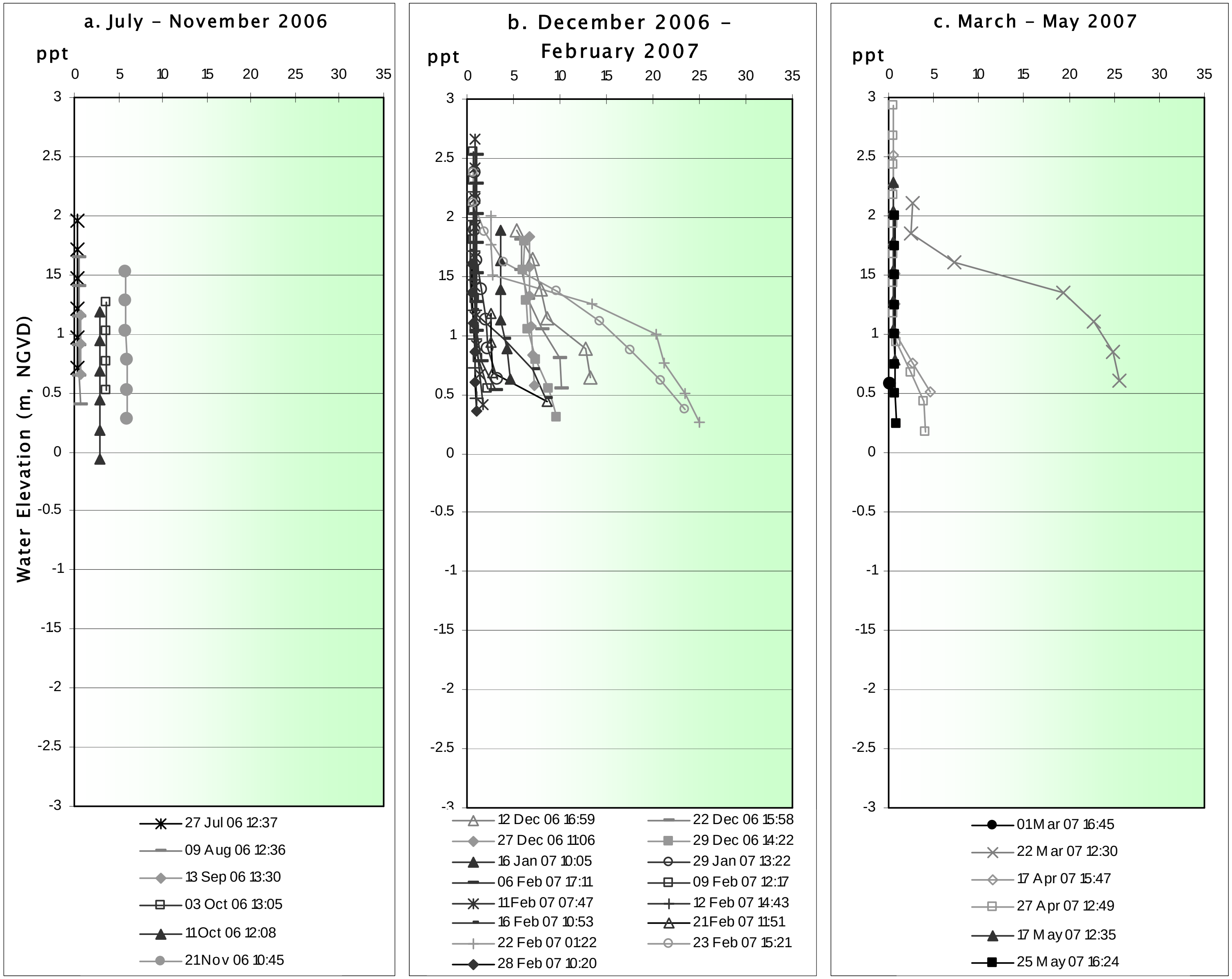


Figure 4-6. Salinity at the north arm of the main lagoon (N1)

O1

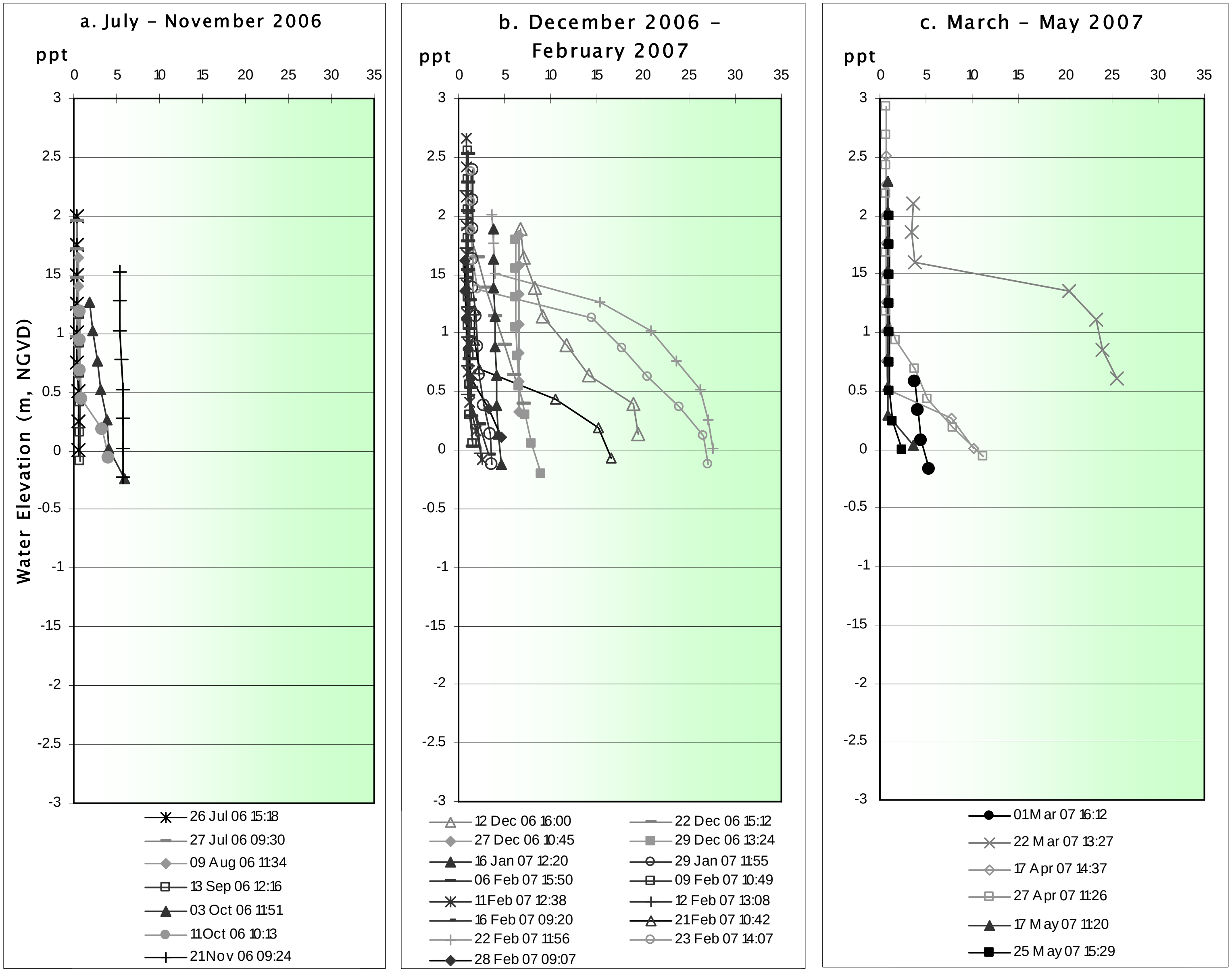


Figure 4-7. Salinity in the main Odello extension (O1)

O2

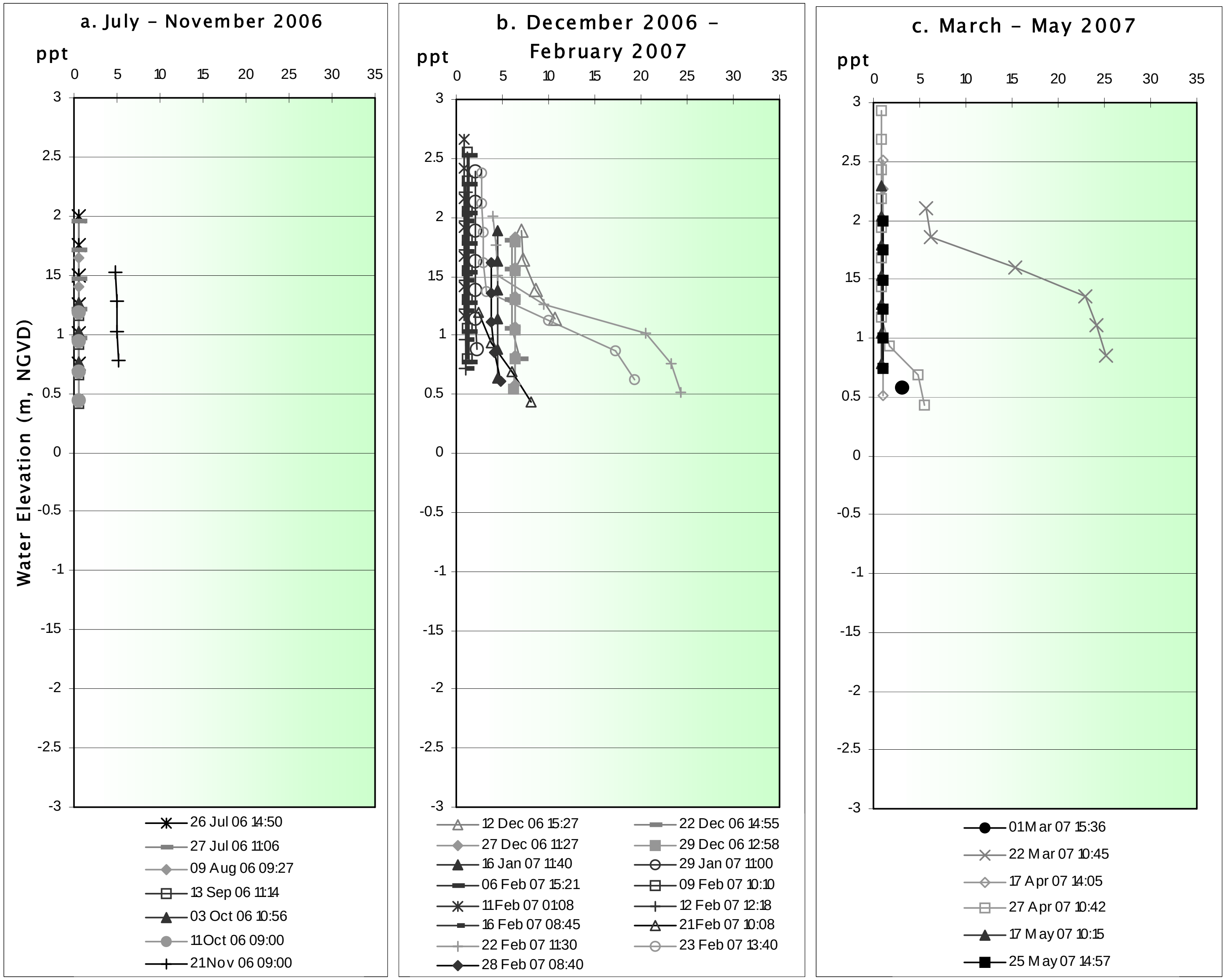


Figure 4-8. Salinity in the North finger of the Odello extension (O2)

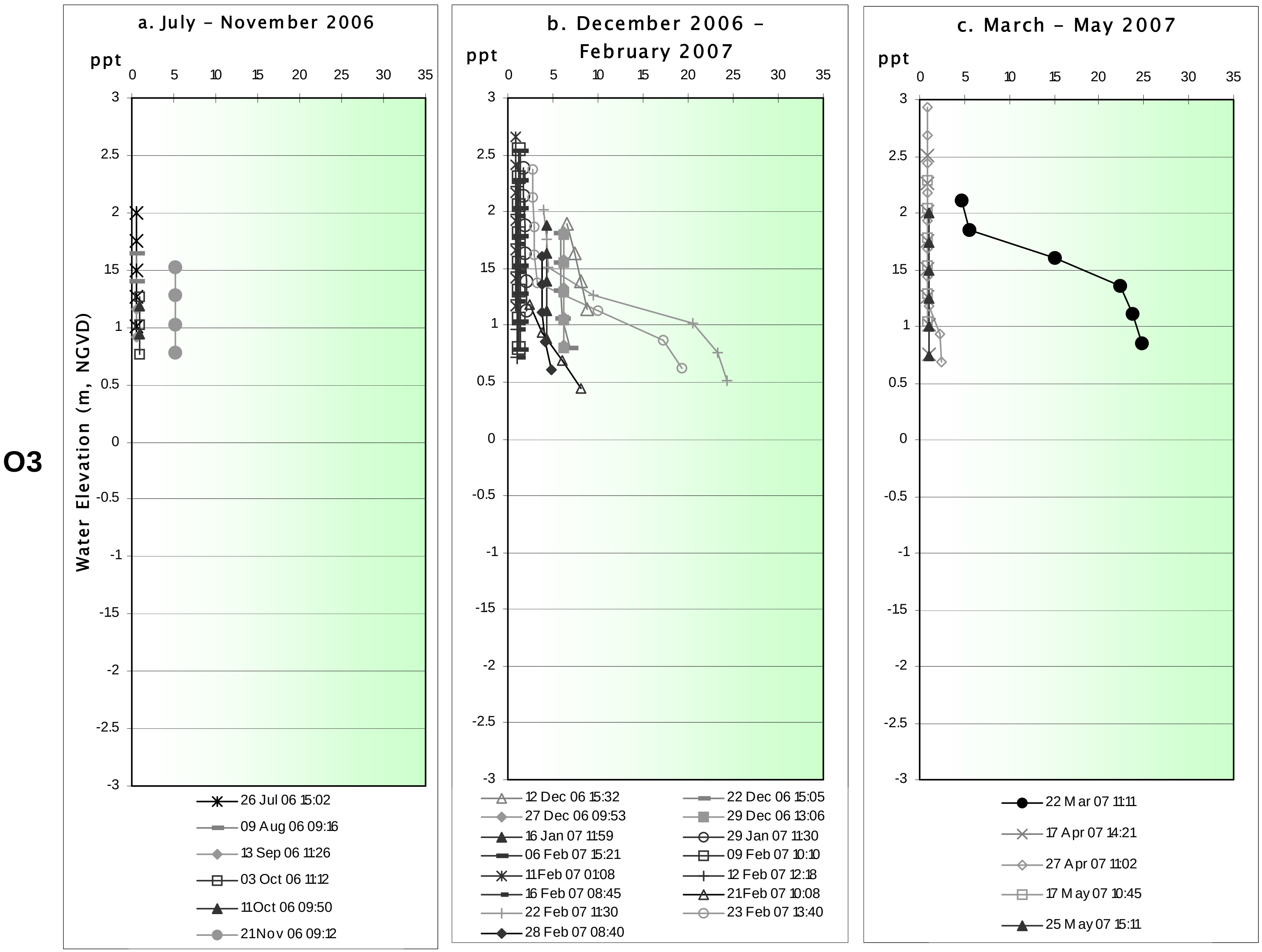


Figure 4-9. Salinity in the South finger of the Odello extension (O3)

4.6 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.

4.6.1 Results

Figure 4-10 displays a one-year time series of Temperature in Carmel River Lagoon; a 5-year time series is available in appendix A.

In July and August temperatures ranged between 20°C and 25°C. throughout the lagoon. Maximum sustained temperatures were observed in the Odello Arm sites (≥25°C) in late July. The only sites that exceeded the 26°C threshold were O2 and O3 on July 26. Furthermore, temperatures were homogenous throughout the water column with slightly warmer temps below 0.0 m NGVD at S2. By September the lagoon cooled to temperatures between 15°C and 20°C and by November the maximum temperature had dropped to below 15°C (Fig.'s 4-10, 4-11a. through 4-17a.)

On December 12, the water column had cooled to 12°C. Cold air temperatures throughout January reduced surface water temperatures to 5°C, while deeper portions below -1.0 m NGVD remained at 12°C. By January 16, the surface temperature in the North Arm (N1) got as low as 3.5°C and by the end of January (29th), the temperature at the surface warmed to 10°C (Fig.'s 4-10, 4-11b. through 4-17b.)

In early February, the Carmel River discharge to the lagoon intensified to 1.98 m^3/sec and water temperatures increased. Just prior to the initial mechanical breach, on February 11, the temperature ranged between 12°C and 13°C. Because the initial breach did not drain the lagoon rapidly, the temperature remained at 12°C throughout the lagoon. It was not until late February when river discharge increased to 5.7 m^3/s and the lagoon breached numerous times , that water temperatures changed significantly. On February 27, 2007 a pseudo-natural breach occurred and completely drained the main embayment within a few hours. Measurements the following day indicated the surface to 0.5 m NGVD had cooled to 9°C, while the remaining water column remained at 12°C to 13°C (Fig.'s 4-10, 4-11b. through 4-17b.).

By mid-March, river discharge decreased and the sandbar reformed at the breach site. This along with a lowered sandbar at the breach site allowed surf to enter and almost completely fill with ocean water. This resulted in lagoon temperatures similar to ocean temps of 12°C from 2.0 m to -2.0m NGVD with. By the end of May, the surface temperature in the main lagoon warmed to 18°C at 1.5 m NGVD to 0.0 m NGVD. Temperatures in the South Arm and Odello section were slightly warmer at 20°C. (Fig.'s 4-10, 4-11c. through 4-17c.).

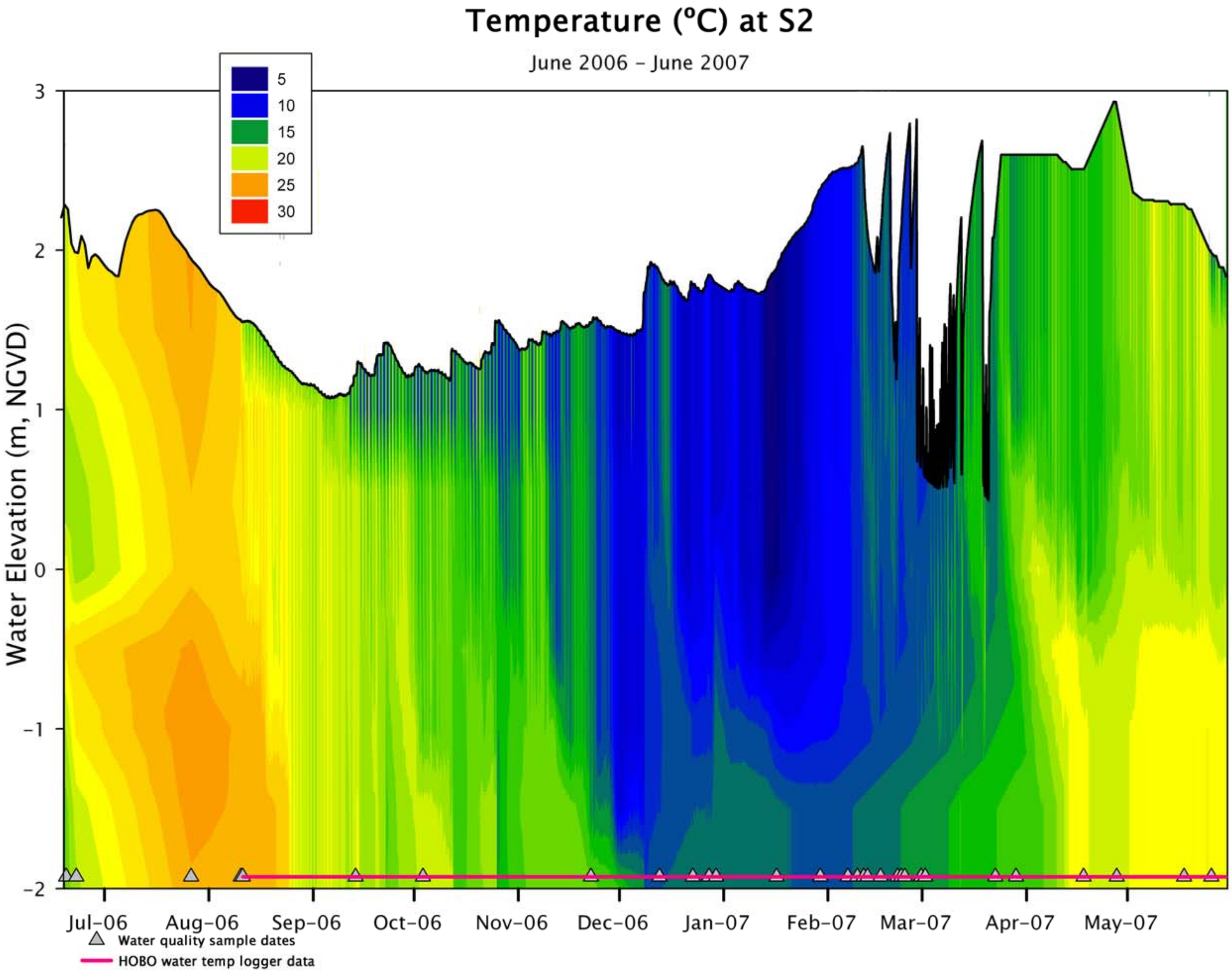


Figure 4-10. Temperature profile time series at the South Arm Pipe (S2)

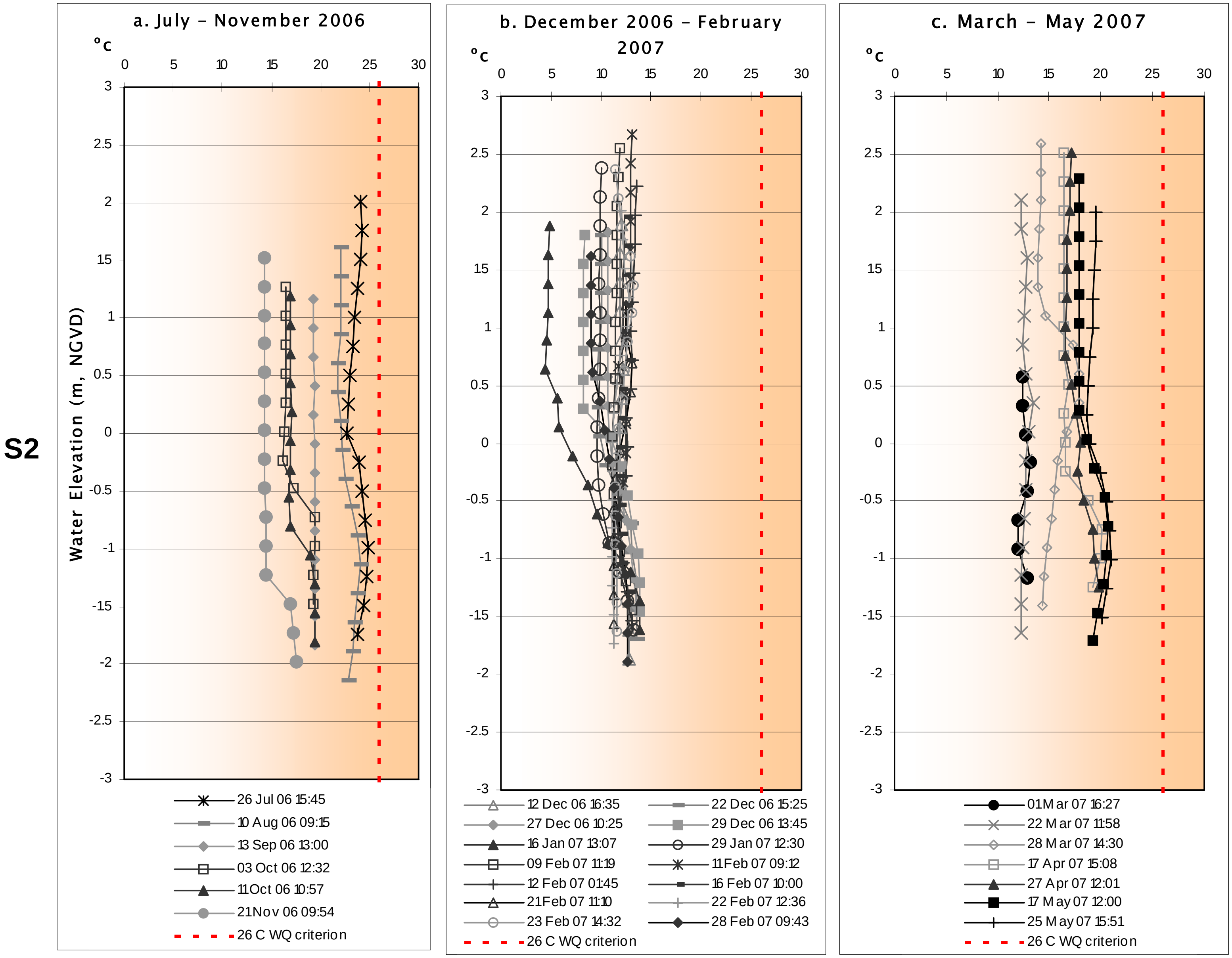


Figure 4-11. Temperature at the South Arm Pipe (S2)

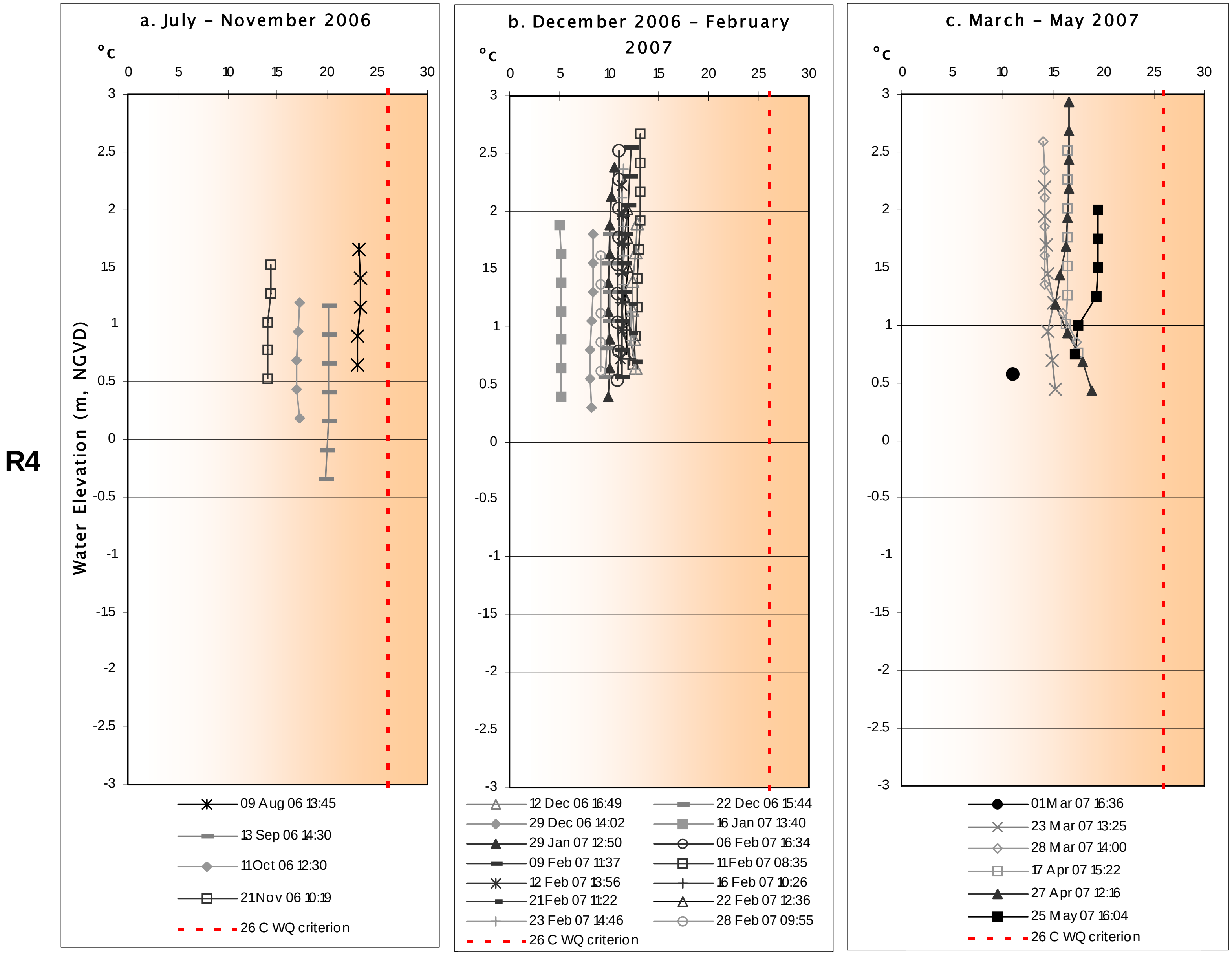


Figure 4-12. Temperature at the river mouth near the main lagoon (R4)

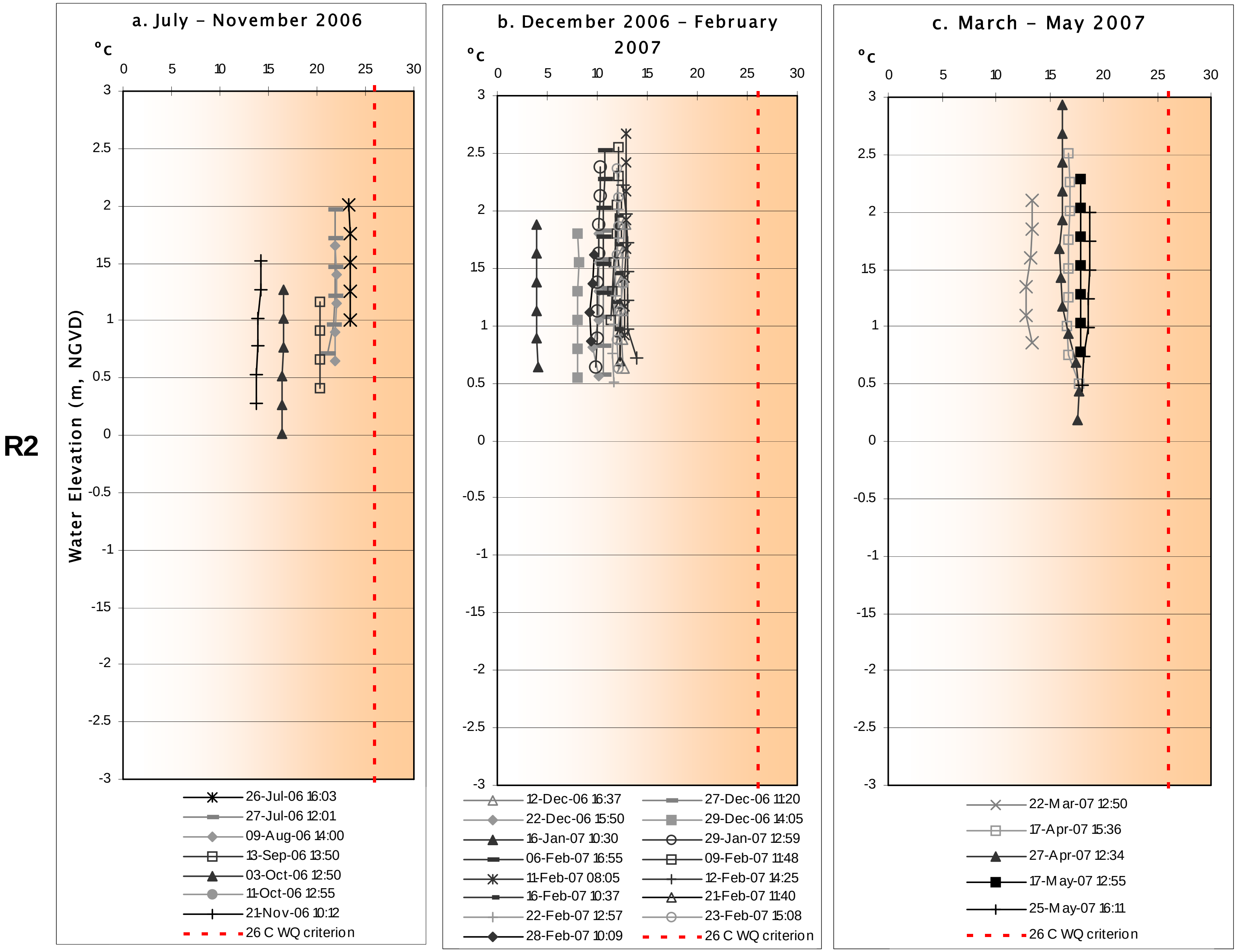


Figure 4-13. Temperature in the main body of the lagoon (R2)

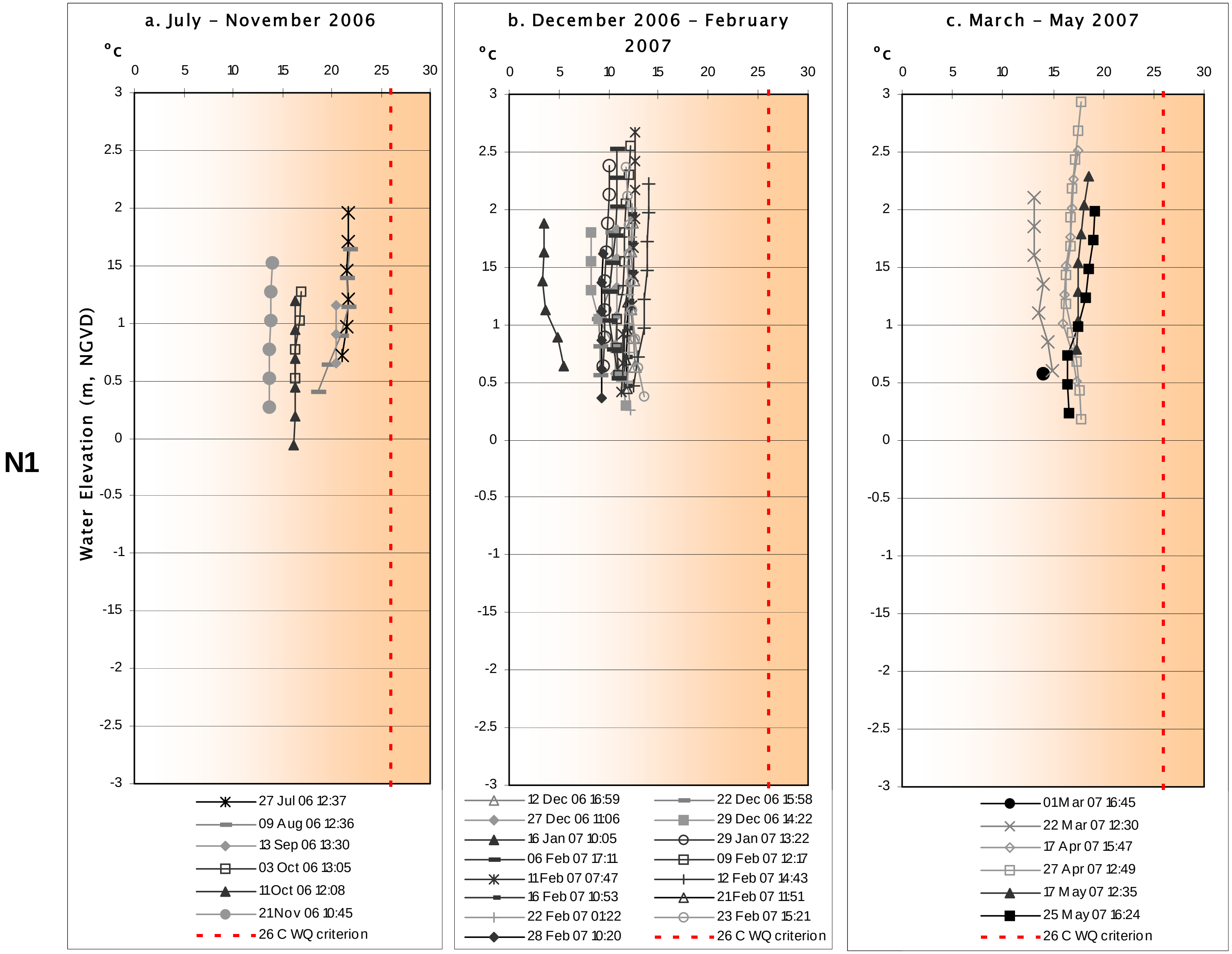


Figure 4-14. Temperature in the North arm of the main lagoon (N1)

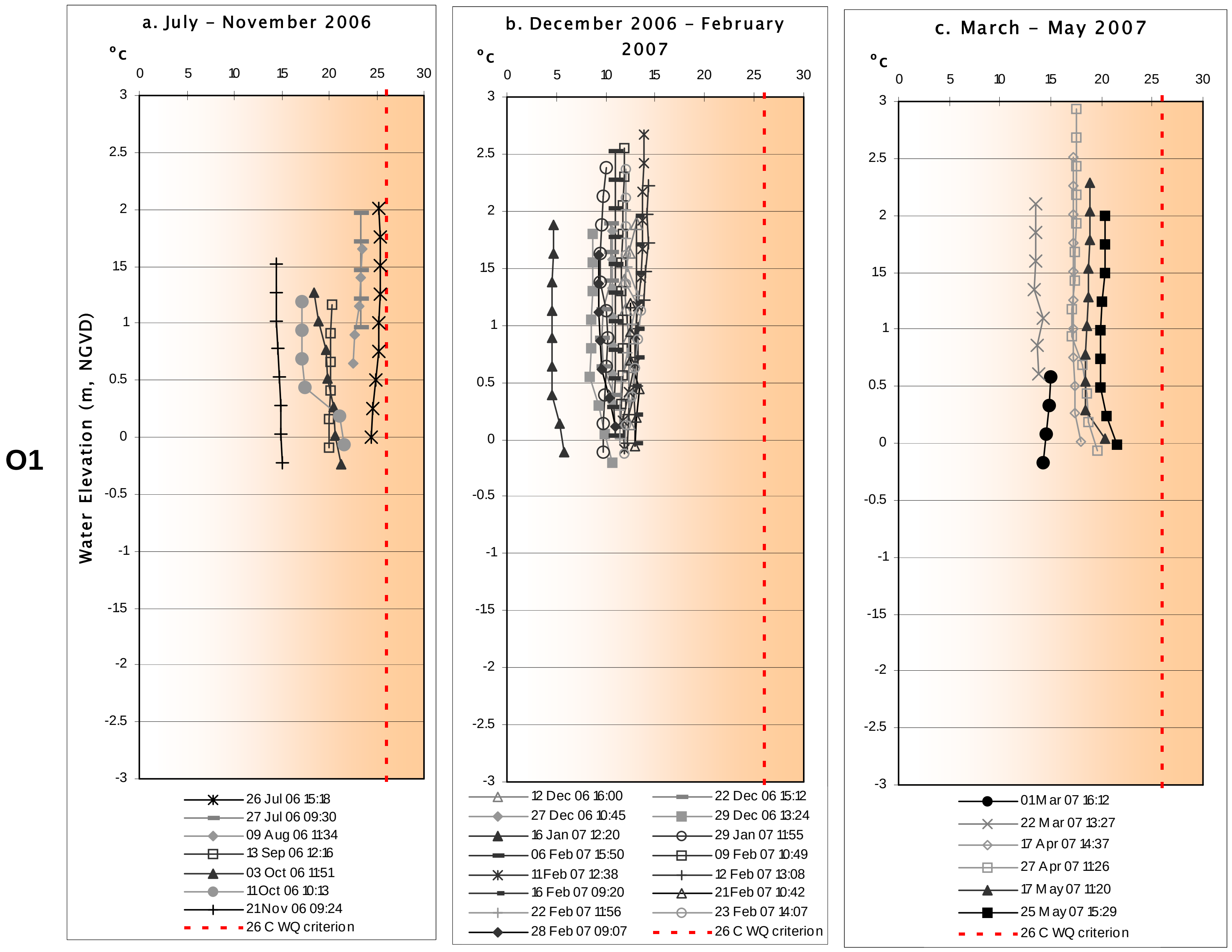


Figure 4-15. Temperature in the main Odello Extension (O1)

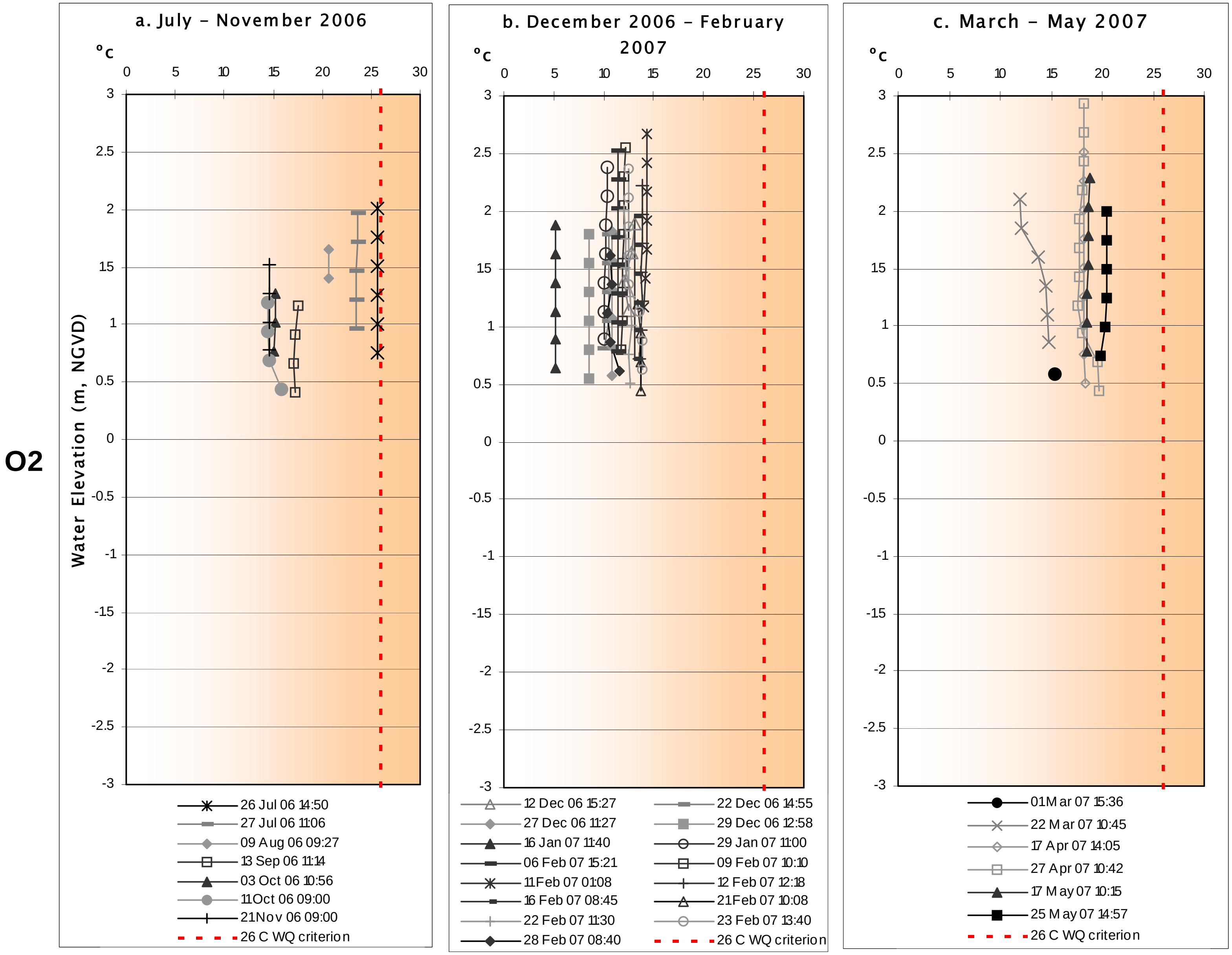


Figure 4-16. Temperature in the North finger of the Odello Extension (O2)

O3

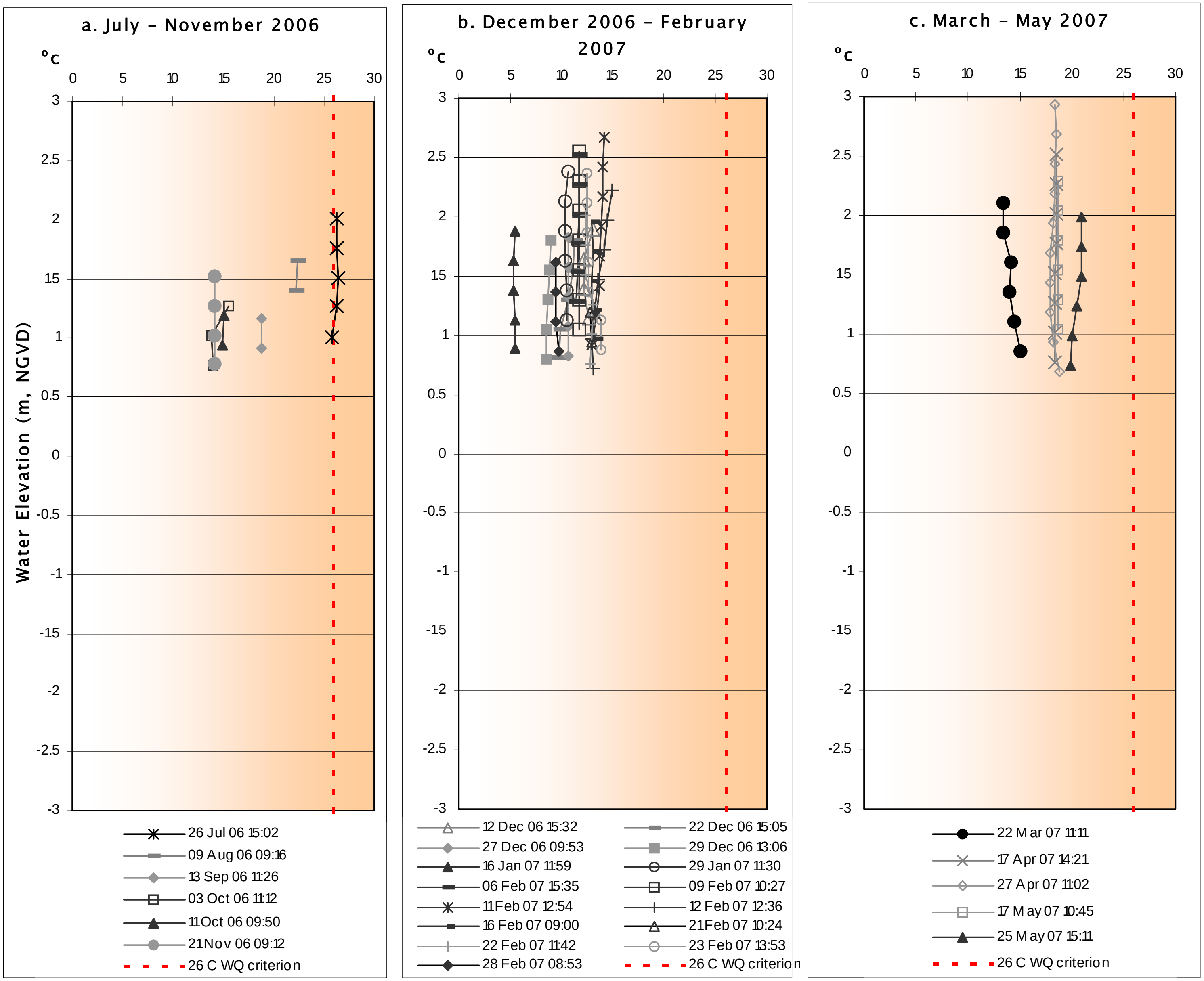


Figure 4-17. Temperature in the South finger of the Odello Extension (O3)

4.7 Dissolved oxygen

Dissolved oxygen (DO) 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 during overcast days. Dissolved oxygen was specified to remain above 5 mg/L during the project, as directed by NMFS Biological Opinion.

4.7.1 Results

Figure 4-17 displays a one-year time series of dissolved oxygen in Carmel River Lagoon; a 5-year time series is available in appendix A.

Dissolved oxygen in Summer and Fall of 2006 showed similar patterns to previous years with near saturation at the surface, a hyperoxic zone at -0.5 m NGVD and a hypoxic zone at -1.0 m NGVD. This was the typical pattern at the deeper S2 sample site, while DO in the main embayment was saturated throughout the entire water column. DO concentrations showed rapid drops from July 26 to July 27. For example, on July 26, 2006, at R2, O1, and O2 DO levels were 10mg/L and the next day on July 27, 2006, DO concentrations dropped below the 5 mg/L criterion. .

By Fall the hyperoxic zone disappeared while the hypoxic zone remained at -1 m NGVD. However, on September 13, 2006 at S2, two aerators were running and the hypoxic zone had disappeared also, with DO concentrations stabilized from 1.2 m NGVD to -2.0 NGVD at over 8 mg/L (Fig.'s 4-16a & 4-17). Then in October and November the hypoxic zone returned in the deeper portion of the lagoon below -1.0 m NGVD (Fig.'s 4-17 & 4-18a through 4-24a). At this time of year pondweed (*Potamogeton sp.*), which is extensive on the bottom of the South Arm and Odello Arm areas, dies and its decomposition contributes to the hypoxic conditions observed in fall and early winter.

The Winter of 2006/2007 also showed similar patterns as previous years with a persistent hypoxic zone below -0.5 m NGVD. With the lack of precipitation and river flow, combined with wave overwash, this hypoxic zone persisted throughout December. On December 29, 2006, kelp debris was observed at the pipe in the South Arm. The decaying kelp and other organic matter on the bottom apparently increased the elevation of the hypoxic zone from -0.5 m NGVD to 0.0m NGVD (4-16b). However, all other shallow sites, with the exception N1, showed DO concentrations at 10mg/L. At N1 large amounts of decaying seaweed (*Ulva sp.*) were observed which in part may explain the decreased oxygen concentrations at depth (Fig 4-16c).

Although the river had connected to the lagoon since December 30th 2006, flows were not apparently significant enough to reduce anoxic conditions, which persisted until after the sandbar was breached on February 11th 2007. On Feb 16 the lagoon stage dropped below 1.0 m NGVD and the hypoxic zone disappeared (Fig.'s 4-17 & 4-18b through 4-24b).

Numerous pseudo-natural breaches occurred in early March draining most of the lagoon water within four hrs. On March 1st, monitoring was conducted to assess conditions following a pseudo-natural breach. Sites O2 and N1 were shallow, with less then 0.5 m of total water depth and were only connected to the lagoon through small streams and pools with afternoon DO levels below the 5 mg/L. Criterion (Fig.'s 4-23c and 6.1 1c). Site O3 was completely drained and did not maintain surface waters.

By late March, the sandbar had closed, riverflow decreased and ocean waves inundated the lagoon causing DO levels to increase. On Mar 22, 2007, the lagoon was almost completely filled with seawater and DO levels stabilized in the river channel at 8mg/L,all other sites showed decreased stratification with DO concentrations ranging between 6 and 7mg/L at the bottom. Then by the middle of April, stratification returned to S2 with reduced DO levels below -0.75 m NGVD. By the end of May the lagoon had closed and the thickness of the freshwater layer increased as fresh river waters were trapped behind the sandbar; but DO levels below -2.0 m NGVD decreased to <5mg/L(Fig.'s 4-17 & 4-18c through4-24c).

a. Aerators running at S2 on Sept. 11, 2006

b. Floating kelp and debris at S2, Dec. 29, 2006

c. Seaweed (*Ulva sp.*) covering the shore of N1 Feb. 21, 2007

Figure 4-16.

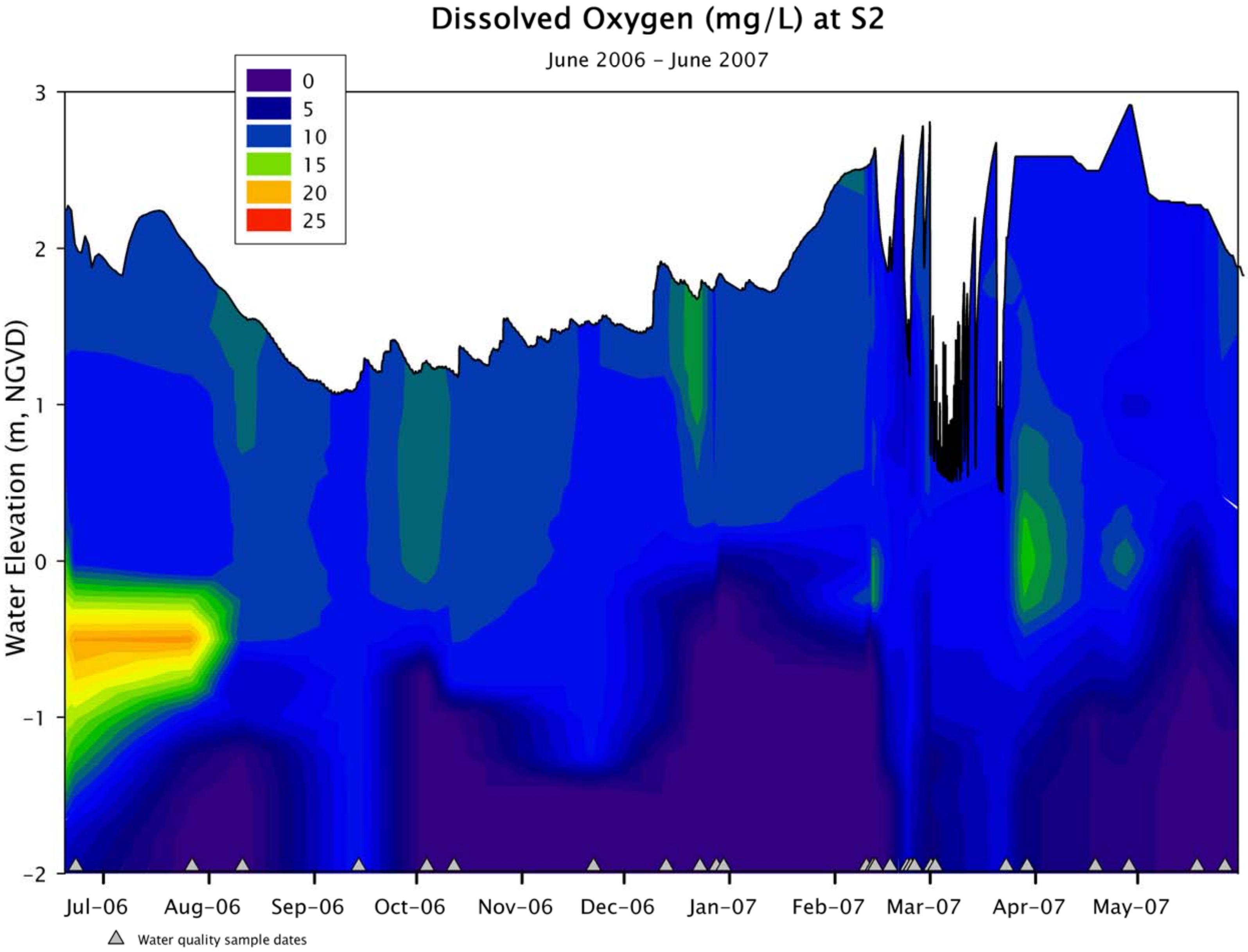


Figure 4-17. Dissolved oxygen profile time series at the South Arm Pipe (S2)

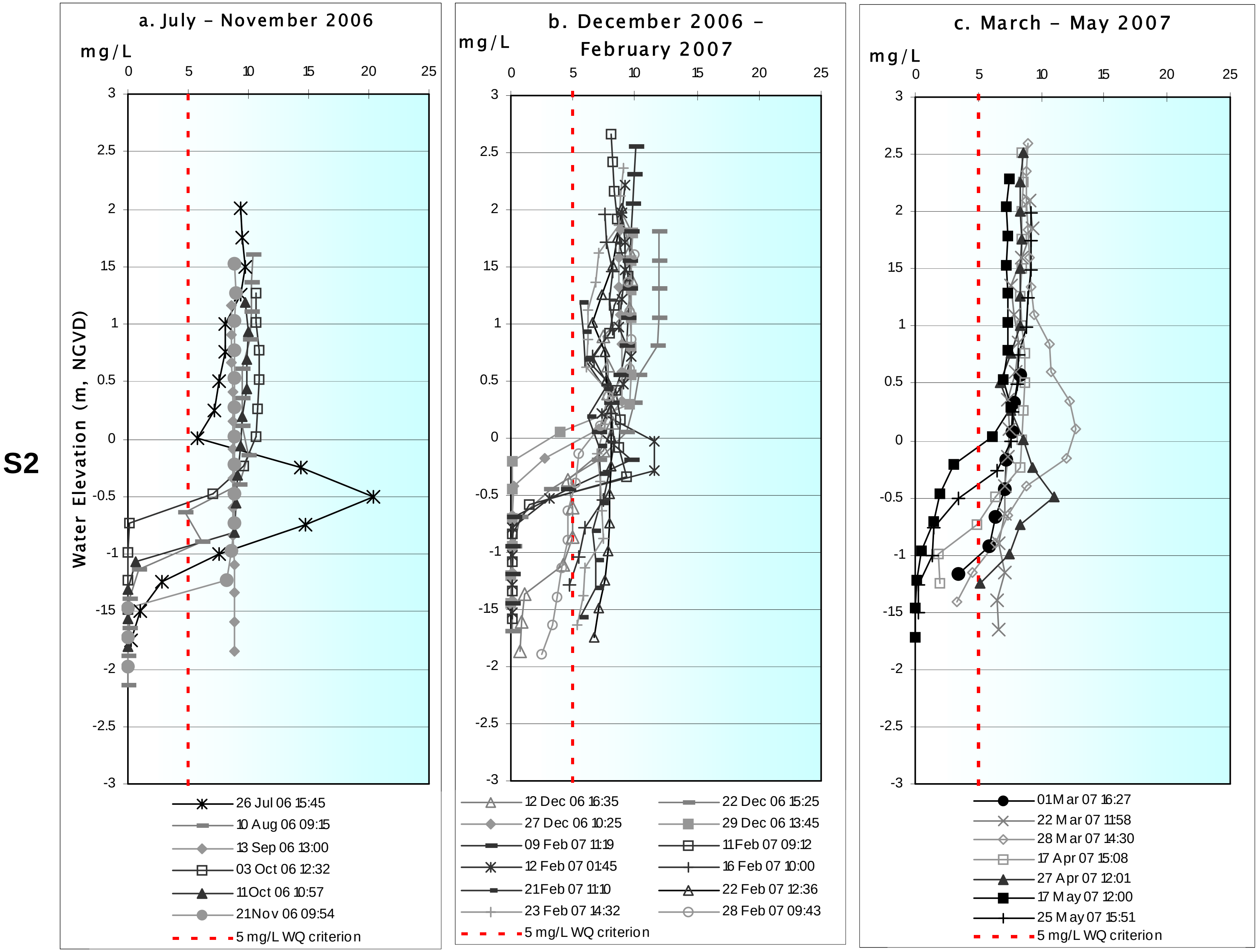


Figure 4-18. Dissolved oxygen at the South Arm Pipe (S2)

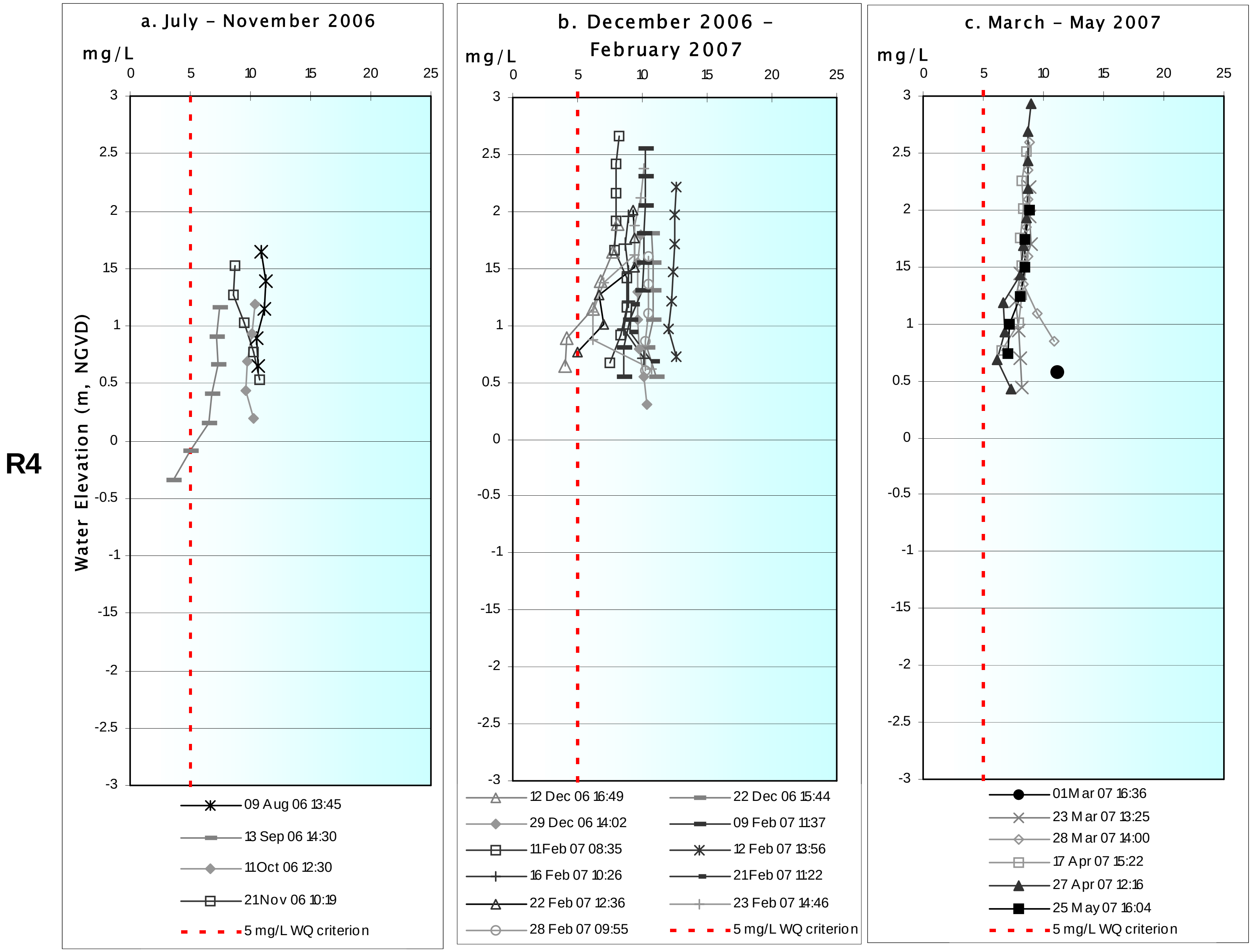


Figure 4-19. Dissolved oxygen at the river mouth near the main lagoon (R4)

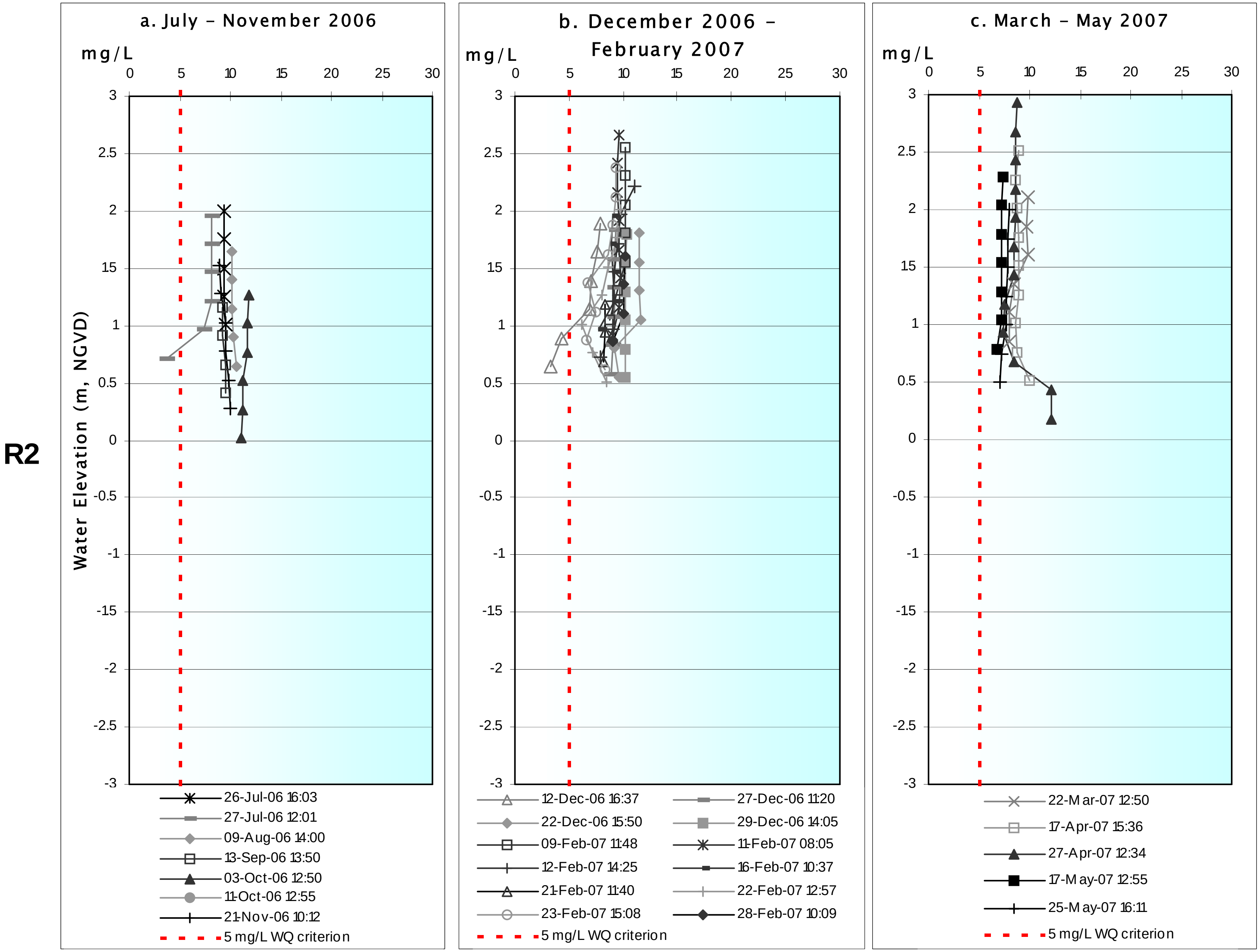


Figure 4-20. Dissolved oxygen in the main body of the lagoon (R2)

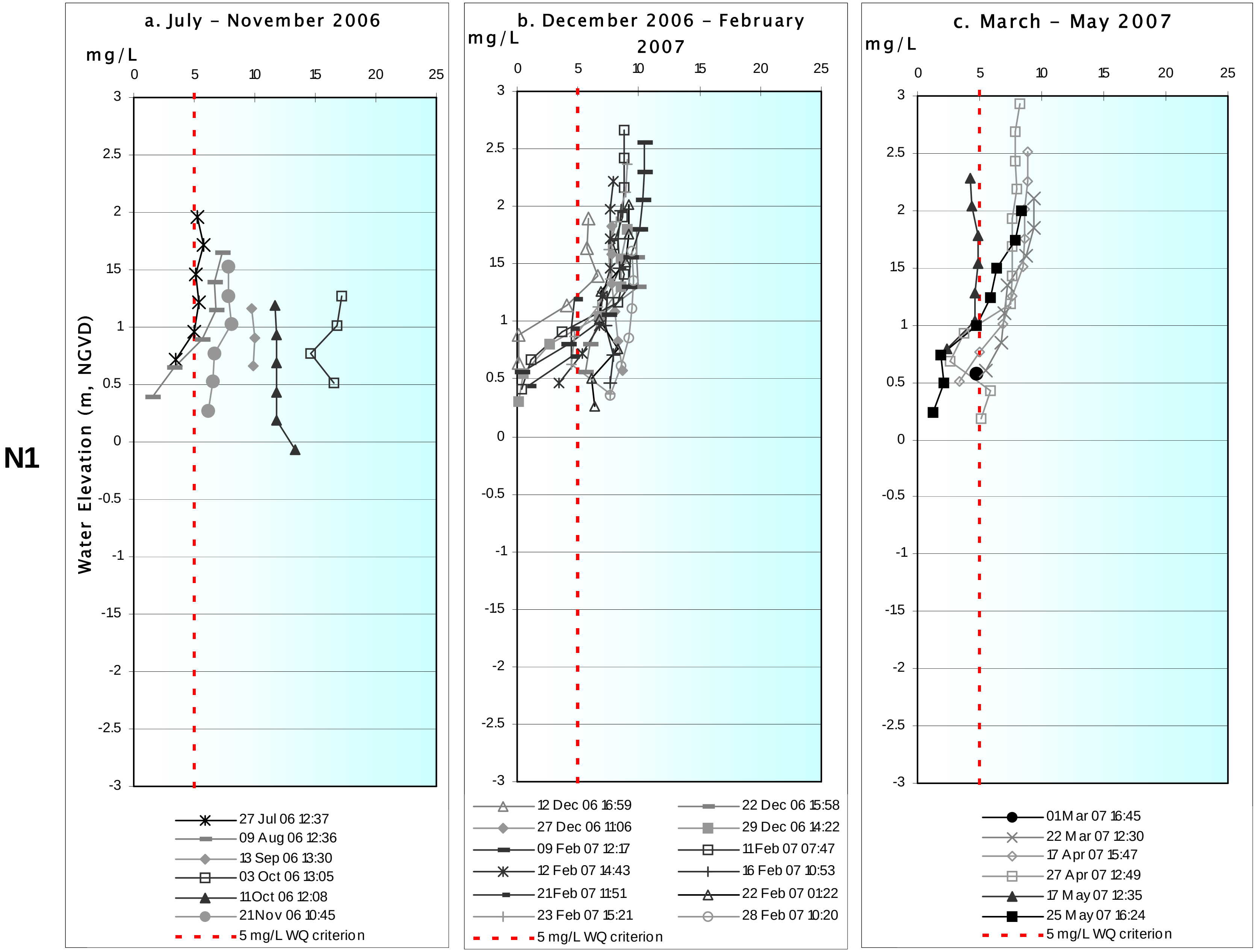


Figure 4-21. Dissolved oxygen in the North arm of the main lagoon (N1)

O1

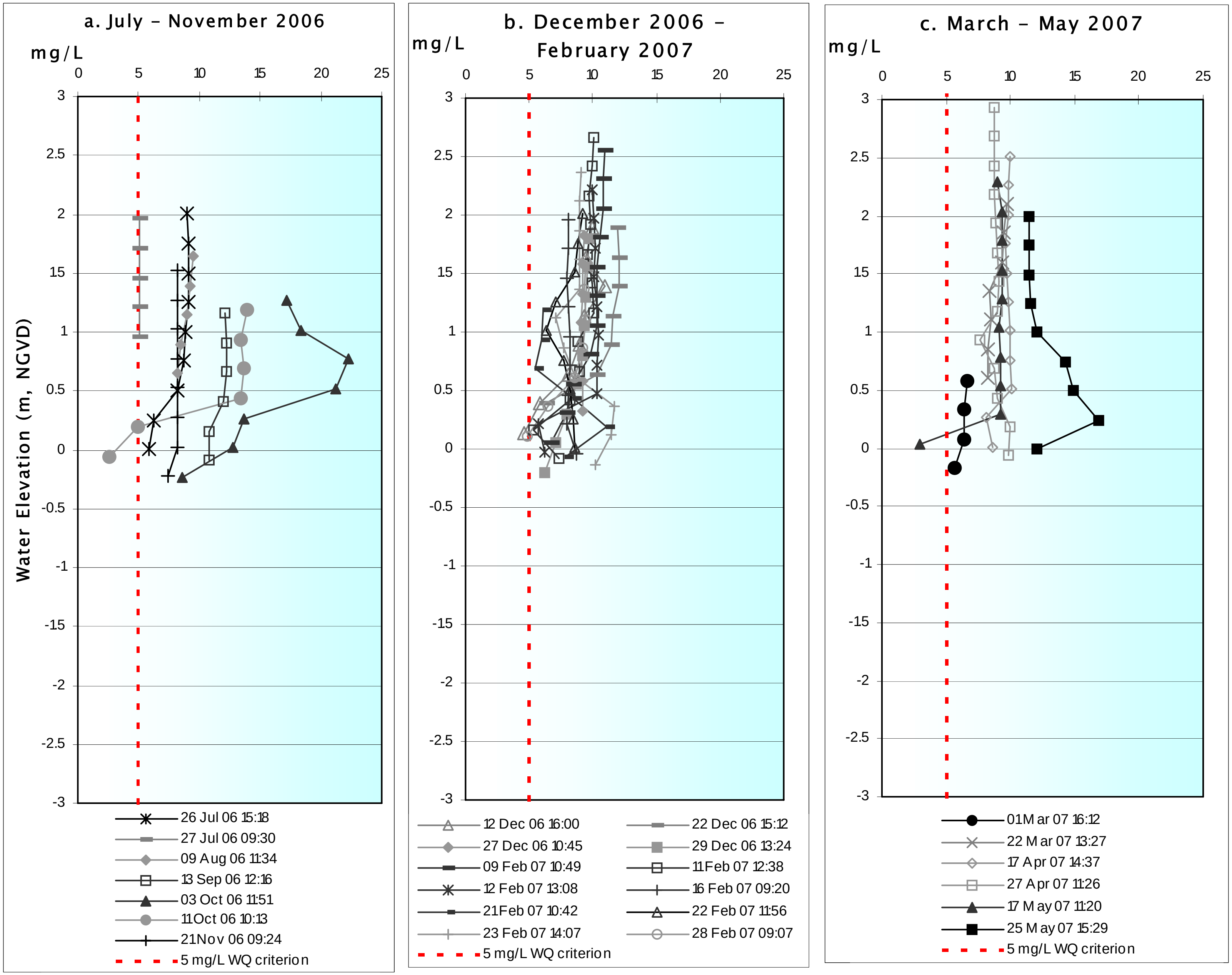


Figure 4-22. Dissolved oxygen in the main Odello Extension (O1)

O2

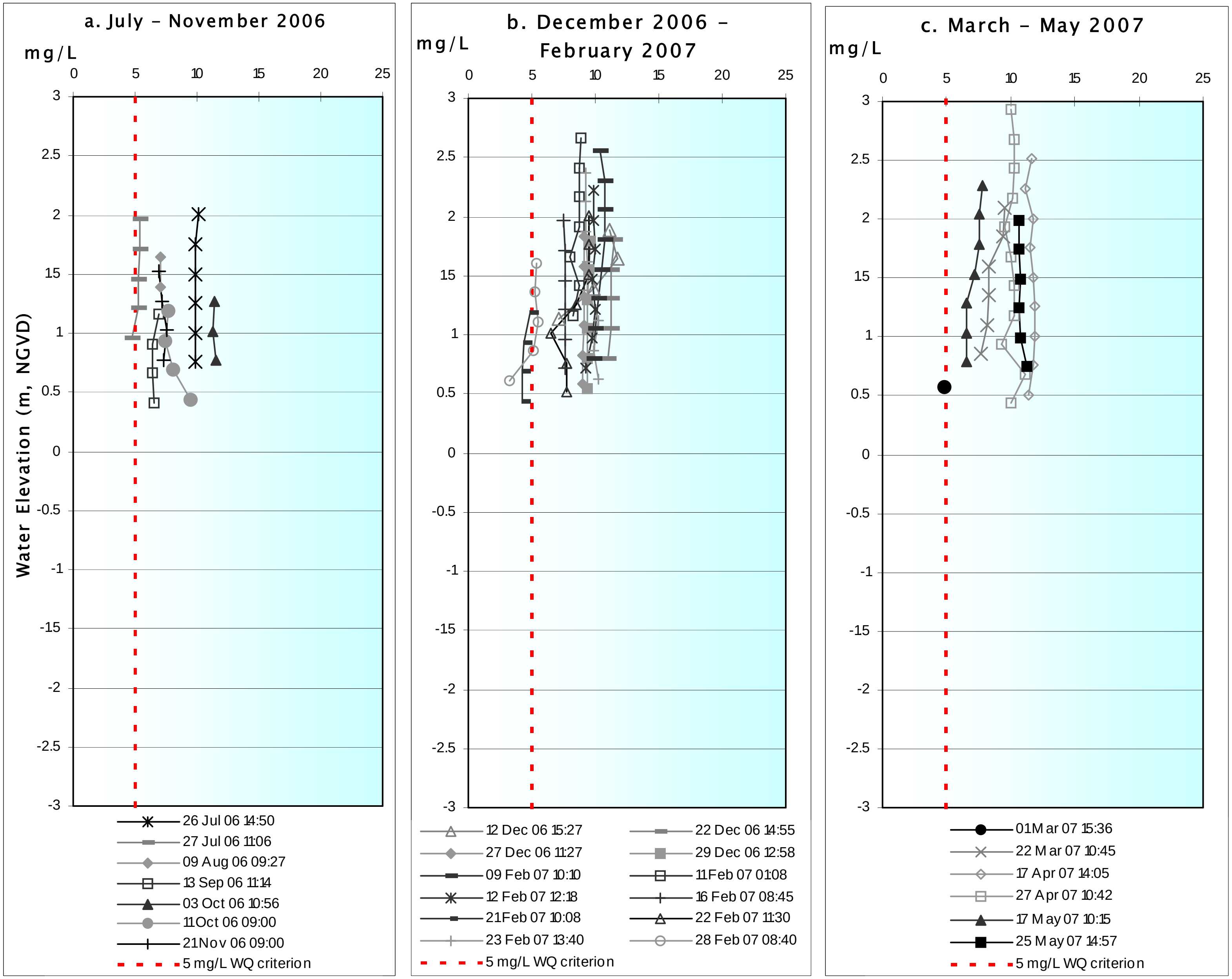


Figure 4-23. Dissolved Oxygen in the North finger of the Odello Extension (O2)

O3

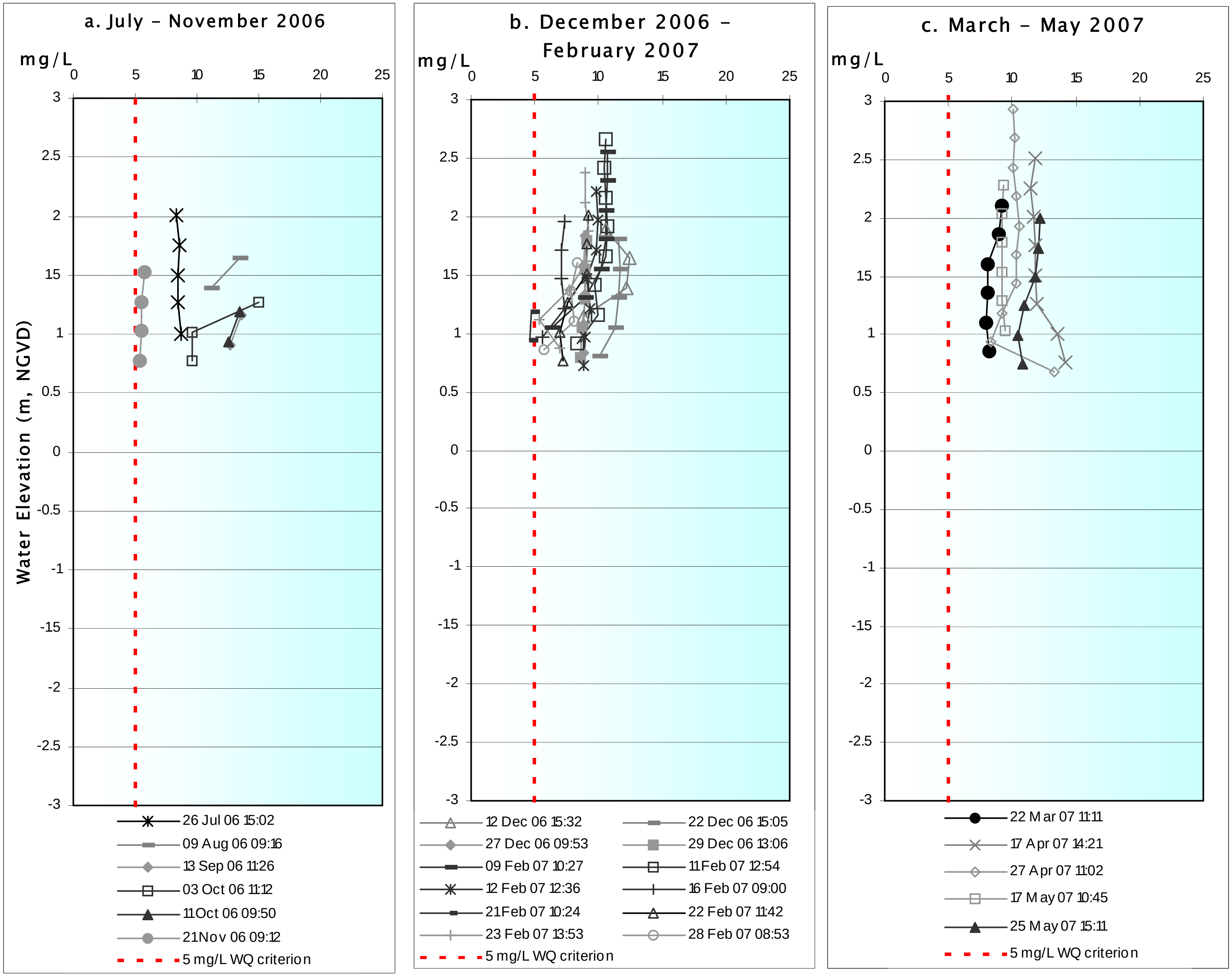


Figure 4-24. Dissolved Oxygen in the south finger of the Odello Extension (O3)

4.8 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 surface runoff from exposed banks can carry fine sediment particles into the lagoon.

4.8.1 Results

Fig.'s 4-26 and 4-27 display a 1-year time series of suspended sediment concentration (SSC) and turbidity. A 3-year time series is in Appendix B.

Due to the lack of heavy sustained rains, decreased river discharge and increased shoreline vegetation, spikes in SSC and turbidity were much less frequent in 2006-7 than in previous years. The main Odello arm (O1) on March 1, 2007 was the only site and sample date in which SSC and turbidity exceeded the 50 mg/L and 20 NTU criterions. This sample date followed a rapid draining of the lagoon when the stage was less than 1.9m NGVD, which allowed fine sediments near the bottom of O1 to become entrained in the water column. Furthermore, there was only two other sample dates with elevated SSC concentration and turbidity. On December 27, 2006 after a storm event, SSC and turbidity increased to 30.6 mg/L and 16.3 NTU, respectively. Then on February 21, 2007, after numerous pseudo-natural breaches, SSC and turbidity increased to 36 mg/L and 16 NTU, respectively.

a. Site O3 on Mar 1, 2007 (stage: 1.22 m).

b. Site O2 on Feb 21, 2007 (stage 1.23 m).

Figure 4-25. At stages below 1.25 m, the North and South fingers of the Odello section expose their fine sediment bottom to wind and waves which can increase SSC and turbidity.

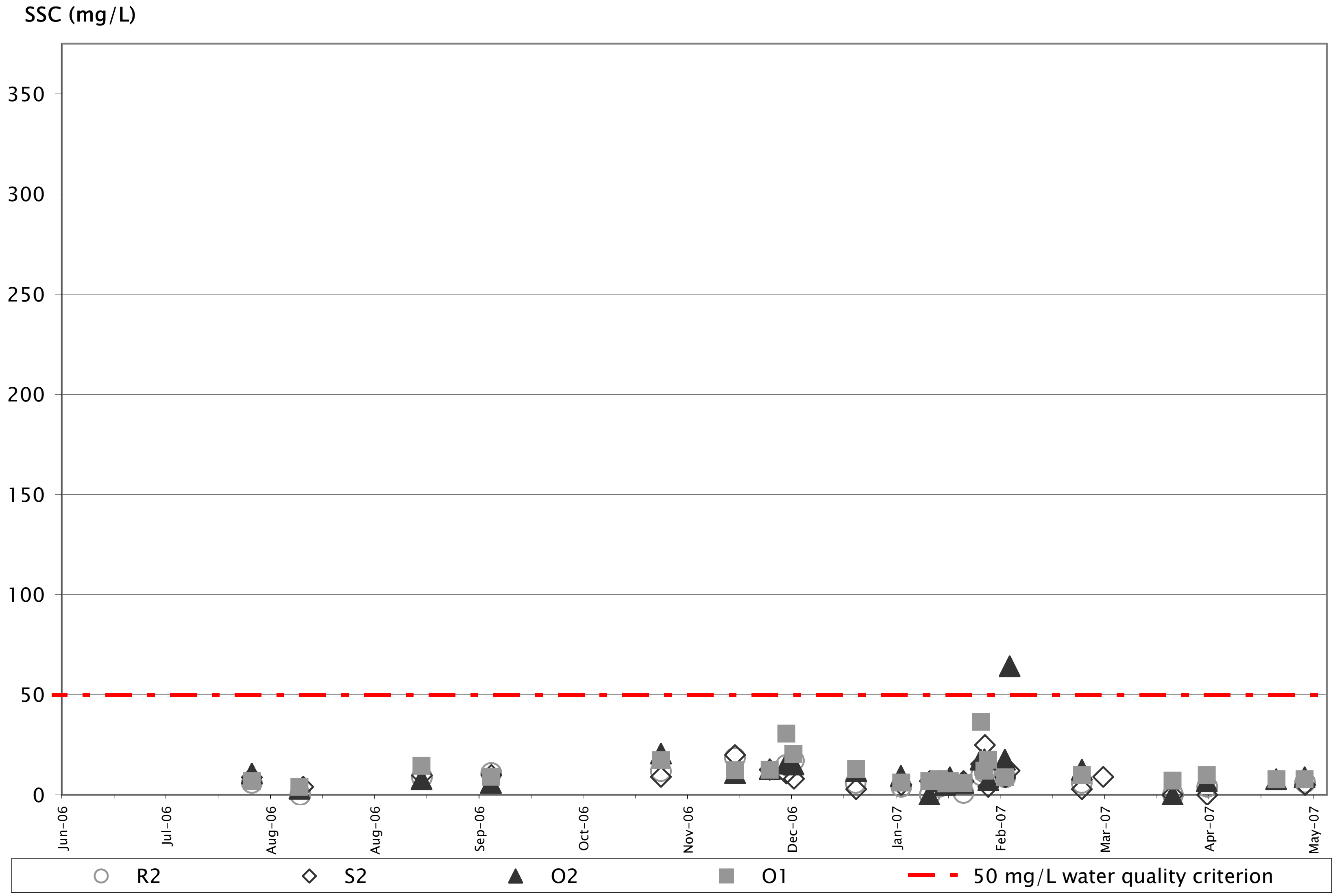


Figure 4-26. Suspended sediment concentrations June 2006 through May 2007.

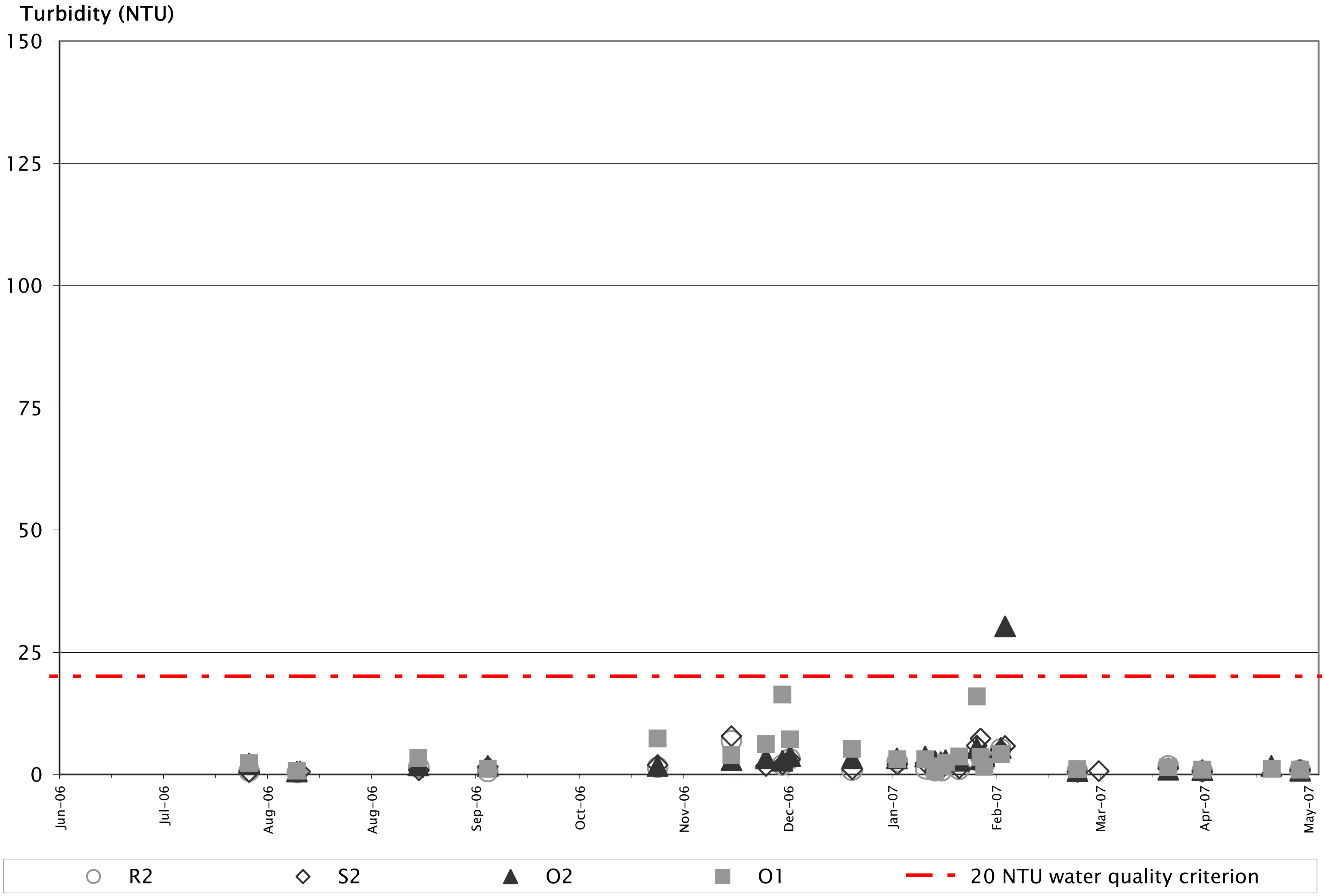


Figure 4-27. Turbidity from June 2006 through May 2007.

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 three sites within the Odello portion of the lagoon, as well as four sites in 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 important 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 (Robinson 1993). Unlike streams, lagoon macro-invertebrates are dominated by four taxa including 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 and other Central California estuarine fishes, were the amphipods *Anisogammarus (Eogammarus)* and *Corophium*, the isopod *Gnorimosphaeroma*, and the mysid *Neomysis* (Fields 1984, Martin 1995).

5.2 Sampling Methods

Seven sites were sampled on nine occasions over a two-and-a-half 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 and third years 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.). Samples were taken from standing on the bank or by wading a short distance into the water as far as 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 represents one sample.

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 the water was too deep.

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 three sweeps per sample). The volume of water per sample was calculated to be 0.84 m^3.

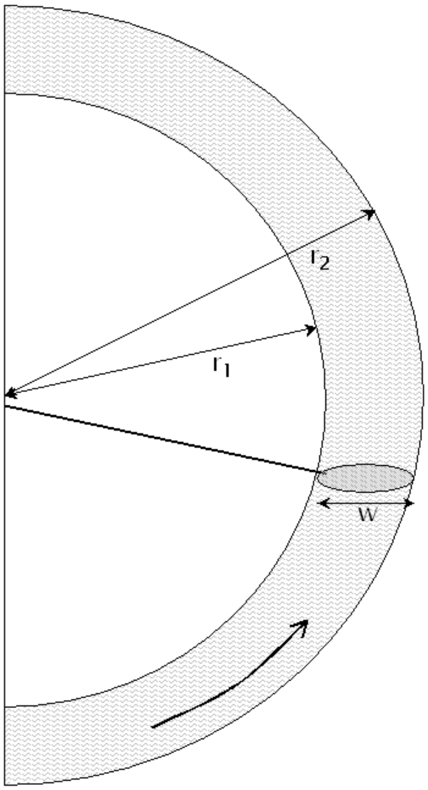
The epibenthic collection method consists of a sweep perpendicular to the bank: the net was extended out from the body, placed in the water, then gently pulled back towards the body across the bottom as lightly and quickly as possible in order to catch as many invertebrates as possible without greatly 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 three sweeps per sample). The area of eipbenthos per sample was calculated to be 1.46 m^2.

Figure 5-1 D-net used for sampling macroinvertebrates

Through March 2005, a total of three sweeps were done per stance; the net was moved back and forth three 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.

5.3 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.



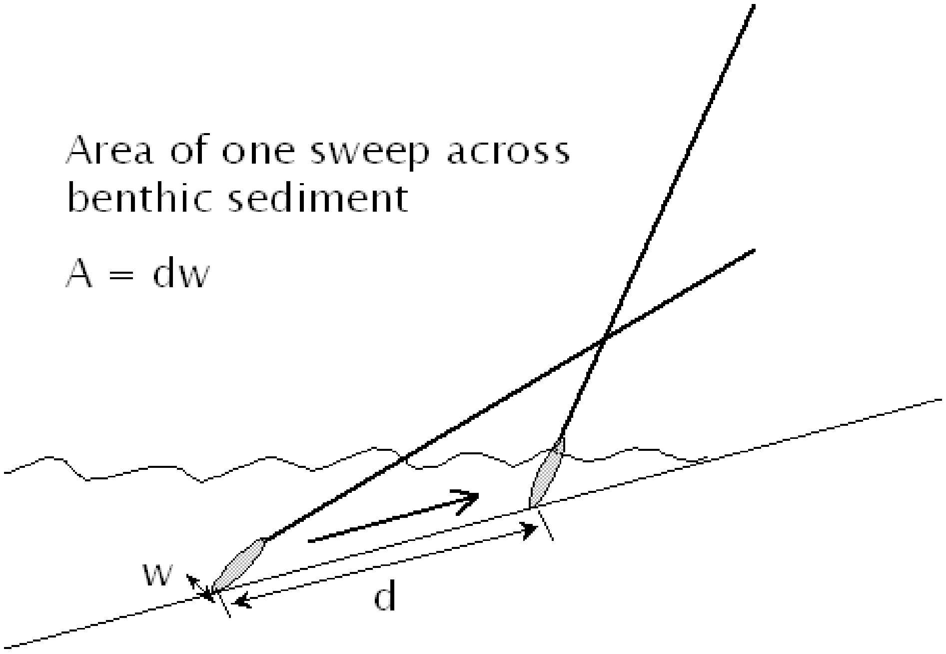
Volume of one sweep through the water with the D-net

$$V = \frac{\pi w}{2}(r_2^2 - r_1^2)$$

Where:

W = Average Width of D-net

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



Area of one sweep across benthic sediment

$$A = dw$$

Figure 5-3 Geometry of sampling for epibenthic invertebrates.

5.4 Results

5.4.1 Taxa Present

Table5 -1 is a list of all observed taxa in the lagoon. Photographs of most 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 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 as were Gomphidae, Ameletidae, and Dixidae on January 16, 2007. 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 and Spinicaudata.

5.4.2 General characteristics

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

All four taxa that Fields (1984) 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 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).

5.4.2.1 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).

5.4.2.2 Isopoda

Gnorimosphaeroma is the genus of Isopod that is present in 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).

5.4.2.3 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).

Table5 -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	Diptera	**Dixidae**		Meniscus Midge
Arthropoda	Insecta	Ephemeroptera	**Baetidae**		Mayfly larvae
Arthropoda	Insecta	Ephemeroptera	**Ameletidae**		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	Insecta	Odonata	**Gomphidae**		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
Arthropoda	Arachnida (Subclass **Acari**)				Water mite
Mollusca	Gastropoda	Pulmonata	**Physidae**		Aquatic snail
Mollusca	Gastropoda	Pulmonata	**Gyraulus**		Aquatic snail
Nematoda					Round worm

5.4.3 Abundance

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 5-4 through 5-5. Specific analysis was performed to determine the variation in the abundance of the four Peracarid crustaceans, which is presented in Fig.'s 5-6 and 5-7.

The following general observations are based on Figures 5-4 through 5-7.

- Invertebrate community composition was similar between the pre-existing and Odello sections.
- In the water column, abundance (per unit volume) of most taxa declined sharply in 2007 relative to previous years. The decline of peracarids began as early as mid-2005 (perhaps a steelhead predation effect?).
- In the epibenthos, Corophium, Eogammarus, and Ostracoda generally increased over time in the Odello section, while Neomysis slightly declined. This is consistent with gradual establishment of a stable, productive substrate following excavation. Trends were less apparent in the pre-existing lagoon.
- There is variance on isolated dates from these general trends.
- The most consistently present and abundant taxa were the peracarids (Corophium, Eogammarus, Gnorimosphaeroma, and Neomysis), the chironomids, and recently in the Odello section, Ostracoda.
- The most substantial difference between the pre-existing and Odello sections was the near dominance of Ostracoda (in numeric terms) in the Odello epibenthos following their establishment in late 2005 – compared with their near absence in the pre-existing lagoon.
- Relative to other taxa in the same habitat, chironomids were predominantly found in the water column as opposed to the epibenthos (direct comparison of abundance cannot be made between water column and epibenthods because their abundances are measured in different units – volumetric versus real)
- Relative to other taxa in the same habitat, Neomysis were predominantly found in the epibenthos as opposed to the water column.

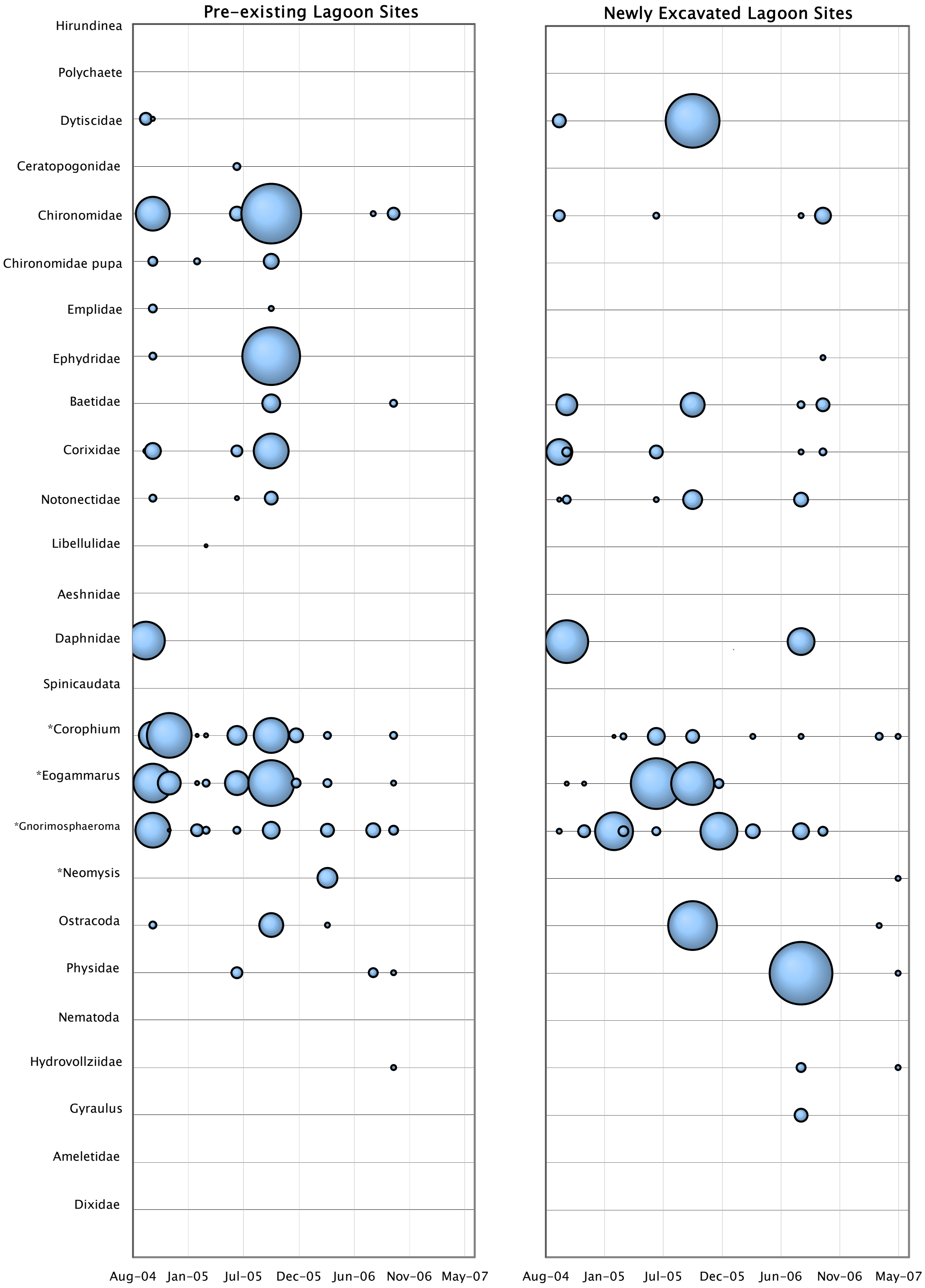


Figure 5-4 Invertebrate abundance in water column samples in the pre-existing and newly excavated lagoon areas. Sizes of bubbles represent relative abundance (m-³). * Found in Steelhead stomachs (Fields, 1984)

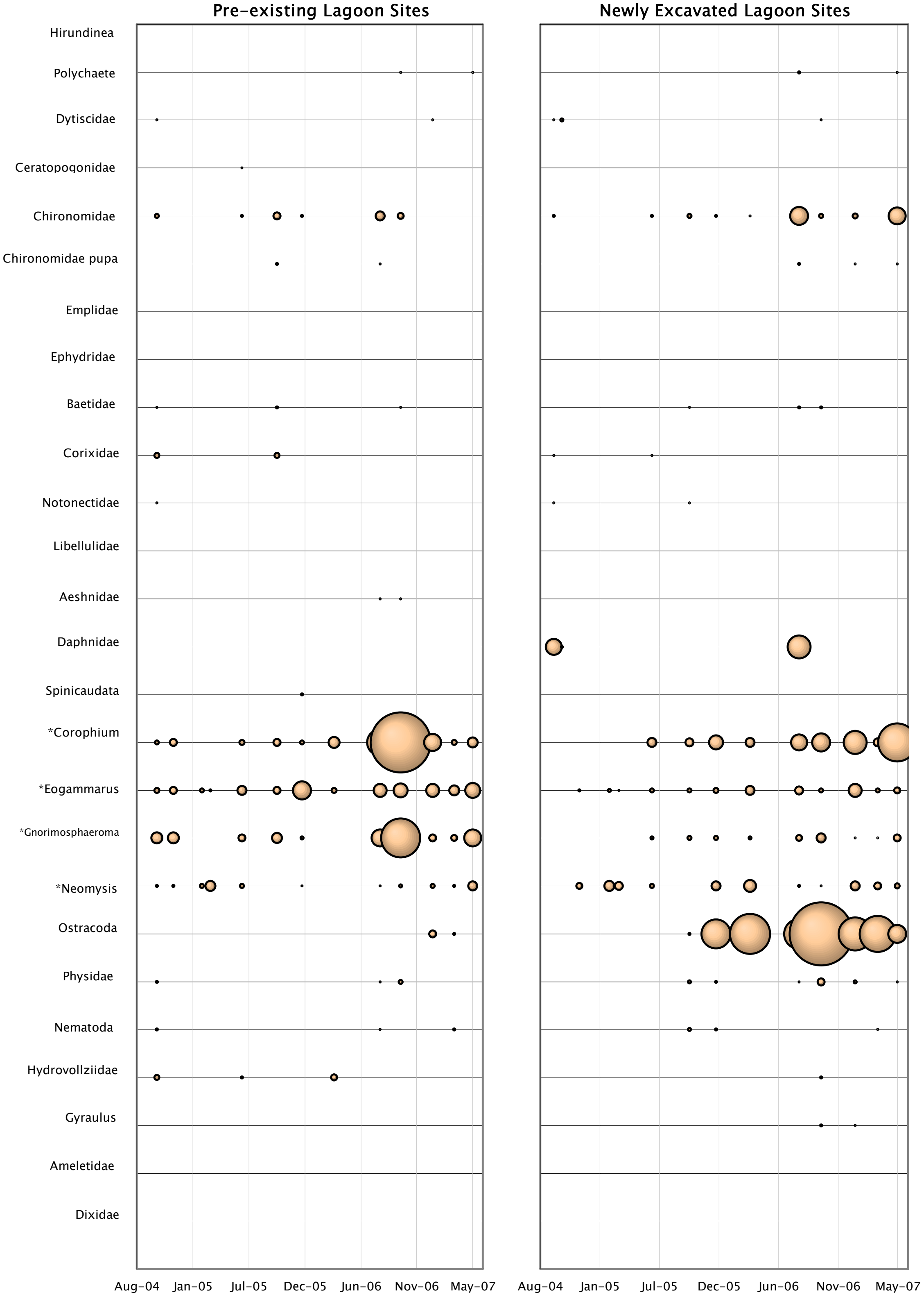


Figure 5-5 Invertebrate abundance in epibenthic samples in the pre-existing and newly excavated lagoon areas. Sizes of bubbles represent relative abundance (m-2). * Found in Steelhead stomachs (Fields, 1984)

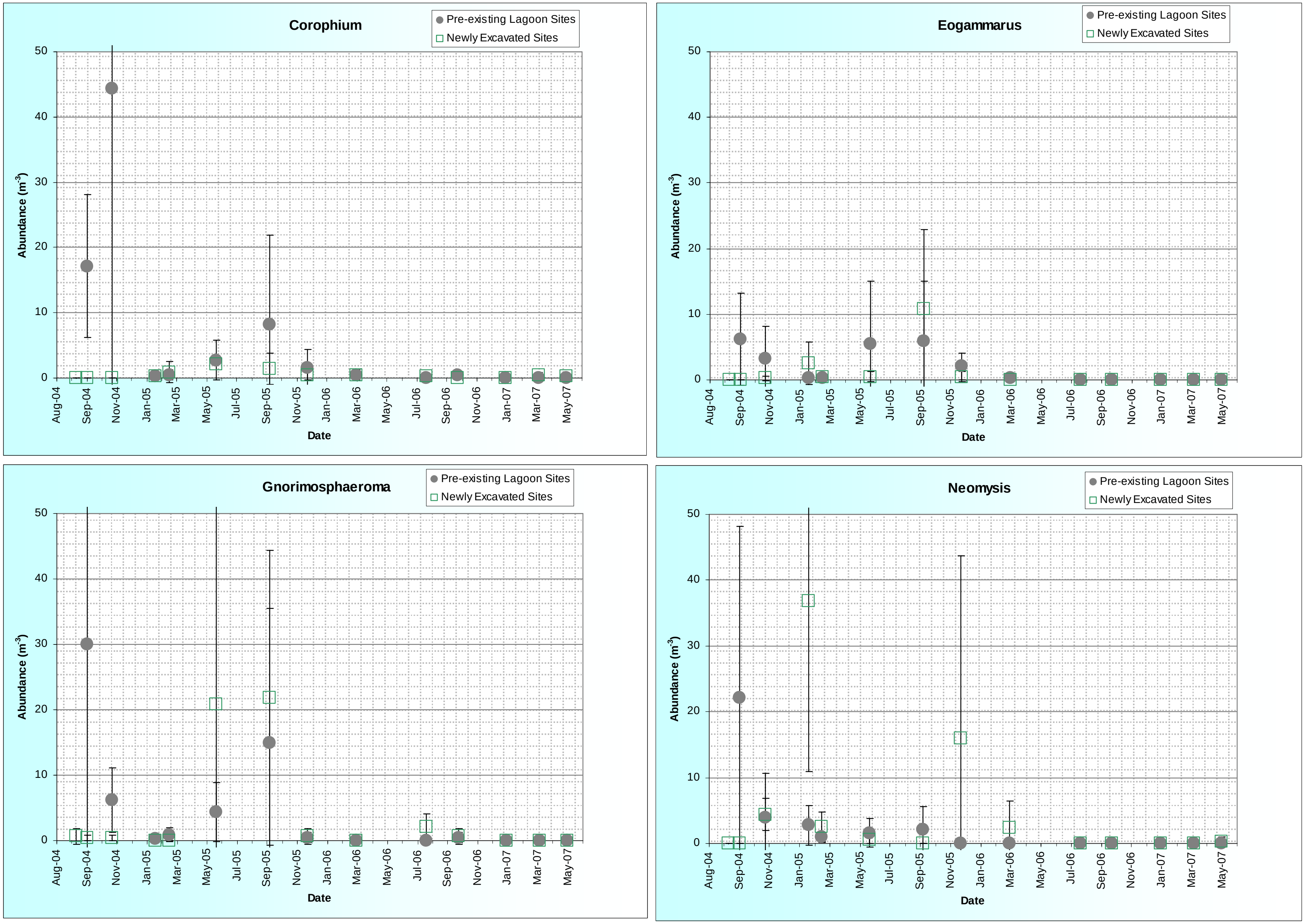


Figure 5-6 Peracarid_invertebrate abundance in water column samples in the pre-existing and newly excavated lagoon areas.

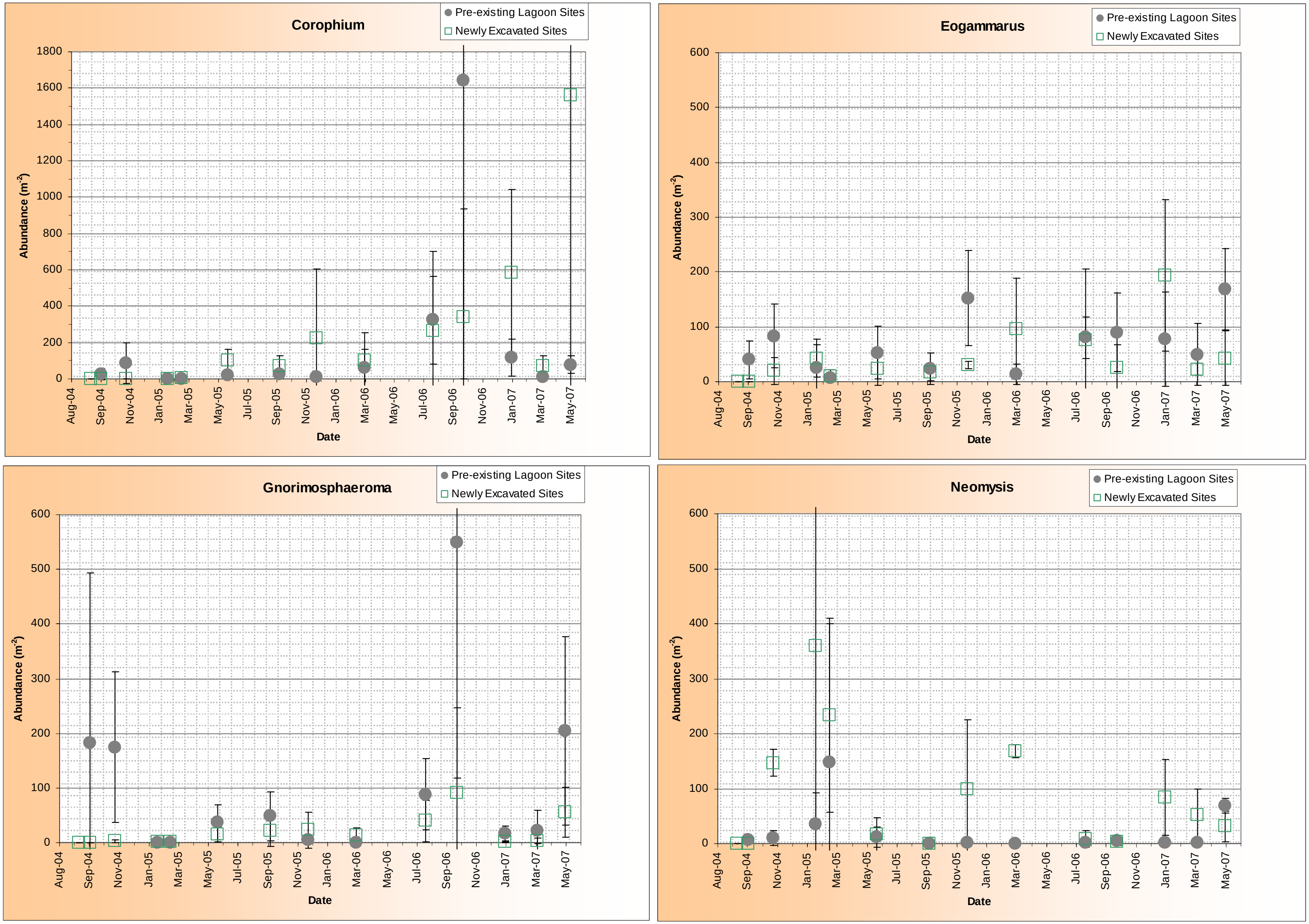


Figure 5-7 Peracarid invertebrate abundance in water column samples in the pre-existing and newly excavated lagoon areas.

5.4.4 Diversity

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.

Diversity in the newly enhanced Odello was initially less than what was seen in the pre-existing sites. However, by March of 2005 diversity in the epibenthic samples was the same between sites, while the water column diversity was slightly lower in the new Odello sections. By September 2005, the Diversity in the water column was similar between sites and epibenthic diversity was slightly higher in the new enhancement area. Finally, on the last three sample dates, water column diversity dropped to zero in both sections due to the total lack of invertebrate abundance but the epibenthic diversity at both the new Odello section and in the pre-existing lagoon ranged between 0.6 and 1.2.

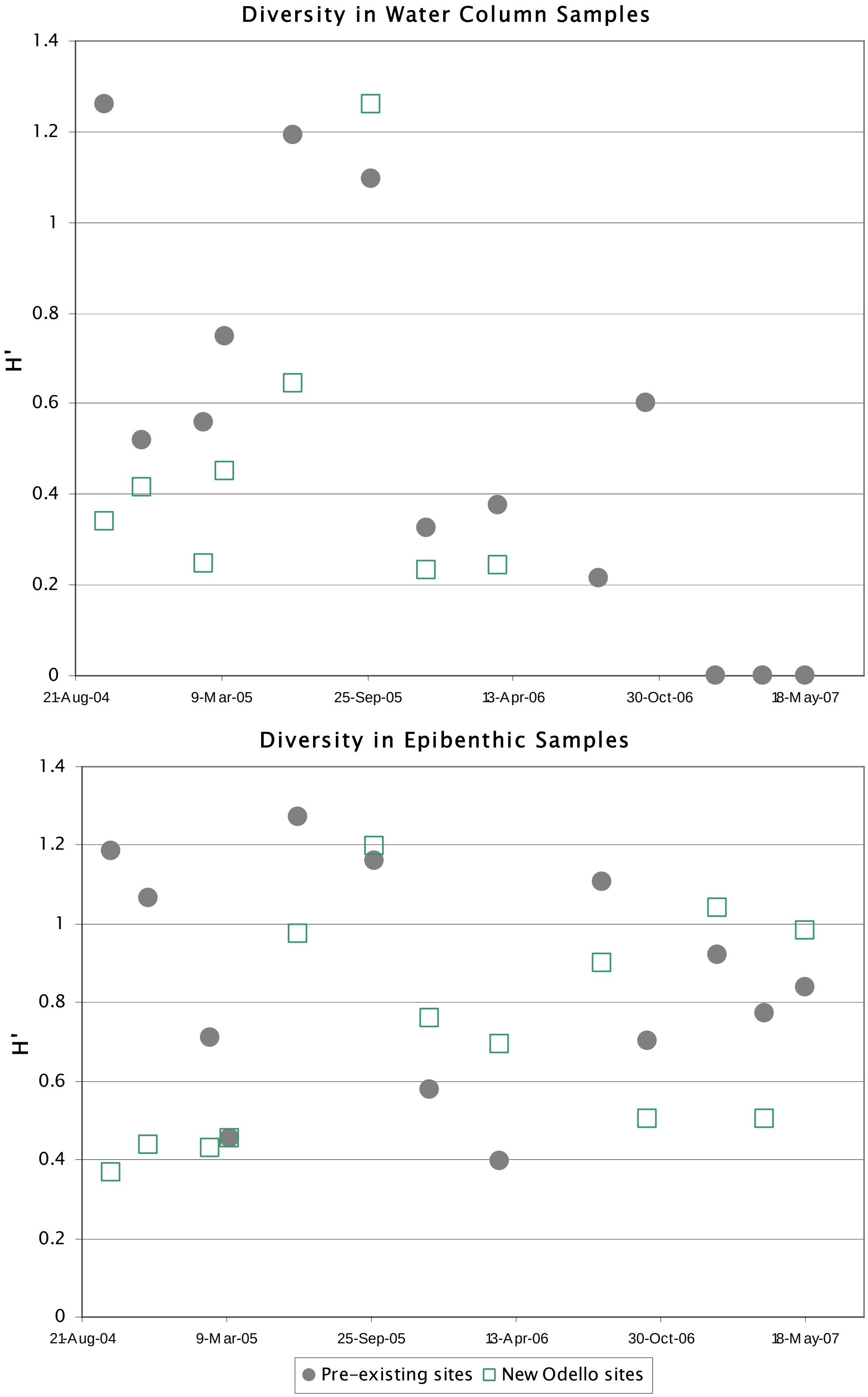


Figure 5-8 Changes in taxa diversity overtime.

5.4.5 Water Quality Relations

The range of salinity, temperature, and dissoled oxygen values that each taxa occured in are summarized using Box & Whisker plots in Fig. 5-10. An explanation of the descriptive statistics that are displayed in this plot is in Figure 5-9. It should be noted that just because taxa were observed in a specified salinity, temperature or oxygen concentration, it is not an indication of preference or tolerance, but is largely dependant on the availible water quality conditions present in the lagoon at the time of sampling. Note also that this analysis only includes epibenthic invertebrate presence in relation to water quality measurements at the bottom to a maximum depth of 1 m.

5.4.5.1 Salinity

The peracardis and ostracods showed no obvious intolerance for any specific salinity range. The insects and daphnids showed intolerance to salinity above about 10 ppt. Their absence from higher salinity samples could be due to small sample size in some cases, but not all (e.g. chironomids, which are insects that occurred in many samples).

5.4.5.2 Temperature

The taxa present in the widest ranges of temerpartures were the peracarids, ostracods, and physids. Although most of the peracarids were found between 13°C and 18°C, they were also present in the extremes at 3°C and 29°C. The polychaetes and a number of insect taxa (except chironomids) exhibited seasonal occurrence (summer) which manifested as occurrence only in slightly warmer water than the median temperatures inhabited by the peracarids.

5.4.5.3 Dissolved Oxygen

Peracarids were also found in the widest range of dissolved oxygen concentrations. They were present in hypoxic and hyperoxic water but were most often found in the normal ranges between 8 and 12 mg/L. Chironomidae and Baetidae were the only insects that had outliers outside the 10 and 20 mg/L range. All other insects were found in a narrower range between 6 and 12 mg/L ranges (Fig. 5-10), which may be an artifact of their small sample sizes.

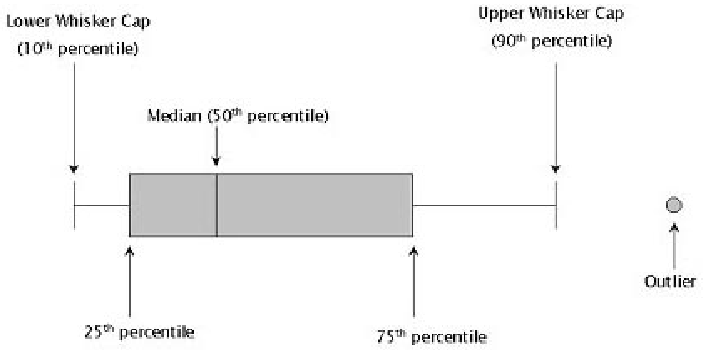


Figure 5-9 Explanation of display of descriptive statistics in Box and Whisker plots.

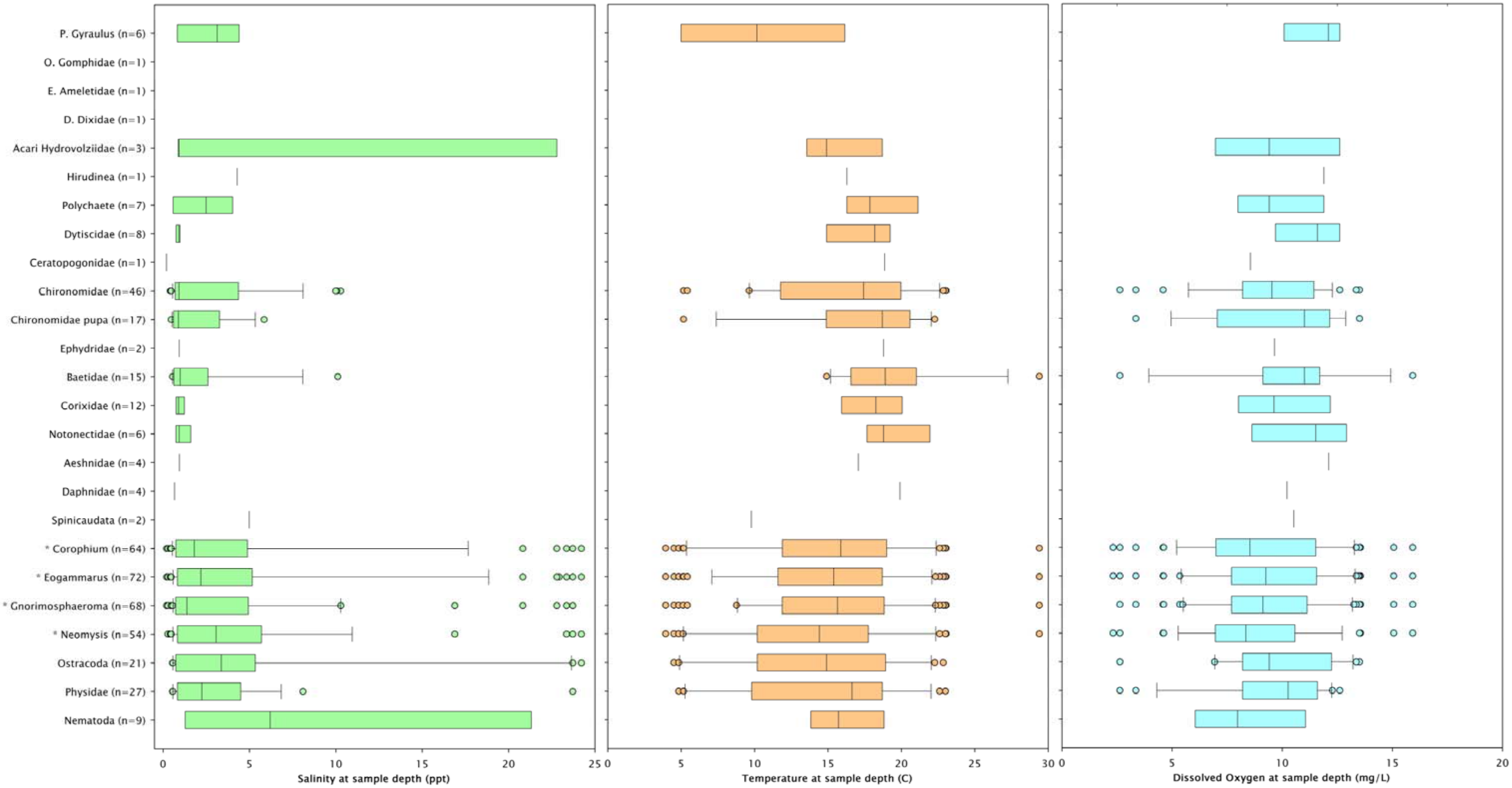


Figure 5-10. Epibenthic macroinvertebrate salinity, temperature, and dissolved oxygen ranges.

6 Video Monitoring for Steelhead

6.1 Introduction

The CRLEP was designed to enhance habitat for steelhead and California red-legged frogs. To help evaluate the success of this project in this respect, we sought a means of quantifying whether steelhead showed preferences for the enhanced habitat in the Odello arm over the original habitat in the pre-existing lagoon. We were specifically interested in which micro-habitats (e.g. logs, tules, etc.) might be preferred.

Perhaps the most common method of survey in these situations is seining, which involves a boat and several people swimming and wading through the lagoon with a large net covering an area of about a third-of-an-acre with each haul. Seining surveys were conducted throughout the project by a number of groups. These surveys are the primary source of information on the overall abundance, size, life-cycle-state, condition, and coarse-scale location of fish in the lagoon. However, they are somewhat invasive, given the special status of steelhead, and they do not yield fine-scale habitat use information. Therefore, while not attempting to replace seining and the information it can yield perhaps by no other means, we sought additional means of observing steelhead.

We developed a small remotely operated boat mounted with a wireless underwater video camera and single-beam sonar system. The goal was that the boat could be a relatively non-invasive, labor-efficient, and spatially detailed means of surveying how steelhead used the lagoon. This is an extension of previous work (Larson et al., 2005) using fixed underwater cameras, which were largely unsuccessful due to poor coverage and limited visibility.

To date, the technological development has been somewhat successful but the use of the technology to actually observe fish has had only marginally positive results, hampered mainly by poor visibility in the Carmel Lagoon. The details of the development process, and some limited results are presented here.

For background and design information on Steelhead monitoring with remotely operated boat, see Larson et al. (2006).

6.2 Design Improvements

At the time of last year's CRLEP report, the use of a remotely operated boat 'Steelhead Boat", was a virtually untested platform. The intervening year has been spent testing and refining the system. Though the basic design concept remains the same, the robustness of the ROV has been greatly improved. Currently, the boat has logged over one-hundred hours of running time at Carmel River Lagoon and elsewhere. Although numerous attempts to obtain video were made between August 2006 and May 2007, most amounted to technology tests or were limited by poor visibility. Table 6.1 displays all the development and testing dates.

Several weaknesses in the system were discovered shortly after initial testing began. The most problematic was a recurrent inability to establish steady wireless (802.11g) network connections between the laptop, router, and camera. The network problems were resolved by replacing all three pieces of equipment with newer upgrades, as well as using a different software package, Axis Camera Station. A new water "resistant" deck was constructed out of acrylic and the original wooden chassis was replaced with a more streamlined aluminum version. To accommodate the added weight of new parts, new and larger PVC pontoons were fashioned and mounted to a frame that allows them to be easily removed. These new pontoons were painted a hunter green color to better blend in with the aquatic environment (fig 6.1).

The steelhead boat was given a second dimension of functionality when a Humminbird PiranhaMax 15 sonar fish-finder was added (Fig 6.2c). The system was again altered. A green, water-resistant box was added to the bow of the steelhead boat to house the camera and the fish-finder display screen. The camera looks directly at the screen and transmits the scrolling display to the recording software. A sonar transducer head was mounted to a pole on the underside of the boat where the underwater camera housing was usually attached. The added weight of the sonar components required larger pontoons and propeller blade for better maneuverability and speed.

The advantage of the boat's new design is that it is modular. It takes approximately twenty minutes to switch from sonar to underwater camera and the change can be made in the field. The boat allows the user to evaluate visibility and choose the equipment that better suits the situation. The boat is also highly portable and can be launched and operated by a single observer. It has battery life that extends longer than three and one-half hours and recharges in roughly two. Streaming video can be collected from as far as one hundred meters away, providing the operator with flexibility to sample a greater area from shore than is possible by eye.

The boat still has some drawbacks. Some are correctable with further fabrication, while several are inherent to the concept itself. Most significantly, the camera is a poor substitute for the human eye. There were several occasions in which poor visibility limited the cameras viewing to less than three feet, yet the operator noted numerous steelhead feeding at the surface near and around the boat itself. Overall, the camera's horizontal visibility is an estimated 66% to 75% less than that of a human snorkeler. Additionally, the lack of depth perception in the recording makes judging relative sizes and depths of fish difficult. Also, the poor visibility and depth perception can lead to mis-identification of species. Hitch (*Lavinia exilicauda*), a native minnow species of the Sacramento/San Joaquin and Salinas/Pajaro River systems but introduced to the Carmel Lagoon, has been observed on several occasions in the Odello and South Arms. Both hitch and juvenile steelhead 'school' in open waters and therefore they could be miss-interpreted for each other during periods of poor visibility. This would also be a limitation of the sonar viewer as well in these habitats. Finally, video review is time consuming and video files consume significant hard drive space.

6.3 Current status

After the extensive network upgrade of the boat in April 2007, it has made successful sampling trips in Carmel River Lagoon. The increased visibility of spring and early summer has allowed it to record over 177 video segments showing steelhead in the main embayment, during the eleven surveys since May 2007. The results of these surveys are being described in a pending student thesis (C. Hanley, B.S. capstone thesis in prep.). Table 6.1 displays dates of video capture since September of 2006.

Although Steelhead Boat has been hampered by many technical problems and poor visibility, several improvements could be made that would greatly enhance the boat's usefulness. The use of a lighter and stronger material, like fiberglass, would be a design improvement. A fiberglass hull would provide better water resistance and increase the craft's seaworthiness. Adding a second camera would allow an underwater camera and a sonar fish finder to work in conjunction to find steelhead. Longer, more streamlined pontoons and a stronger rudder servo would counter the added weight of additional equipment.

The ultimate utility of the boat in the Carmel Lagoon still remains to be seen. It appears to be restricted to use during only those times of year when the visibility is relatively good. It may have greater utility in other low-velocity shallow-water environments where the water is clearer.

Table 6.1 Steelhead Boat monitoring dates with steelhead presence and site.

Date	Recording time (hrs+min)	Parr (#)	Smolt (#)	Adult (#)	Lagoon Site (#)	Notes
4 Sep 06	1:00	0	0	0	N1	
8 Sep 06	0:45	0	0	0	O1	
15 Nov 06	0:00	0	0	0	O1	
18 Nov 06	0:00	0	0	0	O1	
19 Nov 06	0:00	0	0	0	O2, S2, R2	
20 Nov 06	0:00	0	0	0	N1, S2, R2, R4	
21 Nov 06	1:00	0	0	0	01	
22 Nov 06	0:00	0	0	0	N1, O1	Connectivity failure
13 Dec 06	0:00	0	0	0	N1	Connectivity failure
3 Jan 07	0:00	0	0	0	O1	
5 Jan 07	0:00	0	0	0	O1	Connectivity failure
7 Jan 07	1:00	0	0	0	O1	
8 Jan 07	1:30	0	0	0	N1,O1	
9 Jan 07	1:45	0	0	0	R4	
10 Jan 07	0:40	0	0	0	N1,O1, R2	
11 Jan 07	1:30	0	0	0	O1, S2	
15 Jan 07	3:30	0	0	0	Carmel River @ Paso Hondo	
18 Jan 07	2:30	0	1	0	Scotts Creek	Dead Smolt
22 Jan 07	3:00	0	>50	0	Willow Creek	Clear Water
15 Mar 07	2:00	0	0	0	O1, S2	Numerous fish captured on display
7 May 07	2:00	0	>5	<5	R2 / R4	Adults schooling near breach site
9 May 07	2:00	0	0	0	R2 / R4	Numerous fish captured on display
1 Jun 07	1:10	0	0	0	R2	
11 Jun 07	4:25	0	<15	<5	R2	
12 Jun 07	5:20	0	<25	<5	R2	
13 Jun 07	3:35	0	<20	0	R2	
15 Jun 07	2:15	0	<10	>5	R2	
19 Jun 07	3:10	0	>5	0	R2	
20 Jun 07	2:30	0	>5	0	R2	
21 Jun 07	3:30	0	0	0	R4	
30 Jun 07	1:35	<40	>5	0	R4	

a. Steelhead Boat electronics configuration.

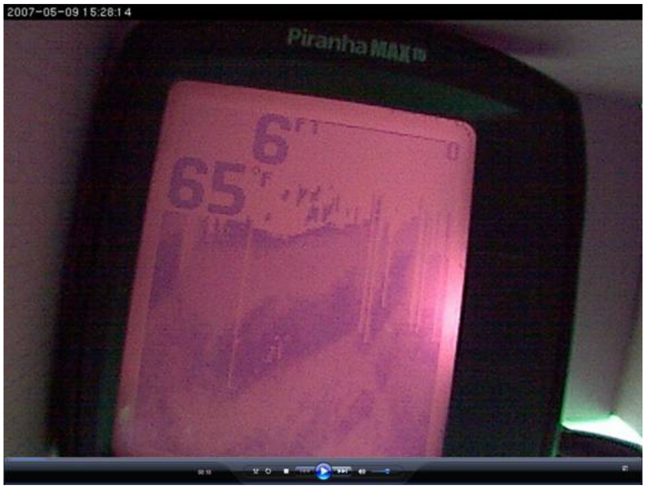
b. Steelhead boat deployed in the main embayment

Figure 6.1 Steelhead boat equipment configuration

a. Adult steelhead in the river channel (Site R4). (7 May 07)

b. Adult steelhead in the river channel (Site R4). (7 May 07)

c. Fish captured on sonar system (Site R2). (9 May 07)



d. Sonar noise or fish (Site R2). (9 May 07)

c. Parr steelhead in the river channel (Site R4). (30 Jun 07)

d. Parr steelhead in the river channel (Site R4). (30 Jun 07)

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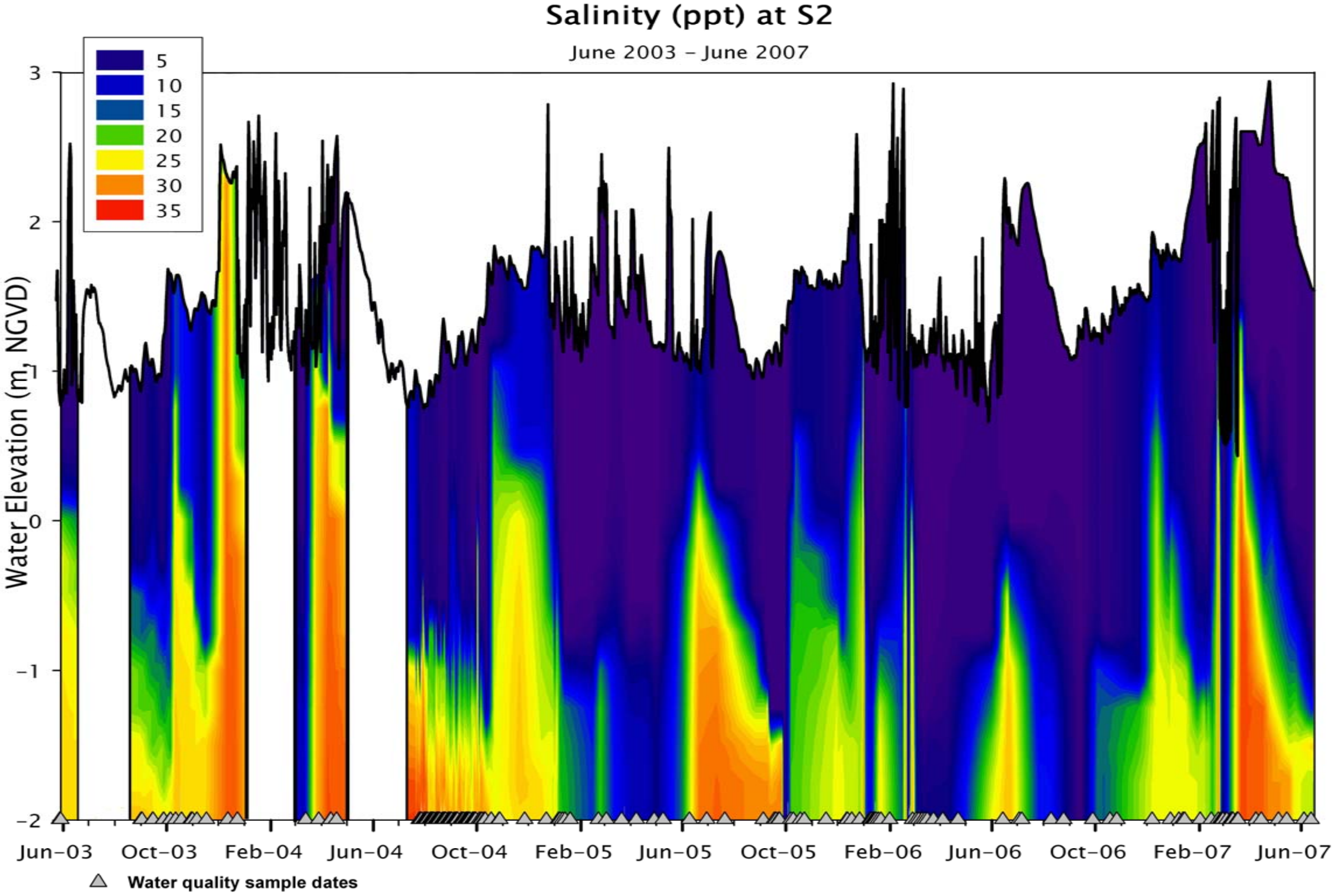
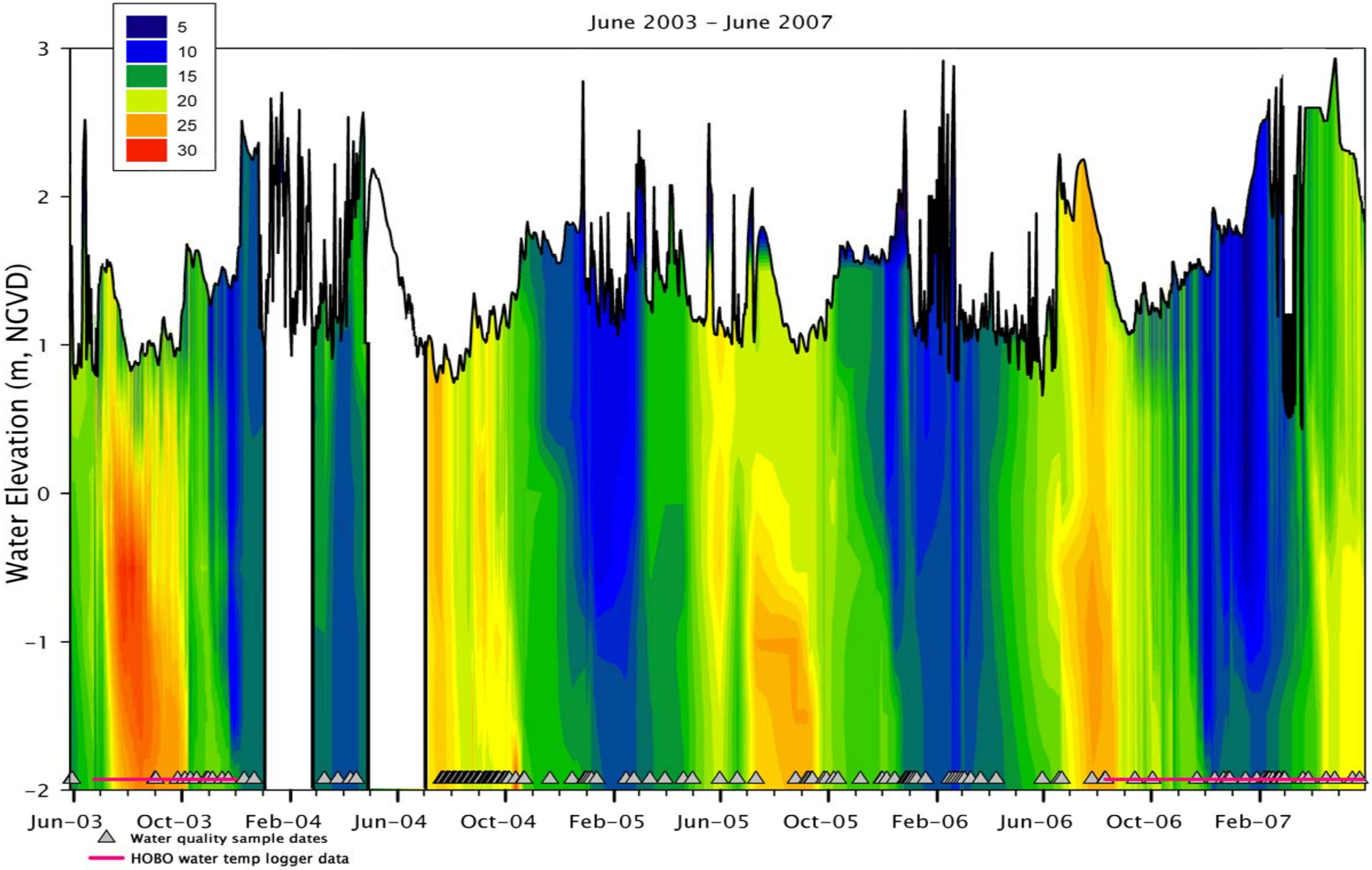
8 Appendices

Included in these appendices are:

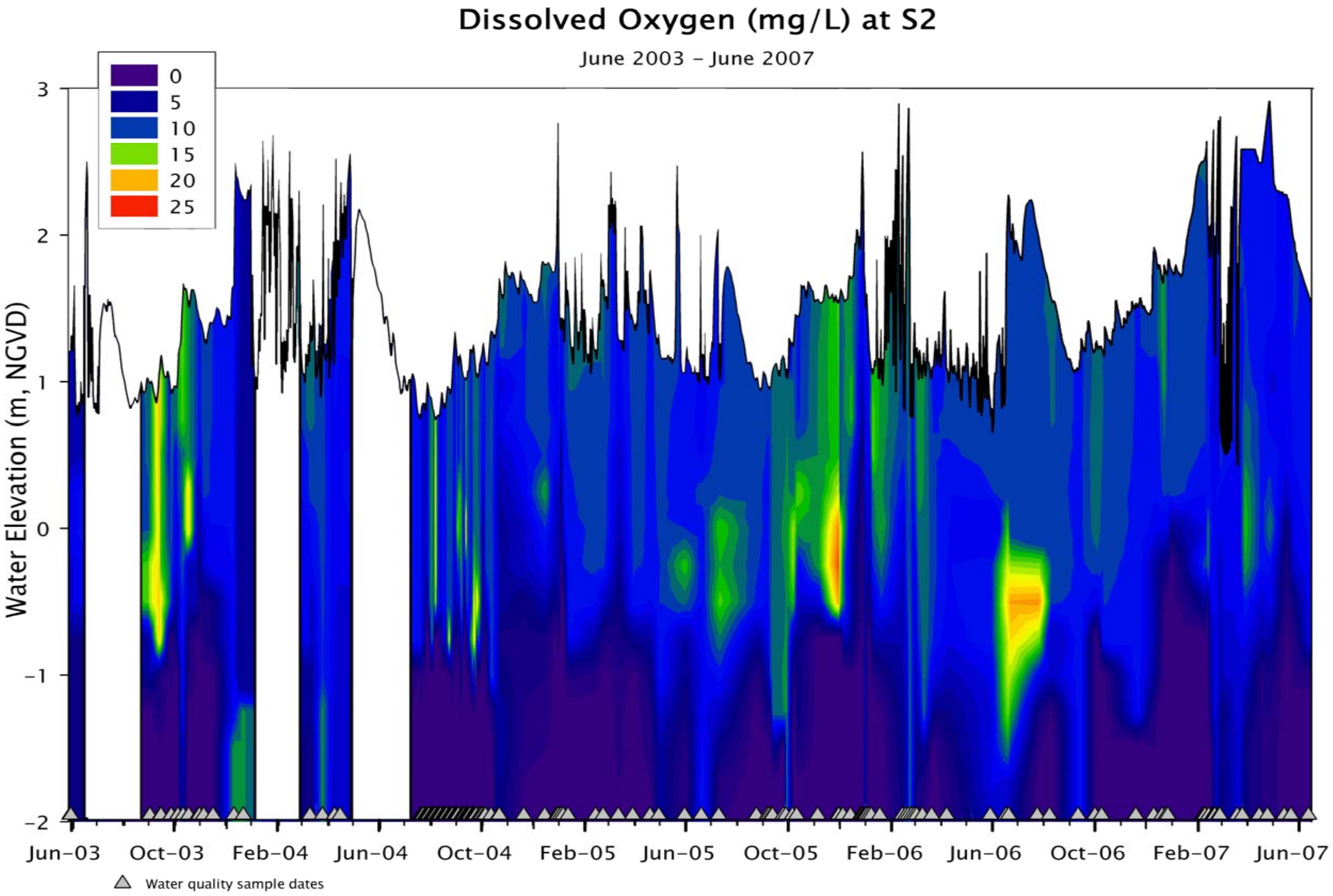
- Appendix A: 2-year time series of depth profiles at S2
- Appendix B: 2- year time series of SSC and Turbidity data
- Appendix C: Macroinvertebrate taxa

8.1 Appendix A: 4-year time series of depth profiles at S2

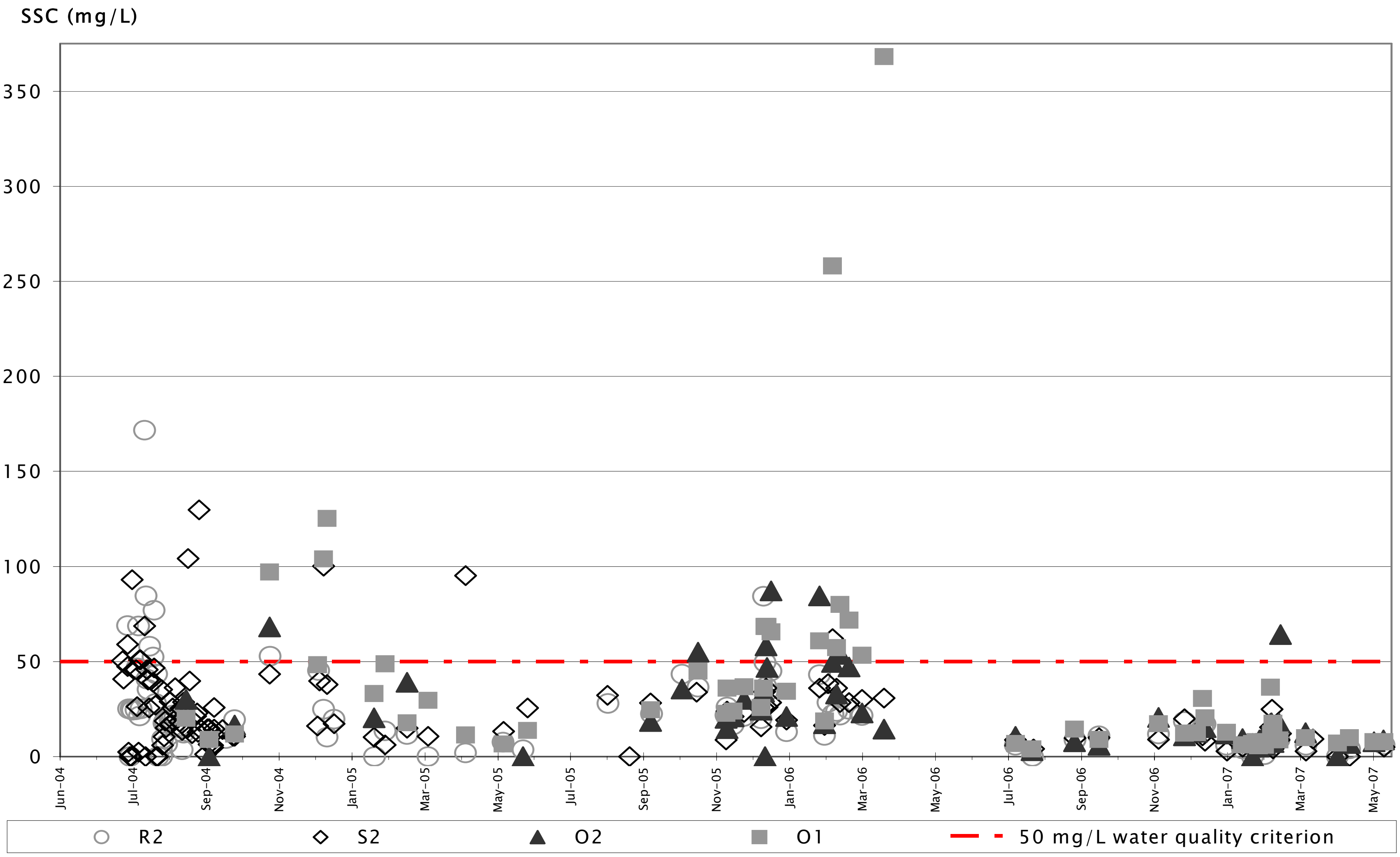


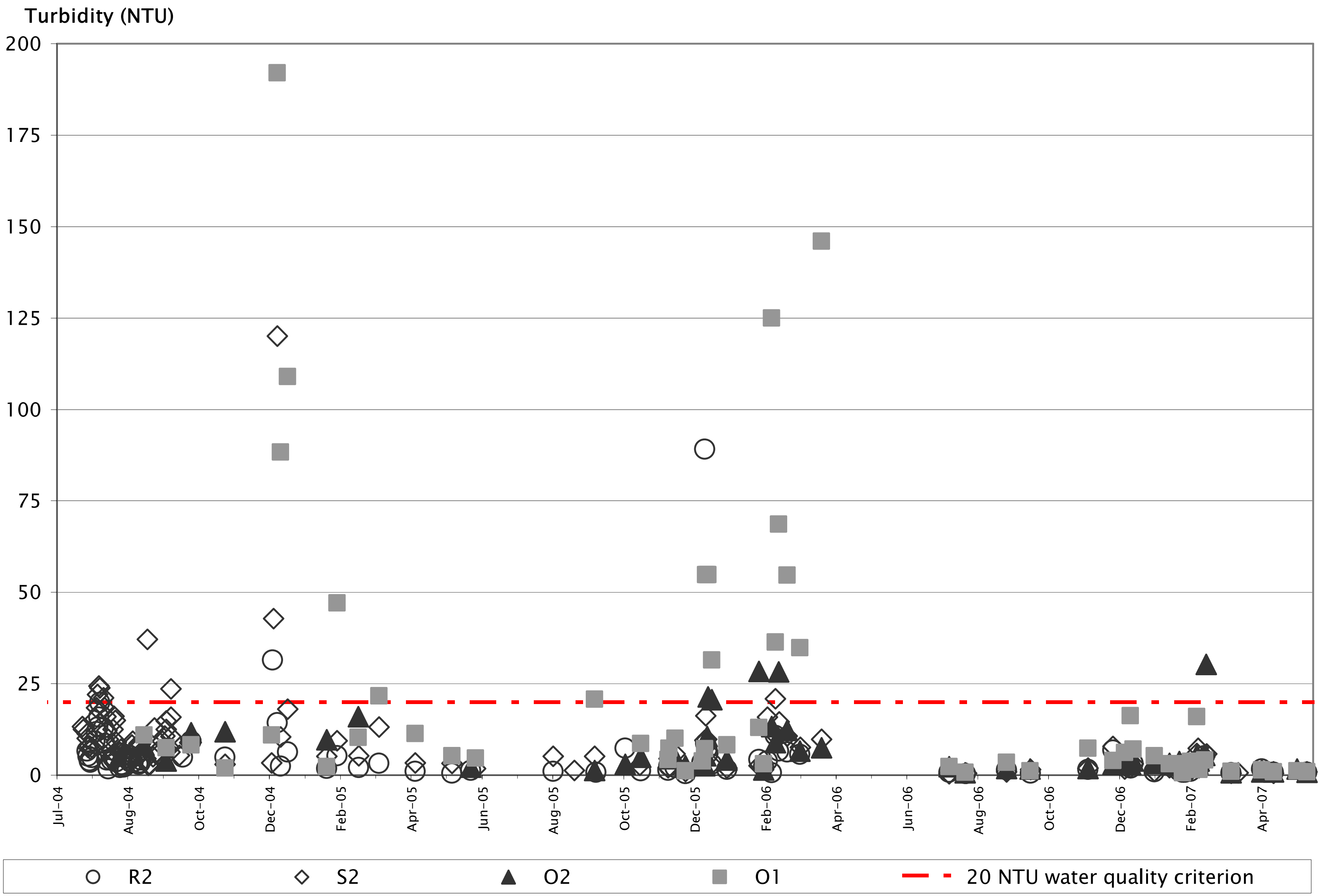

Temperature (°C) at S2

June 2003 – June 2007


Dissolved Oxygen (mg/L) at S2
June 2003 – June 2007
0
5
10
15
20
25
Water Elevation (m, NGVD)
3
2
1
0
−1
−2
Jun−03
Oct−03
Feb−04
Jun−04
Oct−04
Feb−05
Jun−05
Oct−05
Feb−06
Jun−06
Oct−06
Feb−07
Jun−07
Water quality sample dates

8.2 Appendix B: 3- year time series of SSC and Turbidity data




Turbidity (NTU)
200
175
150
125
100
75
50
25
0
Jul-04
Aug-04
Oct-04
Dec-04
Feb-05
Apr-05
Jun-05
Aug-05
Oct-05
Dec-05
Feb-06
Apr-06
Jun-06
Aug-06
Oct-06
Dec-06
Feb-07
Apr-07
○ R2
◇ S2
▲ O2
■ O1
20 NTU water quality criterion

8.3 Appendix C: Macroinvertebrate taxa

Hirudinae

Polychaete

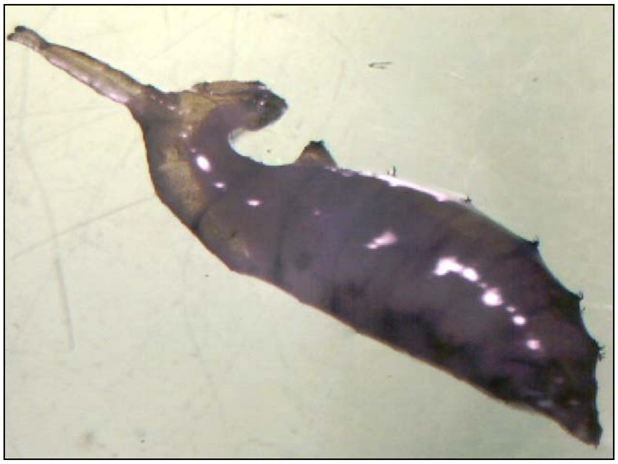
Dytiscidae

Ceratopogonidae

Chironomidae

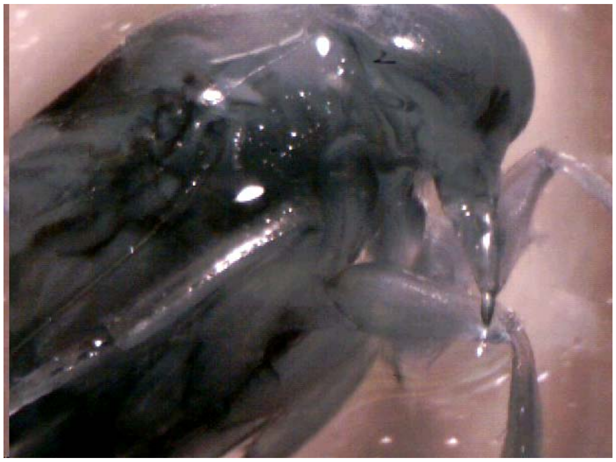
Chironomidae pupa


Empididae

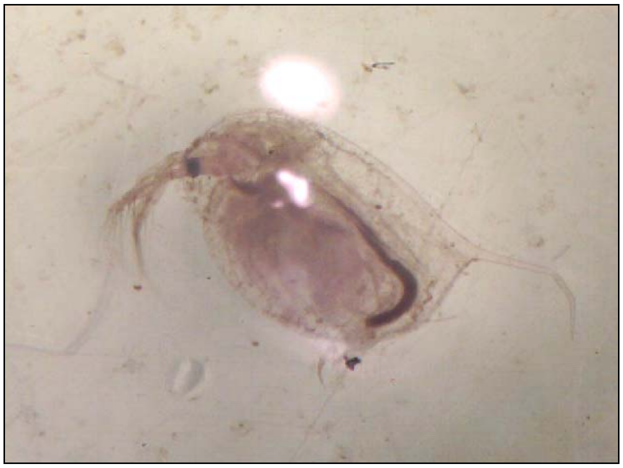

Ephydridae


Baetidae


Corixidae


Notonectidae

Aeshnidae



Dapnidae

Spinicaudata (need picture)

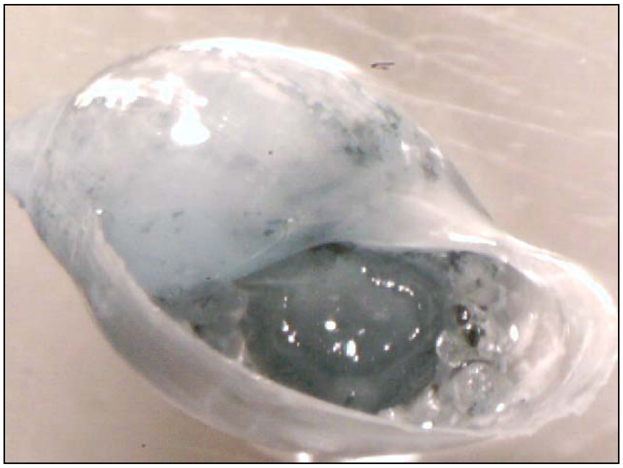
Corophium

Eogammarus

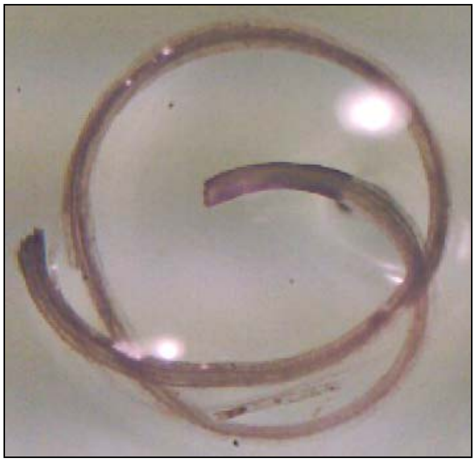
Gnorimosphaeroma

Neomysis

Ostracoda



Physidae



Nematoda

Acari