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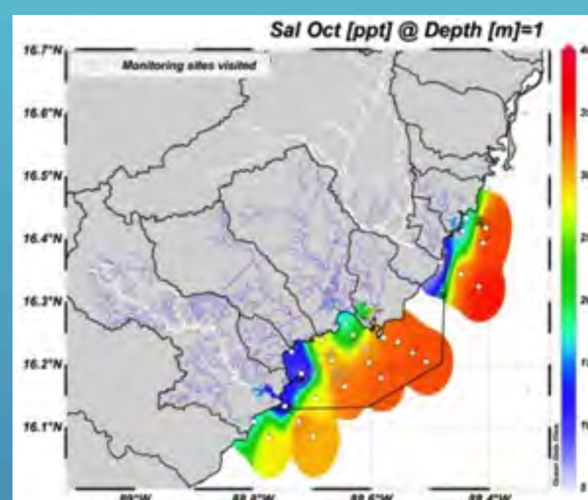
Ridge to Reef Water Quality

Port Honduras Marine Reserve, Monkey River, Rio Grande

TIDE Annual Report 2013

Foley, J., Smith, D.

TIDE Research & Monitoring Department 2014



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ACRONYM KEY

BFD	Belize Fisheries Department
DO	Dissolved oxygen
EDF	Environmental Defense Fund
GUZ	General use zone
NTZ(s)	No-take zone(s)
OUT	Marine areas close to but outside PHMR
PCNP	Payne's Creek National Park
PHMR	Port Honduras Marine Reserve
PRZ	Preservation zone
TIDE	Toledo Institute for Development and Environment
WCS	Wildlife Conservation Society

Units:

cm	Centimetre
$g\ m^{-2}\ day^{-1}$	Grams per metre squared per day
$g\ ml^{-1}$	Grams per millilitre
ppt	Parts per thousand
SE	Standard error
%	Percent

ABSTRACT

Since 2012, the Toledo Institute for Development and Environment (TIDE) has integrated initially separate marine and fresh water quality monitoring programs in order to improve understanding of hydrological and biophysical interconnectivity between land and sea in the Maya Mountain Marine Corridor (MMMC). Results of 2013 analysis are presented here, comparing seasonal dynamics of Rio Grande and Monkey River, and inferences made on their respective influences on conditions in PHMR. Parameters measured were temperature, dissolved oxygen, salinity, visibility, nitrate, phosphate and sedimentation. Condensed comparisons between each year 2009-2013 are also made. General conclusions about each parameter are located in the last part of each section. Trends are becoming apparent over the years 2009-2013 for temperature and salinity, but not so clearly for dissolved oxygen or visibility. Nutrient concentrations tend to be highest during wet seasons, but nutrient data has not yet been collected for enough years to identify trends in rivers from year to year. Overall, sea surface temperatures seem to be decreasing since 2009, a trend observed elsewhere in the world. Impact on the Bladen branch of Monkey River from land use change and agriculture appear to be increasing. Finally, recommendations for stakeholder engagement, research and monitoring, reserve management, education and outreach and capacity building are provided in light of this year's monitoring results.

INTRODUCTION

i. Program integration:

The Toledo Institute for Development and Environment (TIDE) has been implementing both marine and freshwater quality monitoring programs with varying degrees of continuity, and without integration, since 1998. In 2011, TIDE's reseach and monitoring department expanded its water quality monitoring program to include new sites, multiple depths, new parameters and revised and standardised methods. The 2011 marine and fresh water quality annual report provided recommendations for merging the marine and freshwater quality monitoring programs, with the aims of demonstrating interconnectivity between land and sea and creating a more comprehensive picture of the impacts of terrigenous runoff on the marine ecosystems in Port Honduras Marine Reserve (PHMR). By revising methods for data collection, data entry, database management and data analysis, and with the use of the Ocean Data View geospatial oceanic and fresh water mapping software, this has now been achieved, (Section IX Recommendations part (e) pg. 75) This report provides the second integrated marine and fresh water quality monitoring analysis conducted by TIDE. Information derived from this program can inform and facilitate adaptive "ridge-to-reef" management of marine and terrestrial protected areas under TIDE's custody.

ii. **Threats to water quality:**

a. ***Domestic use:*** Local communities in the Rio Grande watershed use this river extensively for domestic purposes such as cooking and cleaning and washing clothes, which often occurs directly in the river.

While this occurs on a relatively small scale, cumulatively this could impact nutrient levels in the river, particularly phosphate, potentially increasing risk of eutrophication and subsequent fish die-offs.

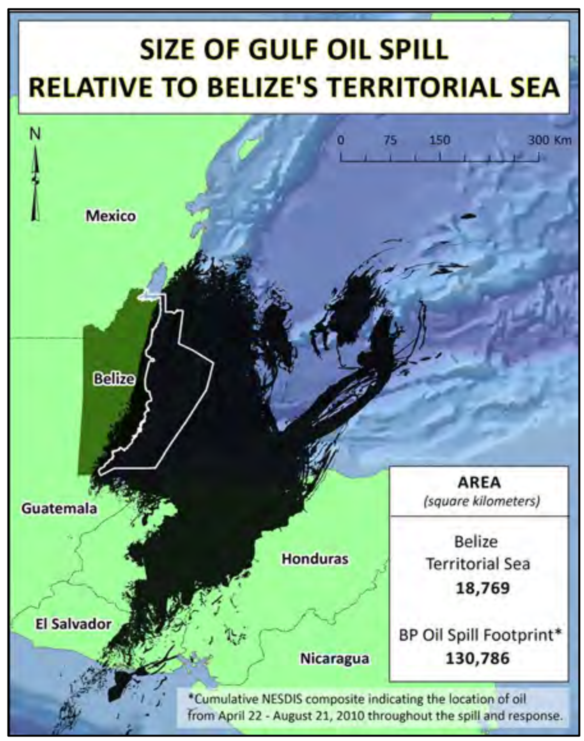
b. ***Fruit plantations*****:** There are extensive banana and citrus plantations in the upper watershed of Monkey River in Swasey and Bladen branches. These sites are known to use large amounts of fertilizers and pesticides, which subsequently leach into the river. It is expected that these would contain high levels of nitrates.

Flat stones in the Rio Grande used for washing clothing. Phosphate rich detergents are probably released into the river in this way,

c. ***Shrimp aquaculture*****:** The area North of Monkey River is the northern limit of TIDE's area of interest. In this area there are extensive land based shrimp farming facilities, some in operation and some disused, that may be flushing harmful waste substances into the local marine environment. TIDE monitors the adjacent waters north of PHMR to determine if there are any impacts of these facilities on the ecosystem health of PHMR. While many of the ponds are abandoned, water from them still drains into PHMR, potentially leaching harmful toxic chemicals into the ocean. Some ponds are still in use to commercially produce an Ecuadorian shrimp species, and may periodically release large quantities of nitrate-rich shrimp feed and shrimp faeces, biologically hazardous antibiotics, escaped exotic shrimp and exotic parasites into the surrounding waters close to Monkey River Village and PHMR.

d. Land burning – land is burned for hunting, clearance for cattle, agriculture or construction. Sometimes fires are started naturally by lightning or intense heat from the sun during hot dry weather. Land may also be burned in a controlled fashion to protect adjacent property as seen in this example, where an area of pine savannah is being burned to protect an adjacent shrimp farm from wildfire. This can be detrimental to rivers if conducted nearby, as soil may wash into rivers, bringing nutrient rich ash with it and elevating nutrient levels and sedimentation in the river. It is important to consider these types of activities when interpreting water quality data.

e. Oil development – currently there is no oil extraction or seismic testing taking place in PHMR, although since US Capital Energy recently set a precedent in Belize by being approved to drill for oil in Sarstoon Temash National Park, the possibility of this happening in one or more of TIDE's protected areas is real, and must be taken seriously. The figure below shows the scale of the BP oil spill superimposed over the Gulf of Honduras and Central America. If a similar oil spill were to occur in PHMR, a very large area of sea, including the entire Mesoamerican Barrier Reef (UNESCO World Heritage Site) and large portions of the territorial waters of Mexico, Guatemala and Honduras would be at high risk of environmental devastation. Even if no accidents were to occur, potential oil development in PHMR could have serious negative impacts on tourism by reducing the pristine aesthetics of the reserve. PHMR is one of the last strongholds for critically endangered goliath grouper, West Indian manatee and hawksbill turtles, and supports a large dolphin population of at least two species. This not only indicates a healthy environment capable of supporting many top end predators, but dolphins are important to future tourism development. There is plenty of research demonstrating the negative effects of acoustic disturbances such as seismic testing on dolphin migration patterns and other behavior (e.g. Castellote et al. 2012). Oil has also directly resulted in mass cetacean deaths (Williams et al. 2011). Water quality standards have been developed for coastal dolphins (Thompson 2007) and need to be applied in the case of future oil development.



BP oil spill footprint superimposed to scale over Belize territorial waters and a large part of Central American and the Gulf of Honduras.

OBJECTIVES

The objectives of TIDE's water quality monitoring program are:

To monitor spatial and temporal variations in multiple water quality parameters in and near Port Honduras Marine Reserve, and associated river catchments, in order to:

1. Establish baseline water quality conditions in PHMR and associated river systems.
2. Understand and determine causes (natural and anthropogenic) of spatial and temporal fluctuations in water quality in PHMR and associated river systems.
3. Understand, characterise and demonstrate water system interconnectivity between terrestrial and marine protected areas managed by TIDE.
4. Provide recommendations in support of an adaptive "management-informed-by-research" approach to TIDE's protected area management and management of the wider MMMC.
5. Inform analysis and interpretation of other TIDE monitoring programs.
6. Demonstrate the importance and vulnerability of water quality in both rivers and the sea for ensuring long term sustainability of river ecosystems and local communities, as well as fisheries and tourism in PHMR.

MONITORING SITES

#	Transect/ Watershed	Site Name	Site Code	NAD27 UTM N	NAD27 UTM W	WGS 84 DD N	WGS 84 DD W
1	1	Joe Taylor Creek	1a	1781833	307682	16.10903	-88.79823
2	1	-	1b	1779038	310370	16.08398	-88.77288
3	2	-	2a	1784468	313282	16.13327	-88.74609
4	2	Rio Grande	2b	1781698	315761	16.10843	-88.72271
5	2	-	2c	1779118	318362	16.08505	-88.69807
6	3	Golden Stream	3a	1794100	314568	16.22041	-88.73483
7	3	Hen & Chicken	3b	1790211	316318	16.18540	-88.71816
8	3	Moho/Stuart	3c	1785783	318890	16.14558	-88.69377
9	4	-	4a	1796168	320109	16.23951	-88.68317
10	4	-	4b	1792449	321864	16.20603	-88.66647
11	4	-	4c	1787860	324113	16.16473	-88.64510
12	5	Deep River	5a	1799120	324355	16.26650	-88.64368
13	5	-	5b	1796974	325754	16.24721	-88.63043
14	5	Man O War	5c	1794495	327860	16.22495	-88.61054
15	5	Wilson Caye	5d	1792062	328604	16.20302	-88.60341
16	5	S. of West Snake Caye	5e	1789373	330680	16.17887	-88.58380
17	6	Punta Ycacos	6a	1796465	331255	16.24300	-88.57893
18	6	S. of Punta Negra	6b	1795445	333825	16.23577	-88.55489
19	6	N. of Middle Snake Caye	6c	1793635	336429	16.21778	-88.53033
20	6	East Snake Caye	6d	1792155	338941	16.20457	-88.50674
21	7	Monkey River Mouth	7a	1809630	341635	16.36267	-88.48273
22	7	-	7b	1807537	345281	16.34399	-88.44846
23	7	-	7c	1805318	348554	16.32415	-88.41768
24	8	-	8a	1815137	345681	16.41270	-88.44522
25	8	-	8b	1812952	349366	16.39319	-88.41058
26	9	-	9a	1817403	346293	16.43322	-88.43964
27	9	-	9b	1815632	349885	16.41744	-88.40589
28	Monkey River	Upper San Pablo	MR_SB_1a	1837392	331439	16.61466	-88.58030
29	Monkey River	Gravel Mining Road	MR_SB_1b	1834166	333790	16.58568	-88.55800
30	Monkey River	Next to Farm 6	MR_SB_1c	1829747	335010	16.54583	-88.54630
31	Monkey River	Swasey Bridge	MR_SB_1d	1826958	333415	16.52052	-88.56100
32	Monkey River	Trio Bridge	MR_TB_1a	1826915	324427	16.51948	-88.64520
33	Monkey River	Upper Trio	MR_BB_1a	1826915	323259	16.51939	-88.65610
34	Monkey River	Bladen Bridge	MR_BB_1b	1821585	324203	16.4713	-88.64690
35	Monkey River	Inside Monkey River	MR_MR_1a	1810318	340397	16.36881	-88.49440
36	Rio Grande	Upper Columbia	RG_CB_1a	1800275	290284	16.27603	-88.96256
37	Rio Grande	Lower Columbia	RG_CB_1b	1799677	291632	16.27074	-88.94990
38	Rio Grande	Upper San Miguel	RG_SM_1a	1804244	294159	16.31222	-88.92670
39	Rio Grande	Lower San Miguel	RG_SM_1b	1801700	294191	16.28924	-88.92610
40	Rio Grande	Upper Big Falls	RG_RG_1a	1799159	297734	16.26658	-88.89280
41	Rio Grande	Big Falls Bridge	RG_RG_1b	1798476	298403	16.26047	-88.88650
42	Rio Grande	Wilson Landing	RG_RG_1c	1786785	310355	16.16764	-88.81030
43	Rio Grande	Esso Landing	RG_RG_1c	1786785	310355	16.15579	-88.77370

Table 1: Marine and fresh water quality monitoring sites 2013: blue: PHMR; red: Monkey River; green: Rio Grande. For PHMR, difference shades denote site groups associated with each transect. For rivers, different shades denote different branches.

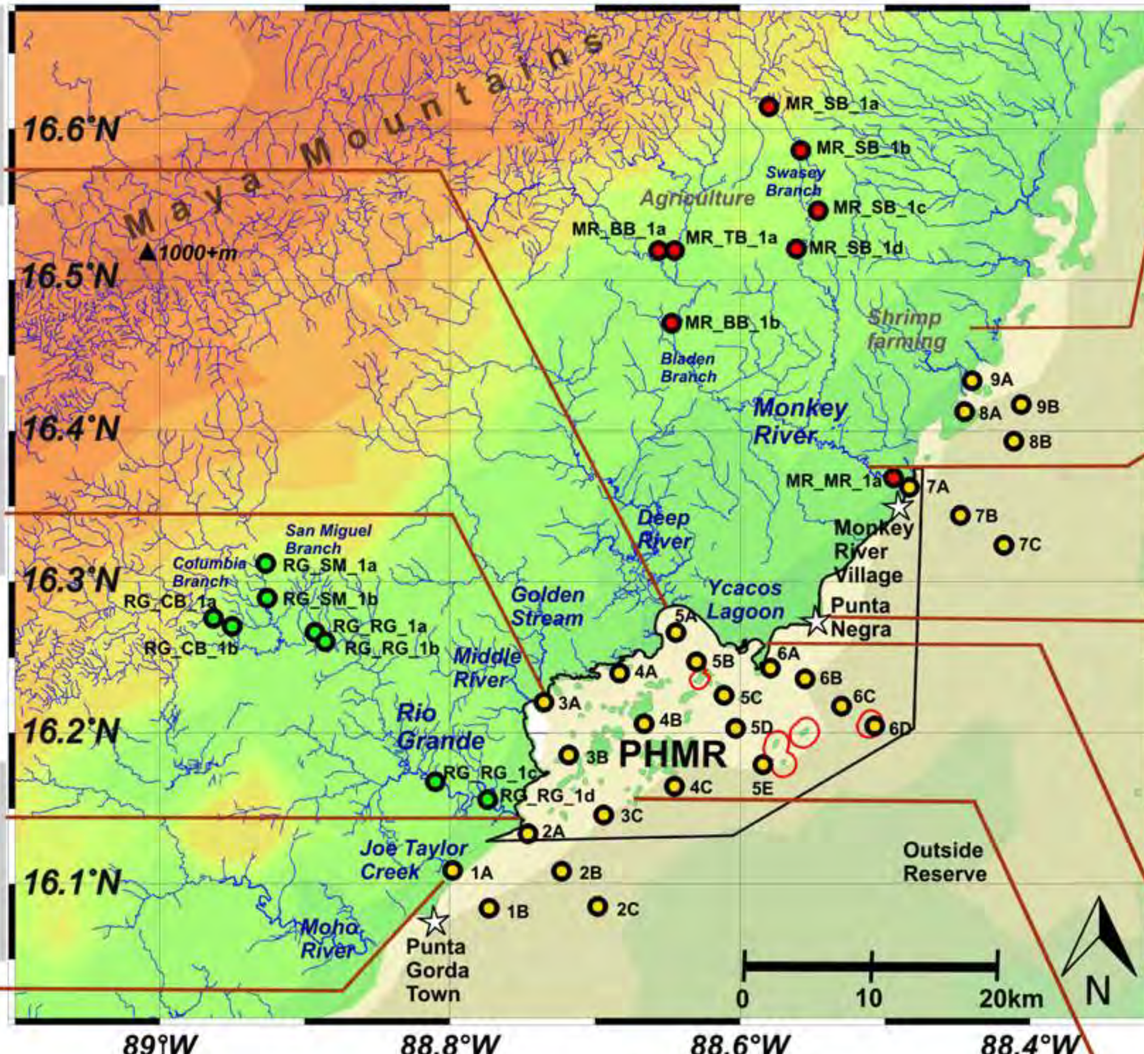
Marine and fresh water monitoring sites 2012: PHMR, Monkey River & Rio Grande

4. *Deep River*: Third longest in study area behind Monkey River and Rio Grande. May be largest by volume. Low impacted. Wide slow, mangrove-lined lower reaches. Western border of PCNP. Farming expanding upstream. Important goliath grouper nursery

3. *Middle River / Golden Stream*: Small rivers, reach PHMR <1km apart. Low impacted. Important in both providing and buffering nutrient and sediment inputs into PHMR. Good baseline rivers. Drain PLI and Belcampo.

2. *Rio Grande*: Large river, low impacted, some communities upstream. Used for small scale domestic purposes & hicatee hunting. Lower reaches near pristine forest & mangroves. Concern of pollution from nearby dumpsite. Southern boundary of PLI.

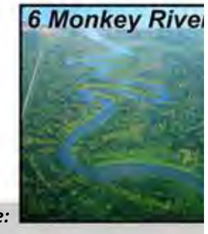
1. *Joe Taylor Creek*: Small river, low impacted until last 1km, where mangrove and forest are disappearing to development. Upstream, dense mangroves remain intact.



Legend

- PHMR marine sites
- Rio Grande fresh water sites
- Monkey River fresh water sites
- General Use Zone
- No Take Zone
- Agriculture — Human Impact
- River
- Bladen Branch — River Name
- Altitude marker
- Town/Village
- Sea
- Land

5. *North of Monkey River*: Northern marine limit of TIDE's management area. Extensive land based shrimp mariculture including Ecuadorian species. Threats include nutrient rich effluent Eutrophication, fish deaths, invasive parasites.



6. *Monkey River & Village:* Largest in Toledo. High impacted by fruit plantations, river gravel mining, riparian deforestation, water pumping; linked to coastal erosion; fishing village; key PHMR stakeholders.

7. *Punta Negra:* Smallest buffer community in PHMR. No rivers nearby, but two fresh water lakes behind village. Important turtle nesting beach. Serious coastal erosion in last 2 years.

8. *Ycacos Lagoon:* Links PHMR to PCNP. Crucial nursery habitat for endangered goliath grouper. Important for migratory birds & endangered yellow-headed parrot. Boat access to PCNP ranger station

9. *PHMR Cayes:* Approx. 138 cayes, mostly mangrove swamps. Critical near pristine environment supporting fisheries, tourism and endangered species

Map features (numbers correspond to map figures):

Left side:

1. **Joe Taylor Creek:** Joe Taylor Creek is a small river which reaches the sea between Punta Gorda and Hopeville. While the upper watershed is relatively non-impacted and thickly fringed with red mangroves, urban development is rapidly spreading upriver from town, with land clearance and mangrove destruction being major threats to water quality both in the river and the adjacent sea in front of Punta Gorda. Riparian zone mangroves are crucial to maintain in this area, not only for ecosystem health in the sea, but also the most popular swimming areas in Punta Gorda are close to the mouth of Joe Taylor Creek.

2. **Rio Grande:** The Rio Grande is a large and relatively non-impacted river, and the lower reaches form the southern boundary of much of TIDE's Private Protected Lands. Dense broadleaf forest meets the river on both sides in the lower reaches, with the last 2km before the sea lined by dense red mangroves. Upper reaches have some impact from agricultural and cattle ranching, but such activities are less significant than on Monkey River. The mouth is located in the southern-most part of PHMR. The river is an important source of water for several villages. Hicatee are hunted in the river by local communities and snook fishing is a common activity in the area where the river mouth meets the sea. Water quality may be threatened by the Punta Gorda dumpsite, located in the lower watershed less than 1km south of the river. TIDE is conducting a dumpsite impact study in 2013 to quantify impacts of this in order to determine management solutions.

3. **Middle River / Golden Stream:** Middle River and Golden Stream are small rivers with smaller catchment areas than Rio Grande or Monkey River, and are currently not monitored by TIDE due to limited funding and difficult access. The mouths of these two rivers are situated close together in the south central coastal area of PHMR. Marine data near to the mouths of these rivers allow inferences to be made about conditions in the watersheds drained by these rivers, and are important to consider when interpreting marine data.

4. **Deep River:** Deep River is a reasonably large watershed, although slightly smaller than Rio Grande and Monkey River. While TIDE does not conduct water quality monitoring in this river, it is an extremely important catchment because the coastal waters adjacent to Deep River mouth are vital nursery grounds for the critically endangered Goliath grouper. The area is also important for bait fishing. There is limited water circulation in this corner of PHMR due to being sheltered from offshore currents, increasing the importance of maintaining good water quality in the river. While the watershed is relatively non-impacted, there are concerns about agricultural impacts further upstream, where some farms have expanded in recent years. The lower reaches form the south western boundary of Payne's Creek National Park.

Right side:

5. **North of Monkey River:** Northern limit of TIDE's management area. Several shrimp farming operations nearby.

6a. **Monkey River:** Monkey River has the largest catchment area in Toledo, and is the 5th largest watershed in Belize. There are two main branches – Swasey branch to the north and Bladen branch to the south. Monkey River has been much more impacted by human activities compared with the other rivers of interest. Extensive banana and citrus plantations have replaced lowland broadleaf forest in the area, leading to soil erosion and excess nutrients from fertilisers entering the water, increasing risk of eutrophication and poor water quality. Deforestation, clearing of riparian zones for subsistence agriculture and water access for cattle, as well as gravel mining in the river have all contributed to changing the shape of the river from a deep rounded profile to a wide shallow profile. This has increased the surface area to volume ratio of the river, rendering it more susceptible to seasonal warming and cooling, and possibly reducing the amount of suspended sediment the river can transport to the sea. This may be a driver of the increased erosion at Monkey River Village, located on the southern bank of the river mouth. The greater seasonal variability in biophysical and hydrological properties of the river water compared with Rio Grande may have reduced species abundance and biodiversity in the river, and ecosystem health is considered to be diminished compared with less impacted nearby rivers. It is important to monitor this river as both the buffer community of Monkey River Village and the health of receiving marine waters around Monkey River depend on its continued health.

6b. **Monkey River Village:** Monkey River is the largest buffer community using PHMR, and is located at the mouth of Monkey River. The settlement was originally established as a hardwood port, when logs were floated down the river for shipment from this village. When the logwood dried up, the community turned to fishing. There has been significant erosion in Monkey River, destroying at least one street and a cemetery. This is thought to be due to changes in sediment load coming from Monkey River watershed as a result of land clearing and river gravel mining. Illegal clearing of the 66ft buffer zone next to river banks upstream is probably a significant cause of a change in river profile, which has become wider and shallower over the years. This will reduce the ability of the river to transport sediment load, possibly contributing to this erosion.

7. **Punta Negra:** Punta Negra is an important buffer community in PHMR, located on the point of a broad sandy headland in the central-northern coastal part of PHMR. No river exists nearby, but there is a fresh water lagoon behind the village, where tarpon have been reported to exist. Water security and coastal erosion are major threats to the long term survival of a permanent community at Punta Negra.

8. **Punta Ycacos Lagoon:** While not technically a river, Punta Ycacos Lagoon is a large area of pristine shallow wetlands draining the southern portion of Payne's Creek National Park. The area is important for many species of bird including the endangered yellow head parrot and several long-distance migratory species. It is also critical nursery habitat for multiple fish species, including Goliath grouper. Many terrestrial fauna species rely on the area for food and water; at least one jaguar has been sighted frequenting the surrounding area in TIDE's camera trapping study. While fishing is prohibited within the lagoon itself, the waterway between the lagoon and PHMR is an important fishing area for local fishers. The area has also revealed important Mayan archaeological sites, with some of the only Mayan wooden

structures and tools ever found preserved in these low-oxygen swamps. TIDE currently does not carry out monitoring in the lagoon, however this is planned to commence in 2014 if further funding can be secured. The area serves critical functions to both marine and terrestrial species, demonstrating the interconnectivity between land and sea and the importance of monitoring and managing these areas with a holistic approach.

9. **PHMR cayes:** There are approximately 138 cayes in PHMR, which can be roughly divided into three zones running southwest to northeast. The inner cayes closest to land tend to be waterlogged mangrove swamps surrounded by shallow brown water. A second band of cayes extends through the middle of the reserve the majority of which form the Frenchman Cayes, an extensive labyrinth of again swampy mangroves. The third group is the offshore Snake Cayes, which form some of the few true islands in PHMR with solid dry ground. These are sandy cayes with small beaches and some broadleaf forest in the interior. A brackish lagoon lies in the interior of West Snake Caye. Water tends to be clearer in this offshore environment, more representative of barrier reef conditions. Fringing coral reefs skirt the windward sides of these islands, and some of the healthiest coral reefs in the entire Mesoamerican Barrier Reef (HRI 2010) are found around East Snake Caye. These four cayes are all geographically separate no-take zones. In 2013 TIDE consulted with buffer community stakeholders over a plan to extend the no-take zones to one contiguous zone encompassing all four Snake Cayes to improve fisheries sustainability in the surrounding general use zone and as a means of improving enforcement in the area. This has resulted in consensus to establish a contiguous Replenishment Zone around Middle, South and West Snake Cayes. This will be enforced later in 2014. There is also a further zoning expansion plan underwater in partnership with TNC. See report on RZ expansion published February 2014 for further details (Foley & Baker 2014).

METHODS

Water quality monitoring is conducted at 43 sites in total; 27 in PHMR divided into nine transects (1-9), 8 in Monkey River and 8 in Rio Grande (Table 1, pg. 8).

Marine monitoring in 2013 was completed at the end of each month by the TIDE Marine Biologist (Marlon Williams until his departure from TIDE in September 2013, and subsequently by Tanya Barona, who became TIDE's marine biologist in October 2013) and TIDE Community Researchers. Where possible, data were collected at depths of 1m, 5m, 10, and 15m at each monitoring site in the Port Honduras Marine Reserve (PHMR). Fresh water monitoring was conducted by Elmar Requena (TIDE Terrestrial Biologist), with occasional assistance from university students.

Parameters: The following parameters are measured at marine and freshwater monitoring sites. pH could not be measured due to lack of a functional pH meter.

Marine:

- Temperature
- Salinity
- Dissolved oxygen
- Turbidity (vertical visibility)
- Nitrate-nitrogen
- Orthophosphate-Phosphorus

Freshwater:

- Temperature
- Salinity
- Dissolved oxygen
- Nitrate-nitrogen
- Orthophosphate-phosphorus

1. Temperature: Measured at the surface, 5m, 10m and 15m depth at all marine sites (depth permitting) at each site using a YSI550A probe. Measured at the surface at fresh water sites (15cm depth).

2. Dissolved Oxygen: Dissolved oxygen (DO) is oxygen that is dissolved in water and is essential for most plants and animals that live in water. Measured with YSI 550A probe.

3. Salinity: Salinity refers to the amount of salt in the water, and is currently measured with a salt refractometer.

4. Turbidity (vertical visibility): The term "turbidity" refers to the "cloudiness" of water, measured using a Secchi Disk.

5. Nutrients:

Nitrate - Nitrogenous compounds (e.g. nitrites, nitrates & ammonia) are essential components of life. Nitrogen is recycled continually by plants and animals, and is found in protein in the cells of all living things. Excess nitrate is introduced into a body of water typically as runoff from various sources when it rains. Sources include agricultural fertilizer, livestock, unmanaged or partially managed sewage, animal wastes (including fish and bird waste), aquacultural waste, and discharges from car exhausts and industrial waste (Cushion 2004). In excess amounts they can cause significant water quality problems for the environment and human health. The United States Environmental Protection Agency advises that drinking water is hazardous to human health if nitrate concentrations exceed 10 milligrams per litre (mg l^{-1}) (EPA 2012), citing symptoms of overexposure among affected infants less than 6 months as shortness of breath and death from 'blue baby syndrome. This it thought to be caused by nitrates impacting the ability of oxygen to bind with haemoglobin in the blood. Lower levels can still be extremely harmful to the environment. Method for analysis is the

Cadmium Reduction Method (Method 8039 from Hach Procedures Manual) (Russell 2011) using a Hach DR2800 Spectrophotometer.

Phosphate - Phosphate in water bodies comes from fertilizers, pesticides, wastes from laundries, industry, and cleaning compounds that are leached into the water. Phosphate also occurs naturally from solid or liquid wastes such as human and animal wastes (one human body releases approximately 0.5kg of phosphorus per year (The Hach Company 2006)) and phosphate-rich rocks. TIDE tests for ortho-(reactive) phosphate because it is the form which plants utilize; therefore, the most cost effective way of gauging eutrophication (The Hach Company 2006). Method for analysis is the PhosVer3 Ascorbic Acid Method (Method 8048 from Hach Procedures Manual) (Russell 2011) using a Hach DR2800 Spectrophotometer.

6. **Sedimentation:** Traps are deployed and collected at the described sites once monthly via scuba diving. Sites are located initially by GPS and once close, by markers previously set and attached to underwater buoys. Once located, a dive team collects the sediment-laden traps for laboratory analysis and sets fresh empty traps. Traps are deployed with caps off, secured with zip-ties in groups of three to reference stakes with a concrete base (except the Abalone Caye sites which are single traps per site due to limited materials). For transect water quality sites, three traps are used to derive a mean value, which makes data more statistically robust and reduces error. Setting three traps also reduces that likelihood of no data being collected from a site in the event that one or more traps are knocked down. Traps must be at least a few meters below the water in calm areas and deeper in exposed areas. After approximately one month these traps are capped, removed and replaced with empty ones. The precise number of days that each trap has been underwater is recorded in order to calculate sedimentation rate in grams per m^2 per day.

   ***Sedimentation laboratory methods*:** Dry weight is measured, which is then used to calculate sedimentation rate in grams per m^2 per day ($g\ m^{-2}\ day^{-1}$). To begin the process, a Petri dish and Whatman 0.45µm filter paper are weighed separately on a microbalance and then added to obtain a combined total. This information is recorded in a spread sheet. Traps are scrubbed clean on the outside to avoid contamination of the sample. The contents are shaken vigorously to ensure uniform suspension of the sediment, the lid immediately removed, and the entire contents of the sample immediately poured through a coarse grade filter (mesh size 0.5mm) into a bowl to remove non-sediment debris. After this primary filtration, the sample is again stirred vigorously to ensure uniform suspension and 100ml poured into a 250ml beaker through a funnel before the sediment settles out again. The remainder of the sample is stored in the bowl until the entire process is complete, in case a sample needs to be rerun for any reason. The sample in the beaker is stirred vigorously and 20ml poured into a graduated cylinder. This sample is passed though the Buchner funnel. 10ml measurements are passed through the Buchner funnel with the intent of getting as close as possible to the saturation point of the filter without actually reaching the saturation point. Once the filter paper is near saturated, the exact amount of sample water that was successfully passed through the filter is recorded. The filter paper is then removed from the Buchner funnel with tweezers to minimize contamination of the sample and placed in a Petri dish. The Petri dish is placed into a drying oven at 70◦C for approximately two hours, or until no weight change can be seen from one hour to the next, indicating that no water remains in the sample. Once the sample is dry, the sample, filter paper and Petri dish are weighed together on the microbalance. The weight of the sample is then derived by subtracting the combined weight of the Petri dish and filter paper. If the sample is found to have no weight or the weight difference is less than the 0.1g resolution of the microbalance, the sample must be re-tested with more water volume until a weight can be detected. The weight of the sample is then entered into a spread sheet. This process is repeated for all of the sediment traps. Finally all equipment and traps are scrubbed clean, and faded site codes are rewritten on the traps.

Sedimentation data analysis methods: The dry weight results are calibrated to the volume of the traps (which are all identical), to account for the varying amounts of water filtered to obtain the dry weight samples. This allows the weights of sediments recorded from each sample to be scaled up to a standard volume of 608.05cm^3. This standard volume has arisen due to the length of the traps being 30cm, while the diameter is two inches, because pipe widths come in imperial measurements in Belize. The area of the trap mouths can be used to standardize the sedimentation rate to grams per m^2 per day, or “g m^{-2} day^{-1}”. The sedimentation rate is calculated using the following formulas:

Constants

- Length of trap (*l*) = 30cm
- Diameter of trap mouth (*dt*) = 2 inches = 5.08cm
- Radius of trap mouth (*r*)= 1 inch = 2.542cm
- Area of trap mouth (*a*) = πr^2 = 20.268cm^2
- Volume of trap (*vt*) = l x πr^2 = 30 x π x 2.542 = 608.05cm^3 = 608.05ml
- Proportion trap mouth area is of 1m^2 (*pa*) = $\frac{10{,}000}{a} = \frac{10{,}000}{20.268} = 493.38131035$ times

1) Proportion of trap contents sampled $(\boldsymbol{pv}) = \frac{\text{Volume of trap } (vt)}{\text{Volume of sample water } (vs)}$

2) Dry weight of total sediment in trap (***tw***) = Dry weight of sediment from sample (*sw*) x *pv*

3) Sedimentation Rate (***S***) (g m^{-2} day^{-1}) = $\frac{\text{tw x pa}}{\text{days at sea}}$

The mean is then calculated for the dry weight results from the three traps (if all three remained intact) at each monitoring site.

RESULTS

1. Temperature

1.1. Mean surface temperature (°C) by month 2013 - PHMR, Monkey River, Rio Grande (Fig. 1a):

- In the previous year (2012), mean water temperature was consistently higher each month in PHMR than in either Rio Grande or Monkey River (see 2012 report). In 2013 however, PHMR temperature was lower than in Monkey River in both February and March, remaining higher as in 2012 for the remaining months where data is available.

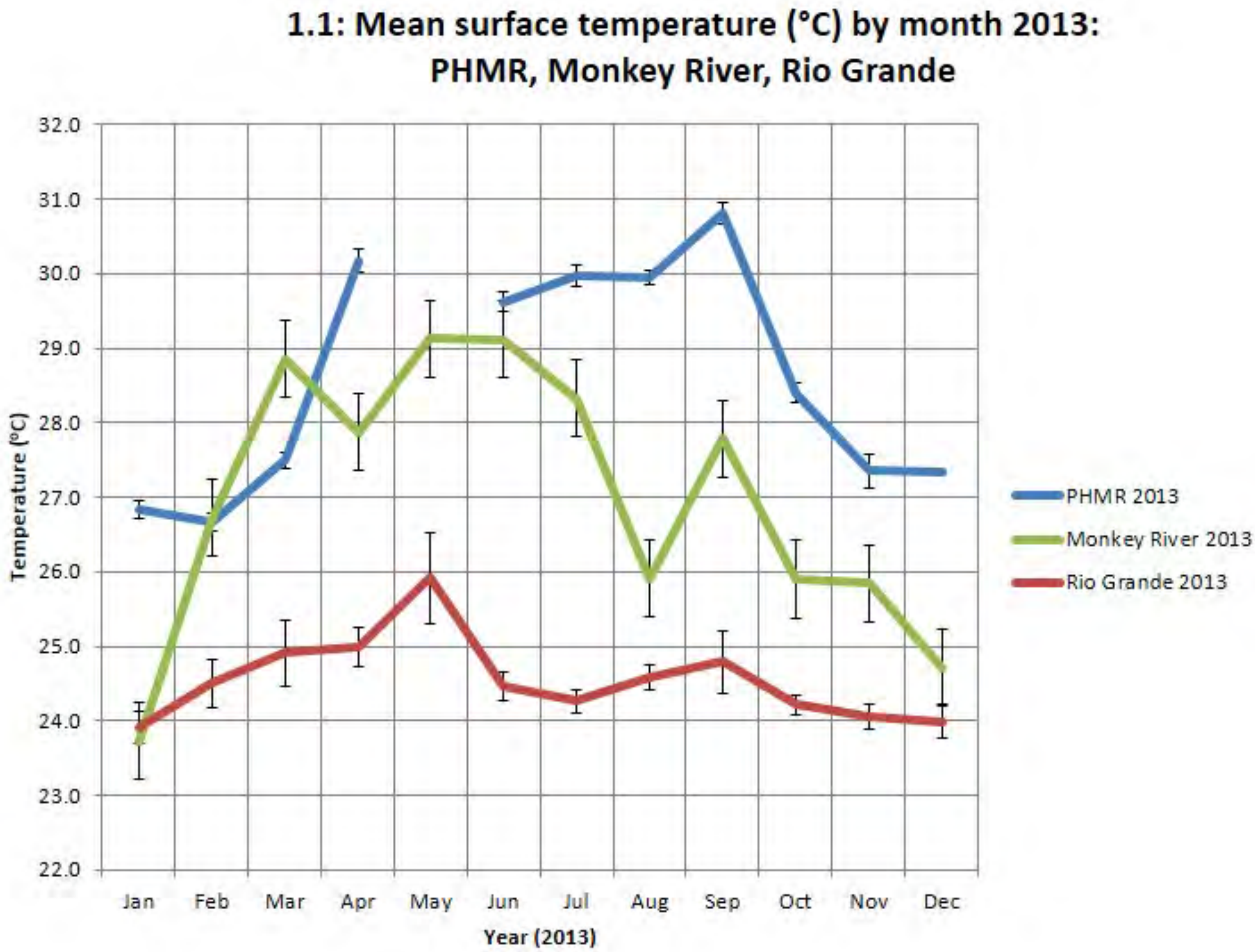
- Mean temperatures in all three areas were generally higher in the months April to September, with river temperatures peaking April-May and a lag time until peak ocean temperatures around September (compared with August in 2012).

- PHMR: Lowest temperature was in January (26.8°C), and then increased to 30.2°C in April. No data was collected in May due to late arrival of funds. Between June and September, temperature increased marginally from 29.6°C to 30.8°C, and decreased continuously thereafter to 27.3°C in December. As in 2012, temperatures remained high in PHMR until much later in the year than in the rivers.

- Lowest temperatures were recorded in January and December in both rivers. The largest month to month temperature increase (3.0°C) occurred in Monkey River between January (23.7°C) and February (26.7°C).

- Monkey River increased dramatically and consistently in the first two months of the year, from 23.9°C to 28.9°C, then remained relatively stable between March and July (range: 27.9°C: 29.1°C). Temperature then decreased to 24.7°C by the end of the year. The temperature range over the course of 2013 in Monkey River (23.7°C -29.1°C, range 5.4°C) was very similar to that of 2012.

- Rio Grande was consistently lower temperature than Monkey River for the entire year of 2013, fluctuating from 23.9 in January to a high of 25.9 in May, thereafter remaining very stable (~24.0°C) for the rest of the year 2013. There is a similar yet even more stable trend compared with 2012..



1.2. 2013 PHMR Mean monthly temperature: 1, 5, 10, 15m depth (Fig. 1.2):

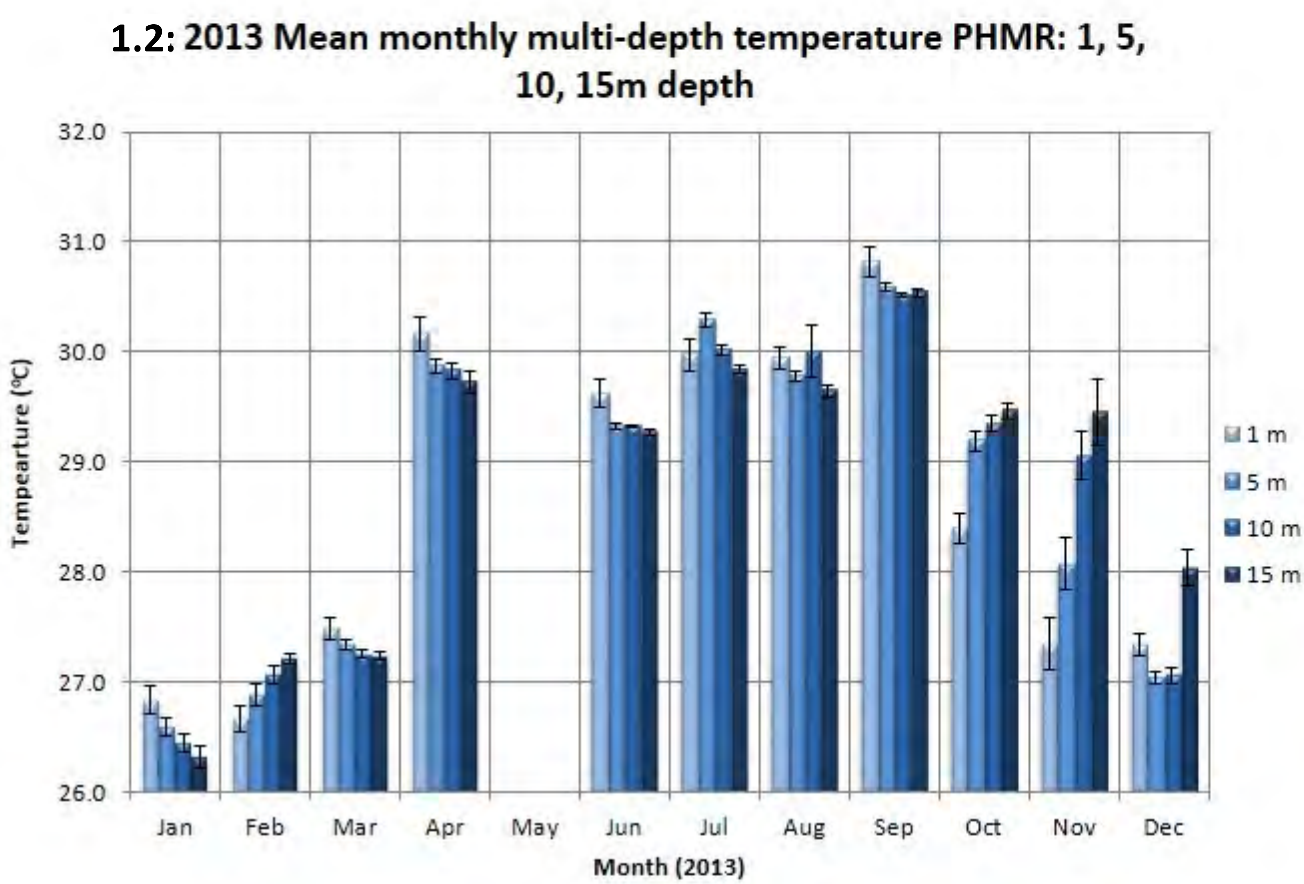
- In the first half of the previous year (2012), mean ocean temperatures rose and surface temperatures increased significantly more than subsurface temperatures. By October the reverse was seen, with surface temperatures dropping significantly below subsurface temperatures, the subsurface remaining warmer until December.

- There is no data for May 2013, masking trends at this critical time of year. After September 2013, the entire water body begins to cool, with surface temperatures dropping markedly (Sept mean temperature 1m: 30.8°C + 0.14 SE; Oct mean temperature 1m: 28.4°C + 0.13 SE; Sept mean temperature 15m: 30.5°C + 0.04SE; Oct mean temperature 15m: 29.5°C + 0.08 SE), with subsurface temperatures dropping less dramatically the deeper they are.

- The hottest month in 2012 was August (2012 August 1m: 31.0°C + 0.1 SE), and in 2013 was September (2013 September 1m: 30.8°C + 0.14 SE). Coolest month for both years was January (2012 January 15m: 26.7°C + 0.0 SE; 2013; Jan 15m 26.3°C + 0.09 SE).

- In 2013, overall, trends were similar to 2012 although less pronounced and with more anomalies to this pattern. There is a general overall increase in temperatures in the first half of the year, although surface temperatures in February 2013 were cooler (mean 26.7°C + 0.12SE) than subsurface temperatures (mean temperature February 2013 at 15m: 27.2°C + 0.04 SE), indicating either climatic cooling in February or heavy rainfall dumping cool fresh water on the surface.

- The highest and the lowest temperatures in 2013, regardless of depth, were lower than the highest and lowest of 2012, reflecting the trend observed in the mean overall annual temperature for PHMR in the same years. (see Section 1.5 Fig. 1.5)



1.3. Temperature maps 2013: multi-depth 1m, 5m 10m, 15m - PHMR, Monkey River, Rio Grande

(Maps shown at end of this section)

a. January 2013 (Fig. 1.3: a1-a4): Both Monkey River and Rio Grande are relatively cool and have little temperature variability throughout their respective watersheds, except colder temperatures in upper Swasey branch (Monkey River: 23.7°C ± 0.2 SE; Rio Grande 23.9°C ± 0.6 SE). In general, marine water temperatures are low in January 2013, around 25.9-28.2°C in most places. Pockets of warmer water are seen just inside the mouths of the Rio Grande and Monkey River, although there is influence of these rivers on sea water temperature. Sea water temperature was cool throughout the water column (25.9-28.2°C), with minimal spatial variation throughout the area.

b. **February 2013 (Fig. 1.3: b1-b4)**: Surface temperatures in south-western PHMR cooled slightly, with notable cooling in coastal areas around Middle River / Golden Stream. While Rio Grande has remained cool, Monkey River has warmed throughout (Bladen branch MR_BB_1a: January 23.3°C, February 26.8°C; Swasey branch MR_SB_1d: January 23.5°C, February 27.6°C). Like January, temperatures were less variable below the surface, although slightly warmer throughout the reserve than in January.

c. **March 2013 (Fig. 1.3: c1-c4):** Considerable warming is seen in the Monkey River, particularly in the Swasey Branch, while the Rio Grande continues to be cool throughout. Surface temperatures in PHMR have warmed throughout, ranging from 27.1°C to 29.3 in most parts, with slightly warmer areas again around the mouths of Middle River / Golden Stream and Joe Taylor Creek. Multi-depth temperatures are slightly higher in general than in January and February (around 27.1-29.3°C).

d. **April 2013 (Fig. 1.3: d1-d4):** Monkey River cooled again in Swasey (northern) branch. Rio Grande again remained comparatively cool (Mean: 25.0 ± 0.68°C). Considerable warming is seen throughout PHMR, especially around Punta Ycacos (30.3°C) Subsurface marine temperatures remain relatively uniform yet warmer than previous months (around 29.4°C -30.3°C).

e. **May 2013 (Fig. 1.3: e1-e4):** No monitoring took place in PHMR due to funding delays. Upper sites in Swasey and Bladen branches of Monkey River warmed, later than last year (April 2012), being around 30°C in places, but still cool at the highest sites (e.g. Upper San Pablo MR_SB_1a: 27.6°C). Rio Grande continues to remain cooler, although warming in the lower reaches (Esso Landing RG_RG_1c: 29.3 °C), pointing to some key difference(s) in environmental factors affecting each watershed.

f. **June 2013 (Fig. 1.3: f1-f4):** Monkey River temperatures are similar to May, warming in mid-reaches, remaining cooler in upper reaches, Rio Grande is considerably cooler throughout than in May, (mean 24.5°C ± 0.20 SE) (Fig 1.3 f1), a similar pattern to that seen in April and May 2012. Surface temperatures in PHMR have cooled somewhat since the last available data in April, but with warmer sports over around Joe Taylor Creek mouth and around the mouths of Middle River and Golden Stream. Surface temperatures exhibit greater variability between sites than in cooler months, with coolest surface areas to the south outside of PHMR, a similar observation to the same area in 2012, supporting the theory of offshore upwellings influencing water quality and fishing in this area.

g. **July 2013 (Fig. 1.3: g1-g4):** Middle reaches of Monkey River have cooled from the previous month. Rio Grande remains much cooler (Mean Rio Grande July: 24.3°C ± 0.15 SE). PHMR surface temperatures are far higher than river temperatures, rising again after the brief drop in June, suggesting the warming period has resumed. This is a similar pattern to 2012, except that in 2012 this dip occurred later, around July. Pockets of warmer water lie at the surface Middle River/Golden Stream, and Garbutt's Range. An area of cooler surface water is seen around the mouth of Punta Ycacos lagoon, suggesting freshwater discharge from Payne's Creek. Multi-depth temperatures remain fairly uniform throughout PHMR at around 30°C, cooling very slightly with increasing depth, a trend associated with spring-season solar warming of the ocean.

h. **August 2013 (Fig. 1.3: h1-h4):** Temperatures in Monkey River cooled slightly compared with June and July 2013, with less temperature variability throughout than earlier in the year and warmer than Rio Grande by several degrees, as in August 2012. In contrast to earlier months, subsurface temperatures around Joe Taylor Creek are warmer than PHMR, also seen in August 2012. Subsurface temperatures remain fairly uniform throughout the rest of PHMR, with the exception of a curious hotspot (Fig. 1.3 h3) seen at 10m depth in the middle of PHMR.

i. **September 2013 (Fig. 1.3: i1-i4):** Temperatures have warmed slightly throughout upper branches of Monkey River. Rio Grande is still comparatively cooler in the upper reaches, but notably warmer nearer the mouth as in 2012. PHMR surface temperatures have warmed considerably, concluding a later peak in warming in 2013 than 2012. Hot spots over 30°C were observed south of the reserve, as during 2012 peak temperatures, and between Deep River and Snake Cayes. Temperatures cool and exhibit less spatial variability with increasing depth.

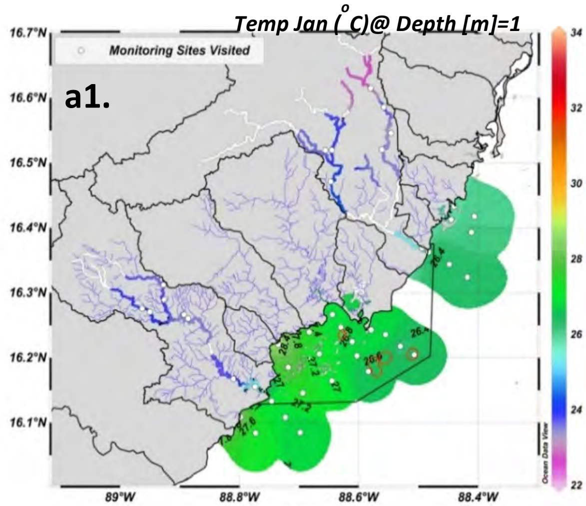
j. **October 2013 (Fig. 1.3: j1-j4):** While river temperatures in both watersheds remain very similar to September, mean surface temperature in PHMR has dropped considerably from an average of 30.8°C $\pm$ 0.14 SE in September to 28.4 °C $\pm$ 0.13 SE in October. This signals a change from seasonal ocean warming to cooling that continues for the rest of the year. This is supported by increasing temperature with depth throughout the reserve. Subsurface warm spots above 29.0°C are seen at 5m depth in coastal waters between Golden Stream/ Middle River and Deep River, cooling off at 5m throughout PHMR with increasing distance from shore. Snake Cayes area at multiple depths also remains slightly warmer than surrounding ocean temperatures (29.2°C).

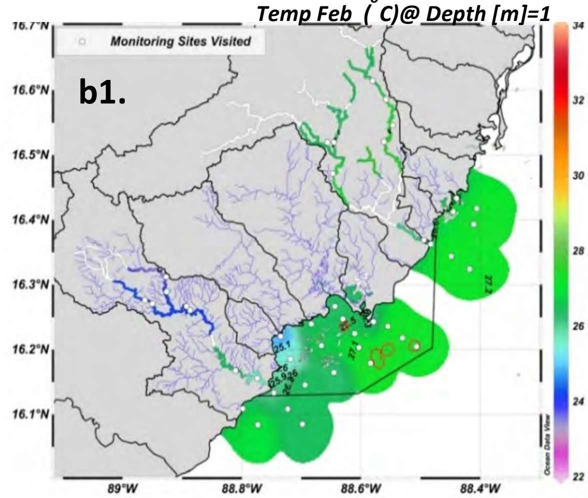
k. **November 2013 (Fig. 1.3: k1-k3):** Temperatures remain cool throughout both rivers, as usual cooler in Rio Grande. Sea surface temperatures have dropped considerably throughout PHMR, with pocket of warmer water around the mouths of Monkey River and Middle River/Golden Stream (Fig. 1.3 k2) Warmer subsurface water remains throughout the majority of PHMR at 10m and below, reflecting further seasonal climatic cooling as the surface loses heat to the atmosphere while deeper waters retain oceanic heat.

l. **December 2013 (Fig. 1.3: l1-l4):** Monkey River was cold throughout, with 24.5°C recorded at Upper San Pablo (site MR_SB_1a). Rio Grande was even colder throughout, similar to November, especially in San Miguel branch (23.4°C). December was considerably cooler and with less surface temperature spatial variability than November (Mean Rio Grande December: 24.0°C $\pm$ 0.23 SE). Marine temperatures are slightly cooler offshore and below the surface, remaining around 27.0-28.0°C at greater depths.

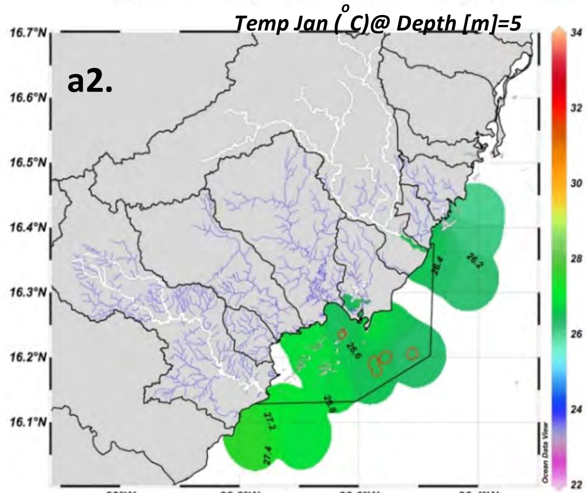
<u>1.3 a, b: Temperature</u> (°C) 2013 by month (left Jan, right Feb) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande

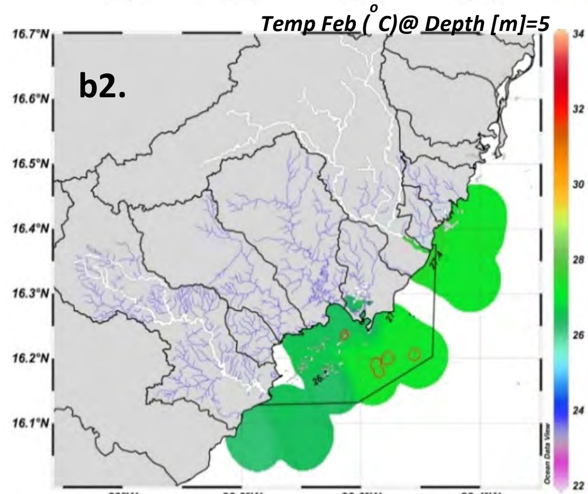
<u>1m</u>



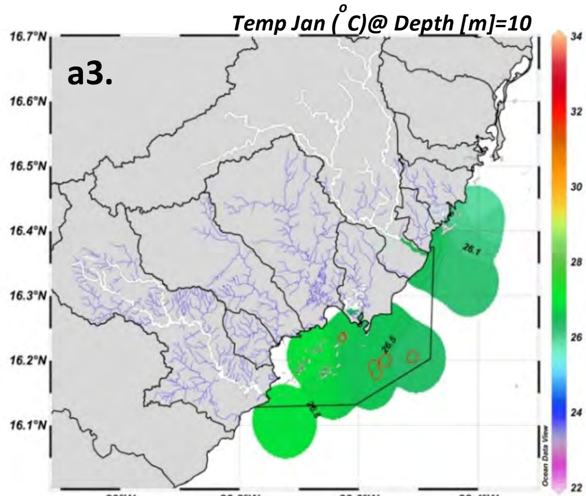


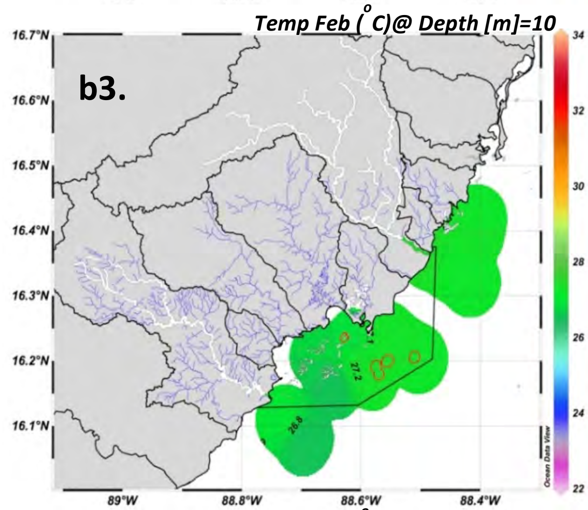
<u>5m</u>



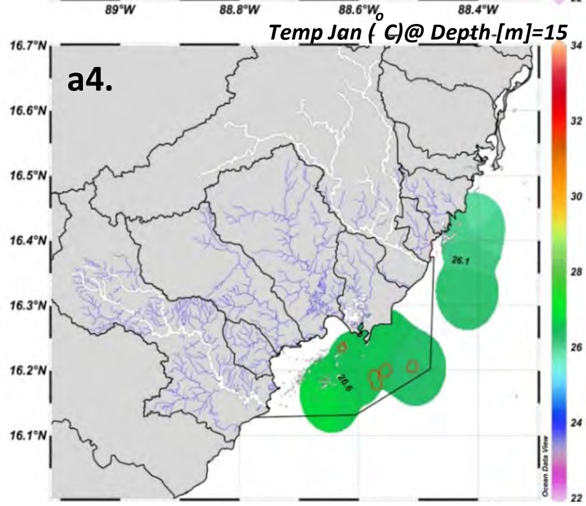


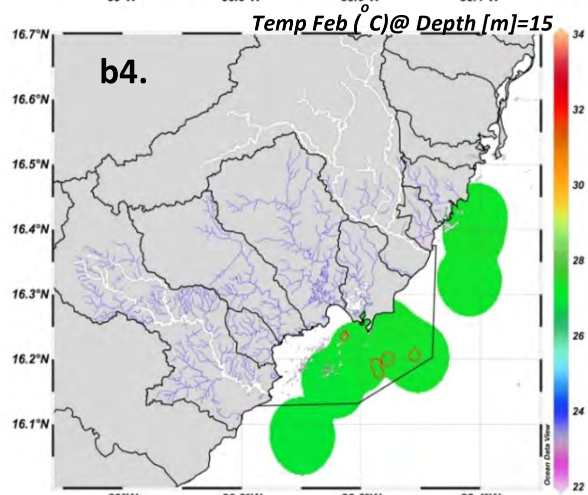
<u>10m</u>



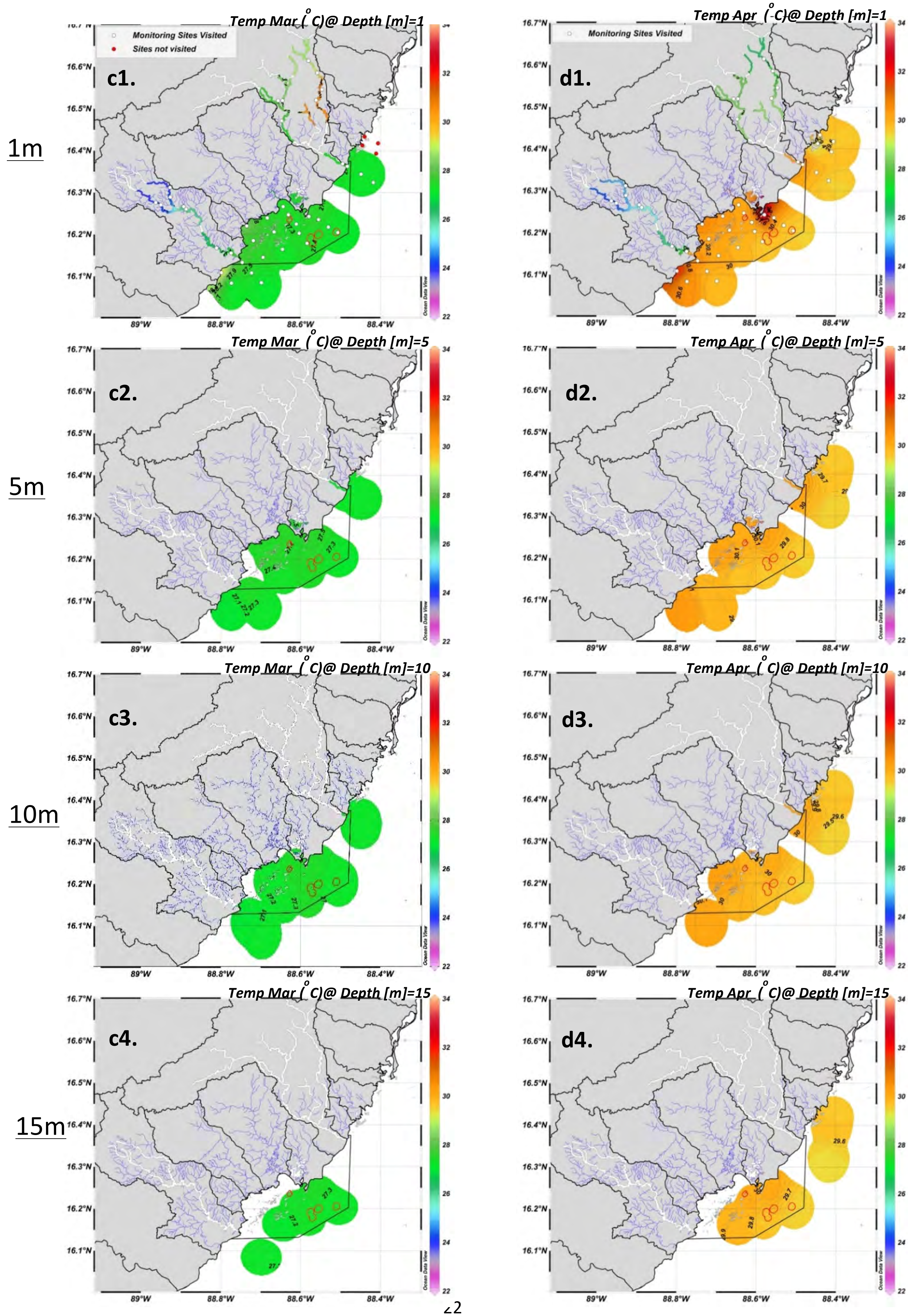


<u>15m</u>



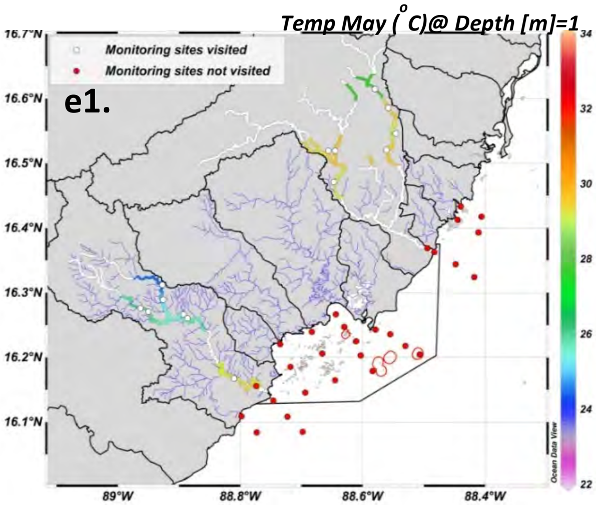


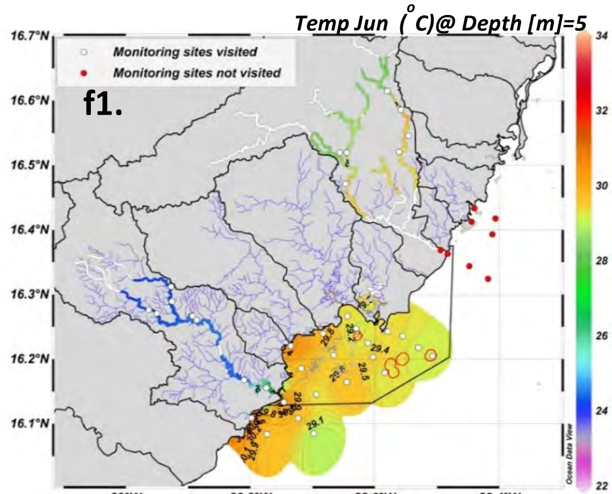
1.3 c, d: Temperature (°C) 2013 by month (left Mar, right Apr) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande



<u>1.3 e, f: Temperature</u> (˚C) 2013 by month (left May, right Jun) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande

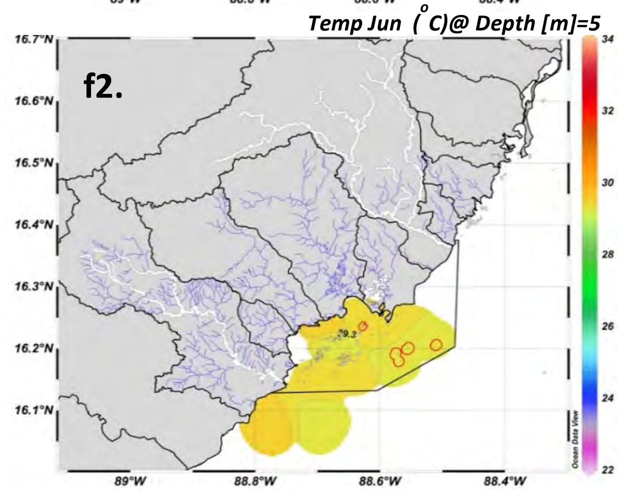
<u>1m</u>





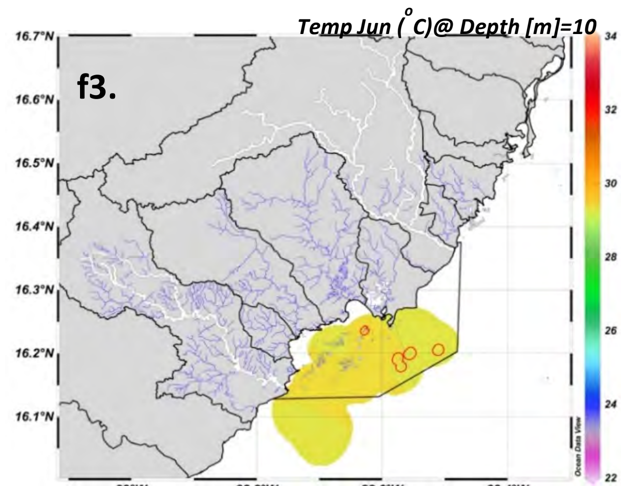
<u>5m</u>

Temp May 5m
No Data Available



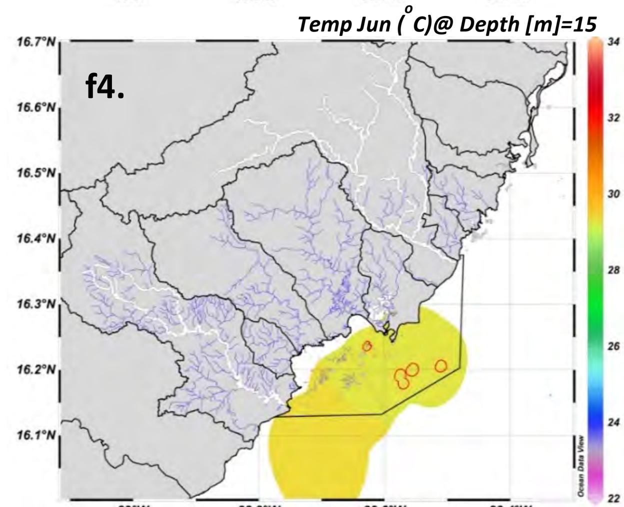
<u>10m</u>

Temp May 10m
No Data Available



<u>15m</u>

Temp May 15m
No Data Available



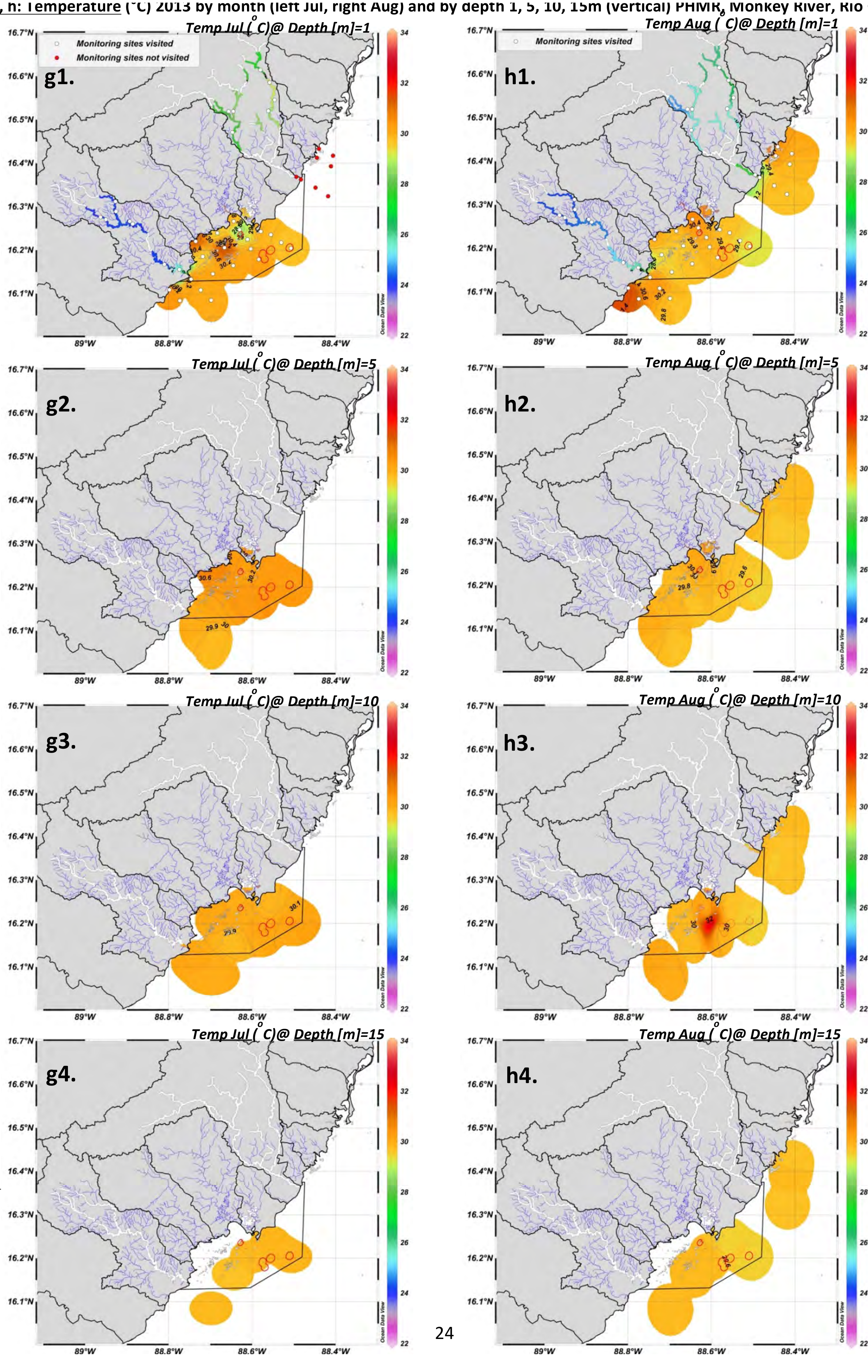
1.3 g, h: Temperature (°C) 2013 by month (left Jul, right Aug) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande

1m

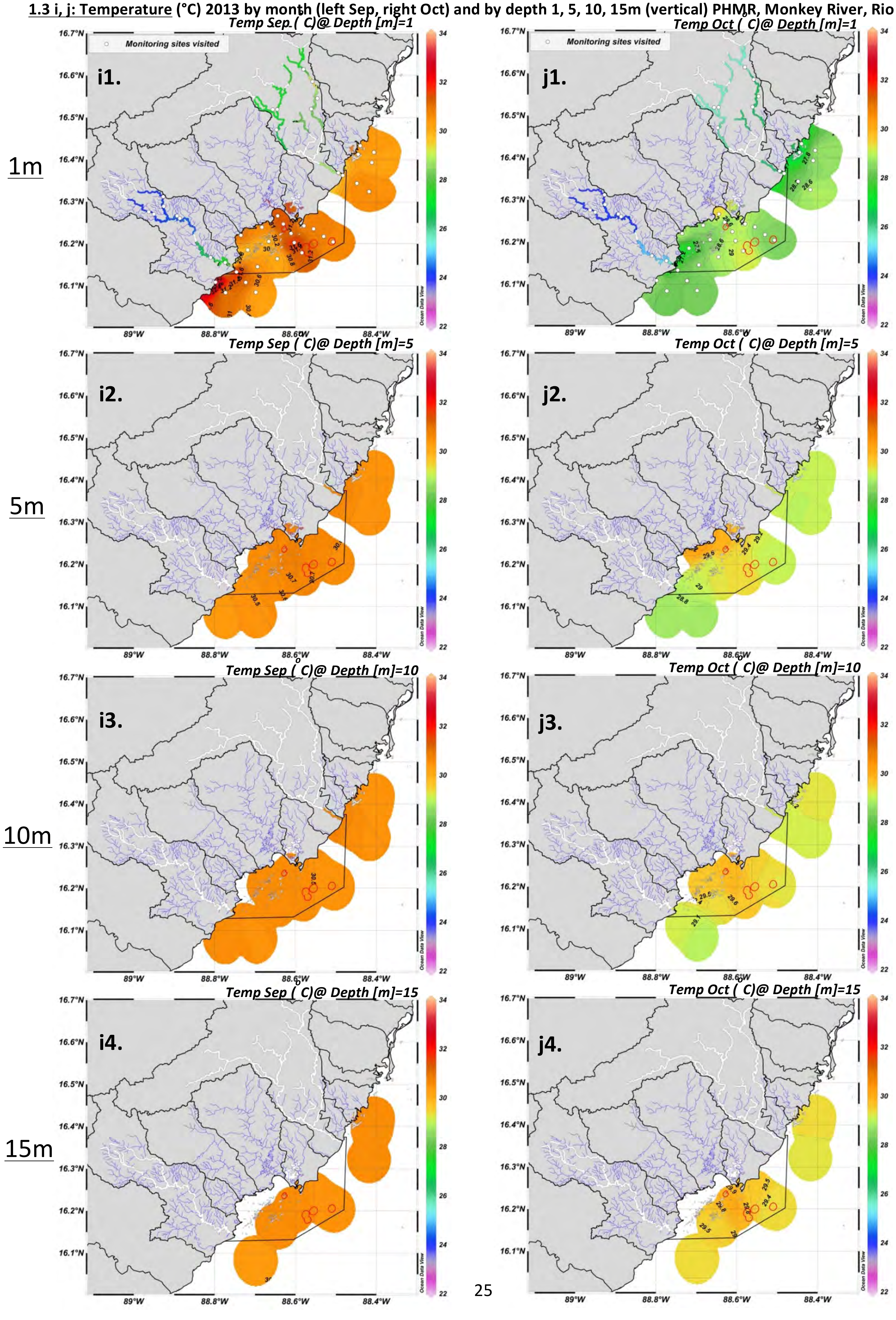
5m

10m

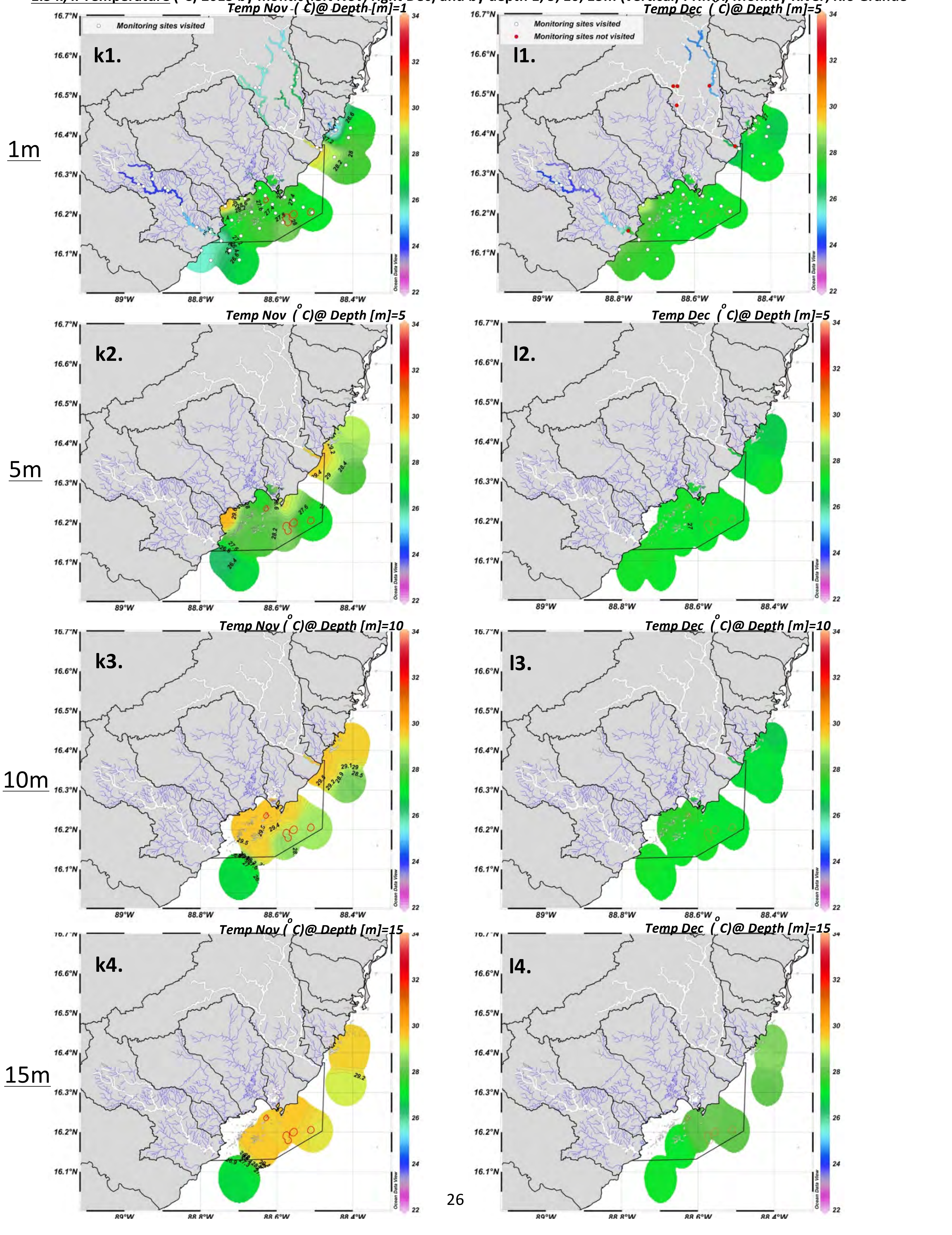
15m



1.3 i, j: Temperature (°C) 2013 by month (left Sep, right Oct) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande



1.3 k, l: Temperature (°C) 2013 by month (left Nov, right Dec) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande



1.4. Mean surface temperature by month PHMR 2009-2013 (Fig. 1.4):

- Mean surface temperature followed a fairly predictable trend overall in each of the years 2009-2013. In general, temperatures started cool (January in all years approx. 26.8°C, rising steadily to between ~29.3°C to ~30.5°C by April in all years. While this trend begins by February in most years, in 2013 there is a lag in increase in mean surface temperature until March, a trend similar to that of 2010.

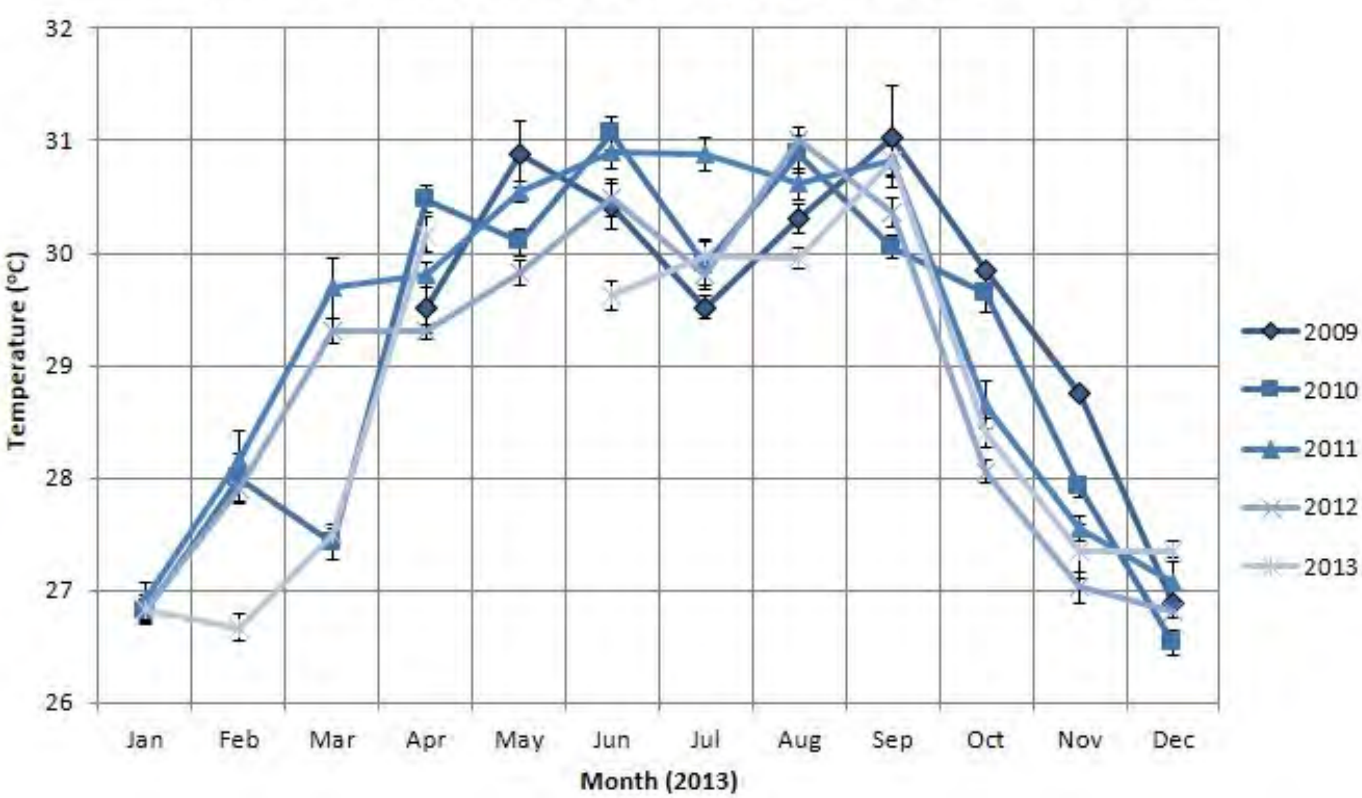
- The rate of increase slows towards June in all years, levelling off at around 31°C for all years until August or September, before decreasing continuously to around 26.8°C again in December in all years. A brief drop in

- Temperatures takes place in July in all years except 2011, possibly indicating higher rainfall at this time during most years.

- In 2013 there were lower than average summer sea surface temperatures, possibly indicating higher rainfall or greater cloud cover. No data is available for May 2013.

- In 2009 and 2010, the rate of decrease from September to November was slightly slower than in the years 2011, 2012 and 2013, although all had reached similar low values of ~ 27°C by December.

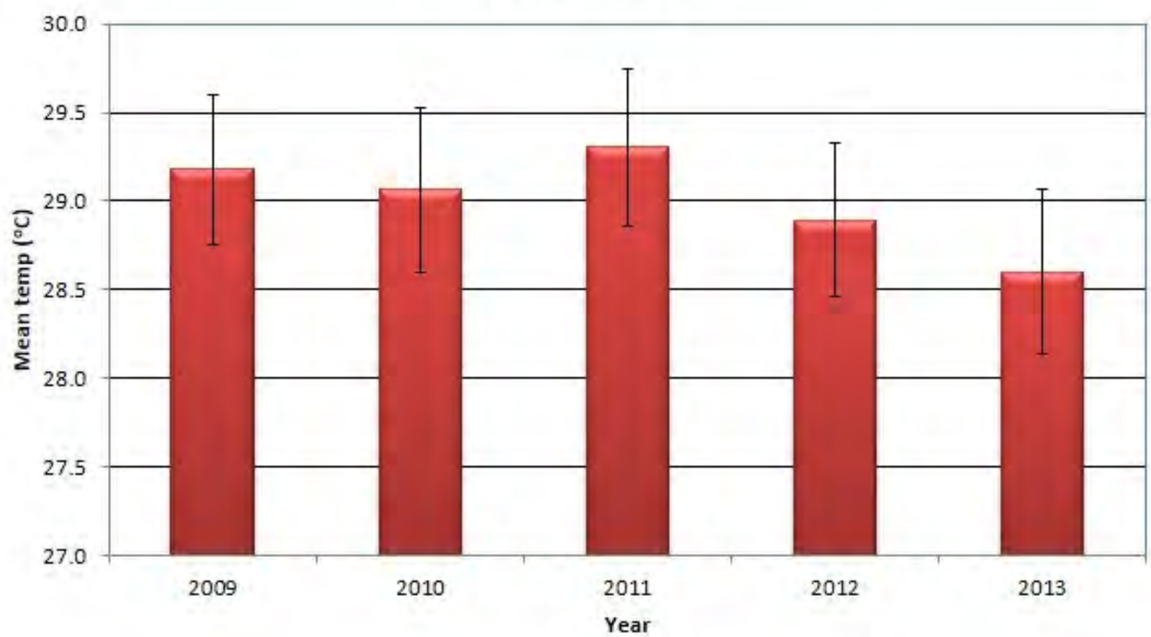
Fig. 1.4: Mean surface temperature (°C) by month PHMR 2009-13



1.5 Mean overall sea surface temperatures 2009-2013 (Fig. 1.5):

- Mean overall surface temperatures continue to decline, a pattern seen since 2009 with the exception of 2011. It is important to note that there is no temperature data for January, February and March in 2009, typically the cooler part of the year, and so the annual mean for 2009 is most likely artificially high. Nonetheless, it appears that overall there has been a gradual cooling of mean ocean temperatures over the last 5 years, with mean overall temperatures in 2013 being considerably lower than in 2009.

Fig. 1.5: Mean overall sea surface temperature (°C) PHMR 2009-2013



1.6: Temperature: general conclusions:

- June was a relatively cold month in 2013 compared with the last five years.

- Peak warming occurred later (September) than in 2012 (August)

- Lack of May data leads to uncertainty whether peak mean PHMR temperatures occurred in May or September, although a dip in the warming season occurred in June, earlier than every other year since 2009 (all years July), suggesting a cooler May than the previous four years.

- Monkey River continues to be more susceptible to solar warming during summer months, due to exposure of river to sun from riparian deforestation. Rio Grande continues to exhibit much cooler and more stable temperatures. These more stable and sheltered conditions are likely due to intact nature of riparian forests in Rio Grande, providing shade to the river, retaining bank structure and thereby river profile, and minimizing input of profile-flattening sediment into the river. The human impacts on Monkey River make it a more dynamic and therefore less favourable environment for aquatic life than Rio Grande, demonstrating the impact that land use change has on river ecosystems that support local livelihoods.

- There is an apparent inverse relationship in 2013 between DO% and temperature. See Section 2.5 dissolved oxygen general conclusions for further details.

2. Dissolved Oxygen

2.1. Mean surface Dissolved Oxygen (%) by month 2013 - PHMR, Monkey Rio Grande (Fig. 2a):

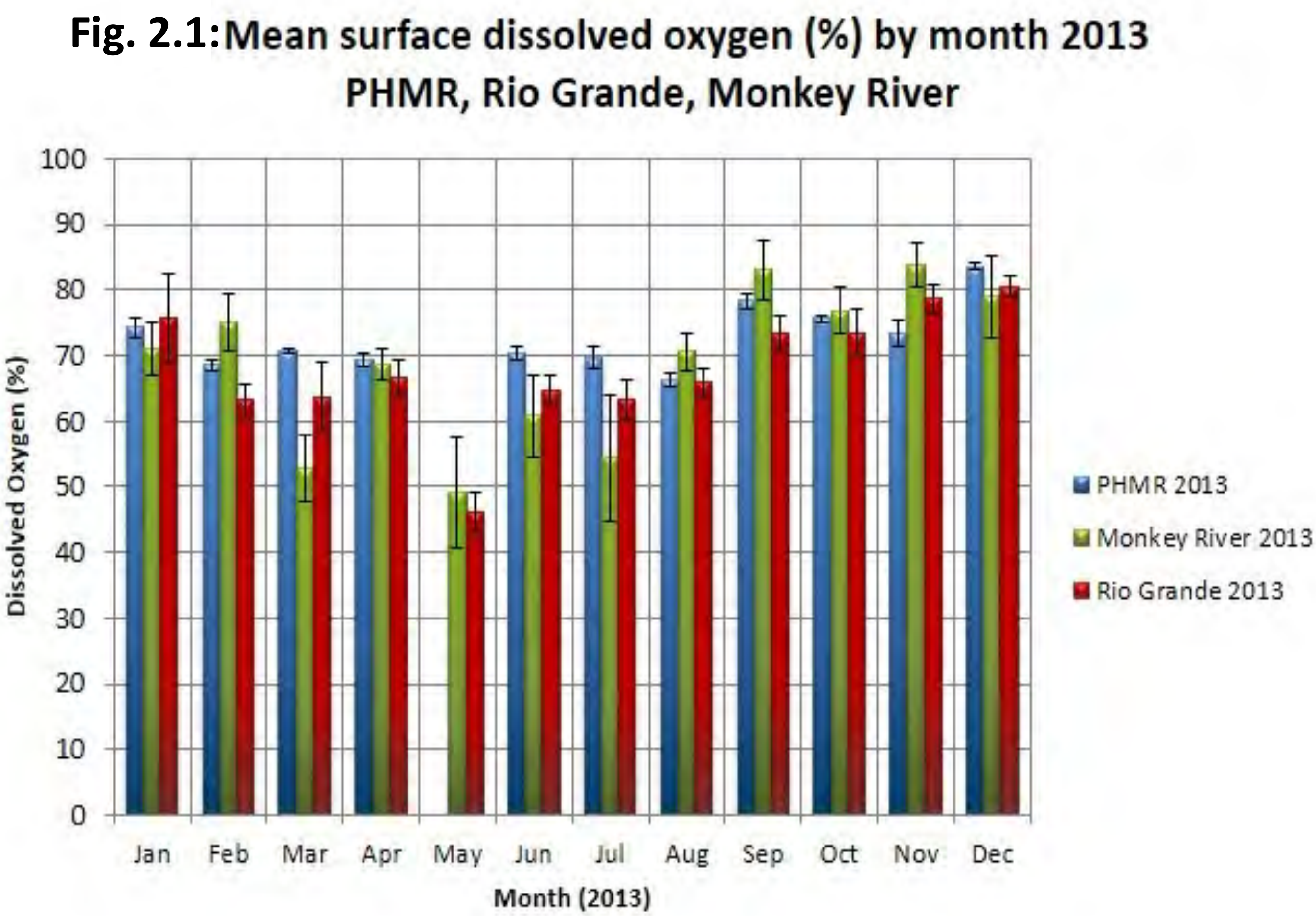
- Overall, a similar trend in both rivers and the sea of higher dissolved oxygen levels in early and late ends of the year, with lower levels in the March to August period, dropping significantly in both rivers in May. No data available for PHMR in May due to funding issues.

- Dissolved oxygen trends in 2013 were markedly different from 2012. DO% remained relatively stable throughout 2012 in PHMR and Monkey River, dropping in the second half of 2012 in Rio Grande. These trends were not repeated in 2013.

- Whereas in 2012, PHMR almost always had highest DO%, Monkey River almost always second highest, and Rio Grande almost always lowest, in 2013, the area with the highest, middle and lowest DO% varied from month to month.

- 2013 DO% fluctuations correlated between different areas in each of the two years, yet the overall trends from one year to the next were completely different. Unfortunately, as there is no PHMR May data it is not possible to determine if the marked drop in DO% in the rivers in May was replicated in PHMR.

Fig. 2.1:



2.2. 2013 Mean monthly dissolved oxygen: 1, 5, 10, 15m depth (Fig. 2.2):

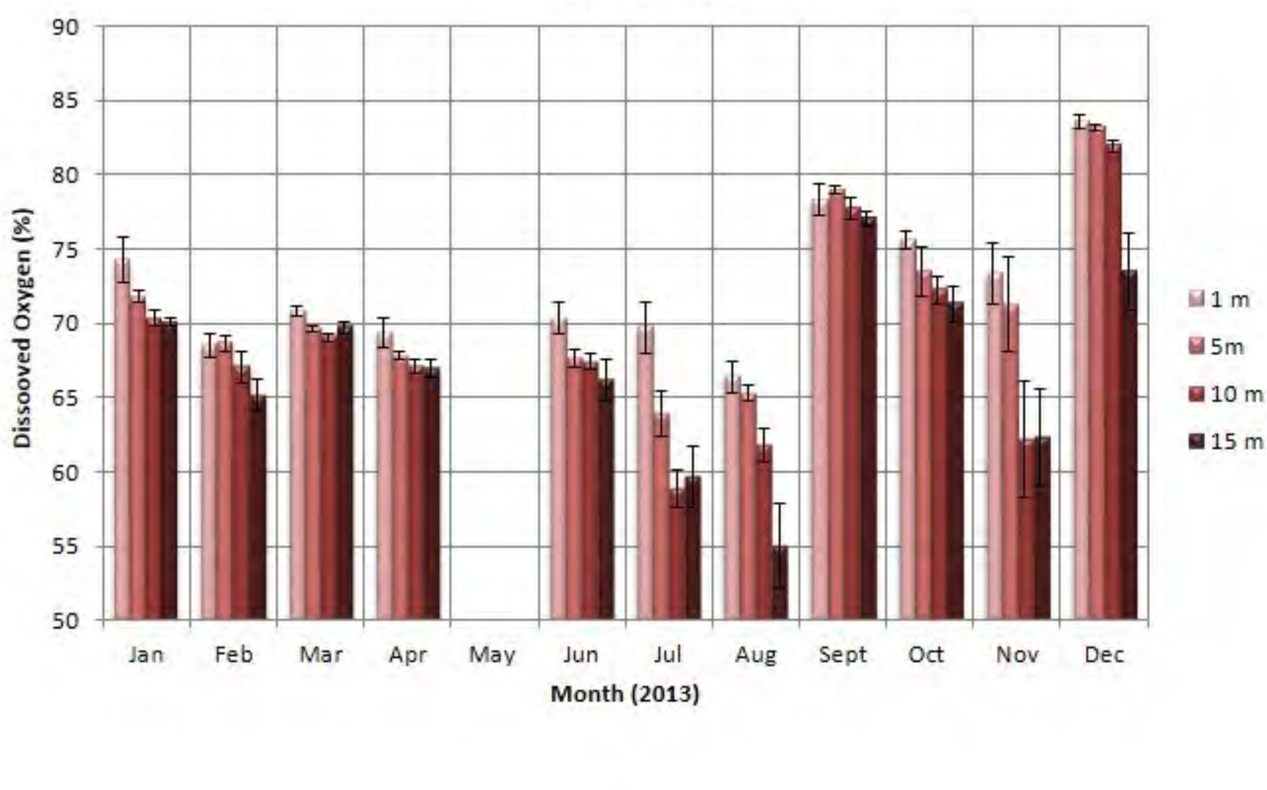
- Overall, there was greater variability month to month in 2013 than in 2012 (excluding January 2012 data as extreme high values in this month are thought to be an equipment error). In 2012, excluding January, the range observed throughout all depths over the year was ~64% to ~80%. In 2013, this range was between ~55% and ~84%.

- In 2012 there was less depth related stratification of DO% within any given month. In 2013, there was modest stratification of DO% with depth in the period January – June (January high 1m: 74.3%, low 15m: 70.1%; February high 1m: 68.5%, low 15m: 65.1%; March high 1m: 70.8%, low 10m: 69.1%; April high 1m: 69.4%, low 15m: 66.9%; no data for May; June high 1m: 70.3%, low 15m: 66.1%.

- In the period July to August there was greater stratification of DO% with depth, being highest at the surface and largely reducing with increased depth (July high 1m 69.7%, low 10m: 58.8%; August high 1m: 66.4%, low 15m: 55.0%). DO% increased significantly in September, but with less stratification in DO% values with depth (September high 5m: 79.0%, low 15m: 77.1%).

- In October and November, DO% decreased gradually, becoming increasingly stratified (October high 1m: 75.7%, low 15m: 71. 3%; November high 1m: 73.3%, low 10m: 62.2%), before increasing significantly again at all depths in December with modest stratification in the 1-10m range and lower DO% at 15m (December high 1m: 83.6%, low 15m: 73. 5%).

Fig. 2.2: **2013 mean monthly multi-depth dissolved oxygen: PHMR: 1, 5, 10, 15m**



2.3: Dissolved oxygen maps 2013: multi-depth 1m, 5m 10m, 15m - PHMR, Monkey River, Rio Grande:

(Maps shown at end of this section)

a. **January 2013 (Fig. 2.3:a1-a4):** In general D.O. in PHMR in 2013 exhibited only modest spatial and temporal variability compared with previous years. Surface mean in PHMR was 74.3% ± 1.5 SE with elevated surface DO at the mouths of Middle River and Golden Stream. Monkey River had fairly high DO% in the upper Swasey branch (~16.62°N, 88.64°W) (MR_SB_1b: 86.0%) There was high DO% in the upper Rio Grande, and very low (Esso Landing site RG_RG_1c: 36.3%) DO% in lower reaches. There was little change in DO% with depth throughout PHMR.

b. **February 2013 (Fig. 2.3:b1-b4):** DO conditions similar to January in PHMR. More moderate values throughout Rio Grande watershed. In Monkey River, highest D.O. was seen again in the upper Bladen branch (site MR_BB_1a: 80.3%). There is little spatial variability across marine sites, but slightly lower in coastal areas north of Monkey River, as in February 2012. Subsurface DO% drops below 60% between Punta Negra and Punta Ycacos, possibly due to Punta Negra headland sheltering that area from north-easterly prevailing winds.

c. **March 2013 (Fig. 2.3:c1-c4):** DO rose again slightly throughout PHMR, particularly subsurface. There was little surface DO variability across sites in PHMR. Monkey River DO% dropped considerably in Bladen branch (MR_BB_1a: 54.3%) and at Monkey River mouth (MR_MR_1a: 32.3%).

d. **April 2013 (Fig. 2.3:d1-d4):** Conditions in PHMR remained very similar to March 2013 throughout both watersheds and the sea, although slightly higher in the mid reaches of Monkey River. Higher surface levels around Joe Taylor Creek; lower at 10m outside Rio Grande.

e. **May 2013 (Fig. 2.3:e1-e4):** No monitoring took place in PHMR due to funding constraints. The Bladen branch of Monkey River had very low DO% (MR_BB_1b: 32.7%), and DO% dropped markedly throughout Rio Grande (Mean: 46.1% ± 2.9 SE).

f. **June 2013 (Fig. 2.3:f1-f4):** River DO% was again higher in Swasey branch (~72.5%) than upper Bladen branch (~ 38%) of Monkey River and had resumed higher levels again in Rio Grande. Marine surface DO was fairly unvaried, with areas of slightly lower DO around Rio Grande mouth. There was little DO% variability with depth except around Punta Ycacos at 15m.

g. **July 2013 (Fig. 2.3:g1-g4):** Low DO again in Bladen branch, indicative of agricultural impact, higher levels consistently throughout Rio Grande. More variability in surface readings of PHMR, decreasing with depth, indicative of stratigraphic mixing due to solar heating and lower rainfall, and reducing capacity of water to retain dissolved oxygen with increasing seasonal temperatures.

h. **August 2013 (Fig. 2.3:h1-h4):** DO% higher again in Bladen branch (~70%), and high throughout all rivers. Marked reduction in DO% with increasing depth in PHMR, typical of times of warmest ocean temperatures of previous years. Lowest of year occurring at 15m around Punta Ycacos (site 6b: 35.7%) DO% at depth is typically lower inshore than offshore.

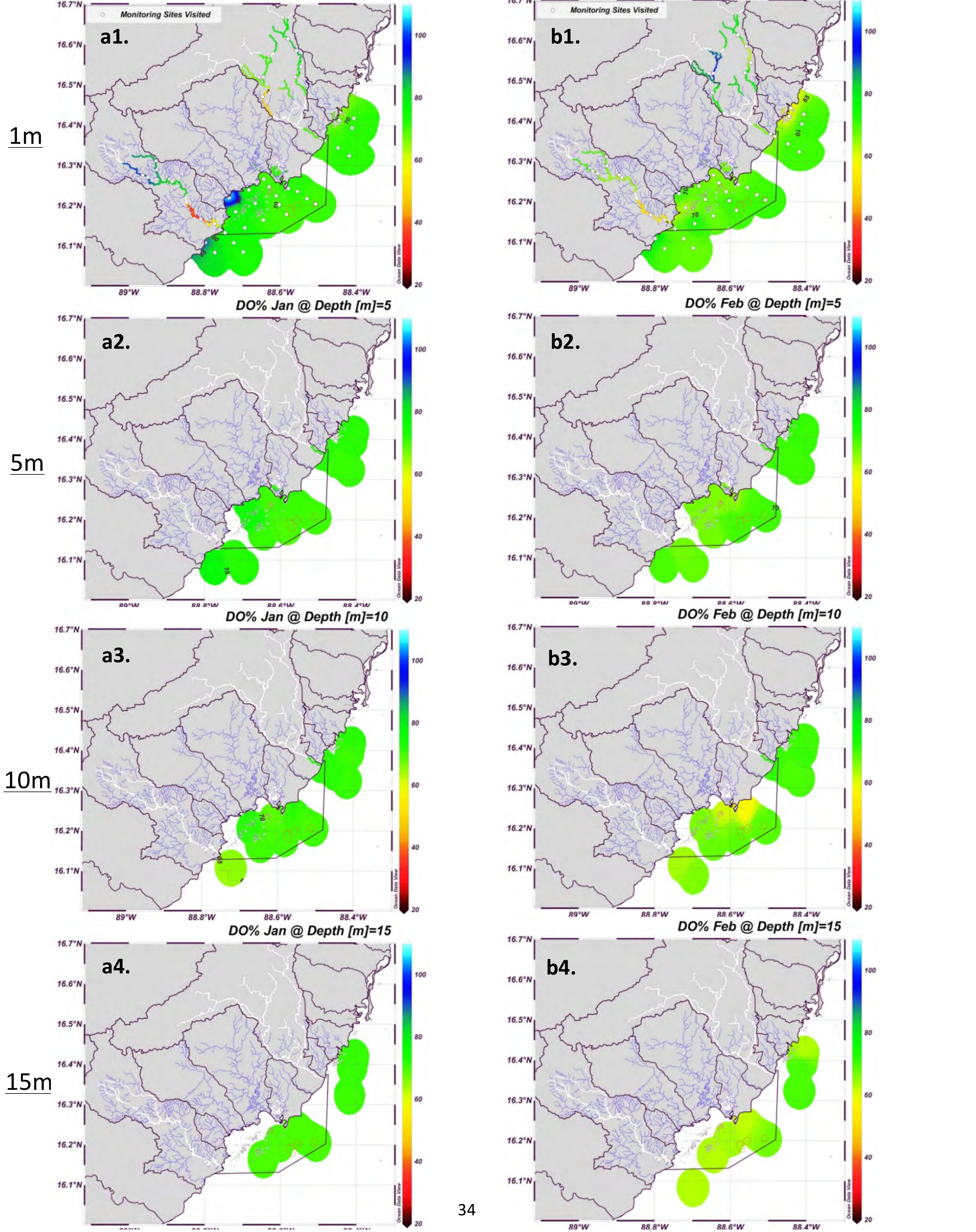
i. **September 2013 (Fig. 2.3:i1-i4):** Swasey branch of Monkey River had highest DO. Rio Grande moderate throughout. DO is generally uniform throughout PHMR (approx. 77.95%) but with higher DO at the surface around Joe Taylor Creek and lower around the mouth of Middle River/ Golden Stream. Little variation with depth throughout PHMR.

j. **October 2013 (Fig. 2.3:j1-j4):** Swasey Branch still had overall highest October river DO (MR_SB_1a: 89.0%). Conditions were uniform in Rio Grande (mean: 73.5% $\pm$ 3.5 SE) In PHMR, conditions are uniform except a pocket of subsurface low DO (site 4a: 43.0%) between Golden Stream and Deep River (site 4a). This coincides with an area of subsurface higher temperature at the same site, as mentioned in section 1.3 j.

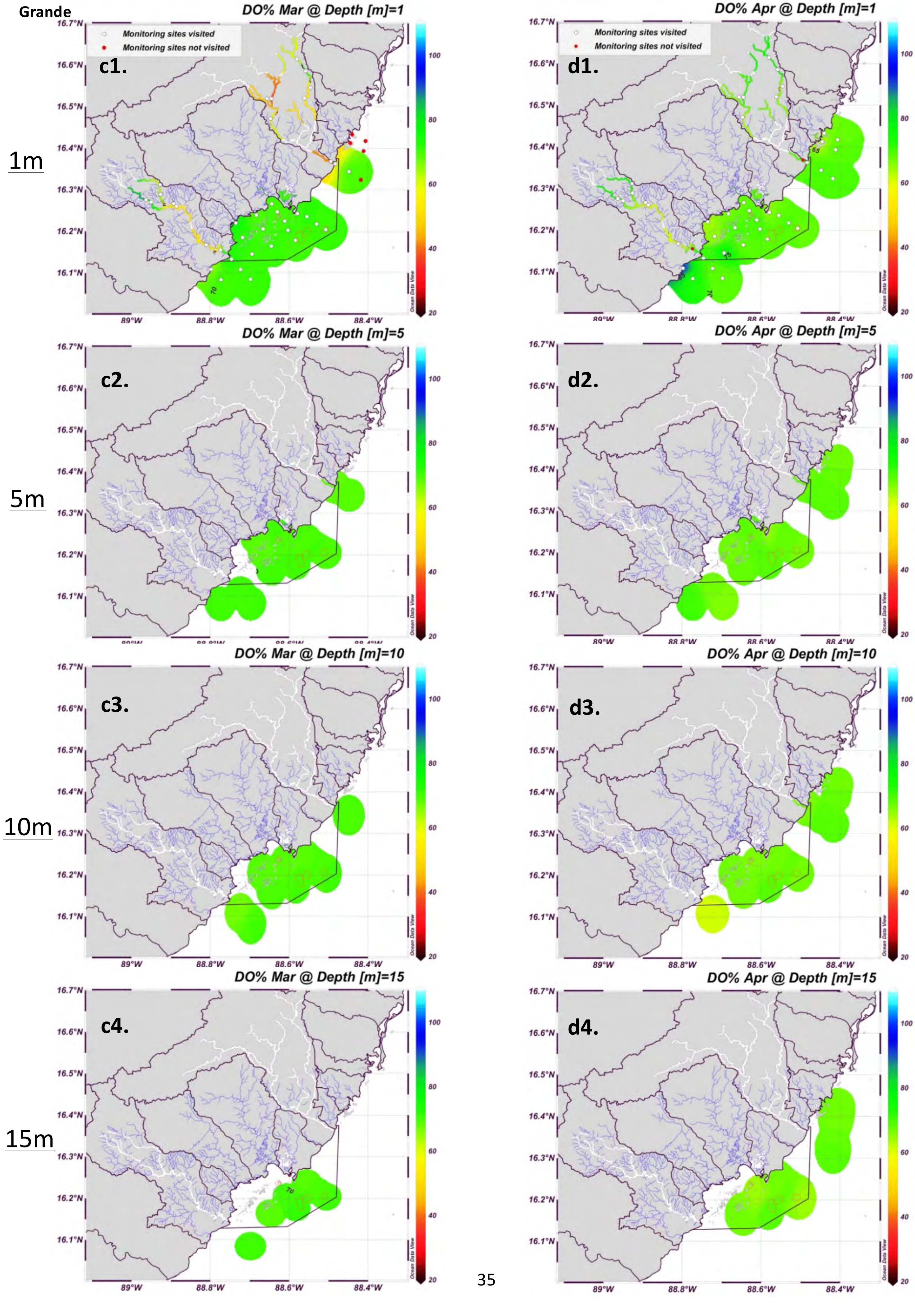
k. **November 2013 (Fig. 2.3:k1-k4):** DO levels in upper Monkey River have risen, being highest in middle Swasey branch, lower in Bladen branch, low in the lower reaches. Rio Grande remains uniform (mean: 78.6% $\pm$ 2.3 SE). Surface DO is similar overall in PHMR to October, but with surface patches below 60% outside Monkey River mouth, that continue down to at least 10m. Could be indicative of high nutrient runoff from Monkey River catchment (this is supported by high nitrate and phosphate levels around Monkey River mouth in November (Figs 5.2k, 5.3k)). Subsurface DO is lower than average in near-shore areas of PHMR.

l. **December 2013 (Fig. 2.3:l1-l4):** Both Monkey River and Rio Grande had high DO% (Mean Monkey River: 79.0% $\pm$ 6.2 SE; Mean Rio Grande: 80.6% $\pm$ 1.7 SE). In PHMR, DO was very high at the surface, continuing to 10m depth before reducing slightly at 15m depth, especially outside Monkey River.

2.3 a,b: Dissolved O_2 (%) 2012 by month (horizontal left Jan, right Feb) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande

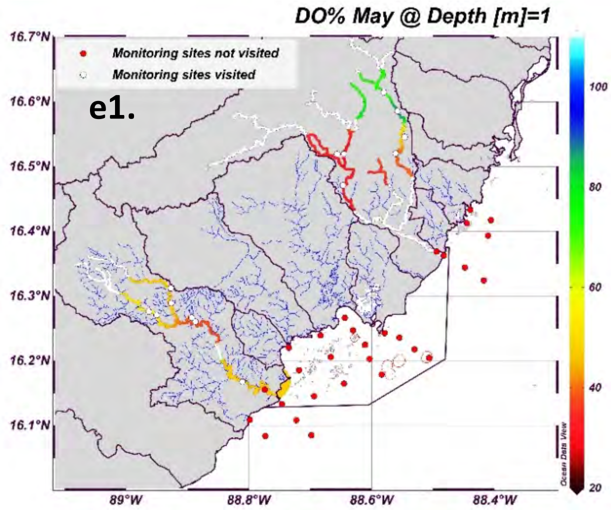


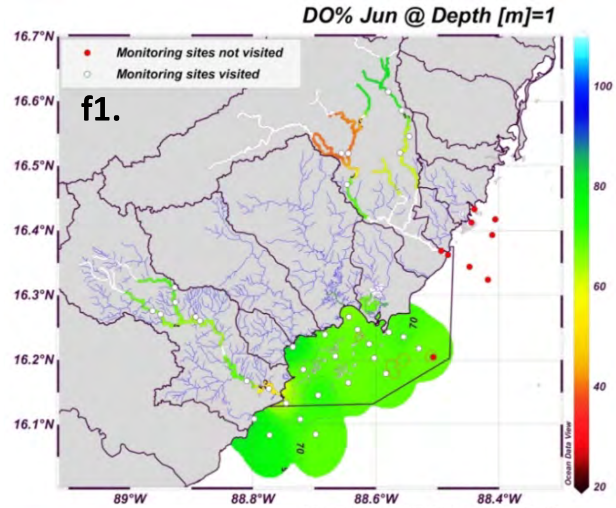
3 c,d: Dissolved O_2 (%) 2012 by month (horizontal left Mar, right Apr) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande



2.5 e, f. Dissolved oxygen (%) 2012 by month (left May, right Jun) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande

1m



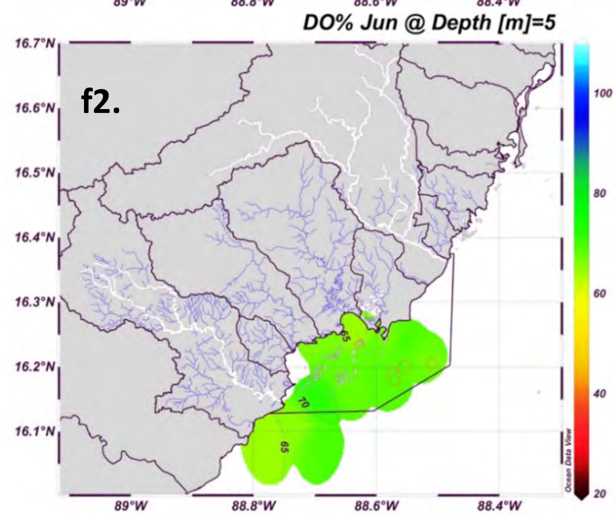


5m

e2.

May DO% 5m

No Data Available

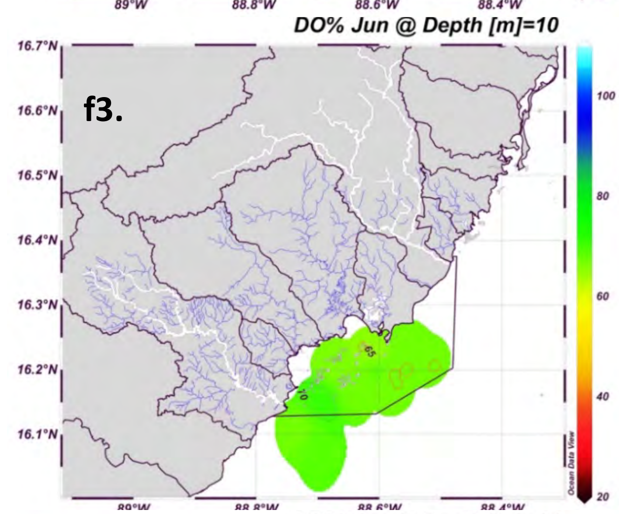


10m

e3.

May DO% 10m

No Data Available

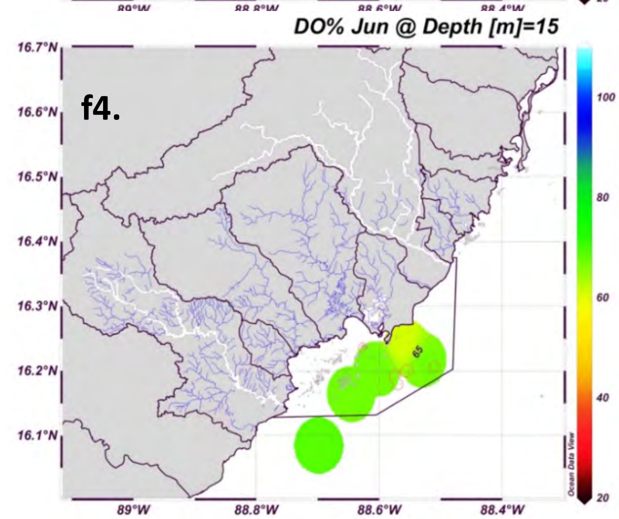


15m

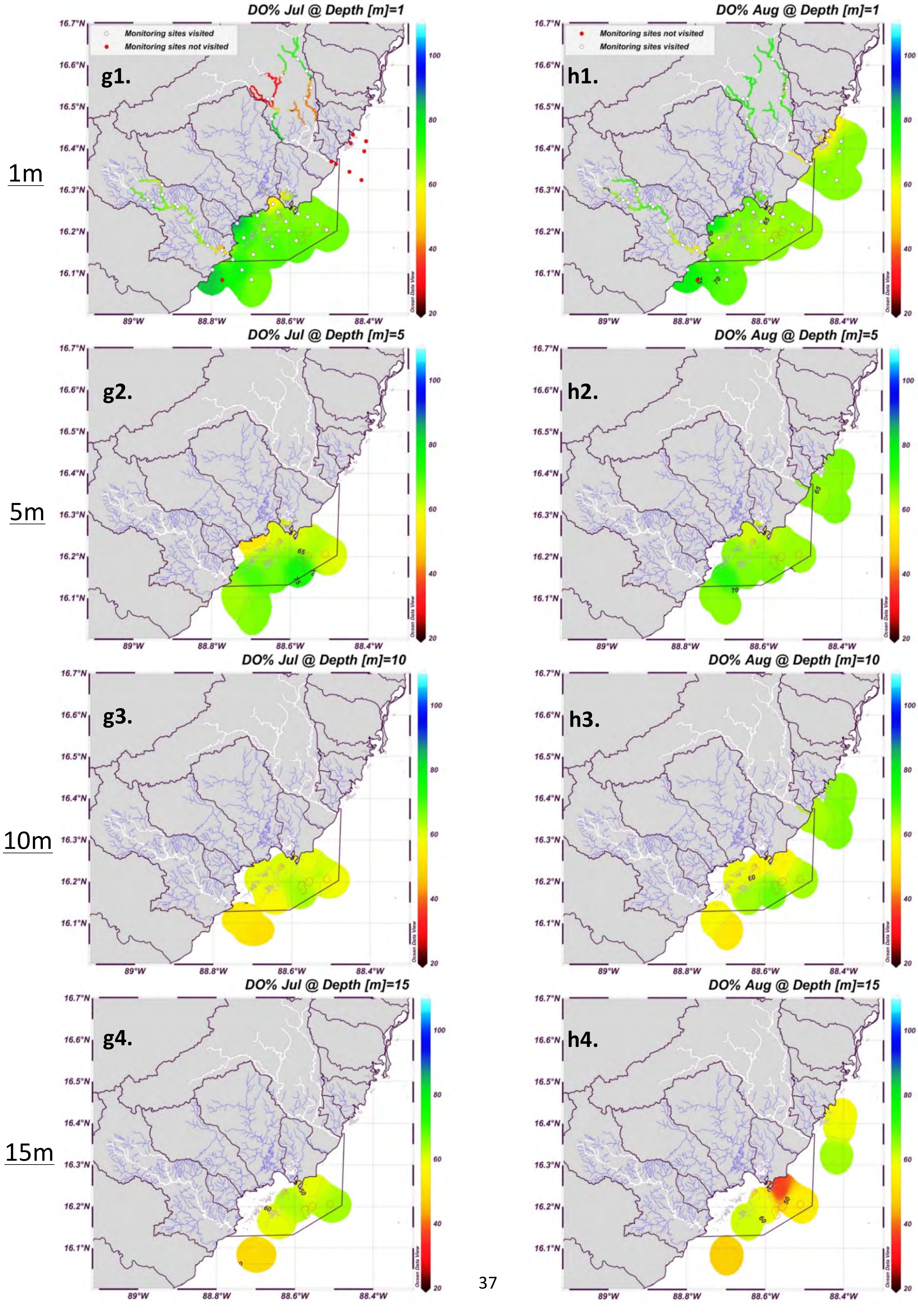
e4.

May DO% 15m

No Data Available



.3 g, h: Dissolved O_2 (%) 2012 by month (left Jul, right Aug) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande



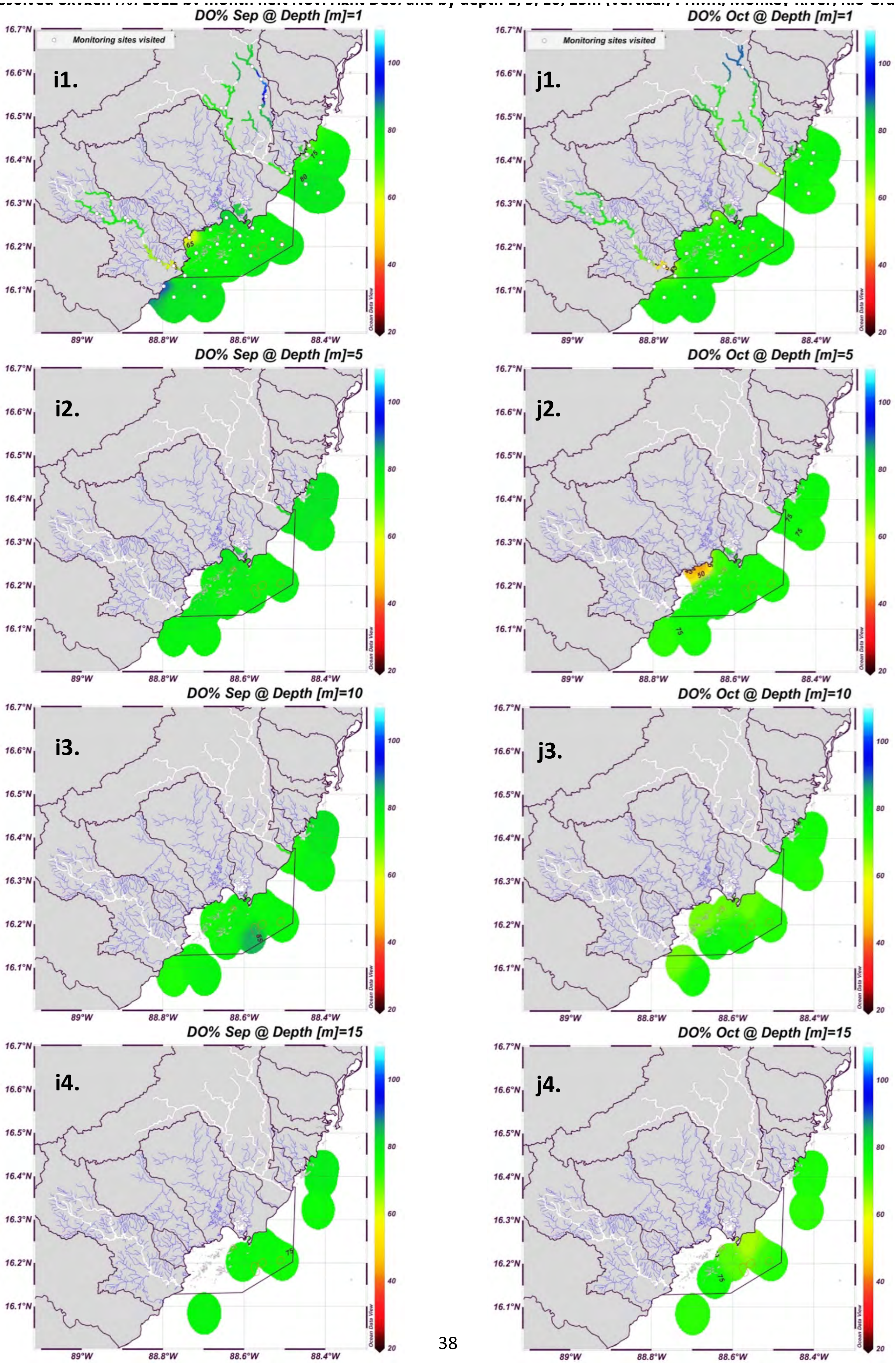
Dissolved oxygen (%) 2012 by month (left Nov. right Dec.) and by depth 1, 5, 10, 15m (vertical) … Monkey River, Rio Grande

1m

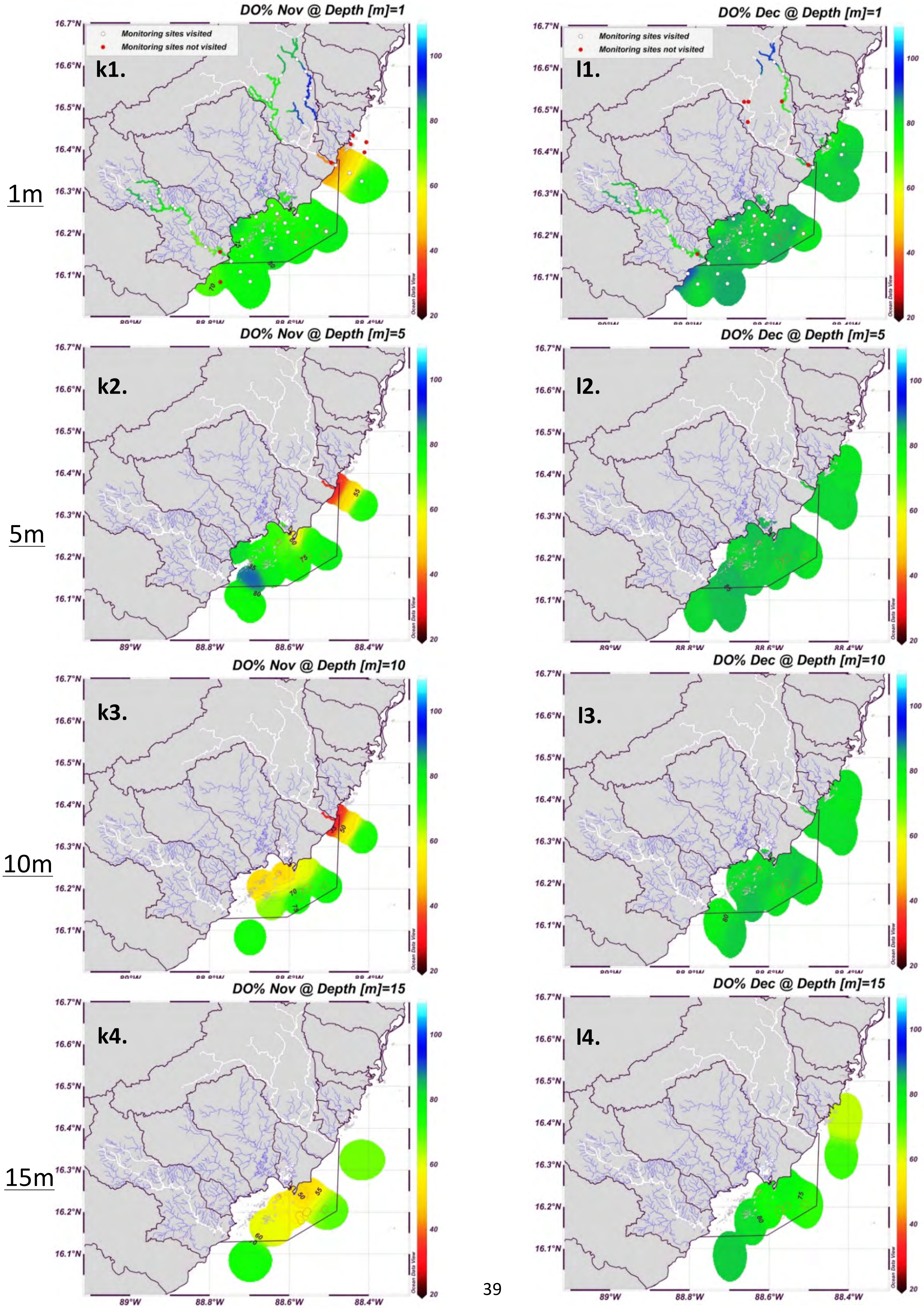
5m

10m

15m



2.3 i, j: Dissolved O_2 (%) 2012 by month (left Sep, right Oct) and by depth 1, 5, 10, 15m (vertical) PHMR, Monkey River, Rio Grande

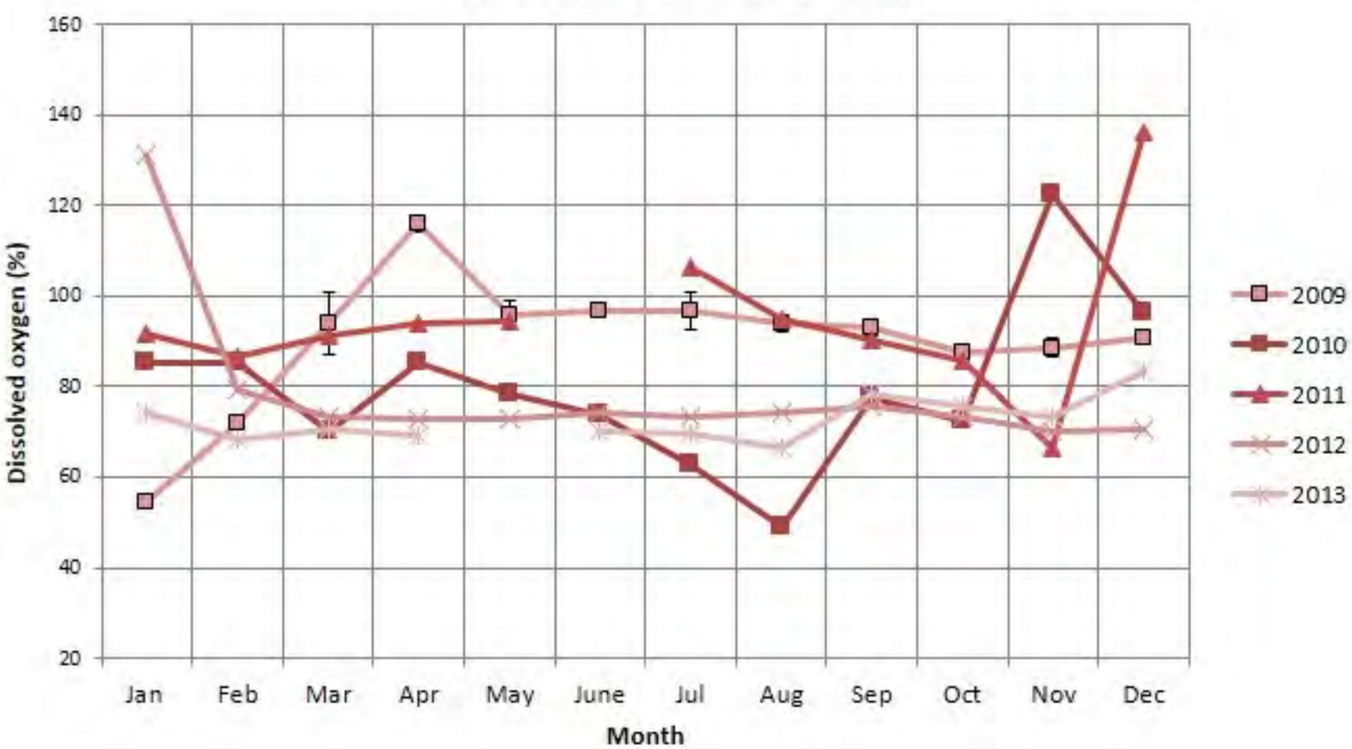


2.4. Mean DO (%) by month PHMR 2009-2013 (Fig 2.4):

- Mean DO (%) remained around 74-78% in nearly every month throughout 2013, although it did rise to around 83% in December. It is necessary to compare values in real terms (mg/l) in order to draw true comparison between months, as the 100% saturation level equates to varying amounts of DO in real terms (mg/l) depending on temperature. Temperature and DO % saturation have an inverse relationship, i.e. the higher the temperature, the lower the maximum quantity of DO can be retained by water. Therefore, 100% saturation at 20°C equates to a higher amount of DO in real terms (mg/l) than 100% saturation at 30°C.

- DO% was very similar in 2012 and 2013. This is to be expected as 100% saturation differs depending on values can only express readings as a percentage of the water to retain DO at the temperature it is at.

Fig. 2.4: Mean surface dissolved oxygen (%) by month PHMR 2009-2013



2.5. Dissolved oxygen - general conclusions:

- **Low DO% in Bladen branch** of Monkey River during warmer months suggests impact from agriculture in this area, but levels tend to recover downstream, suggesting impact is fairly localized. Other possible cause is geological, given this branch has sandstone bedrock while others have limestone bedrocks.

- **Patches with DO below 60%** at the surface extending to subsurface were observed outside Monkey River mouth, down to at least 10m. Could be indicative of high nutrient runoff from Monkey River catchment (this is supported by high nitrate and phosphate levels around Monkey River mouth in November (Figs 5.2k, 5.3k)).

- **Greatest variability with depth took place in July, August and November**. It is possible the July and August low DO at depth is due to climatic conditions that do not promote mixing, summer heat radiation leading to heating from the surface and stratification of the water column with sub-oxic conditions at the bottom. The November low DO around Monkey River could be due to high levels of sedimentation coming from the river, and being washed large distances to affect the northern half of PHMR. Increased sedimentation would likely lead to reduced DO% content due to benthic plant life being unable to photosynthesise to oxygenate the water.

- **Temperature and Dissolved Oxygen:** observations of low subsurface DO coinciding with high subsurface temperatures indicate an inverse relationship between the two under certain conditions, probably due to the reduced capacity of water to retain DO at higher temperatures. This needs to be watched more closely in future years to determine if this is a common event, as the potential for benthic commercial species die-offs e.g. lobster and conch, are higher in such circumstances.

3. Salinity

3.1. 2013 Mean monthly salinity: 1, 5, 10, 15m depth (Fig. 3.1):

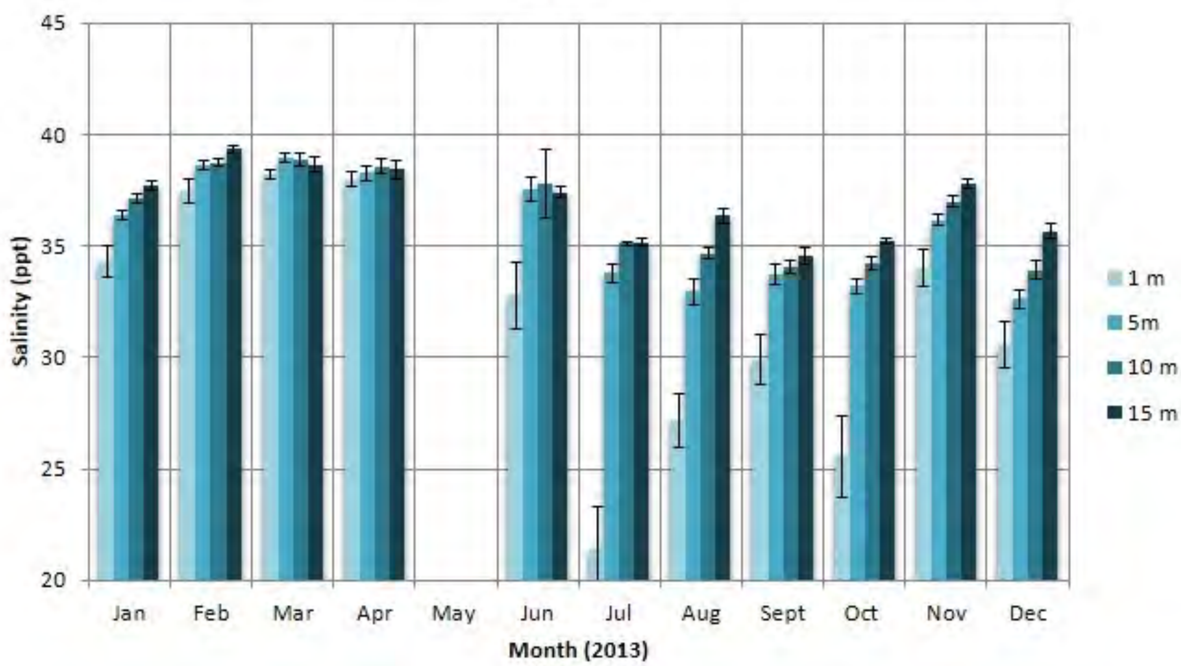
- Overall, salinity trends in 2013 were similar to 2012. There is a general trend overall of higher salinity in the first quarter each year, followed by a general decrease with greater stratification in the second and third quarters, followed by a general overall increase with reduced stratification again in the final quarter. These trends reflect typical rainfall levels, which are higher in the second and third quarters of the year.

- In the first four months 2013 (January-April), salinity was relatively high at all depths with low stratification.

- In the 5-15m depth range in 2012 and 2013 there was relatively little stratification throughout the year, with the greatest variability over time occurring at the surface (1m). Surface readings dropped significantly from June to July in both years, yet with a much greater surface decrease in 2013 (2012 June 1m: 30.7ppt; 2012 July 1m: 28.1ppt; 2013 June 1m: 32.8ppt; 2013 July 1m: 21.5ppt).

- Surface values then increased after July in both years, dropping briefly by a small amount in September for 2012 (30.8ppt) and October for 2013 (25.6ppt), before increasing to a high point in both years in November (November 2012 1m: 35.7ppt; November 2013 1m: 34.0ppt). In 2013 salinity decreased again after November at all depths.

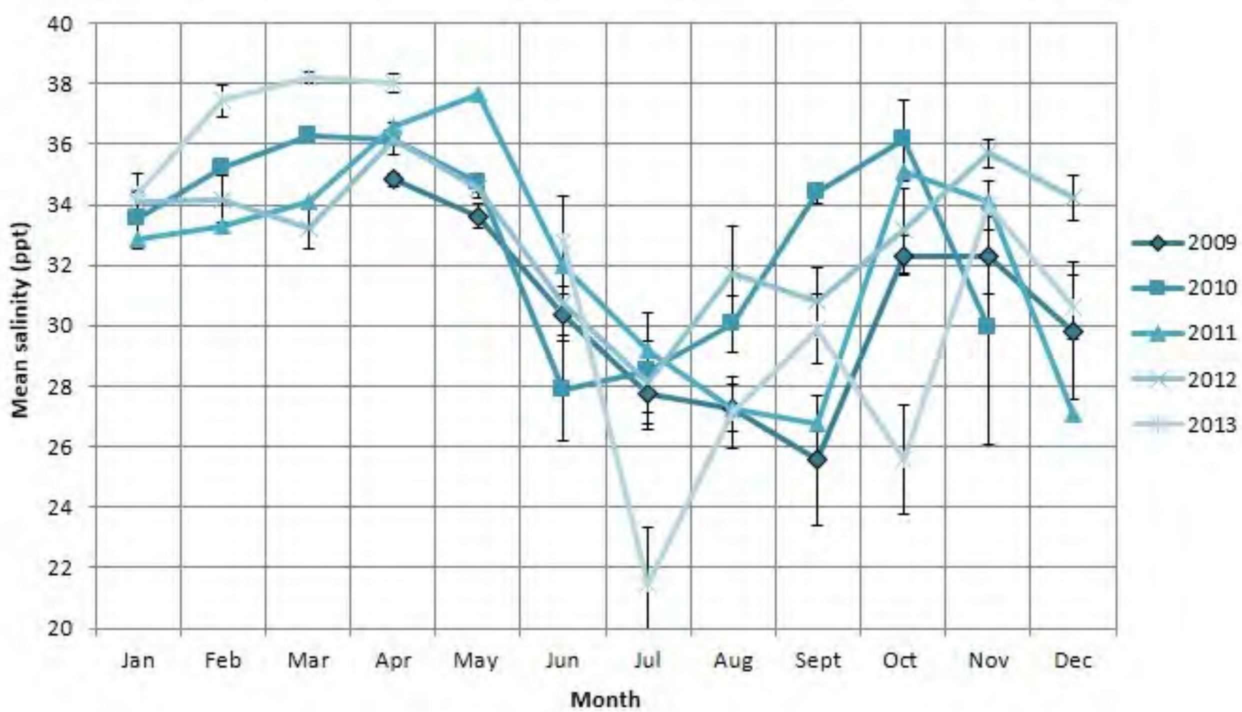
Fig. 3.1: 2013 mean monthly multi-depth salinity (ppt) PHMR: 1, 5, 10, 15m



3.2. Mean salinity (ppt) by month 2009-2013 (Fig 3.2):

- Overall, salinity trends in 2013 were similar to all previous years 2009 to 2012. There is a general trend overall of higher salinity in the first quarter each year, followed by a general decrease in the second, followed by a general overall increase with greater variability in the third quarter, peaking around October-November and dropping again towards December. These trends reflect typical rainfall levels each, which are higher in the second and third quarters of the year, greatly affecting surface salinity. 2013 annual high was March at 38.2°C ± 0.2SE, low was July at 21.5°C ± 1.8SE. High spatial and temporal variability between sites for surface salinity is masked when viewing data as overall means. Refer to maps 7a-l for clearer understanding of surface salinity in 2013.

Fig. 3.2: **Mean sea surface salinity (ppt) by month PHMR 2009-2013**



3.3. Salinity maps 2013: multi-depth 1m, 5m 10m, 15m - PHMR:

Note: no salinity data is collected for Rio Grande and Monkey River

a. **January 2013 (Figs. 3.3: a1-a4)** – PHMR had high surface salinity in the north and apparent high freshwater output of Rio Grande and Joe Taylor Creek. This indicates high rainfall in Rio Grande watershed and drier conditions in the watersheds of Monkey River, Deep River Golden Stream, Middle River and Seven Hills Creek.

b, c, d. February, March & April 2013 (Figs. 3.3: b1-b4, c1-c4, d1-d4): There was little lateral, vertical or temporal variation in salinity in PHMR in this three month period, as expected of conditions typical of dry season. Salinity was ~35ppt across all sites at all depths, comparable to mean Caribbean salinity.

e. **May 2013 (Figs. 3.3: e1-e4):** No data available

f. **June 2013 (Figs. 3.3: f1-f4):** No data available at northern transects 7,8 and 9 due to bad weather. Low salinity around mouths of Rio Grande and Deep River extending at least 10m deep near Rio Grande mouth.

g, h, i. July, August, September, October 2013 (Figs. 3.3:g1-g4, h1-h4, i1-i1, j1-j4): High freshwater discharge from all watersheds, particularly from Deep River southwards in July and August, joined by Monkey River later on. Subsurface mixing starts off low in July, increasing throughout this wet period, but never reduces subsurface salinity to less than high 20s ppt.

j. **November 2013 (Figs. 3.3: k1-k4):** November saw a break in the wet conditions, with surface salinity returning to mean ocean levels in all but a few inshore areas near Middle River / Golden Stream and Monkey River.

k. **December 2013 (Figs. 3.3: l1-l4):** Wetter conditions return again, although more moderate than July-October. Higher discharge from Rio Grande and Monkey River watersheds, much less in others. More subsurface variation, possibly due to cooler conditions that are less likely to cause stratification than warm months.

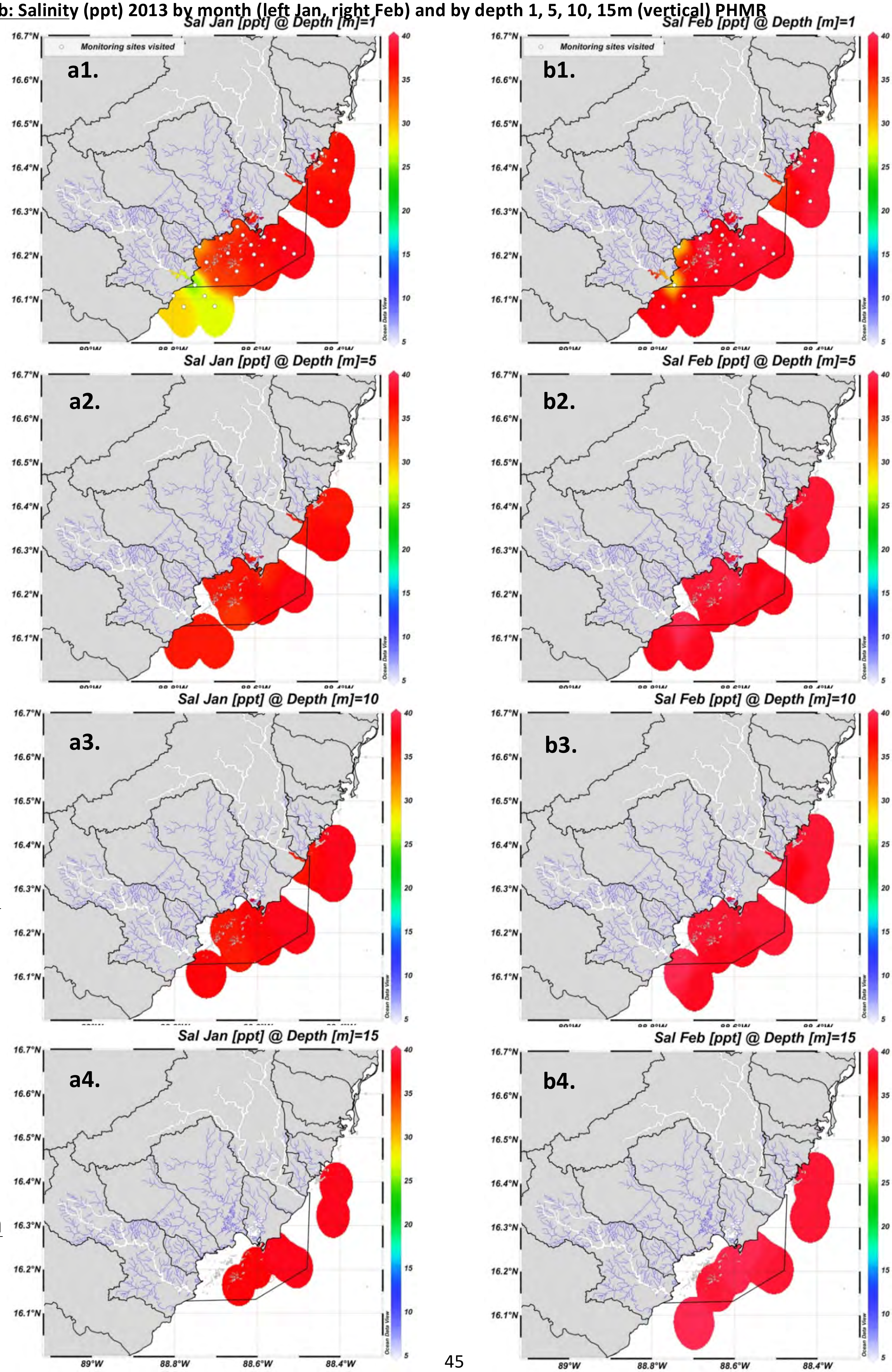
3.3 a, b: Salinity (ppt) 2013 by month (left Jan, right Feb) and by depth 1, 5, 10, 15m (vertical) PHMR

1m

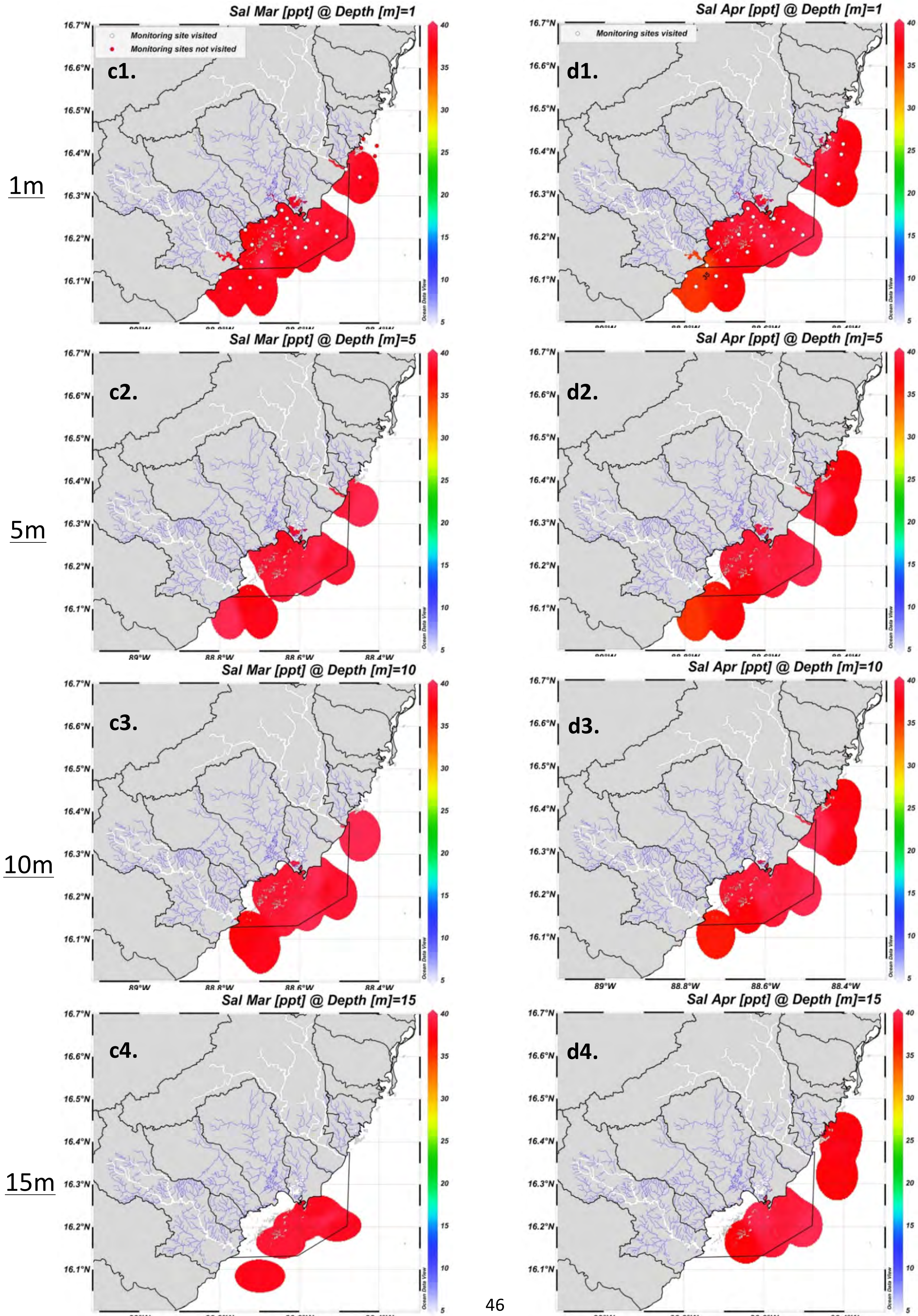
5m

10m

15m



3.3 c, d: Salinity (ppt) 2012 by month (left Mar, right Apr) and by depth 1, 5, 10, 15m (vertical) PHMR

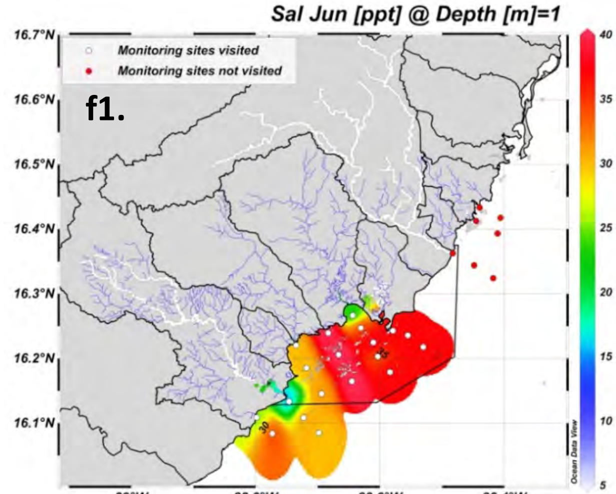


<u>3.3 e, f: Salinity</u> (ppt) 2012 by month (left May, right Jun) and by depth 1, 5, 10, 15m (vertical) PHMR

<u>1m</u>

e1.

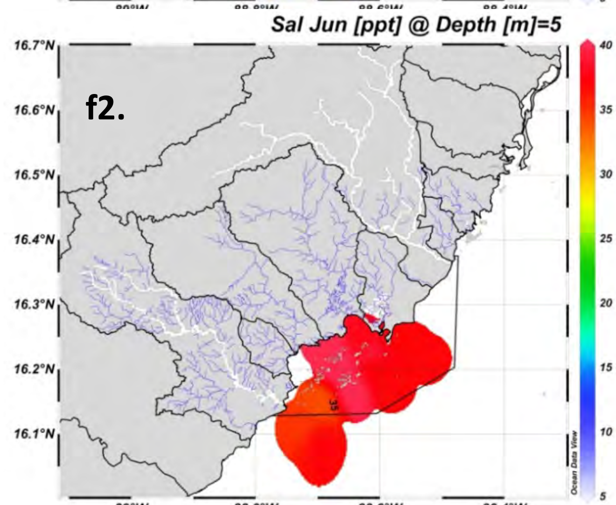
No Data Available



<u>5m</u>

e2.

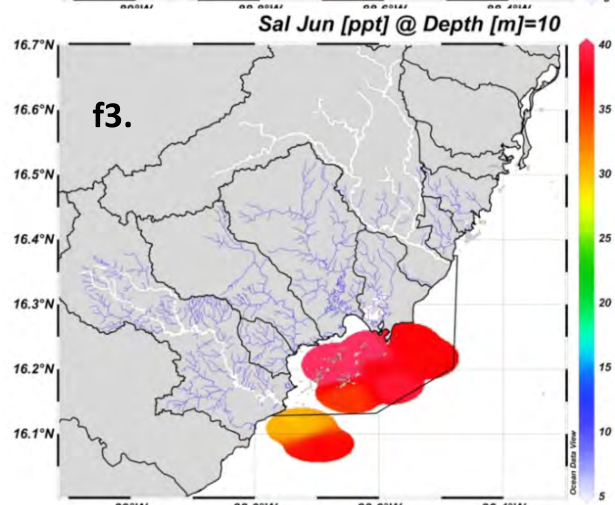
No Data Available



<u>10m</u>

e3.

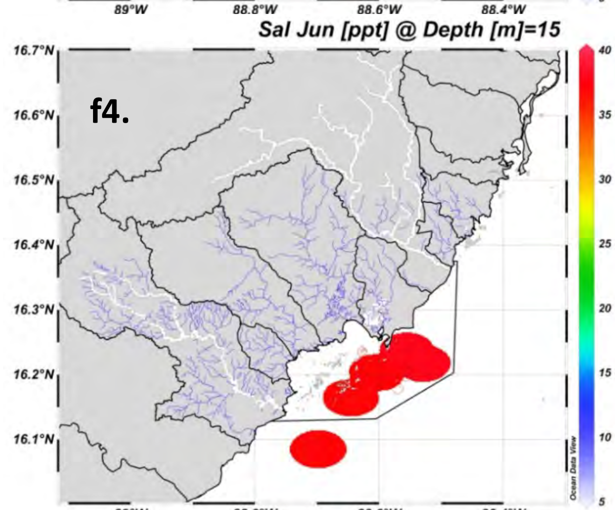
No Data Available



<u>15m</u>

e4.

No Data Available



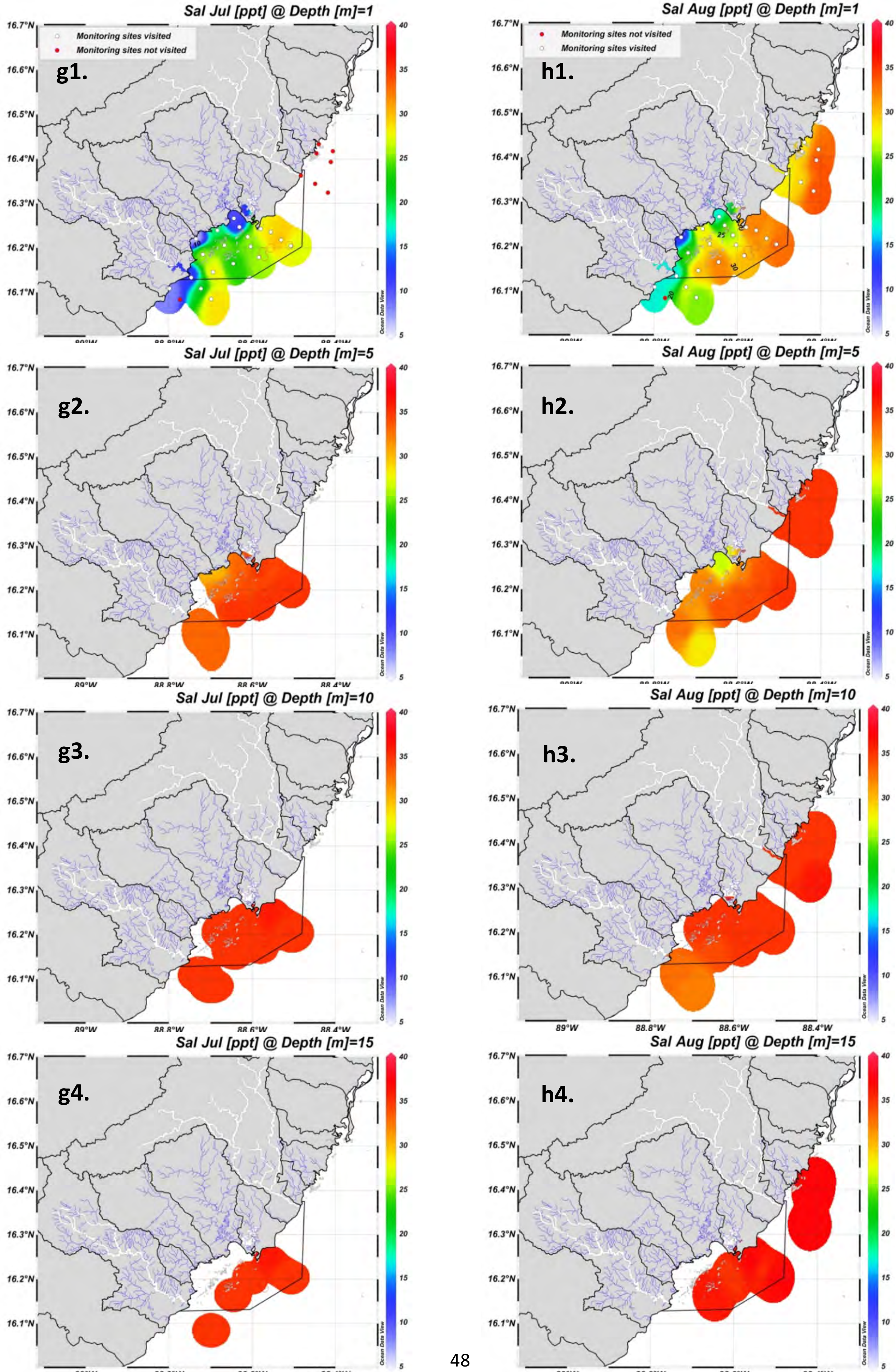
3.3 g, h: Salinity (ppt) 2012 by month (left Jul, right Aug) and by depth 1, 5, 10, 15m (vertical) PHMR

1m

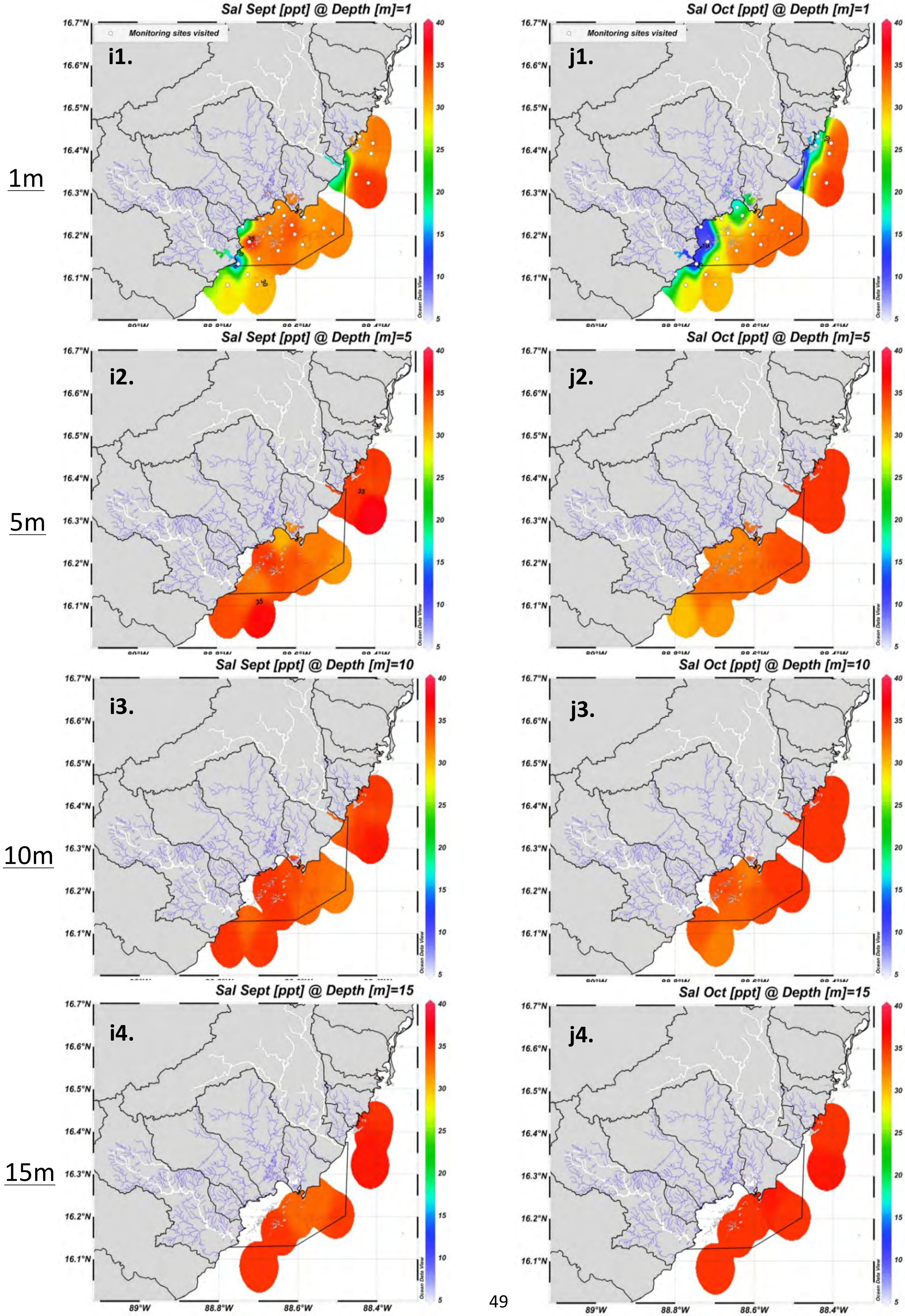
5m

10m

15m



3.3 i, j: Salinity (ppt) 2013 by month (left Sep, right Oct) and by depth 1, 5, 10, 15m (vertical) PHMR



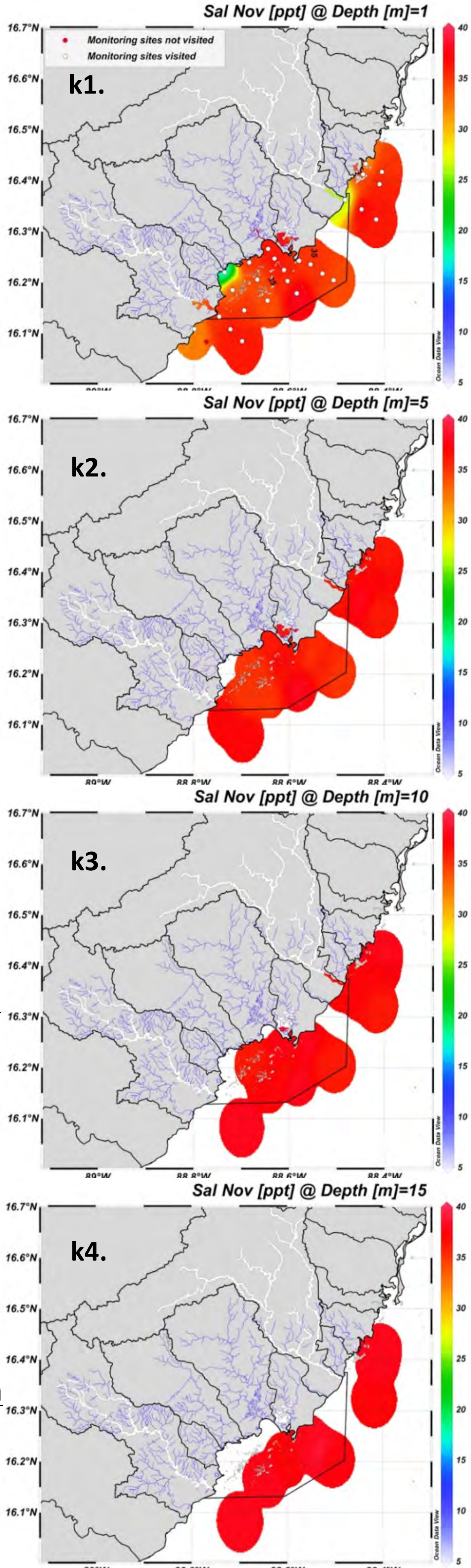
3.3 k, l: Salinity (ppt) 2013 by month (left Nov, right Dec) and by depth 1, 5, 10, 15m (vertical) PHMR

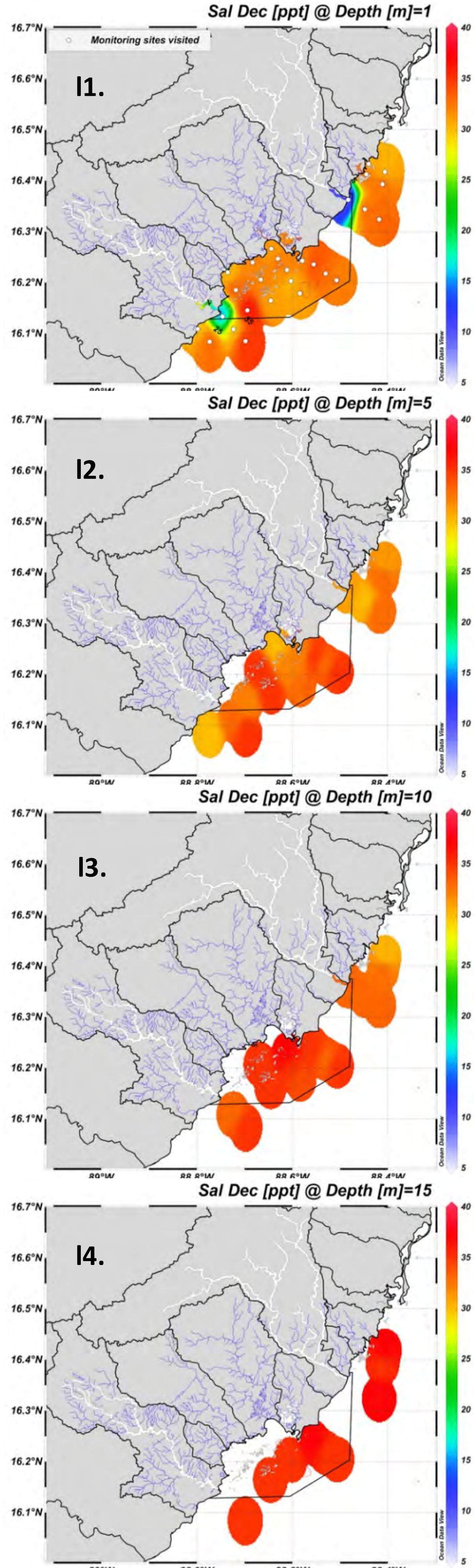
1m

5m

10m

15m





3.4 Salinity - general conclusions:

- **Wettest months were July (Fig. 3.3 g) to October (Fig. 3.3 j) becoming drier in November followed by a wetter December.**

- **During wet periods across the region, Rio Grande and Monkey River watersheds discharge larger volumes of freshwater** and earlier than the smaller water sheds in between, probably due to their larger catchment areas.

- Except for areas immediately adjacent to river mouths, impacts of freshwater input from rivers and from rain falling directly onto the sea are mainly limited to the top few meters of the water column. Large areas of subsurface low salinity would indicate possible deep water upwelling of colder water from offshore, as is believed to have happened the previous year (Foley 2013).

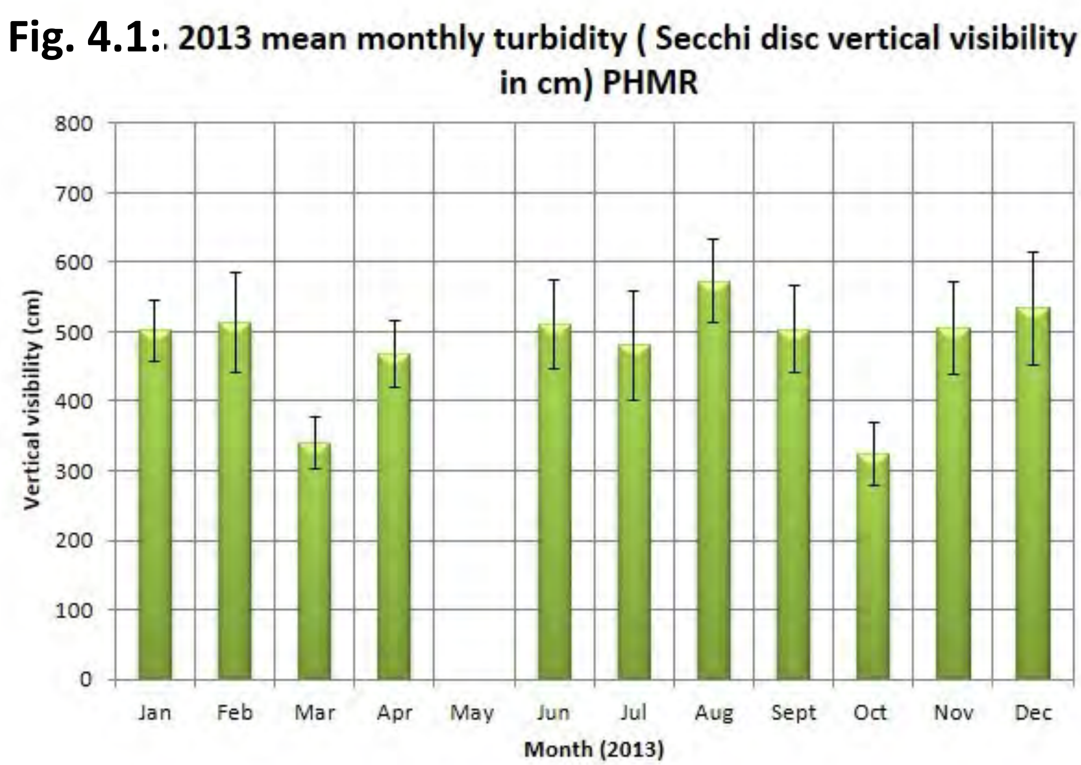
- Higher rainfall in Rio Grande watershed may be due to higher forest cover there.

- **2013 was much wetter than 2012,** a probable cause of cooler overall mean temperature in 2013.

4. Visibility

4.1. 2013 Mean monthly visibility (Fig. 4.1):

- Overall there was a less obvious overall trend in visibility over the year 2013 compared with 2012. While visibility in 2012 increased in the middle of the year and was lower in the first and final quarters, in 2013, visibility was relatively stable (2012 high: July 666.7cm; low December 384.8cm. 2013 high: August 573.1cm; low October 323.3cm). There does not appear to have been a related trend from one year to the next, although the lack of data for May 2013 weakens interpretation of the data set. High variability across sights in both years lessens the utility of attempting to interpret mean values across the dataset.



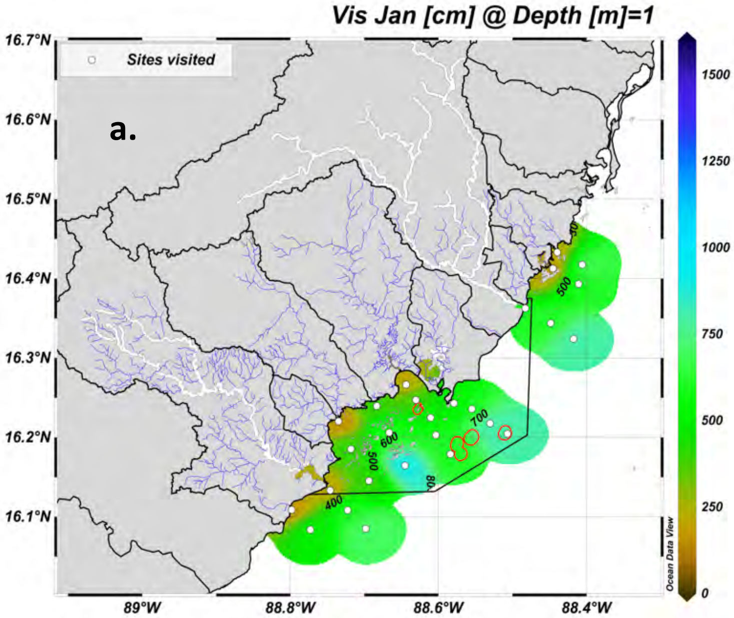
4.2. Visibility 2013 PHMR (Fig. 4.2: a-l):

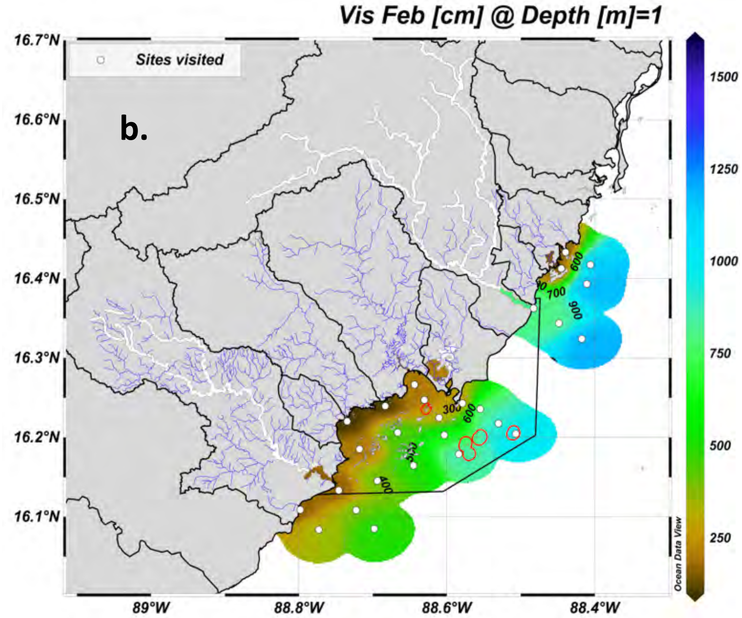
Note, no visibility data is collected for Rio Grande and monkey River

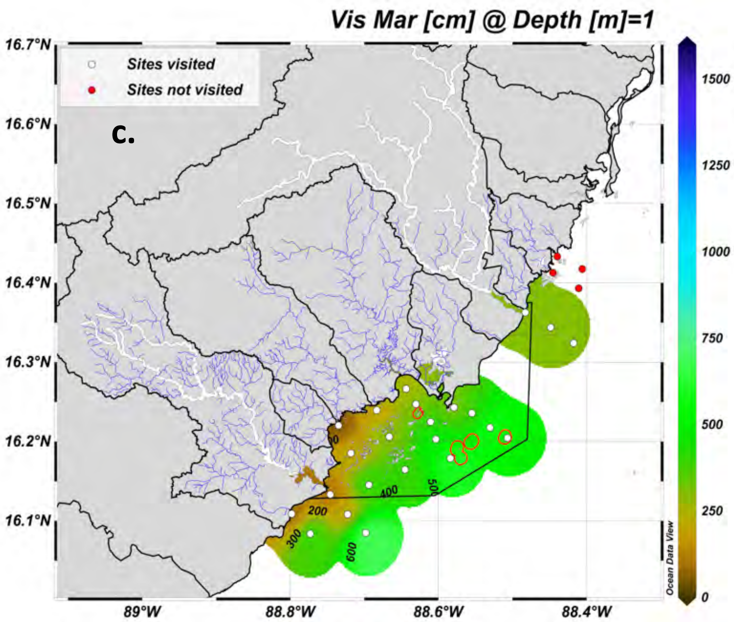
In contrast to 2012, there was no clearly identifiable seasonal pattern in visibility conditions throughout PHMR. Lowest mean visibility months were March and October (Fig. 2d), with a modest peak in August. Overall, 2013 was a year without extremities in visibility. More detail on mean trends in section 2d.
Very clear conditions were seen in offshore areas only, in August (around Moho Caye), September (Snake Cayes) and November (around Moho Caye).

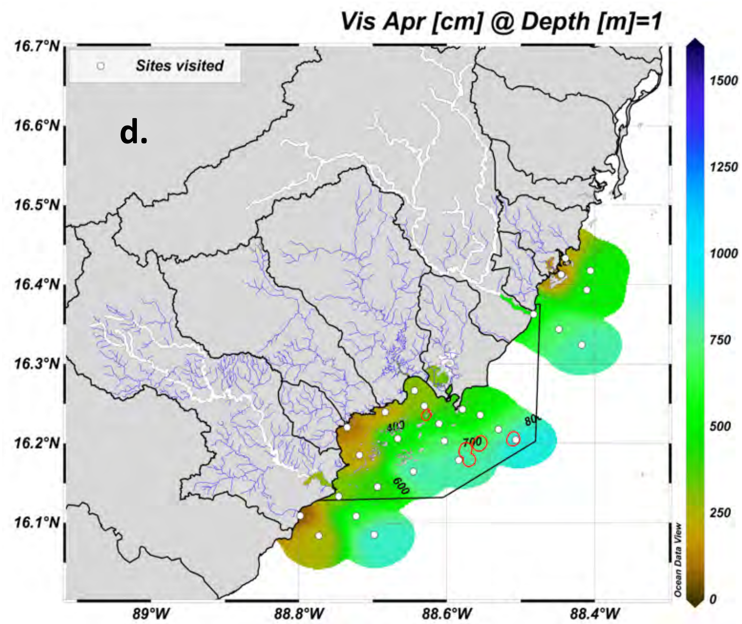
There were very low visibility conditions in coastal areas between Rio Grande and Deep River in February, July, October and December. While poor conditions in the latter half of the year would be expected during wet season, it is unknown why it was poor in February. Salinity data does not suggest high rainfall at this time although comparison with national rainfall data is necessary to confirm this, and visibility in February was good in offshore areas between Snake Cayes and Monkey River, more influenced by oceanic currents.

__4.2 a-f: Visibility__ **(cm) 2013 by month (Jan – Jun) PHMR**



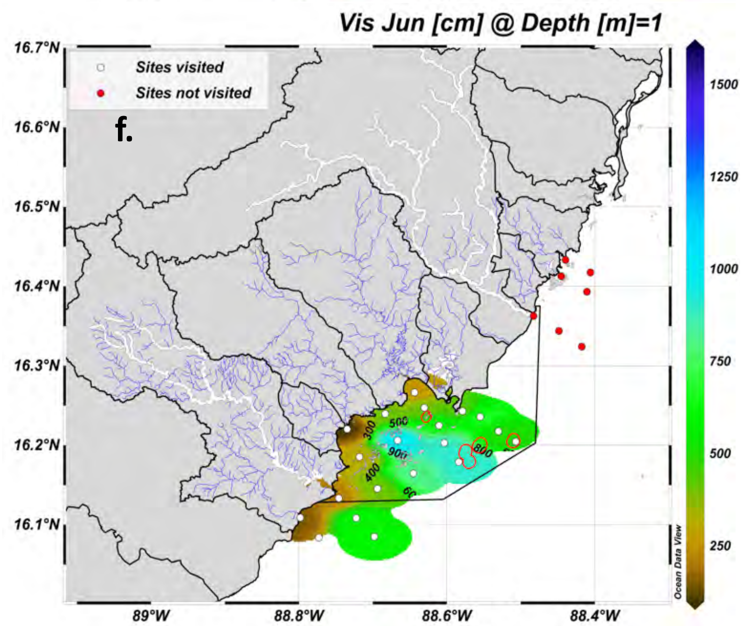




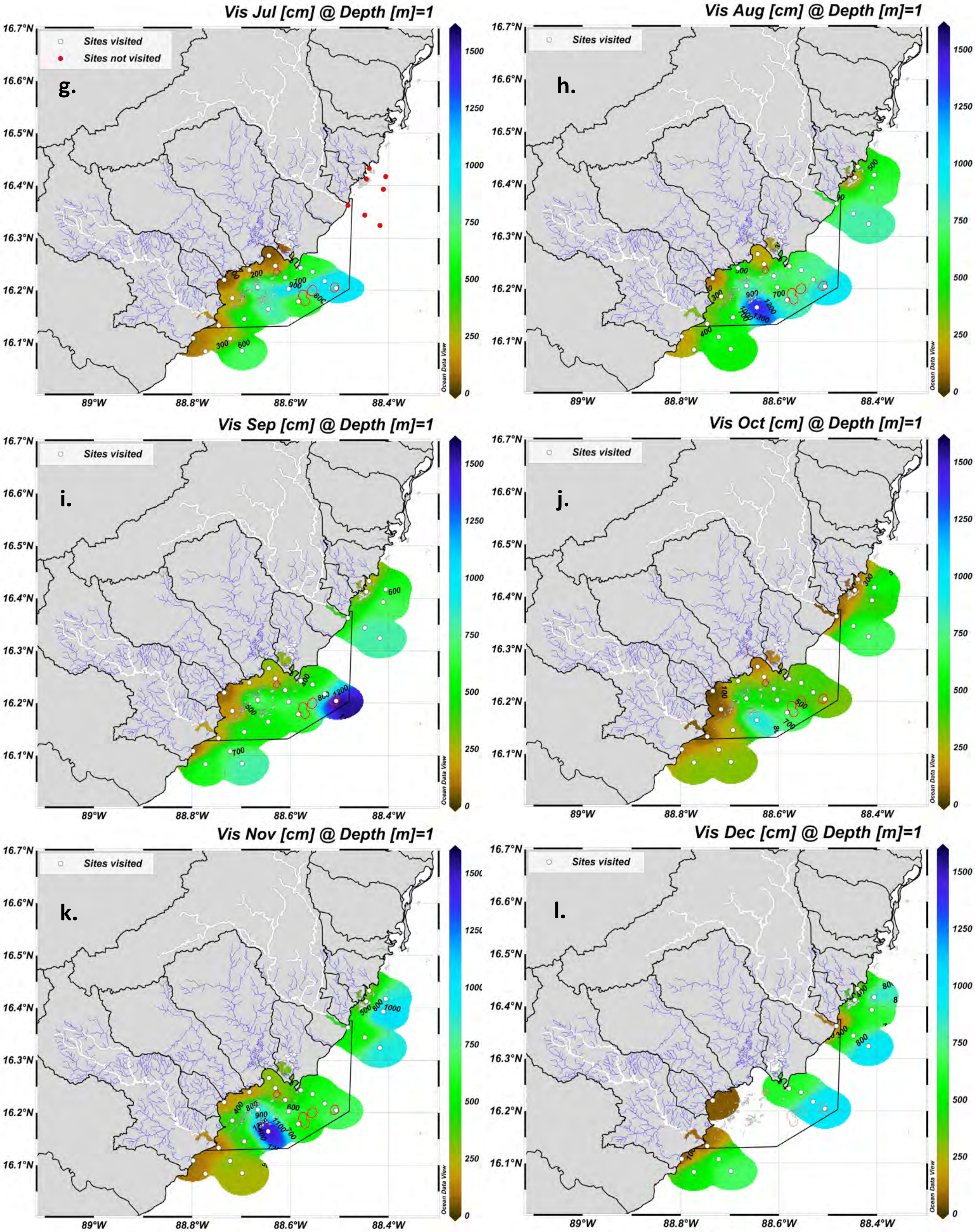


e.

No data Available



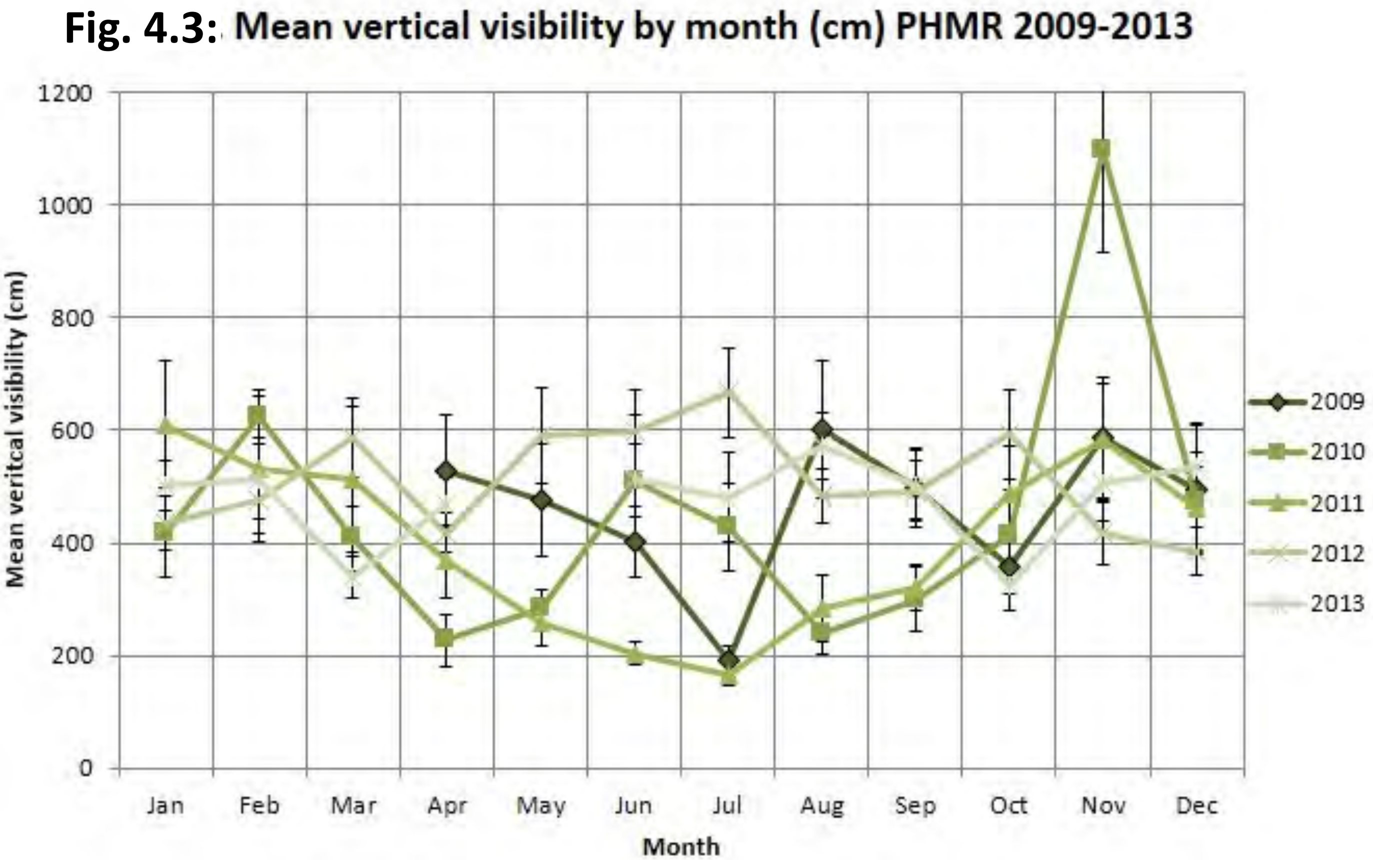
4.2 g-l: Visibility (cm) 2013 by month (Jul-Dec) PHMR



4.3. Mean visibility by month 2009-2013 (Fig 4.3):

- Overall there is not an obvious trend in mean visibility over each year 2009-2013. Visibility can be influenced by many factors on a daily basis, and there is such high spatial variability across the study area between inshore and offshore areas that to produce a mean becomes meaningless. The general trend is that visibility increases further from shore, with offshore visibility worsening and becoming more like inshore areas during periods of high river discharge, rainfall or wind.

Fig. 4.3:



5. Nutrient Analysis: Nitrate & Phosphates:

5.1 Mean surface nutrient concentrations (nitrates and phosphates) by month 2013:

For both phosphates and nitrates, no data is available for the following months in the following locations:

- *PHMR: January, February, March, May, June or December.*
- *Rio Grande: January, February, March, April, November and December.*
- *Monkey River: January, February, March, April, June, August, November and December.*

This has been due to servicing of the spectrophotometer, supporting equipment failure and lack of funding at certain times of the year.

- **PHMR (Fig. 5.1a):** Phosphates increased over July-November, while nitrates were high in September and November.
- **Rio Grande (Fig 5.1b):** Peak nitrate and phosphate values were lower in Rio Grande than in Monkey River or PHMR but follow a similar trend of increasing towards the end of the year, possibly due to increased agricultural runoff during wet months.
- **Monkey River (Fig 5.1c):** Nitrate and phosphate levels followed more similar patterns to each other in Monkey River, suggesting that sources were the same for both nitrate and phosphate. This would be typical of agricultural runoff, as opposed to domestic waste which would tend to be largely phosphates. Highest phosphate levels in October, as in Rio Grande, suggesting release of phosphate is higher in both rivers at this time.

Fig. 5.1a: Mean nitrate & phosphate concentrations (mg l^{-1}) by month 2013:PHMR

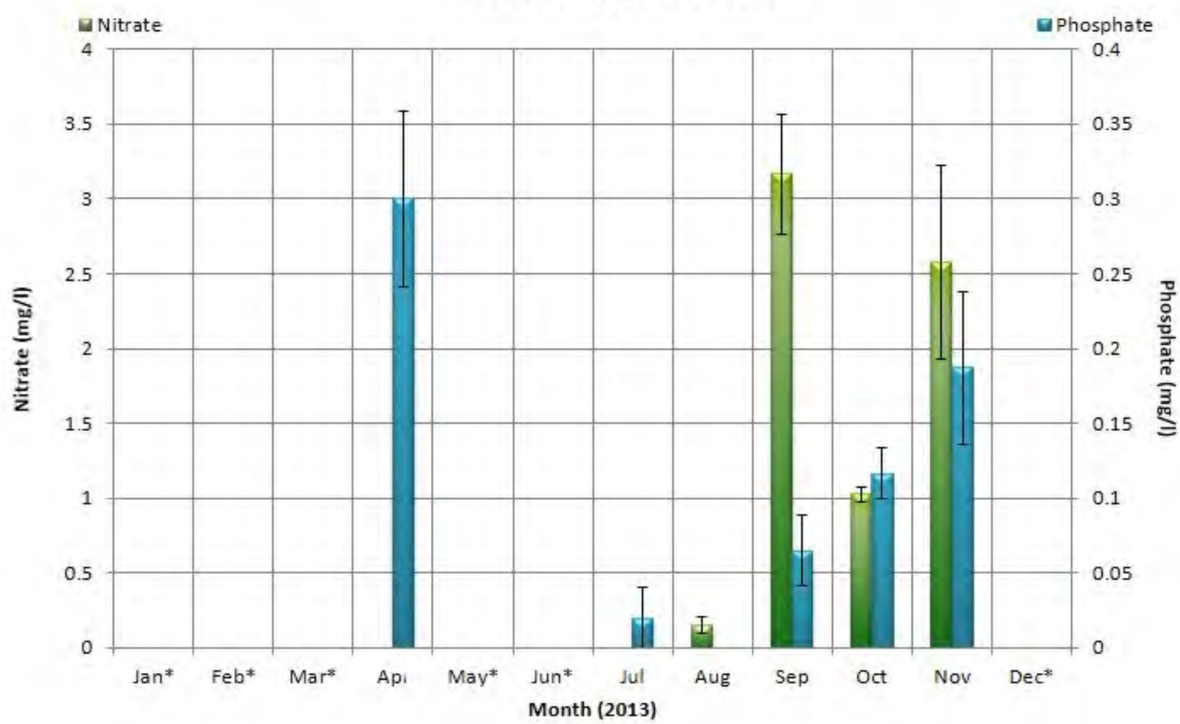


Fig. 5.1b: **Mean nitrate & phosphate concentrations (mg l^{-1}) by month 2013:Rio Grande**

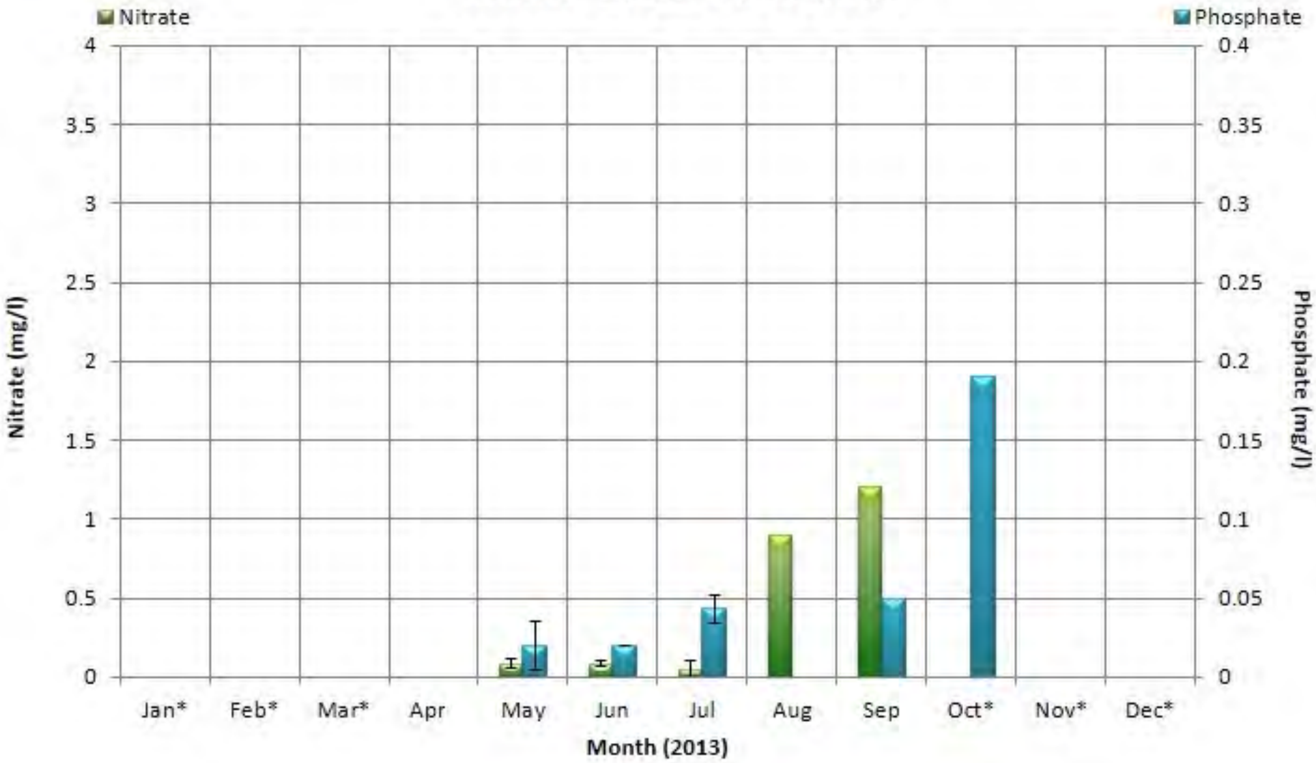
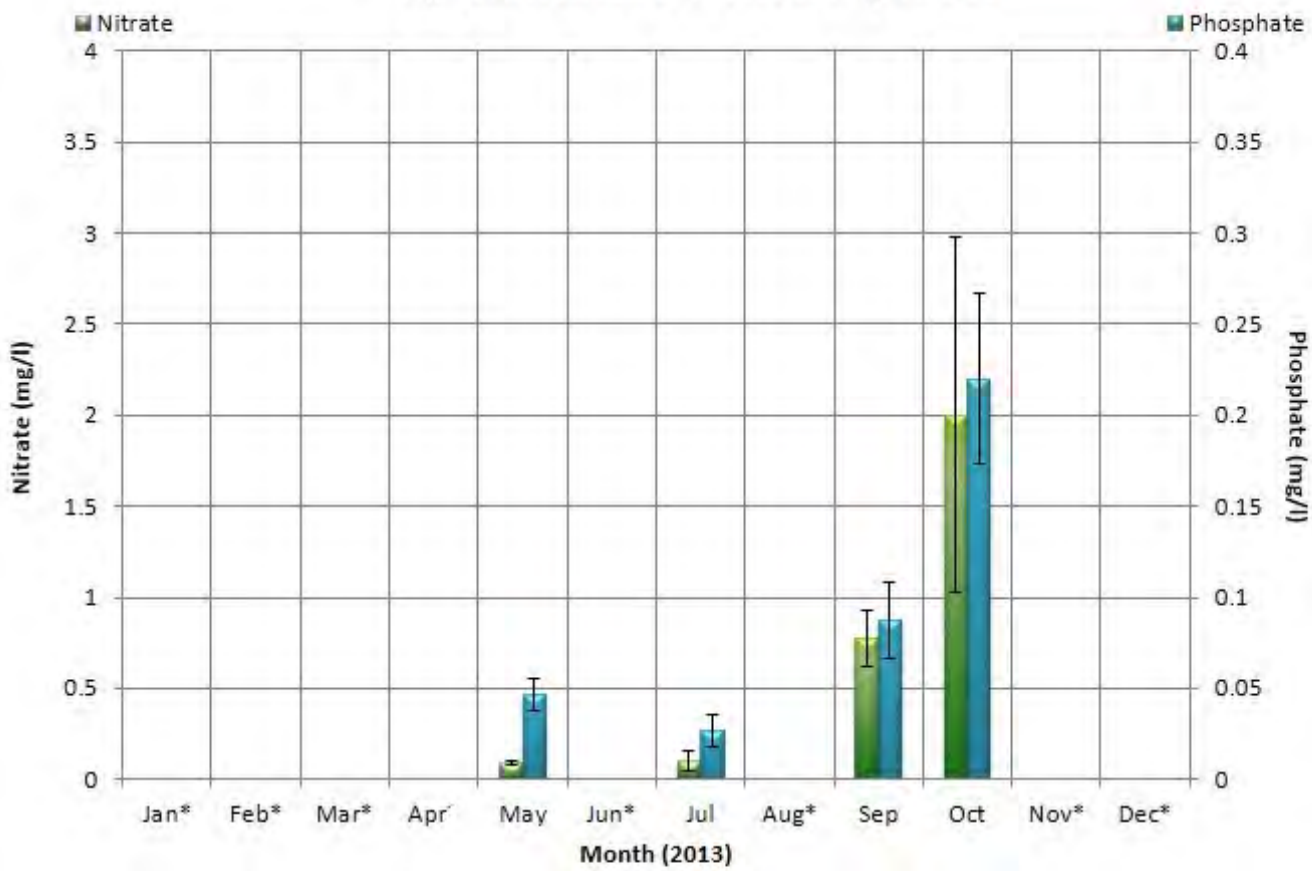


Fig. 5.1c: **Mean nitrate & phosphate concentrations (mg l^{-1}) by month 2013: Monkey River**



5.2. Nitrate 2013: Surface - PHMR, Monkey River, Rio Grande:

- Due to nitrate being an expensive and logistically complicated parameter to measure, only six marine sites and six fresh water sites (three per river) were monitored in 2013, as in 2012. 2013 is the second year of monitoring for this parameter.

- No data is available January – April 2013 because the spectrophotometer was out of country being serviced. Between May-August, levels remained low in both rivers where monitored, and low in PHMR, being slightly higher around Deep River mouth and around the Snake Cayes. In September, much higher levels (~3-4mg l^{-1}) were seen at all marine nitrate monitoring sites, remaining higher until the last monitoring of the year in November.

5.2a-f: Nitrate (mg l^{-1}) 2013 by month (Jan – Jun) PHMR, Monkey River, Rio Grande

a.

Nitrate Jan

No data Available

Spectrophotometer sent away for servicing

b.

Nitrate Feb

No data Available

Spectrophotometer sent away for servicing

c.

Nitrate March

No data Available

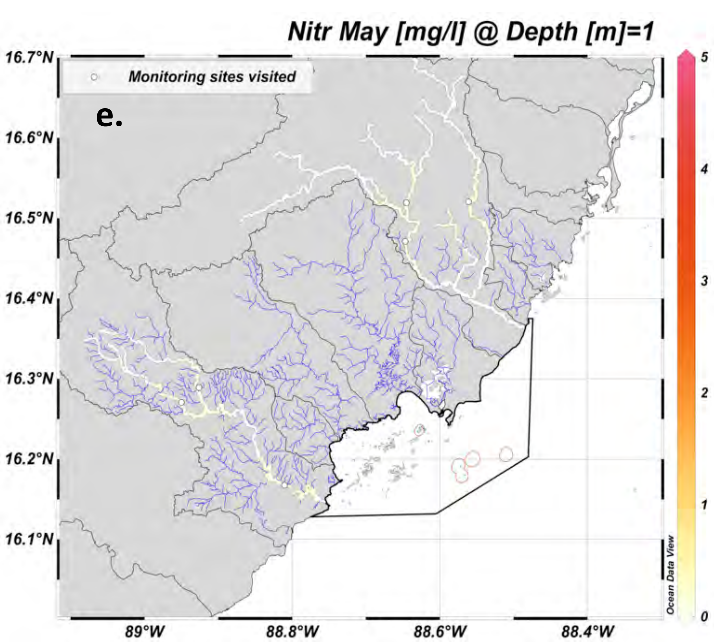
Spectrophotometer sent away for servicing

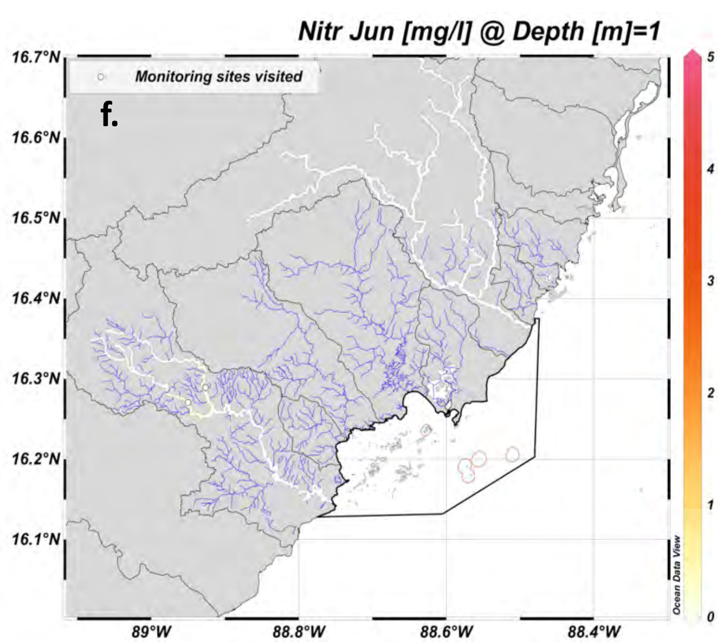
d.

Nitrate April

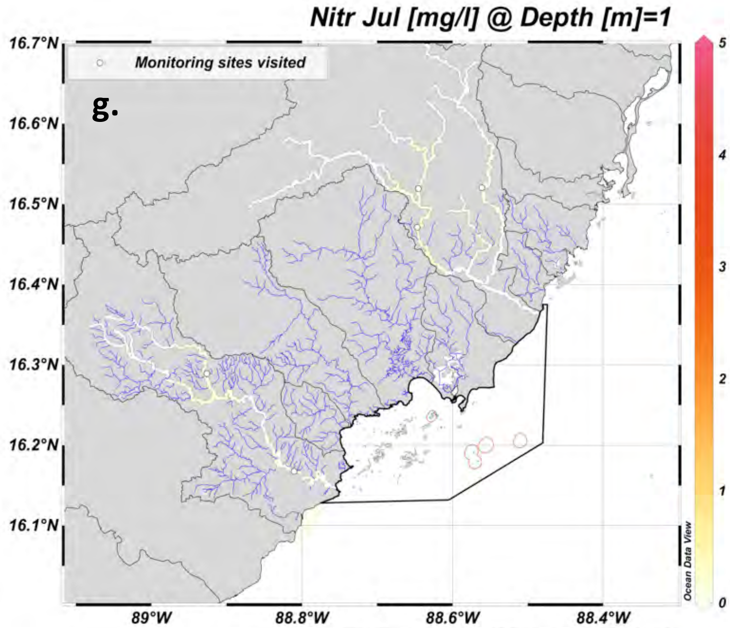
No data Available

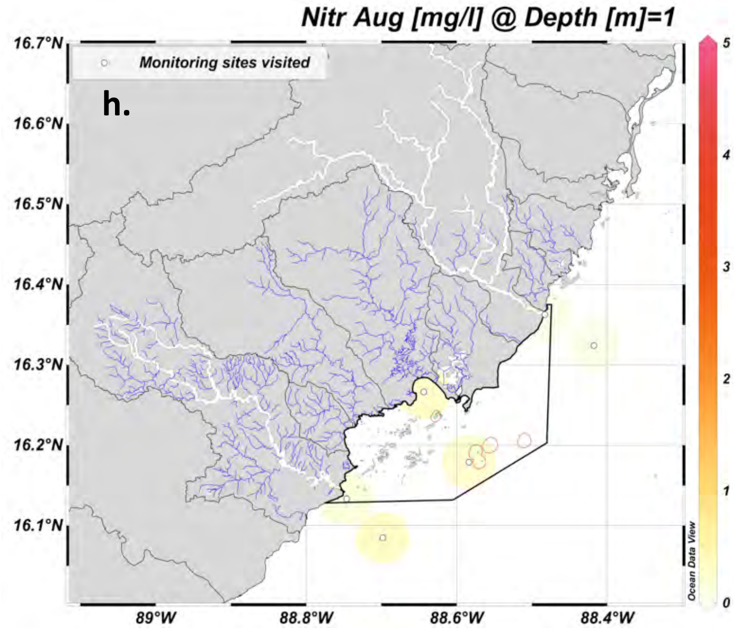
Spectrophotometer sent away for servicing

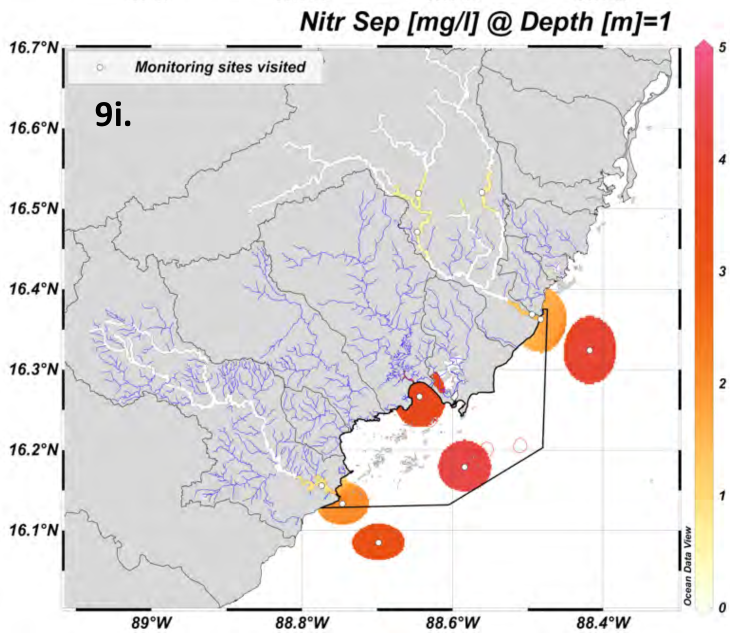


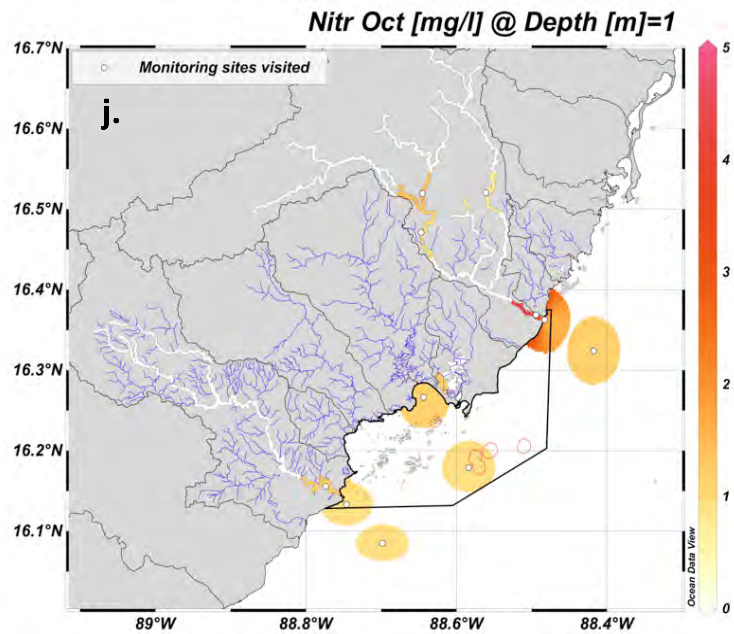


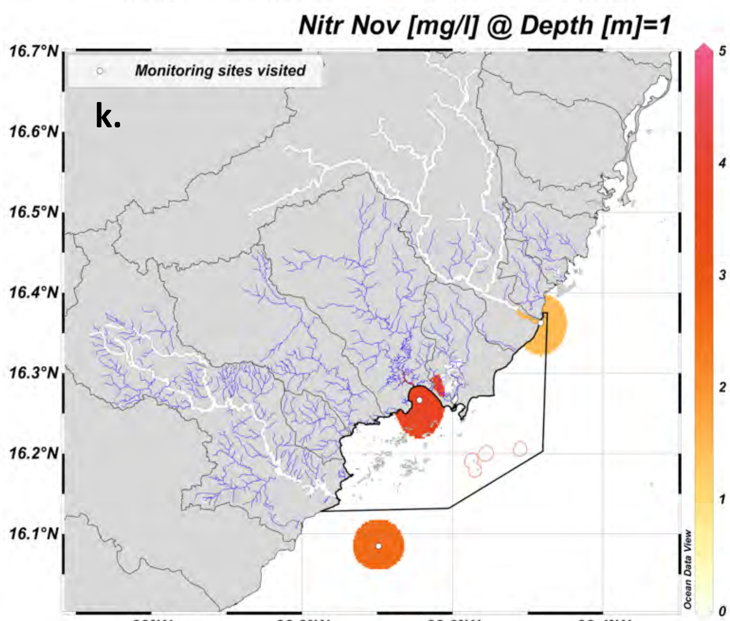
5,2g-l: Nitrate (mg l^{-1}) **2013 by month (Jul - Dec) PHMR, Monkey River, Rio Grande**











l.

Nitrate Dec

No data available

Water pumps for nutrient analysis broken

5.3. Phosphate 2013: Surface - PHMR, Monkey River, Rio Grande:

- Highest phosphate readings were in April, especially high outside Monkey River. This may suggest high domestic waste input, with agriculture as another possible source. It is also possible that the spectrophotometer was still not calibrated properly as it was the first month in use since its return from servicing. This machine is routinely calibrated before every use. Unfortunately, lack of accompanying nitrate data for April precludes further investigation of whether agriculture was a source or simply a calibration problem.

- Phosphate levels were low throughout rivers and PHMR from May to July.

- No data available for August.

- Increasing levels are seen from September to November, with highest readings offshore in November. This is suggestive of increased impact from terrestrial runoff on the marine coastal environment during wet months.

- Phosphate is high in both upper branches, Bladen and Swasey, of Monkey River in October, as is nitrate, suggesting agricultural runoff and possibly domestic waste water to be especially high at this time.

5.3a-f: Phosphate ($mg\ l^{-1}$) 2013 by month (Jan – Jun) PHMR, Monkey River, Rio Grande

a.

Phosphate January 2013:

No data

Spectrophotometer sent away for servicing

b.

Phosphate February 2013:

No data

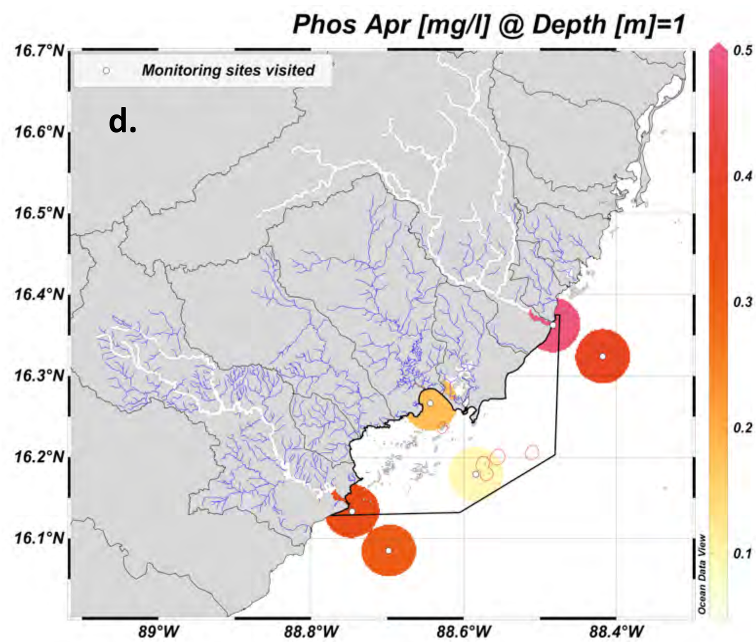
Spectrophotometer sent away for servicing

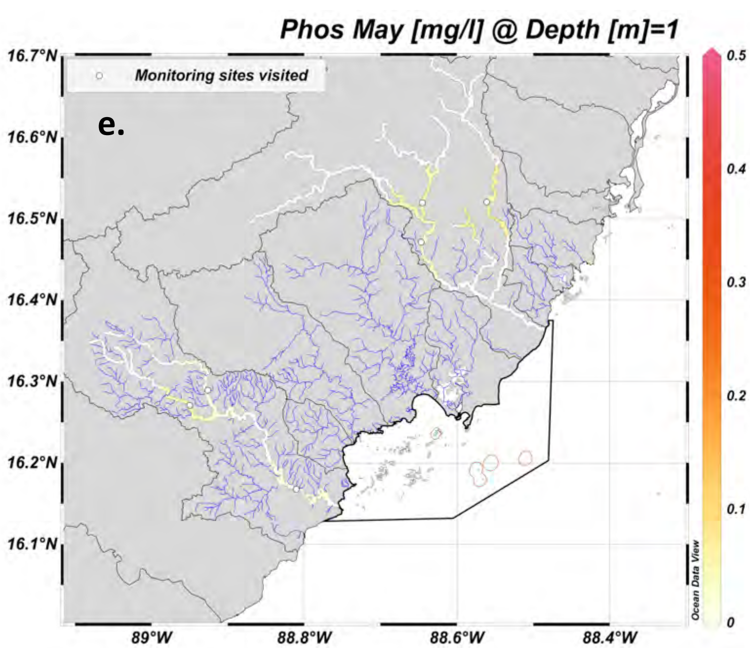
c.

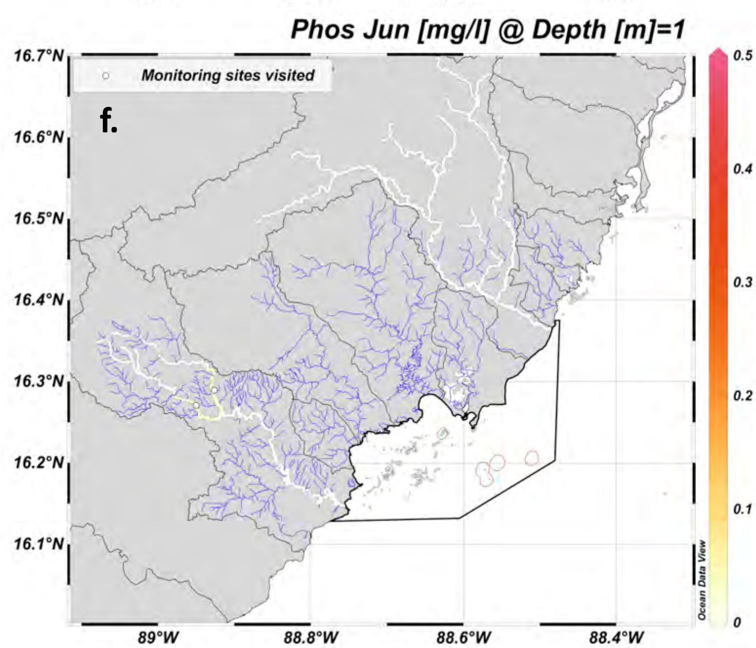
Phosphate March 2013:

No data

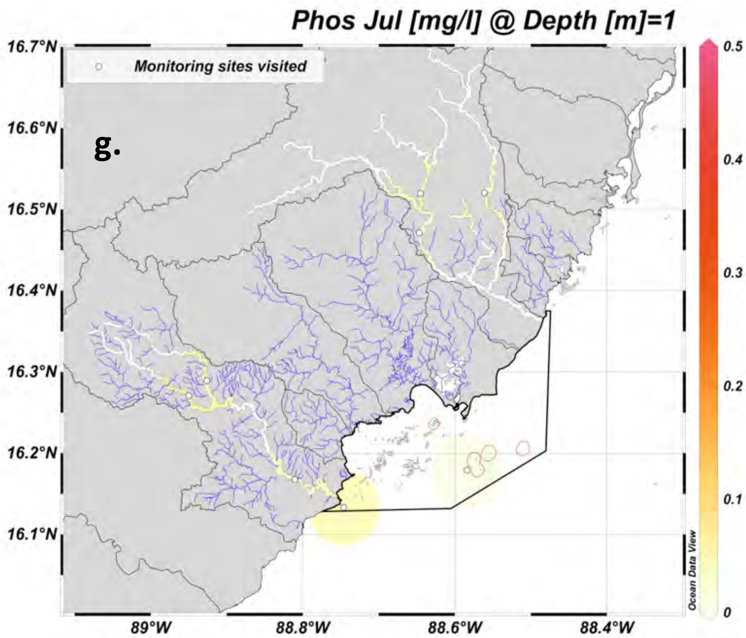
Spectrophotometer sent away for servicing







5.3g-l: Phosphate (mg l^{-1}) 2013 by month (Jul – Dec) PHMR, Monkey River, Rio Grande

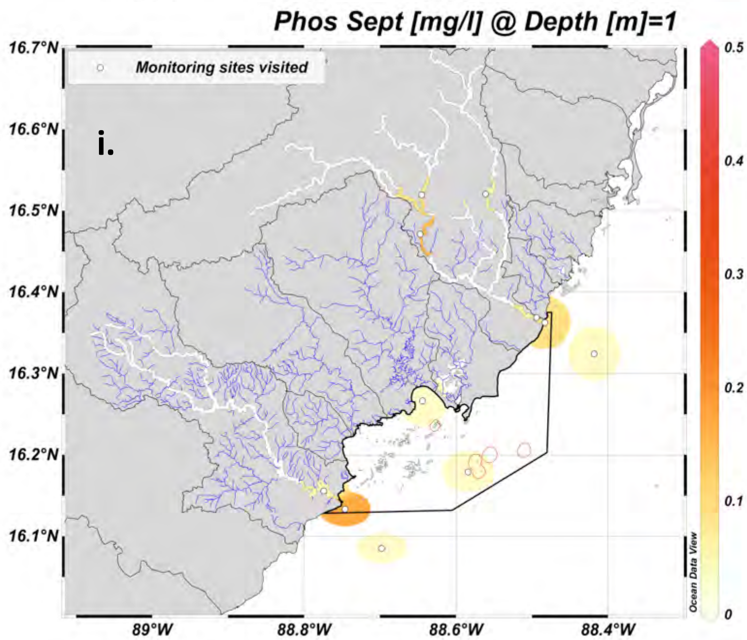


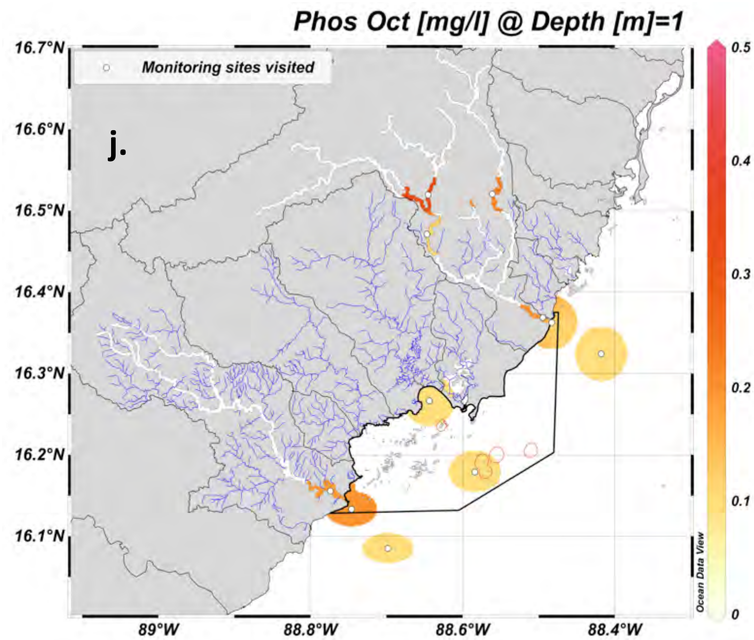
h.

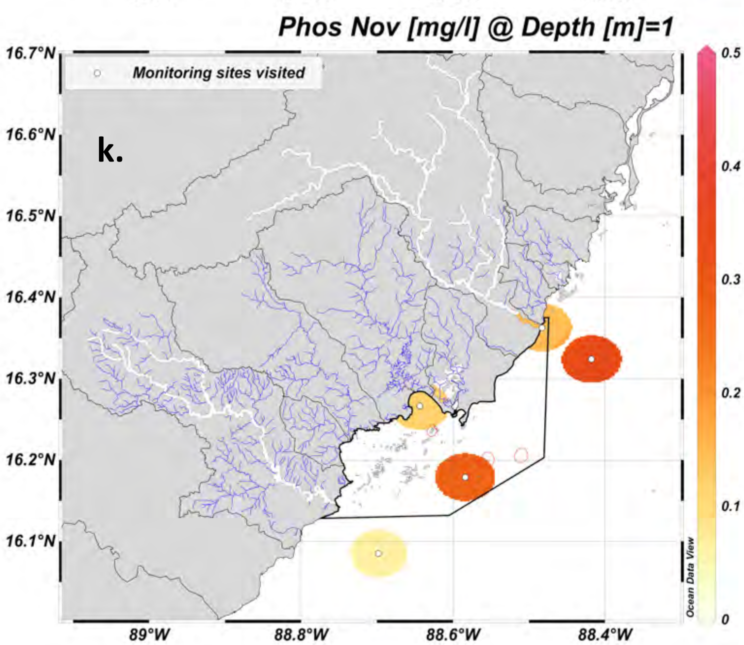
Phosphate August 2013:

No data

Spectrophotometer sent away for servicing







l.

Phosphate December 2013:

No data

Water pumps for nutrient analysis broken

5.4. Nitrate and Phosphate: general conclusions:

- High nitrate and phosphate in general in PHMR in November, this coincides with drier conditions in November as seen from November salinity data. Could indicate that marine **nitrate and phosphate may not always be due to runoff from land.**

- Relative proportions of nitrate and phosphate can enable inferences to be made on sources. High nitrate and phosphate together may be more indicative of agricultural runoff, whereas high phosphate alone would be more indicative of domestic grey water.

- **There was a general increase in nitrate and phosphate levels in both rivers and the sea between May and October, the wet season.**

- **There appears to have been an increase in phosphates in Rio Grande since 2012. This could be due to population increase in riparian zone buffer communities of Rio Grande watershed.**

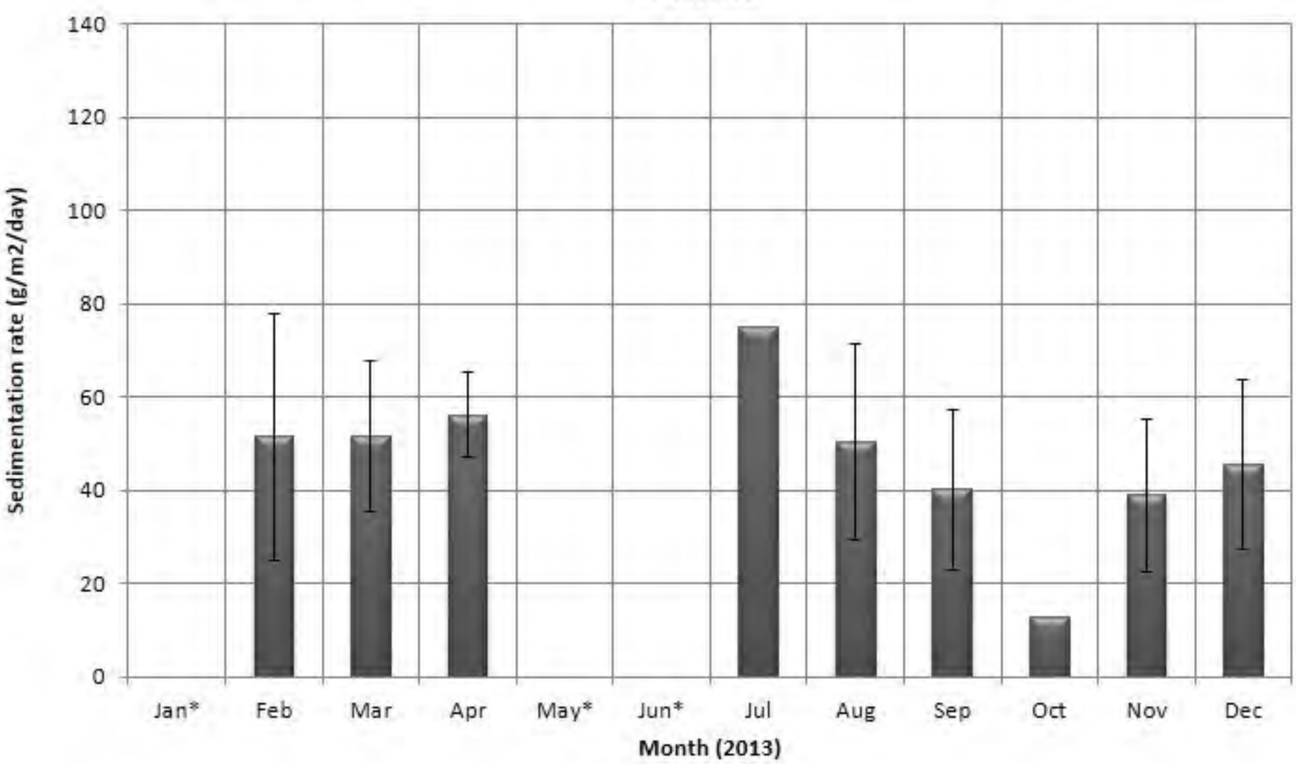
6. Sedimentation

Note: no sedimentation data is collected for Rio Grande or Monkey River.

6.1. Mean sedimentation 2013 PHMR:

- No data is available for January, May or June due to technical issues. February, March and April had moderate mean sedimentation rates, with reducing standard error over time pointing to notable sedimentation at both inshore and offshore areas. July appears highest due to only one trap being possible to visit that month, at Deep River where sedimentation was high, hence standard error of 0. Rates declined steadily to a low of 12.9 g m^{-2} day^{-1} (Table 7) in October, before increasing again through November and December. However, only one site was observable in October (site 7c) and so this cannot be considered representative of general conditions.

Fig. 6.1: Mean sedimentation rates (g m^{-2} day^{-1}) by month 2013: *PHMR*



6.2. Sedimentation 2013: multi-depth 1m, 5m 10m, 15m - PHMR, Monkey River, Rio Grande:

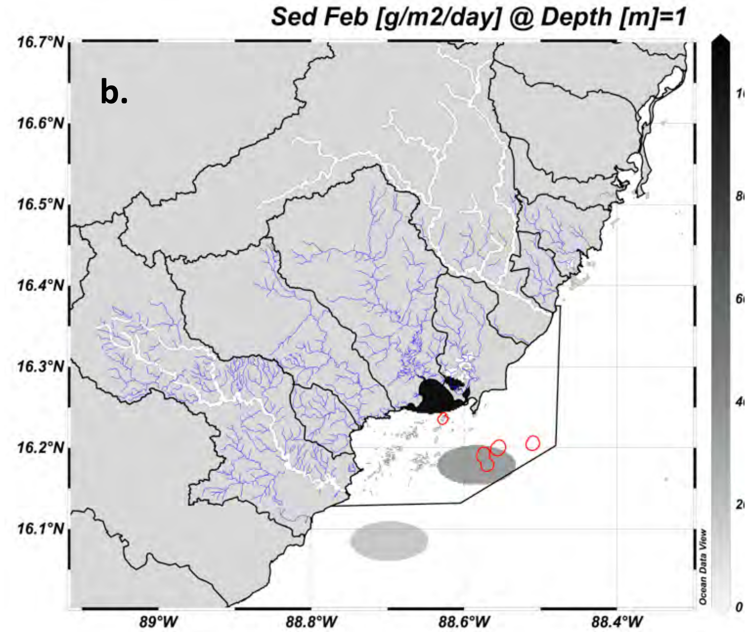
- Sedimentation rates (where known) were usually higher at nearshore sites than at offshore sites. No data is available for January. Between February and April, sedimentation rates were relatively high, around 80 g m^{-2} day^{-1} in Deep river throughout and high around Snake Cayes also. No data is available for May or June 2013. In July and August, rates remained high near Deep River, and very high in Monkey River in August. Moderate rates in coastal areas in September, minimal data for October, higher inshore in November, dropping again in December.

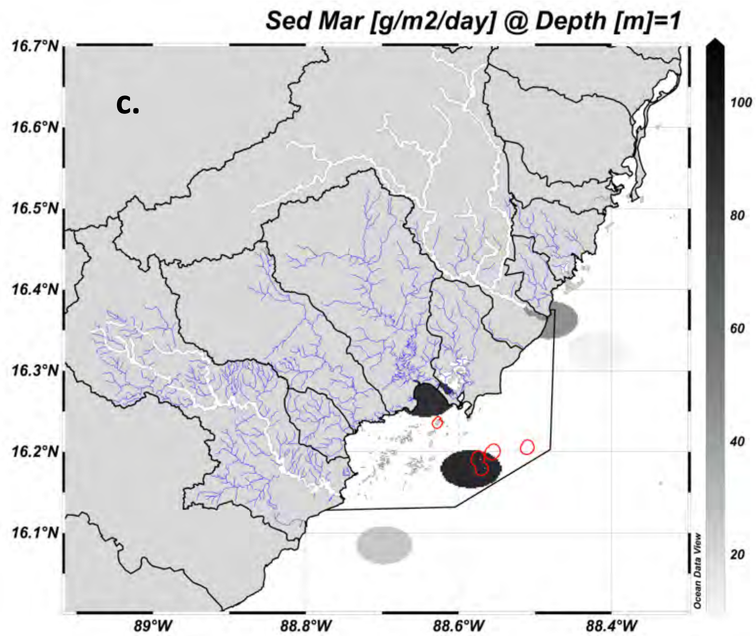
6.2. a-f: Sedimentation (g m^{-2} day^{-1}) 2013 by month (Jul – Dec) PHMR, Monkey River, Rio Grande

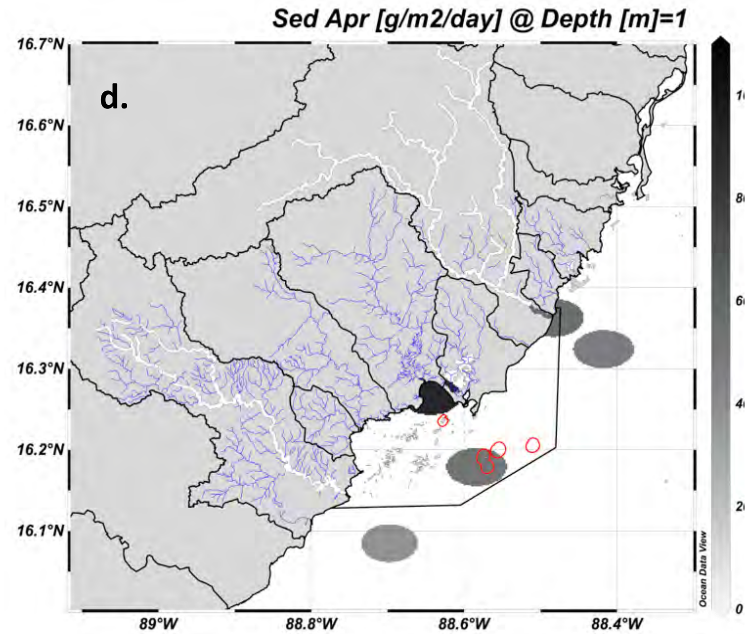
a.

Sedimentation January 2013:

No data







e.

Sedimentation May 2013:

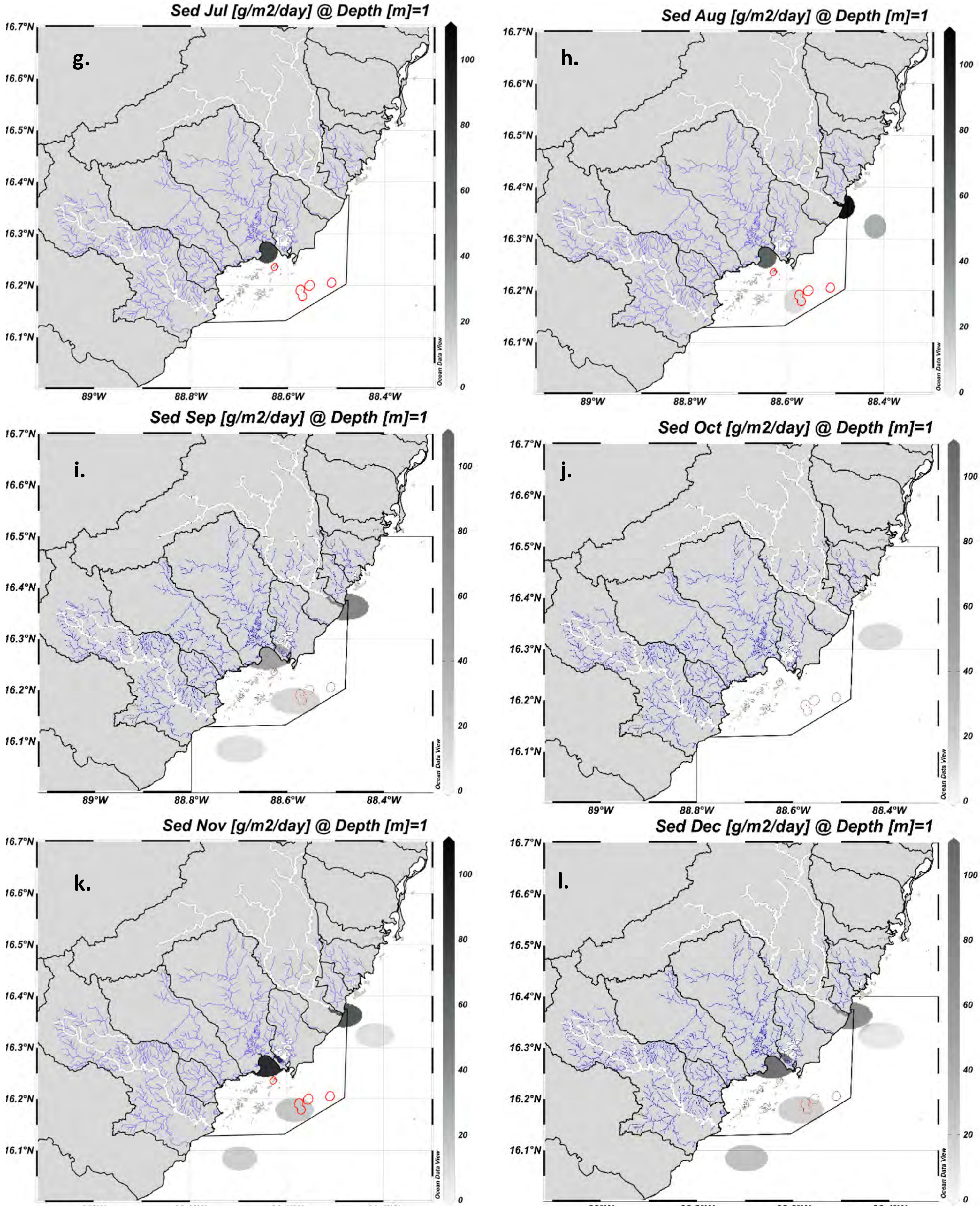
No data

f.

Sedimentation June 2013:

No data

6.2 g-l: Sedimentation (g m^{-2} day^{-1}) 2013 by month (Jul – Dec) PHMR, Monkey River, Rio Grande



DISCUSSION

One objective of the water quality monitoring program is to determine baseline trends in water quality by comparing data over multiple years.

2009-2013 comparison:

- In the years 2009-2013, there were clear trends in salinity and temperature in PHMR (Figs. 1.4 and 3.2). Each year 2009-2013, mean surface temperature was low in January (~26.8°C), typically increasing each month to April. During April to September each year, temperatures remained relatively stable fluctuating from ~30°C to~31°C. After September temperatures decreased to the end of each year, reaching ~27°C in December.

- Mean surface salinity oscillated, being high (~35ppt) in the first four months of the year, and dropping considerably to around 28ppt from June to August, and increasing again to above 30ppt for the rest of the year.

- No clear trends were observed over the last five years in dissolved oxygen or visibility. For visibility, this could be due to several factors including variable cloud cover, sun angle, eyesight of different observers and sea state. TIDE has recently purchased a new YSI ProPlus meter which is capable of measuring total dissolved solids, a more reliable parameter upon which to infer turbidity. It is hoped that this will elucidate trends in visibility in coming years. DO trends could become more apparent now that the DO sensor cap is being regularly maintained. It is unknown whether this was being done regularly before 2011. Also, DO values have for the last couple of years been expressed in % as it was thought easier for stakeholders to understand than mg/l. However, % is normalized to oxygen saturation at a given temperature, so that 100% at 20°C say equates to around 9mg/l, but at 32°C, 100% equates to around 7mg\l. In future, DO will be analysed in mg/l.

- In general, PMHR is warmer than the river with few exceptions. Rio Grande has a much lower mean temperature than Monkey River. Both rivers tend to reach a low mean temperature at approximately 24.0°C in January or December. Both Rio Grande and Monkey River reach a high temperature in May however the increase is more pronounced in Monkey River reaching 29.1°C while the Rio Grande reach a high of 25.9°C.

- There has been a gradual decrease in mean overall temperature of PHMR since 2009 to 2013 (Fig.1.5). This may be due to incomplete datasets in earlier years, although a similar trend has been observed in Pacific waters http://www.nature.com/nclimate/journal/v4/n3/full/nclimate2106.html. Further comparison with regional Caribbean and global ocean data is needed to affirm this observation.

Natural or anthropogenic?

- A second objective of the water quality monitoring program is to understand and determine causes (natural and anthropogenic) of spatial and temporal fluctuations in water quality in PHMR and associated river systems. Monkey River continues to be more susceptible to seasonal changes compared to Rio Grande with respect to temperature increase. Both rivers reach a similar low temperature in January but Monkey River temperature was 3.2°C higher than Rio Grande in May. This is possibly due to greater anthropogenic influences which have led to wider shallow profile compared to Rio Grande, supporting observations made in 2012. See 2012 TIDE water quality report for further details. The effects of this on the ecosystem have yet to be assessed but warrants further targeted research to compare biodiversity of the two rivers. A baseline study of fish biodiversity and water quality by Esselman in 2001 could be used as a comparison, and Halvorson's (2014) ecosystem study of the Rio Grande can also help to inform this research question, to. compare biodiversity between the two rivers and changes in each river over time.

- One point of concern in 2013 is Bladen branch of Monkey River, which exhibited extremely low dissolved oxygen regularly between May and August. While this could be attributed to geology, it is known that this area is subject to rapid land use change and therefore closer attention is recommended, supporting research with outreach and education to communities in this area. Additionally, there appears to have been an increase in phosphates in Rio Grande since 2012. This could be due to population increase in riparian zone buffer communities of Rio Grande watershed.

RECOMMENDATIONS

A series of recommendations for stakeholder engagement, research and monitoring, reserve management, education and outreach and capacity building are provided below in light of the findings outlined in this report.

a. Stakeholder engagement:

- In order for TIDE's large amount of environmental data to be considered in EIAs and development plans, it is important to maintain good communication with the Department of Environment and industry stakeholders. This will enable TIDE to empower affected local communities by putting the tools and information in their hands to know what the long and short term environmental and socioeconomic impacts are, so that **stakeholders may participate in public consultations empowered with factual information upon which to base sound and ethical decision making for the betterment of livelihoods and the environment.**

- Engage with communities in the Bladen branch area about riparian zone management, low impact farming methods and good sanitation.

- Consult with farmland owners in Bladen area to encourage transparent testing of waste water from their land, particularly in September, October and November.

b. Research & Monitoring recommendations:

- **Include Deep River and Punta Ycacos in the fresh water quality monitoring program.** This large and near-flat basin contains vast amounts of water. Given the sheltered nature of the receiving marine environment around Deep River mouth, this area of PHMR may be more vulnerable to riverine impacts than areas around more exposed Monkey River and Rio Grande mouths. Furthermore, it is the **closest watershed to the Snake Cayes and associated Replenishment Zones (RZs), an area of high ecological and economic importance due to its demonstrated function as a commercial species spawning, nursery and larval propagation site, and**

important for tourism as well. This is now more critical as Providence Energy's oil exploration plans may directly impact Deep River and Punta Ycacos lagoon in the near future. Capacity for achieving these objectives can be developed with TIDE's approaching group volunteer program "Ridge to Reef Expeditions", which should also increase financial self-sustainability of watershed scale water quality monitoring and of TIDE as a whole. This is expected to begin mid-2014.

- Increase parameters to include biological and chemical oxygen demand (BOD and COD), pH, conductivity, total suspended solids, total dissolved solids and enterococci in accordance with template requirements for EIA's relating to oil development in protected areas. Monitoring frequency should also be increased.

- Excess nutrients can be devastating for sensitive coastal marine ecosystems. Continued monitoring is needed to determine principal sources of nutrients and other contaminants into PHMR, especially in light of impending oil development plans in the area.

- Begin using YSI ProPlus multiparameter meter in 2014, console purchased, now awaiting cable. While this cannot be used for marine nutrient sampling, it will enable increased accuracy, frequency of sampling and increased number of sites in rivers to be monitored. This will allow the Spectrophotometer to be permanently calibrated to marine conditions, recuding the likelihood of calibration issues switching constantly back and forth from fresh to salt water calibrations. Also the new probe can monitor for total dissolved solids, a better parameter to measure than Secchi disc-based visibility, which is influenced by weather conditions, time of day, light conditions, user subjectivity etc.

- Increase external collaboration to incorporate data from Middle River / Golden Stream with Ya'axche to improve understanding of marine data from close to the mouths of these rivers. The National Coral Reef Monitoring Network (NCRMN) is now spearheading the development of this plan on behalf of the CCCCC. As chair of the NCRMN for 2014, TIDE is guiding the development of the national level water qualty monitoirng strategy based on its experiences with water quality monitoing in PHMR and associated watersheds.

c. Management / outreach recommendations:

- Potential oil development is a new threat to PHMR, and with oil exploration concessions held by Providence Energy in PHMR and Payne's Creek, **TIDE must prepare for increased pressure to drill inside the boundaries of PHMR and other protected areas in the region**

- Educate inland communities about wide reaching downstream impacts of upstream unsustainable activities, using this report and satellite images of sediment plume from Monkey River.

- Education and outreach activities aimed at reducing watershed impacts can use the findings of this report to develop holistic ridge-to-reef educational courses and community based action projects. Improved understanding of environmental and socioeconomic interconnectivity can improve compliance and instil a sense of stewardship among key watershed stakeholder communities.

- Timely reporting of unusual water quality related phenomena, such as dissolved oxygen dead zones, eutrophication, fish die-offs, sargassum rafts and anything else that may occur, in order to improve awareness of TIDE's monitoring, and demonstrating its effectiveness at informing management, outreach and enforcement.

d. Fundraising / capacity building recommendations:

- This empirically based demonstration of the interconnectivity between land and sea can be useful in attracting funding into currently underfunded terrestrial monitoring activities. Marine monitoring has historically been better funded in Belize, probably because Belize is best known worldwide for its reef, even though it is one of the last strongholds for intact rainforests in Central America. If funders understand the impacts faced by the marine environment by land based activities, it may encourage more funding to address these impacts from parties most interested in marine affairs. TIDE is better positioned than other organisations managing marine reserves to manage land based impacts because adjacent watershed areas are also managed by TIDE (PCNP and PLI. Also, through cooperation with other local NGOs such as Ya'axché, human resource and site access issues could be resolved with partnerships. For example, Ya'axché are better positioned to monitor Deep River because their rangers routinely patrol Deep River Forest Reserve. A partnership would not only provide TIDE with data on currently unmonitored watersheds, but increase the utility of Ya'axché's monitoring, enabling both organisations to benefit from the larger scale context of their findings.

2012 RECOMMENDATIONS – PROGRESS REPORT

This section outlines progress made on last year's recommendations from water quality monitoring:

- Dolphin population and migration baseline study to prepare for possible future oil development. – ***Completed – Jorge Rojas conducted this study now publically available from TIDE R&M department.***

- Continued monitoring of cetacean populations, migration patterns navigation and other behaviour in the event that oil seismic testing and / or drilling take place in PHMR or nearby areas. ***- there are plans to conduct manatee baseline study in PHMR tin summer 2014 by ECOSUR student Transito Gonzalez.***

- Build on holistic approach to multiple program analysis and interpretation. Water quality and other environmental conditions need to be built into interpretation of other programs, such as commercial species monitoring, to determine the extent and ways in which these influence commercial species size frequency distribution and spatial / temporal distribution. – ***Underway with Von Bertalanffy modelling of fisheries in partnership with EDF and Belize Fisheries Department.***

- Conduct targeted research using stable isotope analysis may help to determine sources of nutrients as being marine or from a specific watershed. – ***completed, see section below on Rio Grande dump site study of 2013 by C. Halvorson:***

Rio Grande Dump Site Study:

In 2013 a research student, Chantelle Halvorson from University of Victoria, Canada, conducted an ecotoxicological impact study of the Punta Gorda dump site on the ecology and water quality of Rio Grande which indicates possible influence of this municipal refuse on waters in the river and in south PHMR. Initial results have shown leachate from the dump site to be depleted in dissolved oxygen. Underwater surveys in the Rio Grande revealed there to be little to no life in waters of the Rio Grande affected by leachate, in contrast to areas immediately upstream from the impacted area.

THIS YEAR 2014

- **Habitat Mapping in 2014** will strengthen interpretation of water quality data, improving understanding of coastal marine benthic structure, habitat types, water circulation patterns and impacts of river runoff on coastal environments, For example comparison of TIDE's water quality data with satellite information acquired with permission from Remote Sensing Solutions (RSS) in partnership with MarFund, the Snake Cayes are now thought to be under greater influence from oceanic currents and Monkey River to the north and north east, rather than from Deep River.

Rapid Eye image loaned from Remote Sensing Solutions GmbH demonstrating coastal dynamics of PHMR

- **Ridge to Reef Expeditions to support water quality monitoring -** Regular water quality monitoring will be more critical in the Deep River and Punta Ycacos areas in light of impending oil exploration plans of Providence Energy in Port Honduras Marine Reserve, Payne's Creek National Park, TIDE Private Protected Lands and nearby Deep River Forest Reserve managed by Ya'axche. While this is currently beyond the capacity of TIDE's research team, it is hoped that Ridge to Reef Expeditions can provide the financial resources, manpower and regular visits necessary to obtain good quality data to monitor impacts of this activity on the sensitive endangered species ecosystems known to exist in this area. This is planned to commence in summer 2014 with the recruitment of an Expeditions Manager for Ridge to Reef Expeditions in March 2014.

LIMITATIONS OF STUDY

- Sediment, nitrate and phosphate programs need to be expanded to improve statistical rigour and spatial interpretation of the data. Mid-sections of both rivers are currently under-represented. Site access is a limiting factor. A field visit is necessary to identify new sites in these sections. Further funding is needed to achieve this.

- Some important parameters are not currently being monitored under this program, e.g. pH, conductivity, chemical oxygen demand, BOD^5, total suspended solids, total dissolved solids, Enterococci. Some of these could be monitored easily with little extra cost besides purchasing inexpensive equipment, e.g. pH and conductivity. TIDE used to monitor these, but equipment failed in 2010 and it has not yet been possible to replace this due to funding constraints. The other parameters are a bit more complex to monitor, but very important as these are often required during an EIA process. If TIDE is to stand resilient against future development pressure inside PHMR and other protected areas, it needs to begin monitoring these as soon as possible. TIDE has now purchased a YIS ProPlus water quality meter to help address this.

- Fresh water monitoring of Deep River and Punta Ycacos lagoon is needed to better understand their relationship with PHMR, especially in light of the impending Providence Energy oil exploration proposal for the area.

ACKNOWLEDGEMENTS

- Thanks to the OAK foundation and KfW for making this work financially possible. Thanks to the Community Researchers for their commitment and dedication in collecting high quality data. Thanks to the Belize Fisheries Department for their continuing cooperation with TIDE's research and management of PHMR. Sincere thanks to Dr. Daryl Smith Ph.D., Professor from Langara College in Vancouver, Canada, intern of research department at TIDE from October 2013 to July 2014, for his technical support in data analysis and interpretation.

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Appendix:

Tables

Table 1a. Mean monthly temperature (^oC) PHMR 1m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A	28.2	26.6	29.3	31.9		31.1	30.4	31.5	33.4	28.6	25.5	28.3
1B	27.2	26.9	27.1	30.4		29.6			30.9	28.1		27.6
2A	27	26	27.7	30.5		30.6	30.4	30.5	32	28.2	25.7	28.1
2B	26.8	26.5	27.4	30		29.7	30	30.4	31.1	28.2	26.2	27.6
2C	26.7	26.4	27.1	29.8		28.9	30	29.7	30.2	28.3	26.8	27.4
3A	28.5	24.8	28.1	30.6		30.5	31.1	30	30.9	28.8	29.6	29.0
3B	27.8	25.5	27.6	30.2		29.8	29.5	29.4	29.9	27.3	27.0	27.7
3C	27.4	26.5	27.5	30.1		29.3	30.1	29.5	30.4	28.4	27.5	27.3
4A	27.5	26.5	27.5	30.4		29.9	29.5	29.8	30.6	28.5	28.9	27.6
4B	27.1	26.7	27.5	30.2		29.4	31.3	29.6	29.9	28.3	27.7	27.3
4C	27	26.3	27.3	29.9		29.7	30.1	29.7	30.1	28.8	27.7	27.1
5A	26.8	26.3	27.4	30.1		29.4	29.9	30.6	31.3	29.5	27.3	27.3
5B	26.8	26.4	27.5	30.1		29.1	28.5	30.3	31.4	28.4	27.2	27.3
5C	26.8	26.7	27.1	30.1		29.2	29.2	30	31.1	28.9	27.5	27.1
5D	26.7	27.2	27.5	29.9		29.6	30.1	29.9	31.8	29	27.2	27.1
5E	26.5	27.3	27.4	29.6		29.2	30.2	29.8	31.2	29.2	28.4	27.1
6A	26.8	26.1	27.6	33.3		29.4	30	29.7	30.7	29	28.0	27.6
6B	26.8	27.3	27.5	30.2		29.3	29.8	29.7	30.8	28.5	27.3	27.0
6C	26.3	27.3	27.3	29.7		29.1	29.7	29.4	30.8	28.4	27.0	27.3
6D	26.4	27.2	27.1	29.5			29.7	29.2	30.6	28.4	27.0	27.2
7A	27	27.3	27.2	30.3				29.9	30.8	28.3	29.4	26.5
7B	26.3	27.2	27.2	29.9				29.8	30.6	28.2	29.0	26.9
7C	26.3	27.2		29.5				29.7	30.5	28.8	27.7	27.1
8A	25.9	26.9		29.1				30.3	30.3	26.1	24.6	27.2
8B	26.1	27.3		29.7				29.8	30.2	28.6	28.0	26.7
9A	25.9	26.5		29.9				30.4	30.3	27.1	25.5	27.5
9B	26	27.2		29.6				30	30.3	28.8	27.5	26.6
Count	27	27	22	27	0	19	19	26	27	27	26	27
AVG	26.83704	26.67037	27.49545	30.16667		29.62105	29.97368	29.94615	30.81852	28.3963	27.35	27.34691
STD	0.644592	0.610053	0.467493	0.804315		0.568213	0.618997	0.476849	0.736957	0.679073	1.198453	0.517494
ST ERROR	0.124052	0.117405	0.09967	0.154791		0.130357	0.142008	0.093518	0.141827	0.130688	0.235036	0.099592

Table 1b. Mean monthly temperature (°C) PHMR 5m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1B	27.5	26.2	27	30.3		29.5			30.3	28.7		27.3
2B	27	26.5	27.4	29.9		29.3	30	30	30.5	28.8	26.2	27.4
2C	26.8	26.4	27.2	29.9		29.2	29.8	29.7	30.5	28.7	26.8	27.1
4A	26.9	26.5	27.4			29.5	30.7			30.3		
4B	26.9	26.7	27.5	30.2		29.2	30.3	29.8	30.5	29.1	28.1	27.1
4C	26.8	26.3	27.3	29.7		29.4	30.3	29.7	30.6	29.3	27.8	27.1
5B	26.4	26.4	27.5	30		29.3	30.3	30.2	30.7	30	27.3	27.3
5C	26.6	26.7	27.3	30		29.4	30.1	30	30.8	29.3	28.5	27.1
5D	26.6	27.3	27.5	29.8		29.3	30.4	29.9	30.8	29.3	27.9	26.9
5E	26.5	27.3	27.4	29.6		29.2	30.4	29.7	30.7	29.4	28.4	27.0
6A	26.8	26.4	27.6	30.3		29.4	30.4	29.8	30.7	29.5	29.4	27.1
6B	26.7	27.3	27.5	30.1		29.3	30.3	29.7	30.7	29.1	28.8	27.1
6C	26.3	27.3	27.3	29.7		29.2	30.3	29.6	30.7	29	27.1	27.2
6D	26.3	27.2	27.1	29.5			30.4	29.5	30.5	29	27.1	27.0
7A	26.6	27.5	27.2	30.2				29.8	30.7	29.1	29.6	26.7
7B	26.3	27.1	27.2	29.8				29.6	30.5	28.9	29.1	26.8
7C	26.2	27.2		29.4				29.6	30.4	29	27.8	27.3
8B	26.1	27.3		29.7				29.8	30.5	29.1	28.5	26.7
9B	26	27.2		29.6				29.8	30.4	29	29.0	26.6
Count	19	19	16	18		13	13	17	18	19	17	18
AVG	26.59474	26.88421	27.3375	29.87222		29.32308	30.28462	29.77647	30.58333	29.18947	28.08	27.05
STD	0.362819	0.438765	0.166833	0.273981		0.109193	0.219265	0.175105	0.146528	0.405373	0.97	0.23
ST ERROR	0.083236	0.10066	0.041708	0.064578		0.030285	0.060813	0.042469	0.034537	0.092999	0.23	0.05

Table 1c. Mean monthly temperature (°C) PHMR 10m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2B	26.9	27	27	30.1		29.3	30.1	30.1	30.5	29.2		27.3
2C		26.5	27.2			29.3	30	30	30.5	28.9	26.8	27.1
4B	26.9	26.7	27.2	30.2		29.3	30.1	29.8	30.5	29.6	29.6	27.5
4C	26.7	26.5	27.2	29.9		29.4	29.8	29.8	30.6	29.3	29.5	27.1
5C	26.6	26.8	27.4	29.9		29.3	30	29.8	30.5	29.8	29.6	27.6
5D	26.5	27.3	27.4	29.8		29.4	30.1	33	30.6	29.8	29.4	27.0
5E	26.5	27.3	27.4	29.7		29.3	30.1	29.8	30.5	29.6	28.5	27.3
6B	26.6	27.3	27.4	30.1		29.3	29.8	29.7	30.5	29.5	29.5	26.9
6D	26.3	27.2	27.2	29.5			30.2	29.5	30.4	29.3	28.7	27.0
7A	26.5	27.4		30.1				29.8	30.7	29.2	29.6	26.8
7B	26.2	27.2	27.2	29.8				29.6	30.5	29.1	29.5	26.9
7C	26.2	27.2		29.4				29.7	30.5	29.1	28.3	26.9
8B	26.1	27.3		29.7				29.7	30.5	29.3	29.4	27.0
9B	25.9	27.2		29.6				29.8	30.4	29.2	29.5	26.6
Count	13	14	10	13		8	9	14	14	14	13.0	14.0
AVG	26.45385	27.06429	27.26	29.83077		29.325	30.02222	30.00714	30.51429	29.35	29.06154	27.065
STD	0.301705	0.310353	0.13499	0.249615		0.046291	0.139443	0.873951	0.077033	0.271038	0.818857	0.266932
ST ERROR	0.083678	0.082945	0.042687	0.069231		0.016366	0.046481	0.233573	0.020588	0.072438	0.22711	0.071341

Table 1d. Mean monthly temperature (°C) PHMR 15m: 2013												
Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2C		27	27.2			29.4	29.8	29.8	30.3	29.4	26.8	27.2
4C	26.7	27	27.1	29.9		29.3	29.7	29.8	30.6	29.5	29.6	27.1
5D	26.5	27.2	27.3	30		29.3	29.8	29.8	30.6	30	29.5	28.0
6B	26.6	27.3	27.4	30.1		29.3	29.9	29.4	30.5	29.6	29.6	28.2
6C	26.3	27.3	27.2	29.7		29.2	29.9	29.6	30.5	29.4	29.5	28.0
6D	26.3	27.2	27.2	29.4			29.9	29.4	30.4	29.3	29.2	28.1
7C	26.2	27.2		29.4				29.7	30.6	29.2	29.1	28.1
8B	26.1	27.3		29.7				29.8	30.6	29.3	29.5	28.5
9B	25.9	27.2		29.6				29.7	30.5	29.4	29.5	28.4
Count	8	9	6	8		5	6	9	9	9	9	9
AVG	26.325	27.2125	27.24	29.725		29.275	29.84	29.65	30.5375	29.4625	29.44583	28.04167
STD	0.265922	0.116667	0.10328	0.260494		0.070711	0.08165	0.165831	0.105409	0.235112	0.896151	0.489331
ST ERROR	0.094017	0.038889	0.042164	0.092099		0.031623	0.033333	0.055277	0.035136	0.078371	0.298717	0.16311

Table 1e. Mean monthly temperature (°C) Rio Grande: 2013												
Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RG_CB_1a	23.9	24.3	23.8	24.1	26	24.1	24	24.2	24	24	23.86667	24.3
RG_CB_1b	24.2	24.2	24.1	24.3	25.9	24.3	24.1	24.3	23.9	23.9	23.93333	24.26667
RG_SM_1a	23.6	23.4	23.8	24.8	24.4	24.1	24	24.1	24	23.9	23.7	23.4
RG_SM_1b	23.8	24.1	24.3	24.9	24.8	24.2	24.2	24.4	24.2	24.1	23.93333	23.7
RG_RG_1a	23.4	24.1	25.9	25.4	25.1	24.4	24.3	24.5	24.4	24	23.93333	23.5
RG_RG_1b	23.5	24.1	26.1	25.3	25.9	24.5	24.1	24.6	24.4	24.1	24.03333	23.7
RG_RG_1c	23.6	26.4	26.4	26.1	29.3	24.3	24.1	25.1	26.3	24.9	25	25.1
RG_RG_1d	25.3	25.4				25.8	25.3	25.5	27.1	24.8		
Count	8	8	7	7	7	8	8	8	8	8	7	7
AVG	23.9125	24.5	24.91429	24.98571	25.91429	24.4625	24.2625	24.5875	24.7875	24.2125	24.05714	23.99524
STD	0.615136	0.944155	1.16251	0.684175	1.615992	0.557898	0.430739	0.479397	1.21354	0.401559	0.428051	0.600132
ST ERROR	0.217484	0.333809	0.439387	0.258594	0.610787	0.197247	0.152289	0.169492	0.429051	0.141973	0.161788	0.226829

Table 1f. Mean monthly temperature (°C) Monkey River: 2013												
Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MR_SB_1a	22.7	26.4	28.7	26.3	27.6	28.3	27.4	26.1	27.2	25.5	25.2	24.53333
MR_SB_1b	23.8	27.1	29.2	27.3	29.5	30	29.2	26.9	29.5	26.4	26.06667	24.8
MR_SB_1c	23.3	27.3	31.2	27.8	29.1	29.5	29.1	26.3	28.5	26.4	26.4	24.8
MR_SB_1d	23.5	27.6	30.4	28.7	29.5	29.3	28.6	25.4	28.2	26.3	26.43333	
MR_TB_1a	24.2	25.9	29	28.1	30.1	29.1	29.1	26.3	27.4	25.5	25.03333	
MR_BB_1a	23.3	26.8	27.3	28.4	29	28.1	27.3	24.1	26.9	25.6	25.83333	
MR_BB_1b	24.3	27	27.5	28.5	29.1	29.5	27.6	25.3	26.6	25.9	25.93333	
MR_MR_1A	24.7	25.7	27.5					26.9	28	25.6		
Count	8	8	8	7	7	7	7	8	8	8	7	3
AVG	23.725	26.725	28.85	27.87143	29.12857	29.11429	28.32857	25.9125	27.7875	25.9	25.84286	24.71111
STD	0.65192	0.671353	1.421267	0.838082	0.771825	0.684175	0.863548	0.941788	0.952347	0.40708	0.545593	0.15396
ST ERROR	0.230489	0.237359	0.502494	0.316765	0.291723	0.258594	0.32639	0.332972	0.336705	0.143925	0.206215	0.088889

Table 2a. Mean monthly dissolved oxygen (%) PHMR 1m: 2013

Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1A	89.7	80.3	66	92		80.7	84	78.3	91	72	69.66667	90.66667
1B	80.3	68.7	70.7	72.7		77.3			80.3	78.3		82.33333
2A	79	69.3	73.3	71		64	73	69.3	80.7	70.3	76.33333	84.33333
2B	74	68	70.7	68.3		71.7	78.3	72.3	82.3	77.7	77.33333	85.33333
2C	73.7	68	71.3	68.3		68.3	66.3	68	80	79	77.33333	86
3A	105.7	71	75.3	64.3		81	87	81	58.3	71.7	83.66667	80.33333
3B	76	64	72	65		68.3	73	63.7	77.7	75.3	74.33333	85
3C	75	73	71.3	75.7		72.7	67	66	77.7	78.3	76.33333	85
4A	74.3	67.7	69.3	67		69	70	66.3	76.7	74.3	71	86
4B	75.7	68	70	69.7		68	66.7	66.3	75.7	76	79	83
4C	71.3	67.7	71	68.7		68	70	66	77.3	75.3	81.33333	83.33333
5A	70	65.3	70	67.7		66	53	67.7	82.7	66.3	71.33333	84.33333
5B	71	67.7	70.7	69		68.3	68	67	80.7	75.7	72	82
5C	71	67	69.7	70		69	65.7	65.7	79.7	76	75	82.33333
5D	69.7	71.3	71.3	69.3		67.7	68	63	78	76.3	75.33333	83.66667
5E	70.3	70	70	69		68.7	68.7	65.3	80	76.7	78	85
6A	72.7	66.3	70.7	65		69.3	65.7	64.3	79.3	76.7	72	83.33333
6B	71.7	70	72.3	68.3		71	66.7	65.3	76.7	75	76.66667	84
6C	71.3	70.3	70.7	69.7		67.3	66	65.3	79.3	78.3	78	86.33333
6D	71	71.3	71	68			67.3	64.7	80	77	79.33333	80.66667
7A	71.3	65.7	70	68.3				67	79.3	78.7	41	83
7B	71.7	70.3	70	70				66.3	81.3	78.7	52.33333	83
7C	72.3	70.3		69.7				65.3	80.3	74	76	83.33333
8A	67.3	58.3		62				57.3	73.3	78		80
8B	72.7	72		69				65.7	80	76.7		84.33333
9A	64.3	58		67.3				52.3	67.7	72		77.66667
9B	72	70.3		68.3				66.3	78.3	78.3		82.66667
Count	27	27	22	27		19	19	26	27	27	22	27
AVG	74.25926	68.51111	70.78636	69.38148		70.33158	69.70526	66.37308	78.30741	75.65185	73.33333	83.59259
STD	7.793501	4.270591	1.701063	5.212488		4.614597	7.354777	5.354965	5.52177	3.018835	9.439868	2.441334
ST ERROR	1.49986	0.821876	0.362668	1.003144		1.058661	1.687302	1.050195	1.062665	0.580975	2.012587	0.469835

Table 2b. Mean monthly dissolved oxygen (%) PHMR 5m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A												
1B	77	69.7	70.3	70		64.7			78.7	71.7		82.7
2A												
2B	72	67	70.3	67		65.3	63.3	65.7	79	75.3	76.0	84.3
2C	73	68	70.7	66.3		69.3	66	65.3	77.3	75	76.3	84.3
3A											81.7	
3B												
3C						72	70	72.7	80	76.7	89.0	85.3
4A	74	67	68.3			66.3	51.7			43		
4B	75	66	68.7	67		68	64.7	65.3	77.7	75	74.7	82.7
4C	71	67	70.3	68		68	67	66	78	77	79.3	83.7
5A												
5B	70.3	66	70	68.3		64.3	60.7	61	80.3	71	71.7	84.3
5C	71	65.7	69	68.3		68.3	63	64.7	79.7	75.3	68.7	83.0
5D	69.7	70	70	68.7		68.3	66.7	65.3	78	76.7	72.0	83.3
5E	69.7	70	70	69		68.7	76.3	66	79	77	76.0	82.7
6A	71	64.7	69.3	65		66.7	59.7	61.7	77.3	75.3	56.0	84.3
6B	71.3	70	69.7	68.3		70	62.3	63.7	76.7	74.3	74.7	83.3
6C	70.3	70	70	68		67.3	64	64.7	78	75	77.7	84.0
6D	70.7	70	69.7	67			59.7	65	79	75.3	79.0	81.7
7A	71.7	70.3	68	68				65.3	80	74	34.0	82.7
7B	71.3	70	69	69				64.7	80.7	76.3	50.7	82.3
7C	71.3	70.7		68.3				66.3	79.3	73.3	74.3	82.7
8A												
8B	72	71.3		68				65.3	81	75.7		82.0
9A												
9B	72	70.7		66.7				66	81	76.7		81.0
Count	19	19	16	18		14	14	18	19	20	17	19
AVG	71.80526	68.63684	69.58125	67.82778		67.65714	63.93571	65.26111	78.98421	73.48	71.27451	83.17544
STD	1.839225	2.069946	0.783342	1.16053		2.105931	5.626532	2.333172	1.312446	7.356601	13.09858	1.090749
ST ERROR	0.421947	0.474878	0.195836	0.27354		0.562834	1.503754	0.549934	0.301096	1.644986	3.176871	0.250235

Table 2c. Mean monthly dissolved oxygen (%) PHMR 10m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A												
1B									73.3			
2A												
2B	65	63.7	67	61.7		67	54.3	57.7	76.7	66.7		79.0
2C		66.7	70			69	51	53	78.3	76	75.0	83.3
3A												
3B												
3C						71						
4A												
4B	72.3	66	68.7	67		66	59.7	59	74.7	66.7	51.0	82.0
4C	70	67.7	69.3	67		67.3	57	64	77	77.3	65.3	84.0
5A												
5B												
5C	68.7	60.7	68.3	66.3		64.7	60	56.3	77.7	67.7	50.3	81.7
5D	69.3	66.7	69	67		68	63	65	77	74	60.0	84.0
5E	70.3	68.7	70	69		67	63.7	67.3	85.7	75	75.7	81.0
6A												
6B	71.7	56.3	69	67		67.3	59	55.7	76.3	67.3	59.0	83.3
6C	69.7	69	69.3	68		66.7	62.7	61.3	78	71.7	71.3	84.3
6D	70	69	70	67			58	64	77	72.7	77.0	80.7
7A	72	71.3		66.3				63	73.3	73.3	33.0	81.7
7B	72	69.3	69.3	69				64	79	73.7	54.0	81.7
7C	71.3	69.7		68.3				66	78.7	72.3	74.7	82.0
8A												
8B	70.3	71		67.7				66	80.3	74		80.3
9A												
9B	72	70		67.3				65	80.7	75.3		80.66667
Count	14	15	11	14		10	10	15	16	15	12	15
AVG	70.32857	67.05333	69.08182	67.04286		67.4	58.84	61.82	77.73125	72.24667	62.19444	81.97778
STD	1.917702	4.085316	0.881837	1.760994		1.698365	4.001444	4.405873	3.000382	3.516058	13.53145	1.550559
ST ERROR	0.512528	1.054824	0.265884	0.470645		0.53707	1.265368	1.137591	0.750095	0.907842	3.906193	0.400353

Table 2d. Mean monthly dissolved oxygen (%) PHMR 15m: 2013												
Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1A												
1B												
2A												
2B												
2C		63	70			69	50	47.7	77.3	72	74.3	83.3
3A												
3B												
3C												
4A												
4B												
4C	69.7	62.7	68.3	66.7		67	59.7	61.7	.	75.3	58.7	82.0
5A												
5B												
5C												
5D	69.7	64	70	64		67	63	59.3	76.7	68.7	57.3	75.3
5E			71.3	69.3								
6A												
6B	69.3	62	69	67		60.7	59.3	35.7	76.7	63.3	49.0	78.7
6C	69.3	65	69.3	68.3		67	62	55.3	77	70.3	60.0	76.0
6D	69.7	67.3	70	64.3			64	54.7	74.7	72.7	69.7	71.7
7A												
7B												
7C	70.7	69.7		68.3				64	76	72	67.3	71.0
8A												
8B	71	70.3		67.3				59	79	74		61.7
9A												
9B	71	62.3		67				57.3	79	73.7		62.0
Count	8	9	7	9		5	6	9	8	9	7	9
AVG	70.05	65.14444	69.7	66.91111		66.14	59.66667	54.96667	77.05	71.33333	62.33333	73.51852
STD	0.728991	3.198871	0.95219	1.770201		3.161961	5.077664	8.599564	1.44123	3.601042	8.60663	7.803331
ST ERROR	0.257737	1.06629	0.359894	0.590067		1.414072	2.072947	2.866521	0.509552	1.200347	3.253	2.60111

Table 2e. Mean monthly dissolved oxygen (%) Rio Grande: 2013												
Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RG_CB_1a	91	72	90	76.67	60.67	67.67	67.33	63.33	75.67	80.67	84.33	85.33
RG_CB_1b	90	62.67	74.33	63.33	48	64.33	71.67	66	77.33	77.67	83.33	85.33
RG_SM_1a	85	69	61	75.67	47.67	70.33	60	74.33	79	83.67	82.67	82.67
RG_SM_1b	85	68	60.67	68.33	44.33	68.33	70	62.33	79.33	74.67	81.33	82.67
RG_RG_1a	80	63	52.67	60.67	40.33	62	62	72.67	76.7	75.33	75.33	77.00
RG_RG_1b	81.67	64	54.33	62	35.67	65.33	66	69.33	76.67	76	76.33	76.00
RG_RG_1c	36.33	51	52.67	60.33	46.33	68.67	65	62	64.67	68.33	67.00	75.33
RG_RG_1d	57.33	56				51	45	57	57.67	52		
Count	8	8	7	7	7	8	8	8	8	8	7	7
AVG	75.79125	63.20875	63.66714	66.71429	46.14286	64.7075	63.375	65.87375	73.38	73.5425	78.61905	80.61905
STD	19.09779	6.925731	13.85802	6.986916	7.784713	6.152455	8.356288	5.885054	7.859009	9.799118	6.18669	4.381901
ST ERROR	6.752087	2.448616	5.237841	2.640806	2.942345	2.175221	2.954394	2.080681	2.778579	3.464511	2.338349	1.656203

Table 2f. Mean monthly dissolved oxygen (%) Monkey River: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
MR_SB_1a	79.33	80.33	60	74.67	71.33	81.33	71	73.33	81.8	89	84.00	91.33
MR_SB_1b	86	61.67	73.67	75.67	88	72.5	86.33	81	104	82.67	91.33	73.33
MR_SB_1c	77.67	60.67	56	63.67	49	61.33	39.67	62.33	99.33	82	94.33	72.33
MR_SB_1d	69	81.33	53.33	65.67	39.33	61.33	40.67	73.33	81.67	74	90.67	
MR_TB_1a	76	97	31	75.67	25.67	40.33	32	78.33	84	73.33	73.33	
MR_BB_1a	62.67	80.33	54.33	62	38	38	25.67	71	71	85	80.33	
MR_BB_1b	49.33	74	61.67	63.33	32.67	70.67	85.33	70	71.67	70	72.67	
MR_MR_1A	67.67	66	32.33					55	70.67	59.33		
Count	8	8	8	7	7	7	7	8	8	8	7	3
AVG	70.95875	75.16625	52.79125	68.66857	49.14286	60.78429	54.38143	70.54	83.0175	76.91625	83.80952	79
STD	11.45133	12.22236	14.50712	6.337777	22.52759	16.30546	25.76951	8.409712	12.74067	9.627272	8.759877	10.69268
ST ERROR	4.048657	4.321258	5.129042	2.395454	8.514627	6.162886	9.73996	2.973282	4.504508	3.403755	3.310922	6.17342

3a. Mean monthly salinity (ppt) PHMR 1m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A	29	37	38	35		25	8	17	24	16	32	30
1B	29	38	38	35		34			29	29		33
2A	25	28	38	34		15	11	16	13	10	35	15
2B	27	38	37	36		31	21	27	29	32	36	30
2C	27	38	38	37		30	29	25	30	30	36	35
3A	31	29	37	38		30	6	11	16	11	17	30
3B	35	37	37	38		30	26	24	37	9	34	33
3C	35	38	40	38		31	28	30	32	28	35	36
4A	35	39	38	39		40	19	28	32	28	35	32
4B	36	39	39	39		40	25	29	32	30	34	32
4C	35	38	37	37		40	23	32	33	32	34	31
5A	34	38	38	39		22	10	16	31	16	36	31
5B	36	37	38	39		35	11	25	32	22	36	32
5C	36	38	38	39		38	26	25	34	30	36	32
5D	37	39	40	40		34	25	28	34	32	35	30
5E	36	38	38	39		37	25.7	30	31	33	38	31
6A	38	39	39	37		37	28	32	31	32	35	32
6B	36	39	39	39		37	29	32	31	33	35	34
6C	38	39	38	39		37	30	31	32	33	35	33
6D	38	38	39	40			27	33	32	33	34	32
7A	36	35	39	39				28	16	5	26	10
7B	37	37	38	39				29	35	32	37	33
7C	37	39		37				34	35	35	36	33
8A	36	39		40				29	31	15	35	33
8B	36	39		38				34	31	34	36	33
9A	35	39		39				28	31	16	31	30
9B	37	39		37				33	33	34	35	30
Count	27	27	22	27		19	19	26	27	27	26	27
AVG	34.33333	37.44444	38.22727	38		32.78947	21.45789	27.15385	29.88889	25.55556	34	30.59259
STD	3.700312	2.750291	0.869144	1.593255		6.604535	8.048831	6.044451	5.879124	9.390393	4.137632	5.486061
ST ERROR	0.712125	0.529294	0.185302	0.306622		1.515184	1.846529	1.185414	1.131438	1.807182	0.811456	1.055793

3b. Mean monthly salinity (ppt) PHMR 5m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A												
1B	36	38	40	35					34	30		30
2A												
2B	36	40	37	36		35	33	33	33	33	37	33
2C	36	38	38	37		37	33	28	37	31	37	35
3A												
3B												
3C						34		31	32	33	35	32
4A	36	39	39			40	30			32		
4B	36	39	39	39		40	33	32	35	32	35	35
4C	35	38	39	37		40	35	34	34	33	35	35
5A												
5B	36	39	38	39		38	33	26	30	32	36	30
5C	37	40	39	39		39	34	31	34	32	37	32
5D	37	39	39	40		37	34	34	34	33	36	32
5E	37	38	40	39		37	35	34	33	33	38	33
6A	35	39	39	39		37	35	32	32	33	36	32
6B	36	37	40	39		37	34	34	32	34	35	35
6C	38	39	38	39		37	35	34	33	34	36	33
6D	38	38	39	40			35	35	31	34	35	35
7A	36	39	39	39				35	34.5	35	36	31
7B	37	37	40	40				35	35	35	38	30
7C	37	39		37				35	38	35	36	33
8A												
8B	36	39		38				35	34	35	37	33
9A												
9B		39		37				35	35	35	36	31
Count	18	19	16	18		13	13	18	19	20	18	19
AVG	36.38889	38.63158	38.9375	38.27778		37.53846	33.76923	32.94444	33.71053	33.2	36.16667	32.63158
STD	0.849837	0.830698	0.853913	1.447332		1.853617	1.42325	2.577555	1.924374	1.43637	0.985184	1.770453
ST ERROR	0.200308	0.190575	0.213478	0.34114		0.514101	0.394739	0.607536	0.441482	0.321182	0.23221	0.40617

3c. Mean monthly salinity (ppt) PHMR 10m: 2013

Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1A												
1B									35			
2A												
2B	37	40	37	36		30	35	33	33	34		33
2C		38	38			37	35	32	35	32	38	35
3A												
3B												
3C												
4A												
4B	36	39	39	39		47	35	35	35	34	36	35
4C	36	38	39	37		35	35	34	35	33	37	35
5A												
5B												
5C	37	39	39	39		41	35	35	34	32	38	37
5D	37	39	39	40		37	35	35	34	34	36	35
5E	37	38	40	39		39	35	35	33	34	38	34
6A												
6B	38	39	40	39		37	36	35	33	35	38	35
6C	38	39	38	39		37	35	35	33	35	36	33
6D	38	39	39	40			35	35	32	35	36	35
7A	36	39		40				35	33	35	37	33
7B	37	37	40	40				35	35	35	37	33
7C	38	39		37				36	36	35	36	33
8A												
8B	38	39		38				35	34	35	37	33
9A												
9B		39		37				35	35	35	38	30
Count	13	15	11	14		9	10	15	16	15	14	15
AVG	37.15385	38.73333	38.90909	38.57143		37.77778	35.1	34.66667	34.0625	34.2	37	33.93333
STD	0.800641	0.703732	0.94388	1.34246		4.57651	0.316228	0.9759	1.12361	1.082326	0.877058	1.624221
ST ERROR	0.222058	0.181703	0.28459	0.358787		1.525503	0.1	0.251976	0.280903	0.279455	0.234404	0.419372

3d. Mean monthly salinity (ppt) PHMR 15m: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A												
1B												
2A												
2B												
2C		40	38			37	35		35	35	38	35
3A												
3B												
3C												
4A												
4B												
4C	37	39	39	37		37	35	36	35	35	38	35
5A												
5B												
5C												
5D	37	40	39	40		37	35	35	33	35	37	35
5E				39								
6A												
6B	38	40	38	39		38	36	37	33	36	38	37
6C	38	39	40	39		38	35	35	33	35	39	35
6D	38	39	38	40			35	37	35	35	37	35
7A												
7B												
7C	38	39		37				37	36	36	37	37
8A												
8B	38	39		38				37	36	35	38	35
9A												
9B		39		37				37	35	35	38	37
Count	7	9	6	9		5	6	8	9	9	9	9
AVG	37.71429	39.33333	38.66667	38.44444		37.4	35.16667	36.375	34.55556	35.22222	37.77778	35.66667
STD	0.48795	0.5	0.816497	1.236033		0.547723	0.408248	0.916125	1.236033	0.440959	0.666667	1
ST ERROR	0.184428	0.166667	0.333333	0.412011		0.244949	0.166667	0.323899	0.412011	0.146986	0.222222	0.333333

Table 4. Mean monthly visibility (cm) PHMR: 2013

Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1A	150	150	70	50		150	100	200	50	100	100	50
1B	500	350	400	250					600	300		500
2A	200	150	100	300		200	130	300	200	40	100	70
2B	600	400	200	600		600	250	600	700	250	300	600
2C	700	500	700	850		600	700	500	800	300	250	700
3A	150	100	50	100		100	50	100	70	20	150	50
3B	400	200	200	200		300	200	300	150	50	400	
3C	400	400	400	400		400	500	500	490	250	400	
4A	400	100	200	200		400	150	500	200	300	150	
4B	600	450	300	500		1000	800	800	700	500	900	
4C	900	500	400	800		800	800	1400	500	900	1500	
5A	200	200	250	300		250	50	200	300	90	300	
5B	400	200	300	300		400	100	200	200	250	300	
5C	500	300	400	500		600	500	800	400	400	300	
5D	600	650	500	700		900	1000	600	700	400	700	
5E	600	850	600	800		900	600	800	600	700	500	
6A	500	200	300	400		400	600	600	350	300	400	600
6B	600	850	400	500		700	600	800	500	400	600	600
6C	800	900	600	700		500	1000	700	700	400	600	1000
6D	800	1000	500	900			1000	1000	1600	300	700	1000
7A		800	300	500				600	400	30	500	100
7B	600	800	300	700				800	800	600	500	600
7C	800	1200		800				800	800	700	900	1000
8A	150	100		100				100	280	50	300	400
8B	600	1200		500				700	700	400	1100	600
9A	200	100		200				400	200	100	300	300
9B	700	1200		500				600	600	600	900	900
Count	26	27	22	27		18	19	26	27	27	26	17
AVG	501.9231	512.963	339.5455	468.5185		511.1111	480.5263	573.0769	503.3333	323.3333	505.7692	533.5294
STD	224.268	374.8314	172.3086	251.9723		270.3786	343.9715	301.407	322.8836	232.9411	336.8462	333.6154
ST ERROR	43.98258	72.13634	36.73632	48.49209		63.72884	78.91247	59.11077	62.13899	44.82953	66.06098	80.91363

Table 5a. Mean monthly phosphate (mg/l) PHMR: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A												
1B												
2A				0.35			0.04		0.17	0.2		
2B												
2C				0.31				0	0.03	0.1	0.063333	
3A												
3B												
3C												
4A												
4B												
4C												
5A				0.18					0.03	0.1	0.116667	
5B												
5C												
5D												
5E				0.09			0	0	0.03	0.1	0.275	
6A												
6B												
6C												
6D												
7A				0.49				0	0.1	0.1	0.143333	
7B												
7C				0.38				0	0.03	0.1	0.336667	
8A												
8B												
9A												
9B												
Count				6			2	4	6	6	5	
AVG				0.3			0.02	0	0.065	0.116667	0.187	
STD				0.143944			0.028284	0	0.058566	0.040825	0.114336	
ST ERROR				0.058765			0.02	0	0.02391	0.016667	0.051133	

Table 5b. Mean monthly phosphate (mg/l) Rio Grande: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
RG_CB_1a												
RG_CB_1b					0.05	0.02	0.06					
RG_SM_1a												
RG_SM_1b					0	0.02	0.04					
RG_RG_1a												
RG_RG_1b												
RG_RG_1c					0.01		0.03					
RG_RG_1d									0.05	0.19		
Count					3	2	3		1	1		
Avg					0.02	0.02	0.043333		0.05	0.19		
St Dev					0.026458	0	0.015275					
St Error					0.015275	0	0.008819					

Table 5c. Mean monthly phosphate (mg/l) Monkey River: 2013												
Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MR_SB_1a												
MR_SB_1b												
MR_SB_1c												
MR_SB_1d					0.06		0.03		0.06	0.22		
MR_TB_1a					0.05		0.04		0.08	0.34		
MR_BB_1a												
MR_BB_1b					0.03		0.01		0.15	0.11		
MR_MR_1A									0.06	0.21		
Count					3		3		4	4		
Avg					0.046667		0.026667		0.0875	0.22		
St Dev					0.015275		0.015275		0.04272	0.094163		
St Error					0.008819		0.008819		0.02136	0.047081		

Table 6a. Mean monthly nitrate (mg/l) PHMR: 2013												
Site Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1A												
1B												
2A				0				0.1	2.1	0.93		
2B												
2C				0				0.3	3.2	0.93	2.566667	
3A												
3B												
3C												
4A												
4B												
4C												
5A				0				0.3	3.5	1.17	3.7	
5B												
5C												
5D												
5E				0				0.2	4.3	0.93		
6A												
6B												
6C												
6D												
7A				0				0	1.9	1.03	1.466667	
7B												
7C				0				0	4	1.17		
8A												
8B												
9A												
9B												
Count				6				6	6	6	3	
AVG				0				0.15	3.166667	1.026667	2.577778	
STD				0				0.13784	0.983192	0.117587	1.116708	
ST ERROR				0				0.056273	0.401386	0.048005	0.644732	

Table 6b. Mean monthly nitrate (mg/l) Rio Grande: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
RG_CB_1a												
RG_CB_1b					0.1	0.1						
RG_SM_1a												
RG_SM_1b					0.03	0.07	0.1					
RG_RG_1a												
RG_RG_1b												
RG_RG_1c					0.13		0					
RG_RG_1d								0.9	1.2			
Count					3	2	2	1	1			
Avg					0.086667	0.085	0.05	0.9	1.2			
St Dev					0.051316	0.021213	0.070711					
St Error					0.029627	0.015	0.05					

Table 6c. Mean monthly phosphate (mg/l) Monkey River: 2013												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
MR_SB_1a												
MR_SB_1b												
MR_SB_1c												
MR_SB_1d					0.1		0		0.67	0.73		
MR_TB_1a					0.1		0.1		0.67	1.4		
MR_BB_1a												
MR_BB_1b					0.07		0.2		0.53	0.97		
MR_MR_1A									1.23	4.9		
Count					3		3		4	4		
Avg					0.09		0.1		0.775	2		
St Dev					0.017321		0.1		0.31043	1.9531		
St Error					0.01		0.057735		0.155215	0.97655		

Table 7. Mean monthly sedimentation (g/m2/day) PHMR: 2012												
Site Code	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1A												
1B												
2A												
2B												
2C		16.82695	24.66671	37.05699					10.77849		14.75399	26.62883
3A												
3B												
3C												
4A												
4B												
4C												
5A		103.7039	87.50015	90.54069			75.05167	61.69763	52.95661		87.80484	101.5153
5B												
5C												
5D												
5E		33.84621	90.27793	51.35144				9.551909	14.17281		16.10772	18.65083
6A												
6B												
6C												
6D												
7A			45.2831	55.94415				103.8443	82.60883		67.939	75.00013
7B												
7C			10.2426	46.15392				26.5323		12.86002	8.021601	6.541678
8A												
8B												
9A												
9B												
Count		3	5	5			1	4	4	1	5	5
Avg		51.45901	51.5941	56.20944			75.05167	50.40653	40.12918	12.86002	38.92543	45.66736
St Dev		46.03866	36.2648	20.43426				41.72193	34.17729		36.36941	40.62814
St Error		26.58043	16.21811	9.138477				20.86097	17.08864		16.2649	18.16946