The Deepening, Lengthening and Widening of Berths 203 to 205 at Pier 2 Container Terminal, Port of Durban, KwaZulu-Natal Province

Environmental Monitoring Report

Summer 2021

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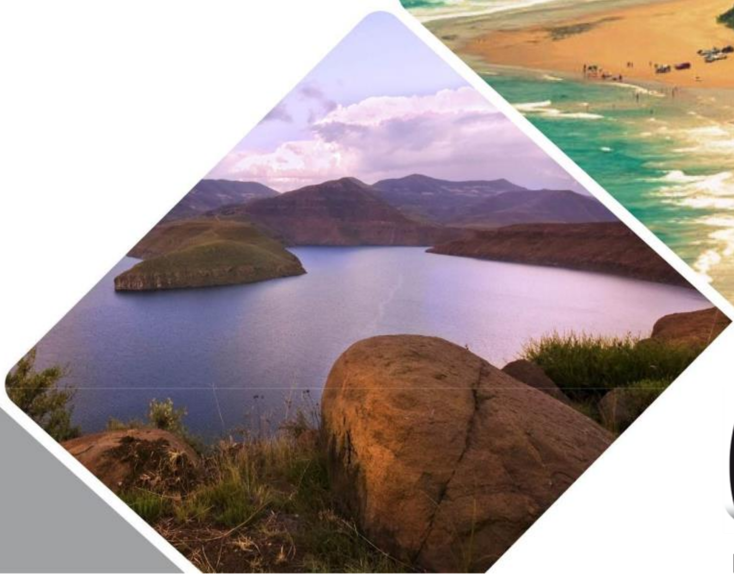
March 2021



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Environmental Monitoring Report, March 2021

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Report Details

1	**Project name**	The Deepening, Lengthening and Widening of Berths 203 to 205 at Pier 2 Container Terminal, Port of Durban, KwaZulu-Natal Province
2	**Report title**	Environmental Monitoring Report, Summer 2021
3	**Authority reference**	No: 14/12/16/3/3/2/275
4	**Report status**	Draft 1
5	**Client**	Transnet National Ports Authority
6	**Scope**	Conduct quarterly monitoring during the two-year construction period of the Sandbank Extension. Thereafter, the monitoring should take once every six months during the construction of the Berth 203 to 205 Expansion
7	**Standard:**	Environmental Authorisation (NEAS: DEA/EIA/0000988/2012. DEA Ref: 14/12/16/3/3/32/275) and Central Sandbank Mitigation Plan (CSMP), October 2017
8	**Objective**	Conduct environmental monitoring, to track the health of the Durban bay over the construction period of the Berth 203 to 205 expansion project
9	**Methodology**	As per the CSMP Rev 06 Report, October 2017
10	**Date of fieldwork**	13, 20, 22, 28, 29 January 2021
11	**Dates of bird fieldwork**	Sampling done on the first spring tide of every month. This report includes bird results from December 2019 – February 2021, with the exception of April – July 2020.
12	**Report publish date**	12 March 2021
13	**Key notes**	Construction had not yet commenced at the time of this sample run
14	**Activity schedule**	<u>**Quarterly Monitoring Events:**</u> • October 2018 (Spring I) – Sampling undertaken 9 - 18 October 2018 • January 2019 (Summer I) – Did not occur, project put on hold. • April 2019 (Autumn I) – Did not occur, project put on hold. • August 2019 (Winter I) – Sampling undertaken 15 - 30 August 2019 • October 2019 (Spring II) – Sampling undertaken 13 - 29 October 2019 • January 2020 (Summer II) – Sampling undertaken 03 - 24 January 2020 • June 2020 (Autumn II) – Sampling undertaken 05 – 23 June 2020. Note that autumn sampling performed in June due to National Lockdown. • July 2020 (Winter II) – Sampling undertaken 05 – 22 July, bird sampling undertaken throughout August. • October 2020 (Spring III) – Sampling undertaken 01 – 28 October • January 2021 (Summer III) – Sampling undertaken 13 – 29 January
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Revision Status

Rev No.	Issue Date	Revision Description
0	13/03/2021	Draft 1 for client review
1	12/04/2021	Draft 2 for client review

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Abbreviations

CSMP	Central Sandbank Mitigation Plan
CTD	Conductivity, temperature, and depth
EA	Environmental Authorisation
ECO	Environmental Control Officer
EIA	Environmental Impact Assessment
EMC	Environmental Monitoring Committee
EMPR	Environmental Management Programme
ERL	Effects Range Limits
ERM	Effects Range Medium
DEA	Department of Environmental Affairs
DEFF	Department of Environment, Forestry & Fisheries
MACE	Marine biodiversity, Aquaculture, Conservation education & Ecophysiology
NOAA	National Oceanic Atmospheric Administration
NTU	Nephelometric Turbidity Units
PPM	Parts Per Million
TOC	Total Organic Carbon
UKZN	University of KwaZulu-Natal
YSI	Yellow Springs Instrument

Executive Summary

GIBB (Pty) Ltd was appointed by Transnet Group Capital, now Transnet National Ports Authority, to conduct environmental monitoring in the Port of Durban as per the requirements of the Central Sandbank Mitigation Plan (Clark et al., 2017). The rationale for the expansion of the Berths is to improve the safety of the Berths and increase the efficiency of the Port (see EIA report for full project description; DEA ref 14/12/16/3/3/2/275). The objective of the monitoring programme is to monitor biotic and abiotic habitats and species count changes measured against the approved baseline which was established per condition 27 of the EA (DEA ref 14/12/16/3/3/2/275) and is contained in Central Sandbank Mitigation Plan (CSMP) (Clark et al., 2017). Monitoring takes place at the sandbank areas and associated infrastructure and is conducted before, during and after the construction and expansion of Berths 203 – 205. As specified in this plan (CSMP), monitoring will be undertaken quarterly during each season (i.e. summer, autumn, winter and spring) for the duration of the sandbank extension period, after which monitoring will be undertaken biannually for the remaining construction period. The quarterly assessment exercise includes monitoring of water and sediment characteristics, benthic microalgae, benthic macrofaunal communities, biomonitoring of mussels, as well as fish and monthly bird surveys on and adjacent to all sandbank habitats in the Port of Durban. This report provides a summary of information gathered during the summer 2021 survey, which commenced on 13 January 2021 and was the eighth sampling event of this programme. Note that construction had not yet commenced at the time of this survey, so all results obtained thus far may be interpreted as building on the baseline data reported in Clark et al., 2017).

The survey was carried out by GIBB Environmental in collaboration with the University of KwaZulu-Natal (UKZN), Marine biodiversity, Aquaculture, Conservation education & Ecophysiology (MACE) Lab at the UKZN, Westville Campus. Field samples were collected over the period of 13 – 29 January 2021 by GIBB personnel and students from the UKZN MACE Lab. The following components are assessed as part of this monitoring programme: water quality, sediment characteristics, benthic macrofaunal communities, benthic microalgae, mussel biomonitoring, fish- and bird communities.

Water Quality

Water quality parameters including temperature, salinity, dissolved oxygen, pH, and turbidity were measured using a YSI (Model: EXO 1 – 18H112179) CTD water quality meter. Measurements were taken at 20 sampling stations distributed along the navigation channels around the intertidal and shallow subtidal sandbank areas in the Port. While no specific limits or thresholds have been set for water quality parameters, the majority of these parameters were similar to the results reported in the baseline study. While substantially elevated salinity levels were recorded in the previous survey (spring 2020), these decreased in summer 2021. This is most likely driven by the rainy season and associated heightened influx of freshwater from nearby rivers and storm water canals. Dissolved oxygen concentrations and pH levels have remained relatively unchanged. Turbidity levels have similarly changed little, but substantially greater turbidity levels were recorded close to the mangroves and the western bank.

Sediment Characteristics

Sediment samples were collected from 64 stations (39 intertidal and 25 subtidal) on sandbanks in the Port. Intertidal and subtidal sites are further divided into impact and control sites, with impact sites being those that will most likely be affected by the planned developments in the Port. Intertidal and subtidal sites on/around the northern bank are control sites, while those on/around the central bank and little lagoon are impact sites. The impact sites are thus also those that are generally more exposed to shipping activity and therefore more susceptible to anthropogenically-induced changes to natural conditions. Several sediment parameters were assessed, including grain size distribution, Total Organic Carbon (TOC) concentration and trace metal concentrations. According to the ranges defined in the baseline study, sediment grain size must be comprised of mostly sandy sediment and very little proportions of mud. As in previous seasons, the proportions of sandy sediments were slightly below the minimum threshold, while subtidal grain sizes were within allowable limits. The TOC content in intertidal and subtidal sediments were below the minimum limits (as in previous seasons) and suggests that sediments in the Port are generally nutrient-deficient. All trace metal concentrations in sediments were within allowable levels, apart from mercury whose concentrations violated the maximum allowable threshold in intertidal and subtidal sediments. These concentrations have increased in intertidal and subtidal zones and requires management attention.

Benthic Macrofauna

Intertidal and subtidal benthic macrofaunal samples were collected from the same stations as sediment samples and results of abundance and species richness are contrasted against season-specific limits defined in the CSMP. Abundance and species richness in intertidal and subtidal zones were substantially lower than the minimum allowable thresholds stipulated in the CSMP. While these parameters were expected to increase from the previous season, they instead demonstrated decreases. As an important indicator of overall ecosystem health, these trends are starting to represent a noteworthy cause for concern.

Benthic Microalgae (Microphytobenthos)

Microalgae are photosynthetically active micro-organisms that contribute significantly to primary production in sediment and pelagic habitats with important trophic linkages with variety of organisms including macrofauna, fish and birds (Pinckney & Zingmark, 1993). In addition to the functional importance of microalgae in estuarine and marine systems, it is also a useful parameter that can be used to assess ecological health and eutrophication levels of these systems (Stevenson & Pan, 1999). The concentration of chlorophyll-a (chl-a) is used as a proxy for the abundance of microalgae. In the latest survey (summer 2021), the overall intertidal concentration of chl-a was greater than in the subtidal, which is likely driven by differences in light availability between these two environments. Median chl-a levels were within allowable thresholds in intertidal and subtidal sites (control and impact habitats).

Biomonitoring Using Mussels (*Perna perna*)

Samples of brown mussels (*Perna perna*) were collected from 14 out of 16 designated channel buoys (2 buoys did not contain mussels) adjacent to the sandbanks and were analyzed at a

SANAS accredited laboratory for trace metals. Apart from mercury, all trace metals were below the maximum threshold values of the baseline study. Not only is this the fourth consecutive season that mercury levels have violated these limits, but in this season these concentrations demonstrated dramatic increases from previous seasons. At impact sites, mercury concentrations exceeded the baseline threshold value by 70-fold and requires urgent attention from Port management authorities as this represents a serious health risks to animals and humans.

Fish

The nearshore fish community in the Port of Durban was sampled using a beach seine net at 14 stations along the margins of the main sandbank areas. No fish were caught at three of these stations. A total of 1211 individuals were caught, most of which was the Bald Glassy (*Ambassis dussumieri*). The abundance of control sites were above the minimum allowable threshold, but not that of the impact sites. In addition, species richness at control and impact sites was below the minimum allowable threshold for another season, indicating that fish communities in the Port might be at risk of losing important species. Biomass was also below the minimum threshold at impact and control sites.

Birds

Monthly bird counts are conducted in accordance with methodology used in long-term avian monitoring programmes in the Port. This is also the methodology that informed the CSMP. These surveys are taking place in five main habitats across the Port (central bank/Little lagoon, northern sand banks, mangrove habitat, island view sand bank, open water). Waders and wading birds dominated the various functional groups, and piscivores and invertebrate feeders dominated feeding groups. Avian abundance and species richness were lower than the minimum values stipulated in the CSMP for another season and is starting to warrant increased management or mitigation interventions. While these results cannot be attributed to the construction phase of this project, the anthropogenic impacts, mostly plastic pollution, in the Port is most likely driving these declines.

Conclusion

The information presented in this report is part of an ongoing quarterly monitoring programme against which the impacts associated with the proposed development at Pier 2 can be assessed. These assessments will inform the Environmental Control Officer (ECO) and Environmental Monitoring Committee (EMC) who will oversee that the sampled parameters for the Port of Durban are maintained during the construction and operational phases of this development. As construction had not yet commenced, the data gathered thus far can be viewed as additions to an ongoing dataset and will ultimately enable more accurate detection of any potential impacts associated with the planned developments when they occur.

However, factors that require increased attention and potential mitigation measures from Port management authorities are (1) the consistently high concentrations of mercury in *Perna perna* mussels, (2) decreasing macrofaunal abundance and diversity, (3) decreasing fish abundance and diversity, and (4) decreasing avifaunal abundance and diversity.

As stated in the previous report, it is possible that the crude oil spill in the Umbilo river that occurred in October 2020 may have impacted abundance and diversity of marine life in the Port. Furthermore, the extent of plastic pollution in this Port has become severe and needs to be urgently addressed. These factors cannot be viewed as separate from this monitoring programme as they ultimately affect the integrity of the environment in which surveys are taking place. The impacts of both oil and plastic pollution on marine life are widely acknowledged. The bird roosting habitats in the Port presently consists mainly of plastic debris and inevitably affects the health of these animals. Marine birds often mistake plastic for food and can feed it to their chicks. It is also becoming increasingly difficult for fieldworkers to conduct counts on sandbanks as plastic debris are obscuring birds. Plastic that has broken down to smaller sizes (microplastics) are also fed on by fish, which can ultimately result in death as it is indigestible. While the effects of microplastics on benthic macrofauna are still being investigated, current research suggests that these communities are also most likely negatively affected.

1 Background

The Port of Durban is located on the east coast of South Africa and occupies the natural area of the Durban Bay, an estuarine embayment fed by the uMbilo, uMhlatuzana and aManzimnyama rivers (Whitfield, 1998). It is one of the few natural harbours on the South African coast and is under the jurisdiction of the Transnet National Ports Authority. Since the development of the Durban Container Terminal in 1977, the Port of Durban has experienced consistently high growth of import and export cargo volumes from around the world. Of the eight commercial Ports in South Africa, the Durban Port is currently South Africa's main general cargo and container Port, handling over 80 million tons of cargo per year (Clark et al., 2016).

Transnet National Ports Authority intends to deepen, widen and lengthen Berths 203 to 205 in the Port of Durban and was granted Environmental Authorisation for the work on 21 January 2015 (EIA and EA reference number 14/12/16/3/3/2/275). The objective is to maximize the efficiency of the Port as well as improve the safety of the Berths. Condition No. 27 of the EA required that baseline monitoring be undertaken for 24 months prior to construction. The EA was appealed and on 9 September 2015 the Minister of Environmental Affairs upheld the EA against the appeal (Appeal Decision Ref LSA 141396) wherein under section 4.2.4 the following was added: *"Amend the EA in line with the eThekwini Municipality's concerns in respect of 4.3.14 below. To this end, the aforementioned EA is amended to include the following condition: the eThekwini Municipality is to be involved in the baseline monitoring of the sandbank and must ensure that the outcomes of the baseline monitoring inform the central sandbank mitigation plan. The monitoring of compliance against the baseline monitoring must solely be the responsibility of the ECO and be independent of the applicant. Construction activities on the central sandbank may only commence upon the successful implementation of the central sandbank mitigation plan".*

Transnet undertook the 24 months of environmental monitoring within the Durban Bay, and as part of the Environmental Management Programme (EMPR) produced a plan specifically dealing with marine works on and around the Centre Sand Bank (the Central Sandbank Mitigation Plan – CSMP; Clark et al., (2017)).

In line with Clause 4.2.4 of the Appeal Decision, the "implementation" of the CSMP was clarified with then DEA (now the Department of Environment, Forestry and Fisheries; DEFF) to mean:

1) the completion and publication of the plan
2) the submission to the Authorities and approval of the plan; and
3) the issuing of the plan to the contractors prior to commencement of construction activities.

The Department was in agreement with this interpretation, and hence construction could commence.

Through an open tender process GIBB was appointed as the ECO on the project and in light of EA condition 27 and Appeal Decision condition 4.2.4, initiated this monitoring programme for all the sandbank areas in the Port during the proposed construction of the Berths. The intention is to thereby assess the impacts of any disturbances associated with this development such as loss of supratidal, intertidal and subtidal habitats within the Port. Monitoring activities include quarterly surveys of water quality, sediment characteristics, benthic microalgae, benthic macrofauna, mussel biomonitoring, fish and a monthly bird survey on and adjacent to all sandbank habitats during the sandbank works, and thereafter bi-annually for the remainder of the construction period.

The development of the Port of Durban, together with the growth and urbanisation of the surrounding city of Durban has resulted in significant changes in the natural functioning of this estuary. However, Durban Bay is still considered an estuary with high national conservation importance, with an overall importance score of 92% (Turpie & Clark, 2007). It is ranked as the 10th most important estuary in South Africa (Turpie & Clark, 2007). In order to secure the benefits provided by this system in terms of ecosystem goods and services, it has been recommended that at least partial protection be assigned to the estuary. This has become an objective of the Bay of Natal Estuarine Management Plan (ERM/MER, 2012) to protect and enhance estuarine habitats, which are characteristic of the original Bay; and to explore opportunities for rehabilitating/improving and expanding existing soft habitat. It is important to conserve and manage the remaining mangroves, mudflats and sandbanks of Durban Harbour in order to retain the valuable ecological functions that they offer to the entire system.

The intertidal sandbank habitats in the Port are important to its ecological functioning (Newman et al., 2008; Weerts, 2010). They have significant ecological importance as they contribute to the various ecosystem goods and services provided by the Port. Intertidal sandbanks in the Port become exposed at low tide and play an important role in the recycling of terrestrial and marine derived nutrients and organic matter (Deborde et al., 2008). The sandbank habitats are important from a conservation perspective as they harbour a diverse community of invertebrate fauna. They are also important feeding areas for fish and birds and thus help maintain biodiversity in the Port (Allan et al., 1999). The Bay of Natal Estuary Management Plan (MER/ERM, 2012) has accordingly identified the sandbank habitat for conservation.

A number of studies have been completed in recent years focusing on the estuarine biota of the Port of Durban (Allan et al., 1999; Pillay, 2002; Blackler et al., 2004; Forbes & Demetriades, 2006; Angel & Clark, 2008; Newman et al., 2008; Weerts, 2010; MER/ERM, 2012; Clark et al., 2016). Key sandbank habitats in the Port include the Centre Bank, Little Lagoon, Northern Banks and the Mangrove area. This document details sampling procedures and information gathered from the winter 2020 environmental monitoring survey.

2 Project Location and Baseline Environment

2.1 Port of Durban

The Port of Durban is considered an estuarine embayment with three perennial rivers that feed into it. The harbour has approximately 57 storm water outfalls, which feed the bay with surface runoff. The total size of the Durban Harbour catchment is approximately 242km^2. The surface area of the Durban harbour bay is approximately $8km^2$, with a shoreline perimeter of approximately 27km (Day & Morgan, 1956; Guastella, 1994*;* Hay et al., 1995).

2.2 Geology

The Durban Harbour is considered a bay, which serves as a major receiver of run-off water from canals and surrounding rivers. The Port of Durban is underlain by Cretaceous, aged siltstone rocks of the St Lucia Formation, Zululand Group, that have weathered to varying degrees. Residual soils have been derived from the *in situ* weathering of the bedrock. Younger unconsolidated alluvial and estuarine sediments referred to as the Harbour Beds unconformably overlie the Cretaceous-aged strata in the Port of Durban (Hindmarch et al., 2008; Cawthra et al., 2012).

2.3 Site Location

The study site (**Figure 1**) is located within the Port of Durban (29°52'17.87"S; 31° 1'9.08"E). The Port occupies the natural expanse of the full Durban Bay, spanning an area of 1850ha ($18.5km^2$) (Transnet National Ports Authority, 2017). The city centre is located approximately 5km north of the Port of Durban, with the residential and industrial area of the Bluff located 10 km south. The Port is one of the few in the world with such a close proximity to the central city.

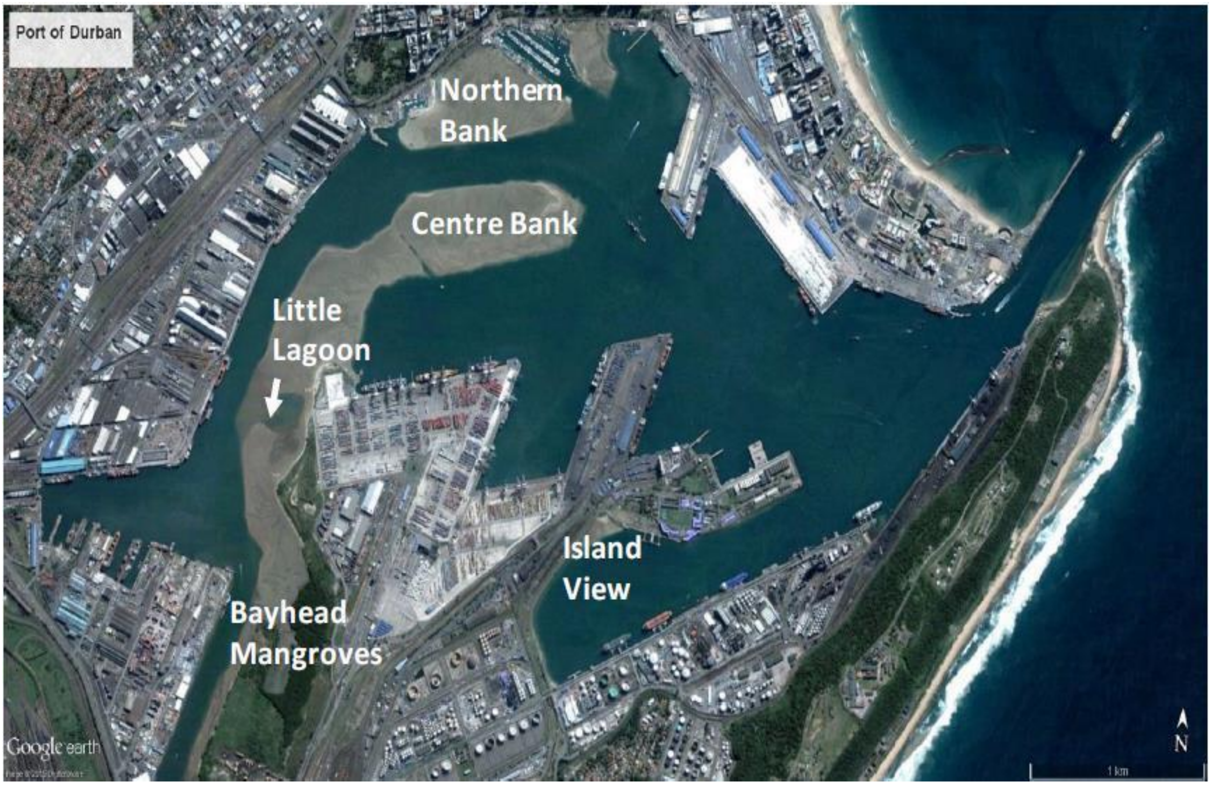

Figure 1: Ariel view of intertidal sandbank habitats (Northern Bank, Centre Bank, Little Lagoon, Island View, Bayhead Mangroves) in the Port of Durban (Google Earth, 2015).

2.4 Aspects of environmental monitoring

The environmental monitoring presented in this report include monitoring of physico-chemical variables and assemblages of fauna and flora in the Port of Durban.

Physico-chemical variables include:

i. Salinity
ii. Temperature
iii. Dissolved Oxygen
iv. pH
v. Turbidity
vi. Sediment grain size distribution
vii. Sediment organic carbon content
viii. Trace metal concentrations in sediment and mussels (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg)

Fauna and flora assemblages include:

i. Benthic microalgae (microphytobenthos)
ii. Benthic macrofauna
iii. Fish
iv. Birds

Detailed methodologies for each of these components are presented in the subsections below. A quarterly (once every 3 months) sampling schedule is being followed for water and sediment quality, benthic microalgae, benthic macrofauna and fish surveys, while a monthly schedule is being followed for bird surveys. Dates of the quarterly surveys were selected to correspond with the middle of each season and are centred around one of the spring tide episodes in each period.

Surveys have been completed in the following months:

- October 2018 (Spring I). Completed.
- January 2019 (Summer I) – This sample run did not occur as Transnet put the project on hold
- May 2019 (Autumn I) – This sample run did not occur as Transnet put the project on hold
- August 2019 (Winter I) – Completed.
- October 2019 (Spring II) – Completed.
- January 2020 (Summer II) – Completed.
- June 2020 (Autumn II) – Completed.
- July 2020 (Winter II) – Completed.
- October 2020 (Spring III) – Completed. Presented in this report.

3 Water Quality

3.1 Introduction

Estuaries are dynamic water bodies, influenced both by the marine environment and freshwater from catchments. The conditions within estuaries vary both seasonally and diurnally (a result of tide, temperature and sunlight). Estuaries are extremely productive ecosystems due to the combination of high nutrient river water with a shallow, sheltered habitat. Parameters typically measured include salinity, temperature, light intensity, dissolved oxygen, nutrients and chlorophyll-a. These parameters help monitor natural phenomena such as stratification and tidal flushing, as well as impacts caused by human activities and from the catchment. Estuaries are important for their role as nurseries for juvenile marine fish and invertebrates that inhabit these protected and nutrient-rich areas during their developmental stages (Beck et al. 2001). However, water quality in the Durban Bay has become severely degraded because of poor catchment management upstream including erosion, pollution, water abstraction, and harbour development (Durban Port). This presents concern for the biota within the systems.

Estuaries are fragile and sensitive ecosystems that are easily affected by changes in land and developments. Monitoring of water quality is important for the identification of pollution events and for identifying areas of chronic contamination. An example is the introduction of organic waste that can result in deoxygenation, eutrophication and/or the formation of algal blooms with potential adverse impacts on biodiversity (Varadharajan et al., 2013). In addition, Port development activities such as dredging can increase turbidity and total suspended solids in water, reducing light penetration and hinder photosynthetic activities in the water column. This invariably affects the ecosystem functioning of higher organisms that directly depend on primary producers (Brzeski & Newkirk, 1997). Basic water quality of the Port is assessed as part of ongoing monitoring for this project. Water quality parameters that are considered include temperature, salinity, dissolved oxygen content, pH and turbidity.

3.1.1 Temperature

Water temperature is closely associated with many of the chemical and biological processes occurring in estuaries (Snow & Taljaard, 2007). Concentrations and saturation levels of dissolved oxygen in the water is directly influenced by temperature. As water temperature increases, the solubility of oxygen decreases. Therefore, cold water generally holds more oxygen than warmer waters (Madeira et al., 2013). Temperature also influences other biological processes such as photosynthesis, animal reproductive cycles, -migrations, -metabolic rates and susceptibility to parasites and disease (Caffrey, 2003; Pillay & Perissinotto, 2008). Water temperature in estuaries can vary with depth, anthropogenic activities, season, atmospheric conditions and tidal phases. Thermal stratification (i.e. water layers with strong temperature differences) can occur when the mixing of water layers is inadequate. If such conditions persist, it could result in hypoxic or anoxic conditions in bottom waters with potential negative impacts on benthic biota (Chadwick et al., 1996).

3.1.2 Salinity

Salinity is a measure of the amount of dissolved salts in water. In estuarine environments, there are significant fluctuations in salinity levels because of the input of freshwater from river inflow or anthropogenic discharge via storm water canals, which can have a direct influence on the type and distribution of plants and animals in an estuary. Salinity levels also fluctuate with season (Kamer & Fong, 2000; Pillay & Perissinotto, 2008). During the rainy season, greater amounts of freshwater enter estuaries thereby lowering salinity levels. In contrast, a dry season could result in increased salinities due to less freshwater coming into the system, and possibly less variation in salinity levels. Just like temperature, salinity stratification could also be a problem in an estuarine environment causing hypoxia and anoxia in benthic habitats.

3.1.3 Dissolved Oxygen

Dissolved oxygen concentration refers to the amount of oxygen present in water and is vital for the survival of most aquatic life. Dissolved oxygen plays an important role in the various chemical and biological processes occurring in estuaries (Reddi et al., 1993). Season, temperature, salinity and plant photosynthetic activity all influence dissolved oxygen levels in an estuary (Attrill et al., 1999). Sufficient levels of dissolved oxygen are crucial for the survival of estuarine fauna and thus have an important influence on their distribution and abundance (Pillay & Perissinotto, 2008). The toxicity of trace metal contaminants such as lead, copper, and zinc can increase with a decrease in dissolved oxygen concentrations. Therefore, the monitoring of dissolved oxygen in estuarine environments is important, as it is a good indicator of estuary health.

3.1.4 pH

pH is a measure of alkalinity or acidity of a solution or substance. It is recorded on a scale of 0 to 14; where 0 – 6 is regarded as acidic and 8 – 14 is alkaline. A pH of 7 is commonly referred to as neutral. In estuaries, it is an important water quality parameter, as slight changes in pH can significantly alter the chemistry of the water and influence biogeochemical processes (Doering, 1996). Changes in pH can influence solubility of some metals such as copper and iron, as well as the toxicity of many harmful compounds such as ammonia (Das & Sahu, 2005). The optimal range of pH values for estuarine fauna is approximately between 6.5 and 8.6 (Clark *et al.,* 2016). pH levels lower than 5 or greater than 9 may be fatal for estuarine fauna and this is often an indication of the introduction of industrial or agricultural pollutants to the estuarine system.

3.1.5 Turbidity

Turbidity is an important measure of water quality especially in estuaries where there is usually mixing and inflow of freshwater from connecting rivers and inland canals (Hellweger et al., 2004). Turbidity is a measure of light penetration in the water column and can be defined as the transparency of water in relation to the amount of light scattered by particulates and dissolved substances, recorded in Nephelometric Turbidity Units (NTU). Monitoring turbidity in aquatic environments is important as changes in turbidity may affect availability of light for plant photosynthetic activities, food availability in the system and other ecological processes such as oxygen production (Moore et al., 1997). Elevated turbidity levels can also influence ecological interactions (e.g. predator-prey interaction) through affecting visibility.

3.2 Methodology

Water quality parameters including temperature, salinity, dissolved oxygen, pH, and turbidity were measured using a YSI (EXO 1 – 18H112179) CTD water quality meter. Measurements were taken at spring tide (high and low) and neap tide (high and low) at all 20 stations distributed in the navigation channels surrounding the main intertidal and shallow subtidal sandbank areas (**Figure 2**).

The YSI water quality meter was held at the surface for approximately one minute to flush the sensors and was then lowered and retrieved at approximately 1 m/s at each station. Data from all sites were subsequently downloaded and processed according to the manufactures' recommendations. Water quality data from each station were further analysed by deriving appropriate summary statistics to investigate spatial physical-chemical variability in the Port.

Figure 2: Water quality monitoring sites (white pins) in the Port of Durban.

3.3 Results

3.3.1 Temperature

Overall, water temperatures were relatively uniform across the water quality stations in the Port and temperature increased as expected in summer. Mean surface water temperatures ranged between 24.98 – 25.88°C and mean bottom water temperatures from 24.92 – 25.28°C (**Table 1**). No substantial decrease in temperatures with increasing depth was observed across all 20 water quality stations. This indicates that the water column is mostly well-mixed at all tidal phases. Overall, temperature readings are similar to those reported in the baseline study (Clark et al., 2017).

3.3.2 Salinity

Previous sampling performed in spring (October 2020) indicated that salinity ranges across the Port exceeded the standard 33 – 36 PSU range for marine systems. In this season (summer 2021), however, salinity ranges across sampling stations were lower and mostly within the typical range for marine systems. There was little variation in salinity levels recorded across stations and depths, with mean surface water salinity ranging from 31.24 – 33.68 PSU and mean deep water salinity from 32.60 – 33.70 PST (**Table 1**). The overall decrease in salinity levels in summer could be driven by the seasonal rainfall patterns and the associated increase of freshwater influxes into the Port.

3.3.3 Dissolved Oxygen

Dissolved oxygen concentrations in estuaries typically range between 6 – 8 mg/L. Concern is warranted when levels below 2 - 5 mg/L persist over long periods, which can result in physiological stress for most estuarine biota. In summer 2021, mean dissolved oxygen concentrations ranged from 6.34 – 7.88 mg/L in surface waters and 5.26 – 6.85 mg/L in deeper water (**Table 1**). These concentrations have remained mostly constant throughout the monitoring events completed thus far.

3.3.4 pH

As with other water quality parameters, pH levels varied minimally across all tidal phases throughout the 20 water quality stations in the Port, with means ranging between 7.73 – 8.07 for surface waters and from 7.70 – 8.04 for deeper waters (**Table 1**). pH values recorded at all monitoring stations in the Port appears to remain constant with depth.

3.3.5 Turbidity

Turbidity levels in summer 2021 ranged from 0.19 – 7.79 NTU (Nephelometric Turbidity Units) in surface waters and from 0.20 – 9.75 NTU in deeper water layers (**Table 1**). Sites WQ1 (mangroves) and WQ3 (western bank) had the highest turbidity. Overall, turbidity levels have not deviated much from those reported in the baseline study (1 – 7 NTU (Clark et al., 2017)).

Table 1: Water quality results of surface (< 1 m depth) and bottom layers following the summer 2021 sampling event. All results given as mean ± standard deviation.

Station	Temperature (°C)		Salinity (PSU)		Dissolved Oxygen (mg/L)		pH		Turbidity (NTU)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
WQ01	25.38 ± 0.02	25.09 ± 0.28	31.78 ± 1.75	32.98 ± 0.91	6.34 ± 0.21	5.37 ± 0.16	7.73 ± 0.07	7.70 ± 0.09	4.55 ± 2.47	9.75 ± 2.76
WQ02	25.88 ± 0.84	24.92 ± 0.41	32.42 ± 1.02	33.49 ± 0.09	6.62 ± 1.41	5.26 ± 0.07	7.90 ± 0.10	7.86 ± 0.04	1.78 ± 0.33	1.24 ± 0.23
WQ03	25.70 ± 0.49	24.98 ± 0.52	30.66 ± 0.77	32.66 ± 1.18	7.26 ± 0.40	5.51 ± 0.40	7.90 ± 0.02	7.87 ± 0.03	7.97 ± 2.76	6.55 ± 5.77
WQ04	25.20 ± 0.03	24.95 ± 0.26	32.85 ± 1.12	33.55 ± 0.26	6.36 ± 0.66	6.32 ± 0.64	7.94 ± 0.02	7.95 ± 0.00	1.71 ± 0.18	1.07 ± 0.91
WQ05	25.81 ± 0.74	25.10 ± 0.20	30.98 ± 0.04	32.68 ± 0.65	7.44 ± 0.05	6.36 ± 0.28	7.96 ± 0.06	7.93 ± 0.02	3.73 ± 0.05	1.59 ± 0.25
WQ06	25.06 ± 0.13	25.07 ± 0.03	32.33 ± 1.44	32.82 ± 0.74	6.65 ± 0.54	6.18 ± 0.24	7.92 ± 0.04	7.93 ± 0.05	1.30 ± 1.61	0.58 ± 0.78
WQ07	25.54 ± 0.43	25.10 ± 0.18	31.24 ± 0.95	32.60 ± 1.28	7.60 ± 0.40	6.47 ± 0.33	7.99 ± 0.10	7.95 ± 0.05	8.23 ± 1.01	2.31 ± 1.02
WQ08	25.29 ± 0.21	25.10 ± 0.15	31.36 ± 1.76	32.86 ± 0.95	7.74 ± 0.07	6.77 ± 0.01	8.01 ± 0.08	7.97 ± 0.04	4.09 ± 1.99	2.36 ± 2.00
WQ09	25.53 ± 0.42	25.01 ± 0.31	31.56 ± 1.09	32.95 ± 1.15	7.88 ± 0.96	6.76 ± 0.02	8.01 ± 0.08	7.97 ± 0.03	4.12 ± 4.09	1.75 ± 2.82
WQ10	25.47 ± 0.49	24.97 ± 0.14	33.14 ± 0.44	33.52 ± 0.34	6.86 ± 0.84	6.61 ± 0.12	7.98 ± 0.05	7.95 ± 0.06	5.50 ± 7.52	5.47 ± 7.03
WQ11	25.05 ± 0.11	25.01 ± 0.29	32.75 ± 1.20	33.55 ± 0.35	7.22 ± 0.59	6.71 ± 0.32	7.96 ± 0.03	7.99 ± 0.03	0.23 ± 0.92	0.53 ± 0.01
WQ12	25.11 ± 0.44	24.98 ± 0.32	32.92 ± 1.37	33.62 ± 0.46	6.99 ± 0.28	6.75 ± 0.19	7.99 ± 0.02	7.99 ± 0.01	1.68 ± 0.64	0.98 ± 0.99
WQ13	25.29 ± 0.08	25.06 ± 0.06	33.28 ± 0.34	33.68 ± 0.21	7.44 ± 0.03	6.85 ± 0.04	8.02 ± 0.00	8.01 ± 0.01	3.06 ± 2.18	1.73 ± 0.57
WQ14	25.38 ± 0.01	25.15 ± 0.09	33.07 ± 0.56	33.57 ± 0.21	7.35 ± 0.27	6.85 ± 0.23	8.03 ± 0.01	8.02 ± 0.03	2.95 ± 0.72	2.39 ± 0.11
WQ15	25.41 ± 0.03	25.28 ± 0.07	33.68 ± 0.02	33.72 ± 0.05	7.58 ± 0.50	6.78 ± 0.23	8.07 ± 0.02	8.04 ± 0.00	2.03 ± 2.07	1.40 ± 2.48
WQ16	25.18 ± 0.25	25.01 ± 0.31	32.81 ± 0.81	33.31 ± 0.58	7.04 ± 0.08	6.63 ± 0.16	7.98 ± 0.02	7.98 ± 0.02	1.10 ± 0.78	0.20 ± 0.18
WQ17	25.36 ± 0.23	25.20 ± 0.04	33.03 ± 0.19	33.24 ± 0.36	7.13 ± 0.36	6.77 ± 0.04	7.97 ± 0.04	7.98 ± 0.01	0.19 ± 0.66	0.56 ± 0.09
WQ18	25.69 ± 0.77	25.16 ± 0.14	33.18 ± 0.67	33.59 ± 0.17	6.49 ± 0.33	6.23 ± 0.01	7.93 ± 0.03	7.95 ± 0.03	0.49 ± 0.96	2.82 ± 2.70
WQ19	25.60 ± 0.63	25.19 ± 0.15	33.11 ± 0.51	33.57 ± 0.09	6.98 ± 0.14	6.15 ± 0.15	7.93 ± 0.04	7.93 ± 0.00	3.15 ± 3.52	1.40 ± 1.67
WQ20	24.98 ± 0.07	24.95 ± 0.13	33.64 ± 0.10	33.70 ± 0.11	7.04 ± 0.41	6.30 ± 0.09	7.96 ± 0.03	7.95 ± 0.04	0.59 ± 0.79	0.73 ± 1.06

3.4 Conclusion

Physico-chemical conditions of water in the Port were mostly uniform across all the water stations surveyed and have demonstrated typical seasonal fluctuations throughout the monitoring conducted thus far. The comparatively high salinity values recorded in the previous survey (spring 2020) have decreased substantially and are most likely reflective of the seasonal rains and associated increased freshwater influx from nearby rivers and storm water. Concentrations of dissolved oxygen, turbidity and pH have remained fairly constant from the previous survey and are in line with the baseline conditions reported in Clark et al. (2017). As Berth construction had not begun, these data can be viewed as a compliment to baseline data used to characterize pre-construction water quality conditions.

4 Sediments

4.1 Introduction

Sediments play an important role in terms of habitat provisioning for aquatic organisms. These organisms, in turn, play a role in the establishment of an ecosystem. Several sediment characteristics are frequently incorporated into long-term monitoring programmes, including grain size composition, concentrations of nutrients such as carbon (measured as Total Organic Carbon) and trace metals. Contaminants present in water can settle in the sediment where they can accumulate over time. As such, sediments can be regarded as a pollutant sink (David, 2006). When these sediments are disturbed (e.g. through dredging), contaminants can become suspended in the water column and become available for uptake by marine biota. In addition, sediment characteristics can also be used to explain the community dynamics of macrofaunal invertebrates (Anthony & Héquette, 2007; Watson et al., 2013; see section 4).

The distribution of different grain sizes are driven mostly by water movement. Finer sediment tends to accumulate in areas with minimal hydrodynamic disturbance, whereas coarser sediment occurs in areas with greater disturbance. Sediments are classified according to grain size (**Table 2**) and studying the composition of grain sizes can reveal areas that are likely to have elevated contaminant levels. This is because pollutants bind more easily to fine or muddy sediments with larger surface areas (Ellingsen, 2002; Austen & Widdicombe, 2006; Anderson, 2008).

Table 2: Sediment grain size characterization.

Descriptive term		**Grain size**
Gravel		> 2000 µm
Sand	Very coarse	1000 – 2000 µm
	Coarse	500 – 1000 µm
	Medium	250 – 500 µm
	Fine	125 – 250 µm
	Very fine	63 – 125 µm
Mud/silt		< 63 µm

Sediment contamination can stem from various activities including wastewater treatment and disposal, runoff, mining, industrial activity, etc. The pollutants introduced from such activities can pose risks to the health and functioning of aquatic ecosystems (Sponseller et al. 2013; Effendi et al., 2016).

Another sediment parameter that serves as a useful metric of overall sediment quality is the concentration of Total Organic Carbon (TOC). While organic matter represents an important food source for organisms such as benthic macrofauna (Lopez et al., 1989; Snelgrove & Butman 1994), an excess of such nutrients may result in negative impacts on these communities. The degradation process of these nutrients in the sediments requires oxygen and can produce toxic by-products (e.g. ammonia, sulphide) (Gray et al. 2002). Areas that have elevated levels of TOC are also likely to contain other contaminants. The proportions of TOC in sediments can be classified into three broad system types: oligotrophic, mesotrophic and eutrophic (Forbes & Demetriades, 2003) (**Table 3**). Habitats with high TOC levels are at risk to become oxygen depleted (i.e. eutrophic).

Table 3: Total Organic Carbon (TOC) classification levels in sediments (adapted from Forbes & Demetriades, 2003).

% Total Organic Carbon	Class	System Type
<0.5%	Very Low	**Oligotrophic**
0.5 – 1 %	Low	very low levels of nutrients
1 – 2 %	Moderate	**Mesotrophic** intermediate level of productivity
2 – 4 %	Medium	**Eutrophic**
>4%	High	rich in nutrients and minerals, can have excessive algal growth and thus diminished oxygen content to the detriment of other organisms

The final sediment characteristic that is considered as part of this monitoring programme is the concentration of trace metals. Trace metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) occur naturally in marine environments and play fundamental physiological roles. They tend to accumulate in fine sediments where they are largely passive (non-threatening) but can become harmful when sediments are disturbed (e.g. through dredging) and subsequently suspended in the water column (Summers et al., 1996; Ellingsen, 2002; Austen & Widdicombe, 2006; Anderson, 2008; CSIR, 2016). Metals may be assimilated by organisms such as filter-feeders and can lead to bioaccumulation in higher order marine organisms which may further result in human health consequences if such organisms are consumed.

In this study, sediment trace metal concentrations are contrasted against the South African regulations and the Effects Range Low (ERL) and Effects Range Median (ERM) concentrations specified by the National Oceanographic and Atmospheric Administration (NOAA) (**Table 4**). The ERL values (lower 10^{th} percentile) and ERM (median) are derived from the literature and refers to the 10^{th} percentile and median concentrations of a particular trace metals at which biological effects of trace metal contamination have been observed.

Table 4: South African and NOAA sediment quality guidelines for trace element concentrations. Concentrations are parts per million (ppm) dry weight (mg/kg), ERL = Effects Range Low, ERM = Effects Range Median (DEA, n.d).

	South African guidelines		NOAA Guidelines	
Metal	**Special Care Range (ppm)**	**Prohibited (ppm)**	**ERL (ppm)**	**ERM (ppm)**
Arsenic (As)	30 – 50	>150	8.2	70
Cadmium (Cd)	1.5 – 10	>10.0	1.2	9.6
Chromium (Cr)	50 – 500	>500	81	370
Copper (Cu)	50 – 500	>500	34	270
Mercury (Hg)	0.5 – 5.0	>5.0	0.15	0.71
Lead (Pb)	100 – 500	>500	46.7	218
Nickel (Ni)	50 – 500	>500	20.9	51.6
Zinc (Zn)	150 – 750	>750	150	410

4.1.1 Sediment Threshold Limits set in the Central Sand Bank Mitigation Plan, 2017

Threshold (warning) levels have been established for grain size (% sand and % mud), Total Organic Carbon concentration (%TOC) and trace metals in sediment samples from the Central Sand Bank Mitigation Plan, 2017 (**Table 5**). If these limits are violated, negative impacts on biota such as invertebrates, fish and birds in the Port could occur.

Table 5: Baseline threshold (warning) levels for sediment parameters (%sand, mud %, Total Organic Carbon (TOC) %, and trace metal concentrations) in intertidal and subtidal sediment samples from control and impact monitoring stations across the Port of Durban (adapted from Clark et al., 2017). Values for grain sizes (sand, mud) must fall between 10 – 90th percentiles whereas values for trace metals must fall below the 90th percentile.

Parameter	Intertidal limits		Subtidal limits	
	10th percentile	90th percentile	10th percentile	90th percentile
Sand (%)	99.6	100	97.4	99.9
Mud (%)	0.0	0.4	0.1	2.6
TOC (%)	1.0	2.0	1.4	6.0
As (ppm)	1.734	4.58	1.734	7.73
Cd (ppm)	n/a	0.58	n/a	1.38
Co (ppm)	n/a	3.93	n/a	7.09
Cr (ppm)	n/a	29.93	n/a	54.59
Cu (ppm)	n/a	16.13	n/a	58.88
Fe (%)	n/a	1.14	n/a	2.19
Mn (ppm)	n/a	214.44	n/a	202.83
Ni (ppm)	n/a	7.38	n/a	15.63
Pb (ppm)	n/a	10.94	n/a	46.70
Zn (ppm)	n/a	25.67	n/a	127.26
Hg (ppm)	n/a	0.10	n/a	0.18

4.2 Methodology

4.2.1 Sampling locations

Sediment samples were taken at 39 intertidal (**Figure 3**) and 25 subtidal (**Figure 4**) sites distributed across the Port.

Figure 3: Intertidal sediment sample sites in the Port of Durban. This included 21 intertidal stations on the existing central sandbank (yellow pins – Int 10-31), 10 intertidal northern bank stations (yellow pins, Int 40-49), and additional 12 intertidal impact-monitoring stations on the central (black pins, Int 2 - 9). Sites immediately adjacent to the newly established sand bank (red pins, Int 53 - 63) will be sampled once development has commenced. Impact monitoring stations: Int2 – Int31, control monitoring stations: Int40 – Int49. Samples were collected at these sites for sediment characteristics, microalgae and benthic macrofauna. The area highlighted in red is where dredging is to take place.

Figure 4: Subtidal sites within the Port of Durban where sediment samples were taken. These sites represent three habitats: the central bank (Sub13 – Sub26), the little lagoon (Sub27 – Sub33), and the northern bank (Sub40 – Sub48). Impact monitoring stations: Sub13-Sub33, control stations: Sub40-Sub48. Samples were collected at these sites for sediment characteristics, microalgae and benthic macrofauna. The area highlighted in red is where dredging is to take place.

4.2.2 Sampling protocol

Intertidal sediment samples were taken at low tide when these sandbanks were exposed. Intertidal sediment samples were collected using a hand corer with a diameter of 18 cm. Once inserted into the sediment, the sides around the tube were dug out to insert the separator. The top surface of sediment was then separated from the remaining layers of sediment with these remaining layers then discarded. The top layers where subsequently transferred to sample containers and stored in a cooler box with ice.

Subtidal (i.e. permanently submerged) sediment samples were collected using a stainless steel van Veen grab. This grab was attached to 50 m long rope that was fixed onto a vessel so the grab could be manually lowered onto the seafloor for benthic sediment collection. The grab was locked in place with a safety pin prior to deployment, after which it was hoisted over the side of the vessel and lowered until it reached the seafloor where sediment samples were collected. Field scientists standing on the vessel lowered the grab at a constant speed to the seafloor bottom. Once the grab made contact with the seafloor the safety pin triggered (indicated by slack in the lowering wire), the tension on the rope was slowly increased, causing the lever arms to close the grab and take a sample. On retrieval of the van Veen grab, water trapped above sediment in the grab was drained through a bleeder hole, taking care to lose as little fine-grained material as possible. The samples were collected with a Teflon scoop and placed in sterile cups, sealed and labelled with cross-referencing to sampling sites.

Following collection, all intertidal and subtidal sediment samples were placed in individual containers and kept on ice in the field until delivery to the Talbot and Talbot laboratory (SANAS accredited). Once in the laboratory they were stored frozen (-4^{o}C) until further processing and analysis. From these samples, the grain size distribution, Total Organic Carbon (TOC) content and trace metal concentrations were established.

4.3 Results

4.3.1 Key results

The CSMP study stipulates that the median values of the various sediment characteristics (grain size, TOC concentration, trace metal concentration) of impact and control sites must be contrasted against the baseline levels established in the CSMP. The key results of all intertidal and subtidal sediment characteristics in relation to these levels are summarised below (**Table 6, Table 7**).

The majority of intertidal sediment characteristics were within allowable limits, apart from grain size proportions, TOC, arsenic and mercury concentrations (**Table 6**). Mercury concentrations exceeded the maximum allowable threshold at control and impact sites.

Table 6: Key results of intertidal sediment characteristics (grain size, TOC, trace metal concentrations) in relation to the 90th percentile threshold limits of the CSMP. Values for grain sizes (sand, mud) must fall between 10 – 90th percentiles whereas values for trace metals must fall below the 90th percentile. Values printed in red are outside of allowable ranges. Sites are grouped as overall (all sites), impact sites (Int3 – Int 31) and control sites (Int40 – Int49).

Characteristic	10th percentile	90th percentile	Median (all sites)	Median (impact sites)	Median (control sites)
Sand (%)	99.6%	100%	**99.24%**	**99.22%**	**99.39%**
Mud (%)	0%	0.4%	0.13%	0.13%	0.24%
Total Organic Carbon (%)	1%	2%	**0.6%**	**0.6%**	**0.55%**
As (ppm)	1.7834	4.58	2.2	2.97	**1.47**
Cd (ppm)	n/a	0.58	0.12	0.13	0.1
Co (ppm)	n/a	3.93	0.47	0.59	0.39
Cr (ppm)	n/a	29.93	4.26	4.43	3.93
Cu (ppm)	n/a	16.13	2.26	2.33	2.15
Fe (%)	n/a	1.14	0.27	0.29	0.23
Mn (ppm)	n/a	214.44	35	41	9.98
Ni (ppm)	n/a	7.38	1.17	1.33	1.06
Pb (ppm)	n/a	10.94	3.26	3.26	3.29
Zn (ppm)	n/a	25.67	5.70	5.86	5.36
Hg (ppm)	n/a	0.1	**0.246**	**0.236**	**0.31**

Similarly, in subtidal sediments all parameters apart from TOC and mercury were within allowable limits (**Table 7**). Detailed descriptions of each sediment parameter follows in the sections below (section 4.3.2 - 4.3.14).

Table 7: Key results of subtidal sediment characteristics (grain size, TOC, trace metal concentrations) in relation to the 90th percentile threshold limits of the CSMP. Values for grain sizes (sand, mud) must fall between 10 – 90th percentiles whereas values for trace metals must fall below the 90th percentile. Values printed in red are outside of allowable ranges. Sites are grouped as overall (all sites), impact sites (Sub13 – Sub33) and control sites (Sub40 – Sub48).

Characteristic	10th percentile (CSMP)	90th percentile (CSMP)	Median (all sites)	Median (impact sites)	Median (control sites)
Sand (%)	97.4%	99.9%	99.5%	99.35%	99.6%
Mud (%)	0.1%	2.6%	0.2%	0.2%	0.26%
Total Organic Carbon (%)	1.4%	6%	**0.7%**	**0.7%**	**0.8%**
As (ppm)	n/a	7.73	2.37	2.61	2.36
Cd (ppm)	n/a	1.38	0.16	0.16	0.21
Co (ppm)	n/a	7.09	0.48	0.50	0.08
Cr (ppm)	n/a	54.59	3.87	3.83	3.99
Cu (ppm)	n/a	58.88	2.97	2.87	3.27
Fe (%)	n/a	2.19	0.32	0.34	0.29
Mn (ppm)	n/a	202.83	40.23	40.23	38.73
Ni (ppm)	n/a	15.63	1.07	1.08	1.01
Pb (ppm)	n/a	46.7	3.26	3.35	2.96
Zn (ppm)	n/a	127.26	5.39	5.62	5.27
Hg (ppm)	n/a	0.18	**0.37**	**0.38**	**0.36**

4.3.2 Grain Size

The proportions of sand at intertidal sites were slightly below the minimum limit stipulated in the CSMP. This result is likely driven by elevated levels of gravel and mud found at some sites on the northern bank (**Figure 5**). The majority of sandy sediments were in the fine (125 – 250 µm) and medium (250 – 500 µm) size classes in intertidal and subtidal environments. While subtidal sites had slightly greater proportions of mud, this was still within allowable limits as per the CSMP (**Figure 6**).

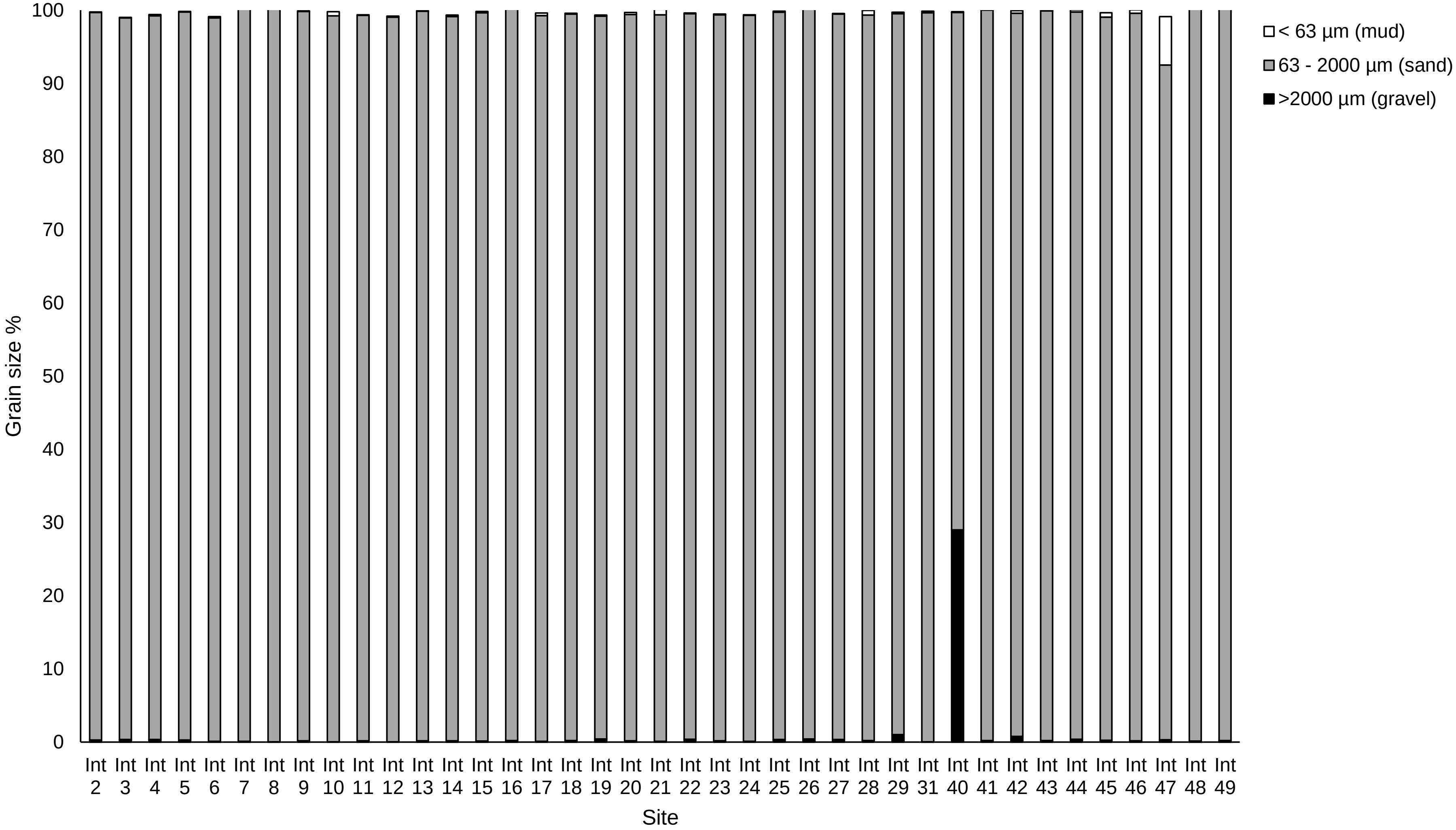

Figure 5: Intertidal grain size distribution of impact (Int 2 – Int 30) and control (Int 40 – 49) sites in summer 2021.

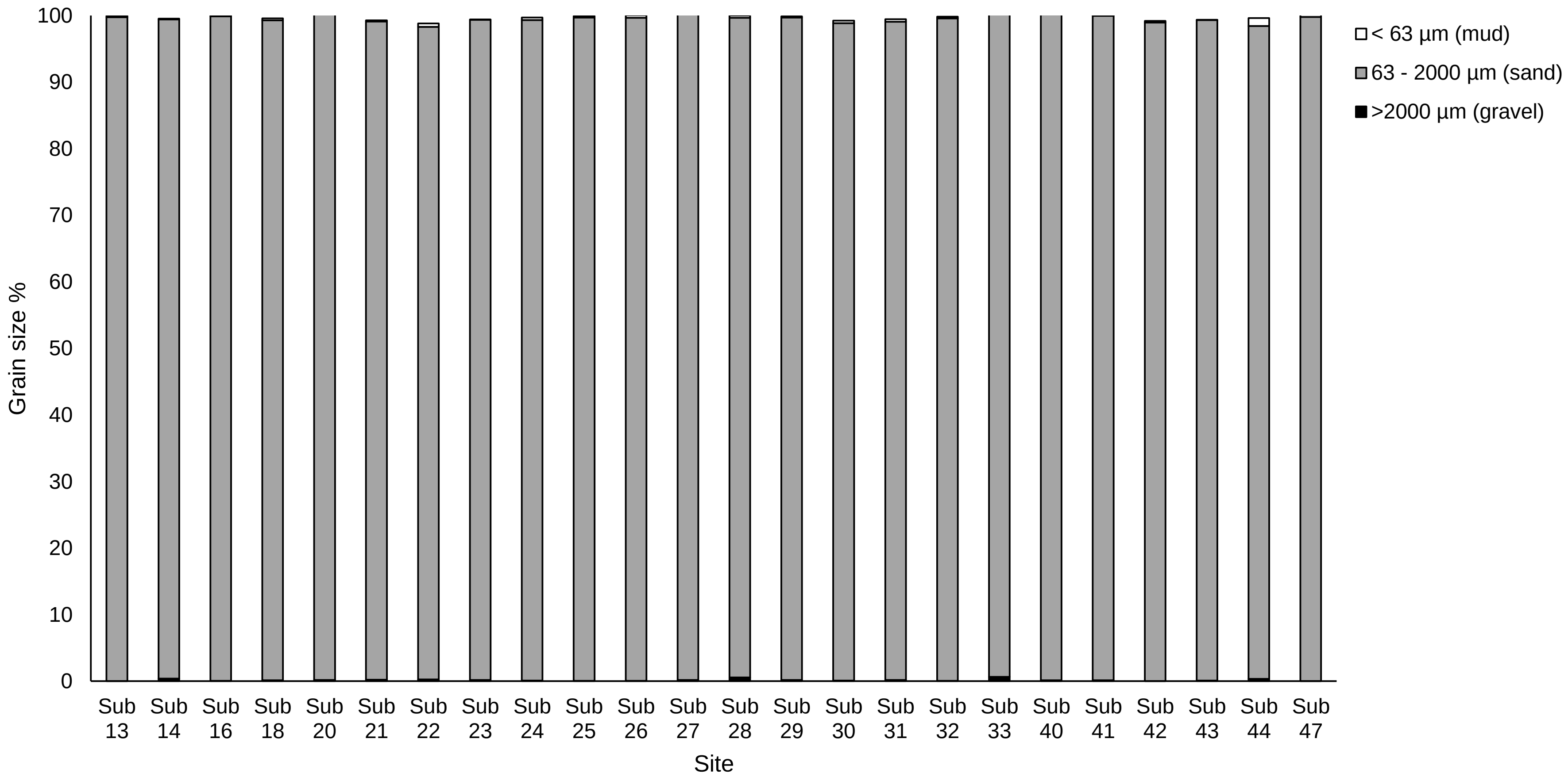

Figure 6: Subtidal grain size distribution of impact (Sub 13 – 33) and control (Sub 40 – 47) sites in summer 2021.

4.3.3 Total Organic Carbon (TOC)

As in previous seasons, Total Organic Carbon concentrations were below the threshold minimum values stipulated in the CSMP (Clark et al., 2017). This was true for intertidal (**Figure 7**) and subtidal (**Figure 8**) habitats. These results suggest that nutrient levels in sediments are very low and characteristic of an oligotrophic system.

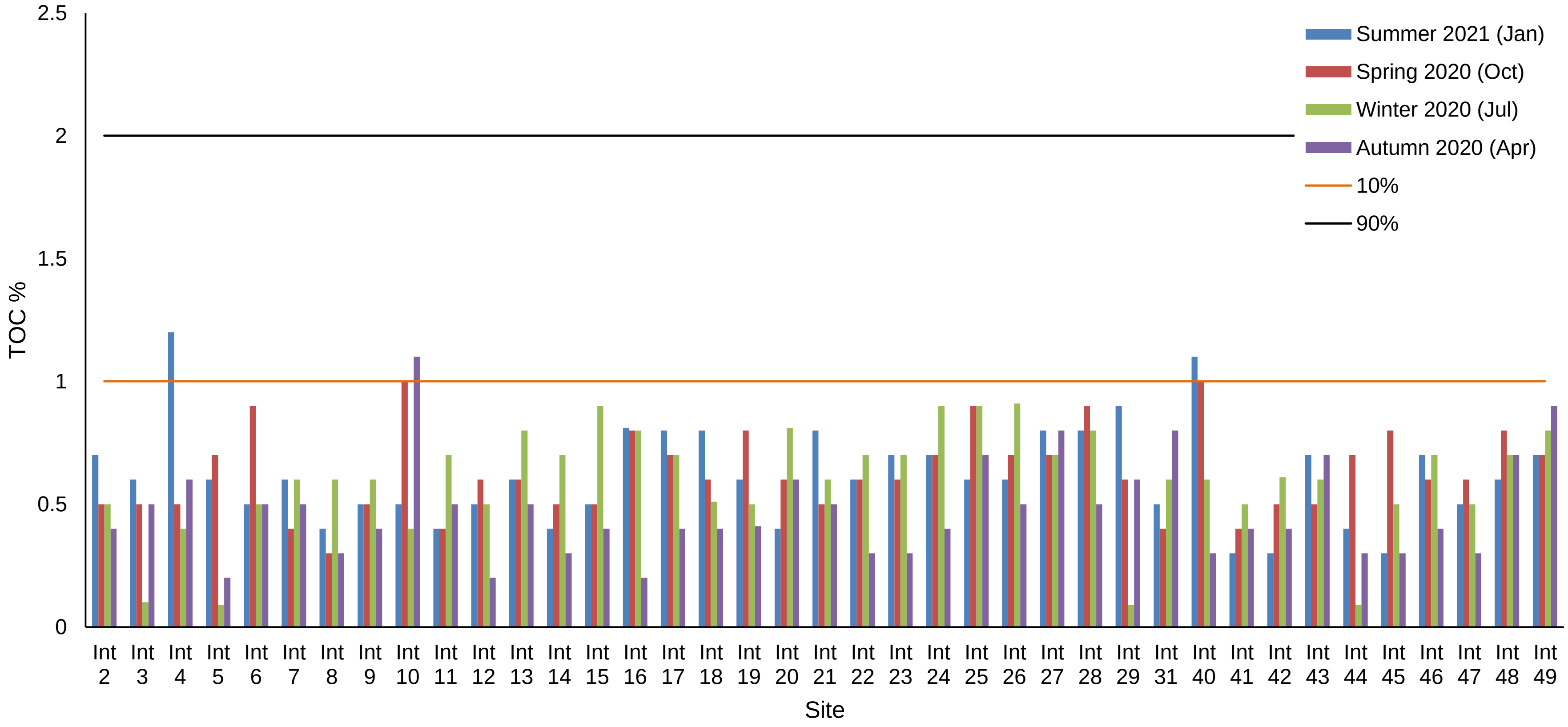

Figure 7: Total Organic Carbon (%) in intertidal sediments of impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Horizontal lines: black – threshold maximum limit (90th percentile), orange – threshold minimum (10th percentile).

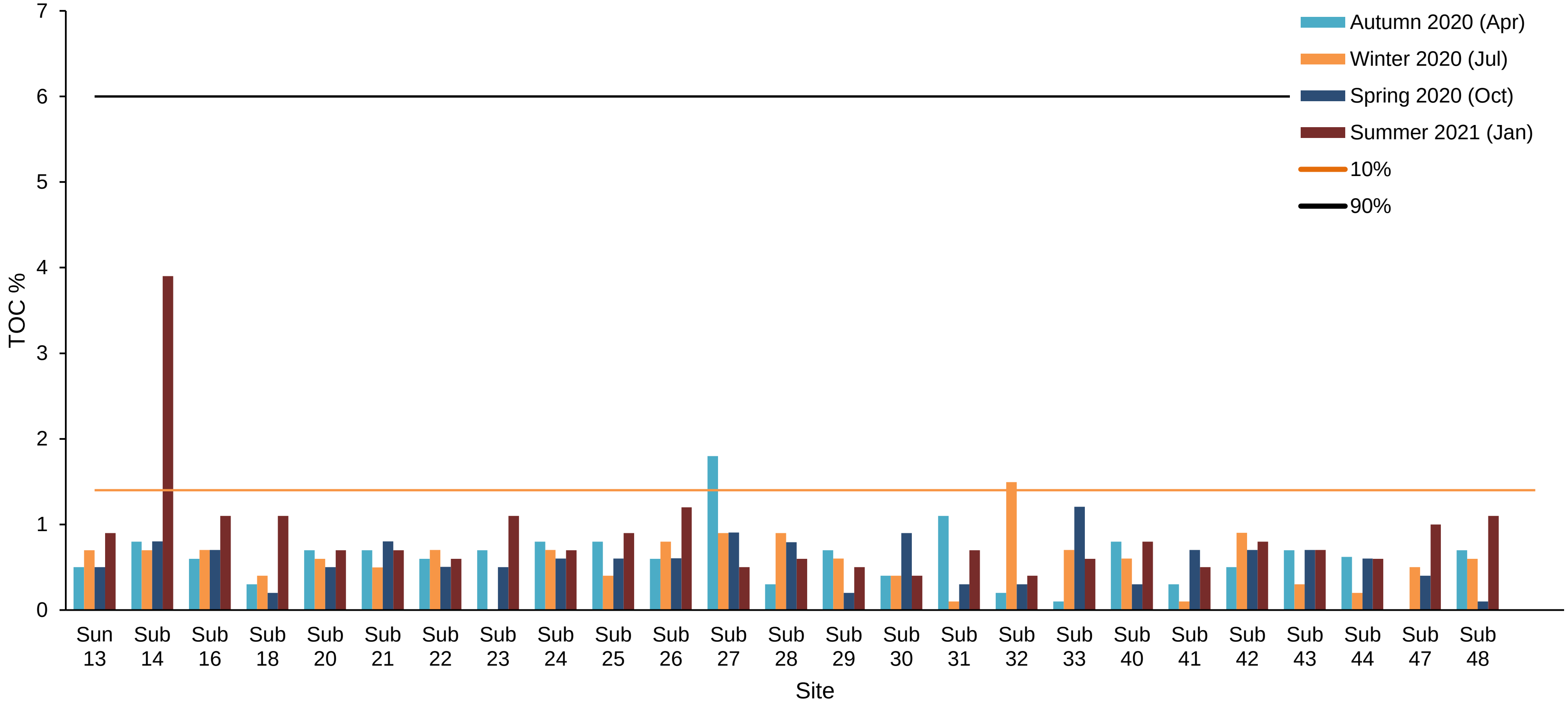

Figure 8: Total Organic Carbon (%) in subtidal sediments of impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Horizontal lines: black – threshold maximum limit (90th percentile), orange – threshold minimum (10th percentile).

4.3.4 Arsenic

While median intertidal arsenic concentrations were within allowable limits, greater concentrations were recorded at impact than control sites, as has been the case in previous seasons as well (**Figure 9**). Subtidal concentrations, on the other hand, were more evenly distributed (**Figure 10**).

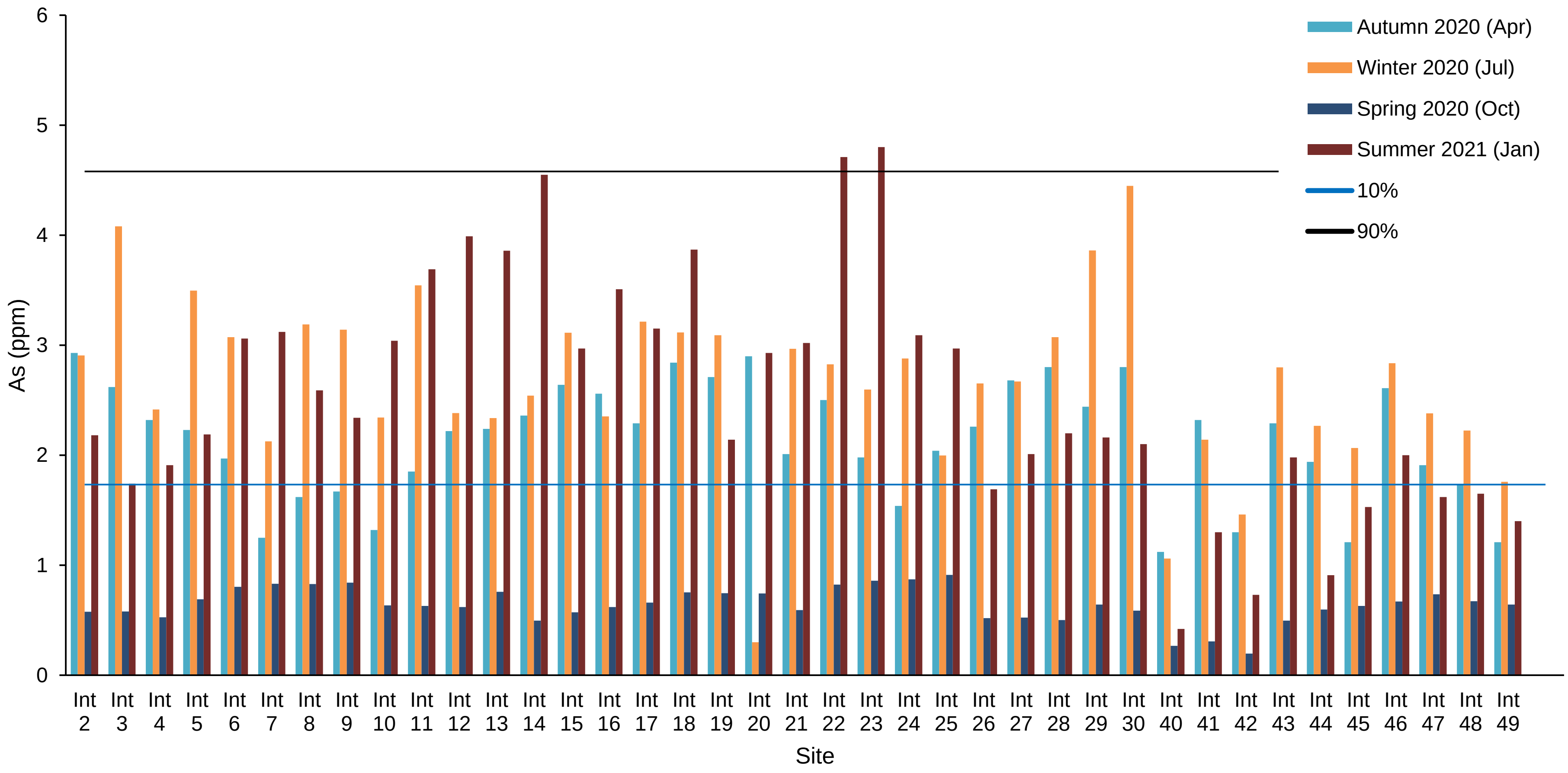

Figure 9: Concentration (ppm) of arsenic in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Special Care (SC) minimum is 30 ppm; special care maximum limit is 50 ppm, not shown on figure) Horizontal lines: Threshold limit (10th and 90th percentile) from the CSMP baseline study.

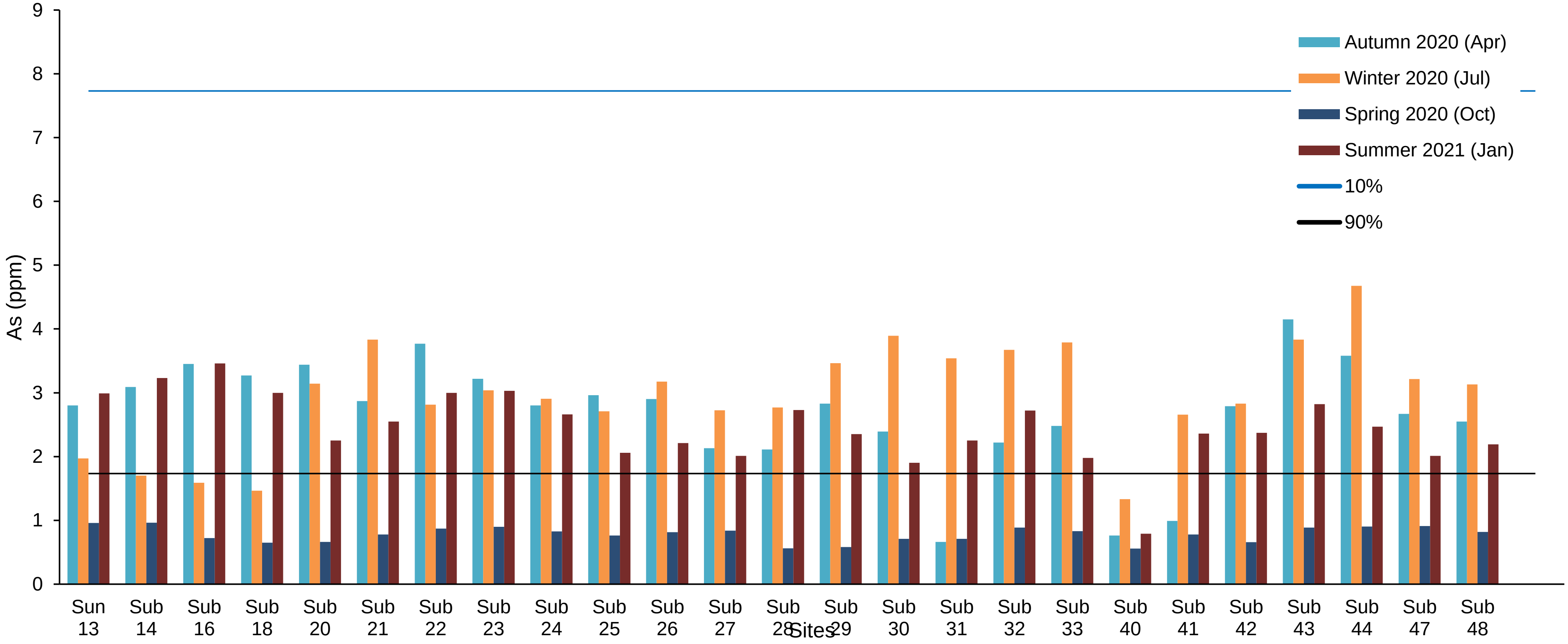

Figure 10: Concentration (ppm) of arsenic in subtidal sediments of the impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Special Care (SC) minimum limit = 30 ppm (not shown on figure), SC maximum = 50 ppm (not shown on figure). Horizontal lines: Threshold limit (10^{th} and 90^{th} percentile) from the CSMP baseline study.

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4.3.5 Cadmium

Cadmium concentrations have been consistently low in both intertidal (**Figure 11**) and subtidal (**Figure 12**) sediments throughout the year. Intertidal concentrations were mostly evenly distributed across sites, while subtidal concentrations spiked at the control sites on the northern bank.

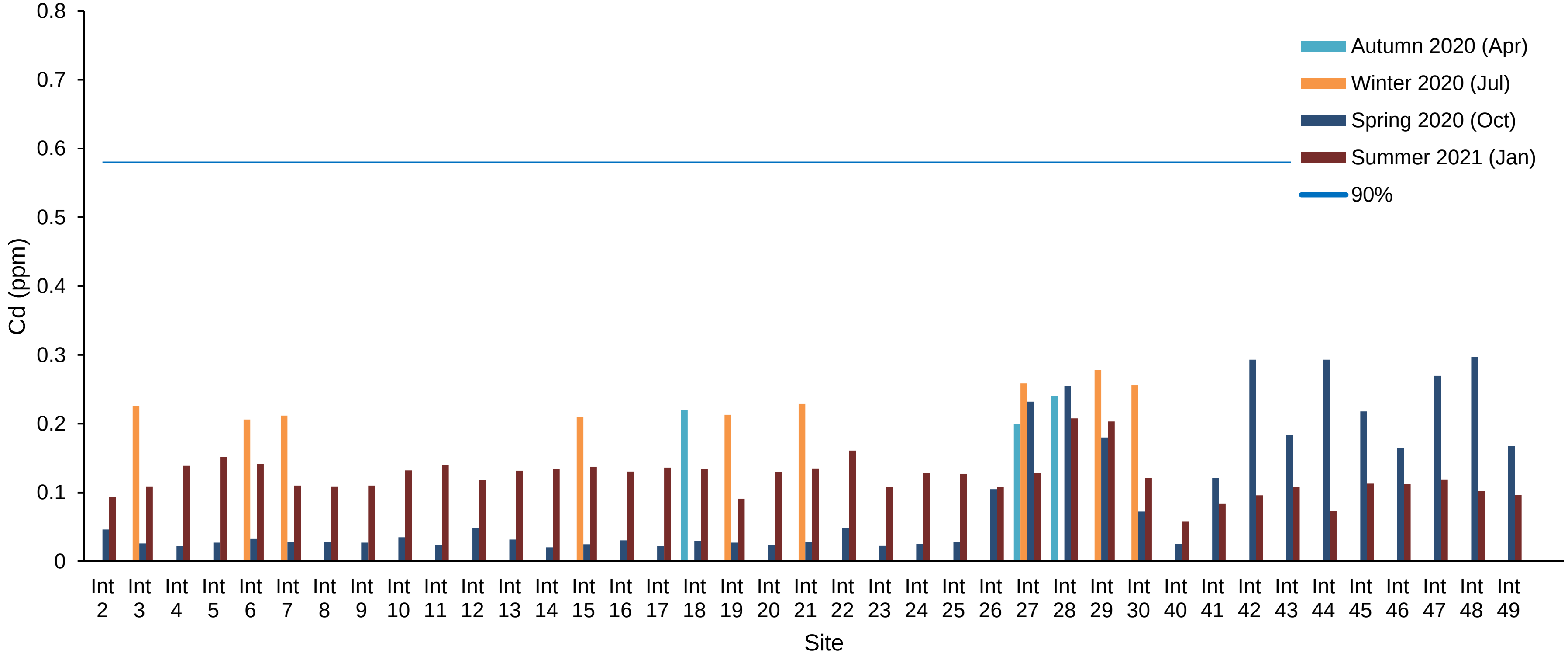

Figure 11: Concentration (ppm) of cadmium in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Blue horizontal line: threshold maximum (90th percentile).

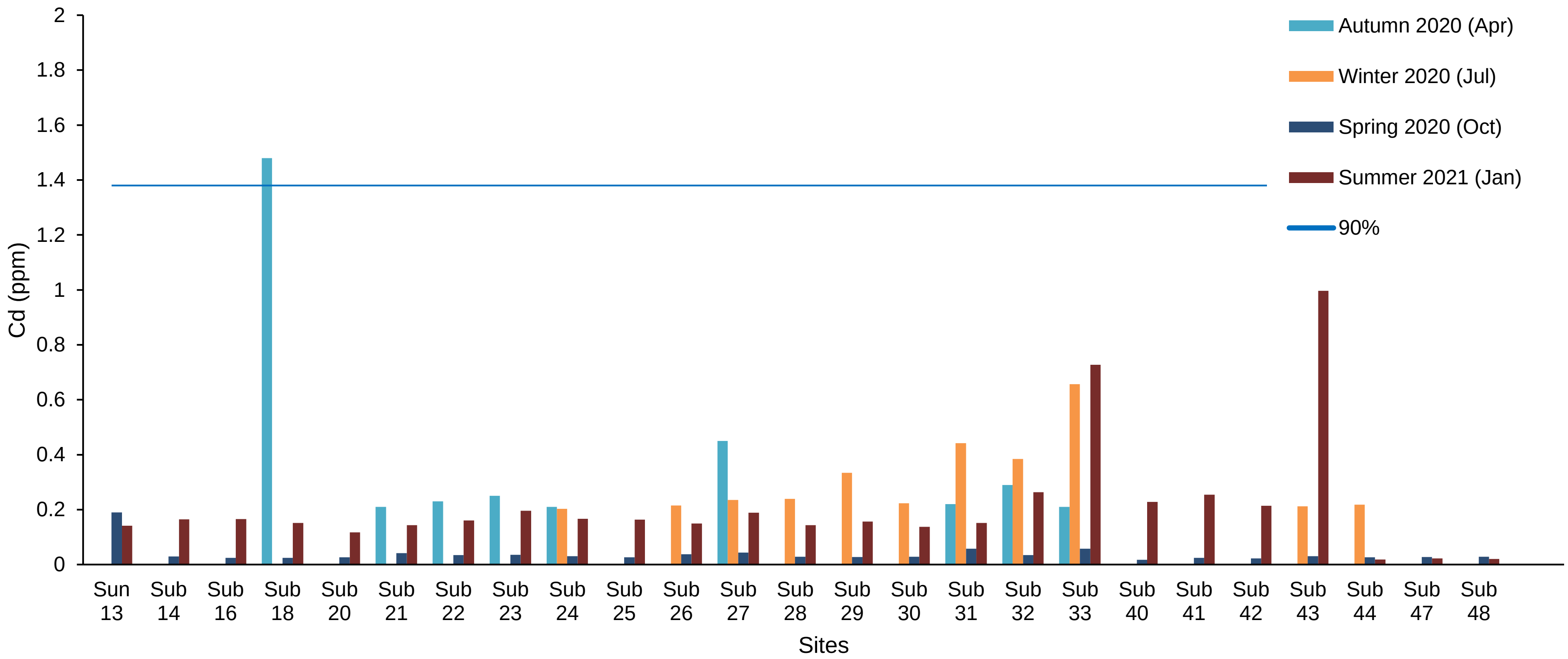

Figure 12: Concentration (ppm) of cadmium in subtidal sediments at impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum (90th percentile).

4.3.6 Chromium

Chromium concentrations have been within allowable limits for the majority of sampling events completed thus far. Intertidal and subtidal concentrations recorded in the most recent sampling event (summer 2021) were lower than those recorded in the previous sampling event and were uniformly distributed across sites (**Figure 13, Figure 14**).

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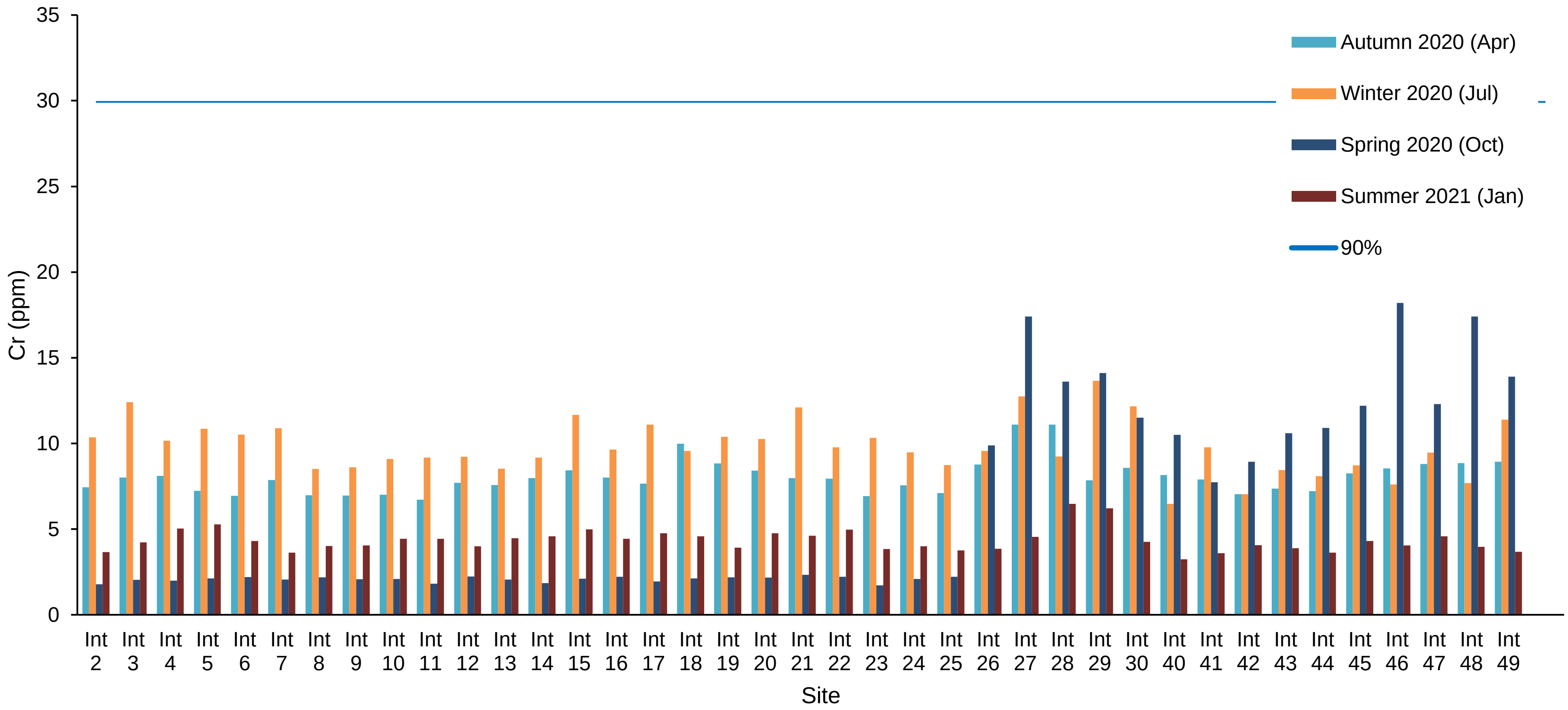

Figure 13: Concentration (ppm) of chromium in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Horizontal blue line: threshold maximum limit (90th percentile) from the CSMP baseline study.

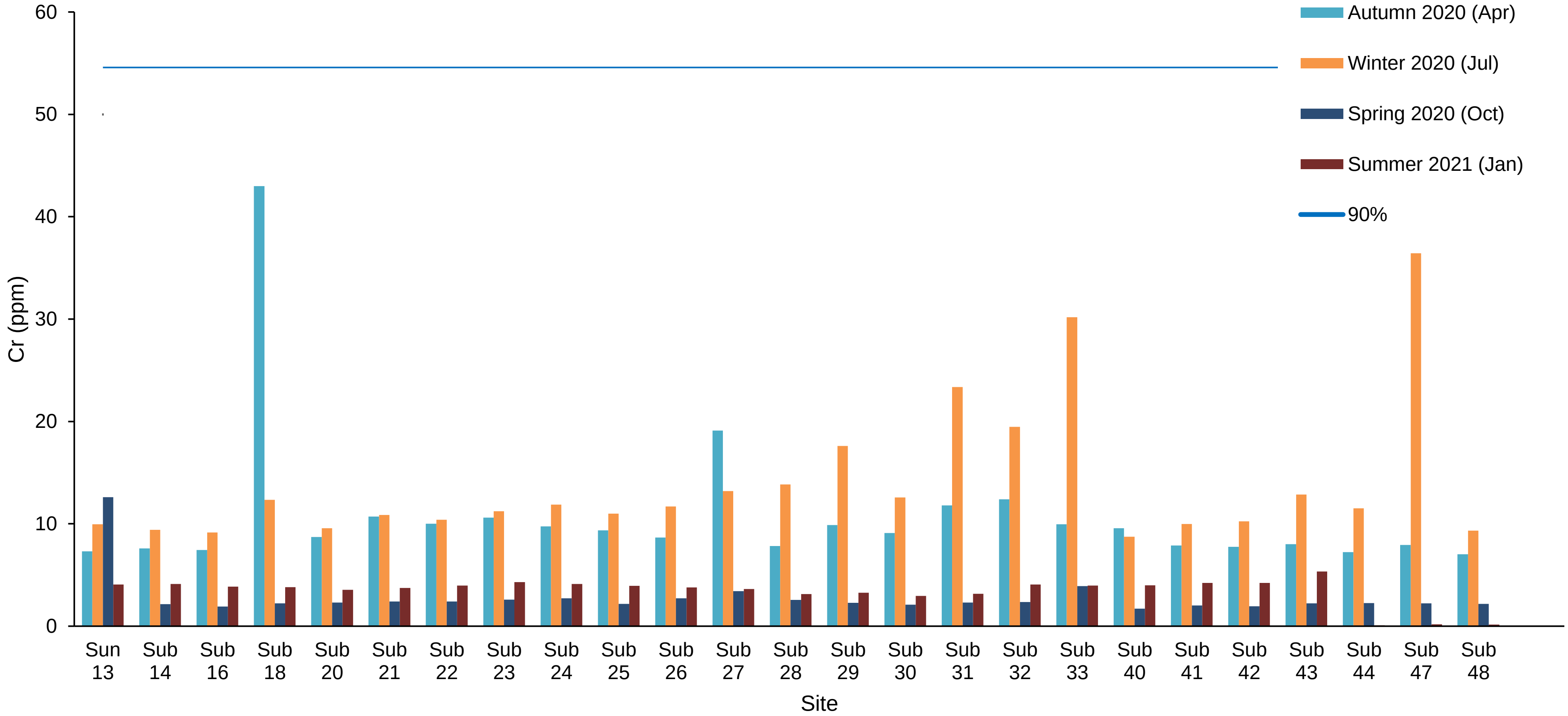

Figure 14: Concentration (ppm) of chromium in subtidal sediments of impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline report.

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4.3.7 Copper

While median intertidal copper concentrations were below the allowable threshold maximum, an extremely elevated copper concentration was recorded at control site Int 45 (**Figure 15**). This could be a result of local (site-specific) contamination as this high concentration was not found at other intertidal nor subtidal sites. This site is located in close proximity to a storm water drain so there is a possibility that pollutants may have been introduced in this way. Copper concentrations at subtidal sites demonstrated a more uniform pattern, with the lowest concentrations found at the control sites (**Figure 16**).

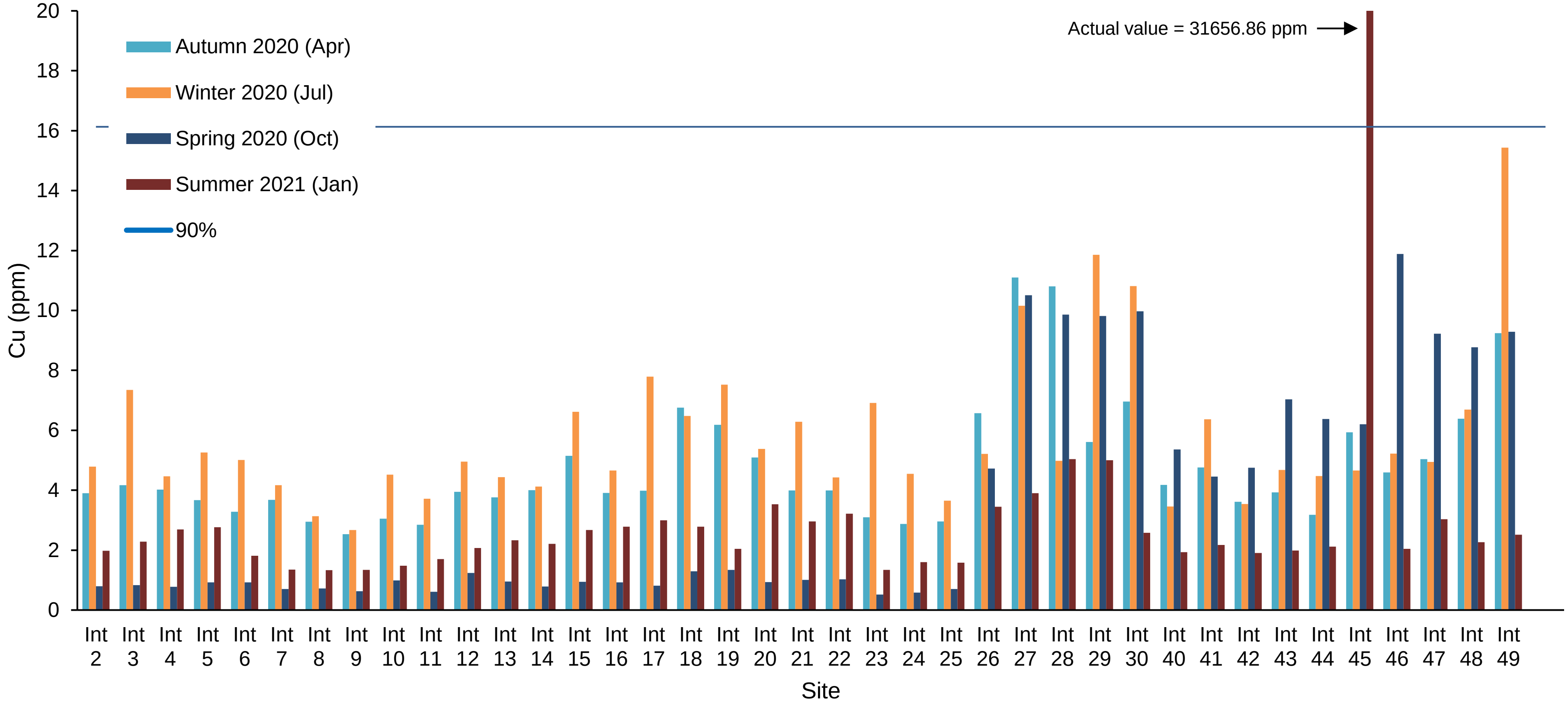

Figure 15: Concentration (ppm) of copper in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. The concentration at site Int 45 is 31656.86 ppm and not 20 ppm (graph scale adjusted for ease of interpretation). Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

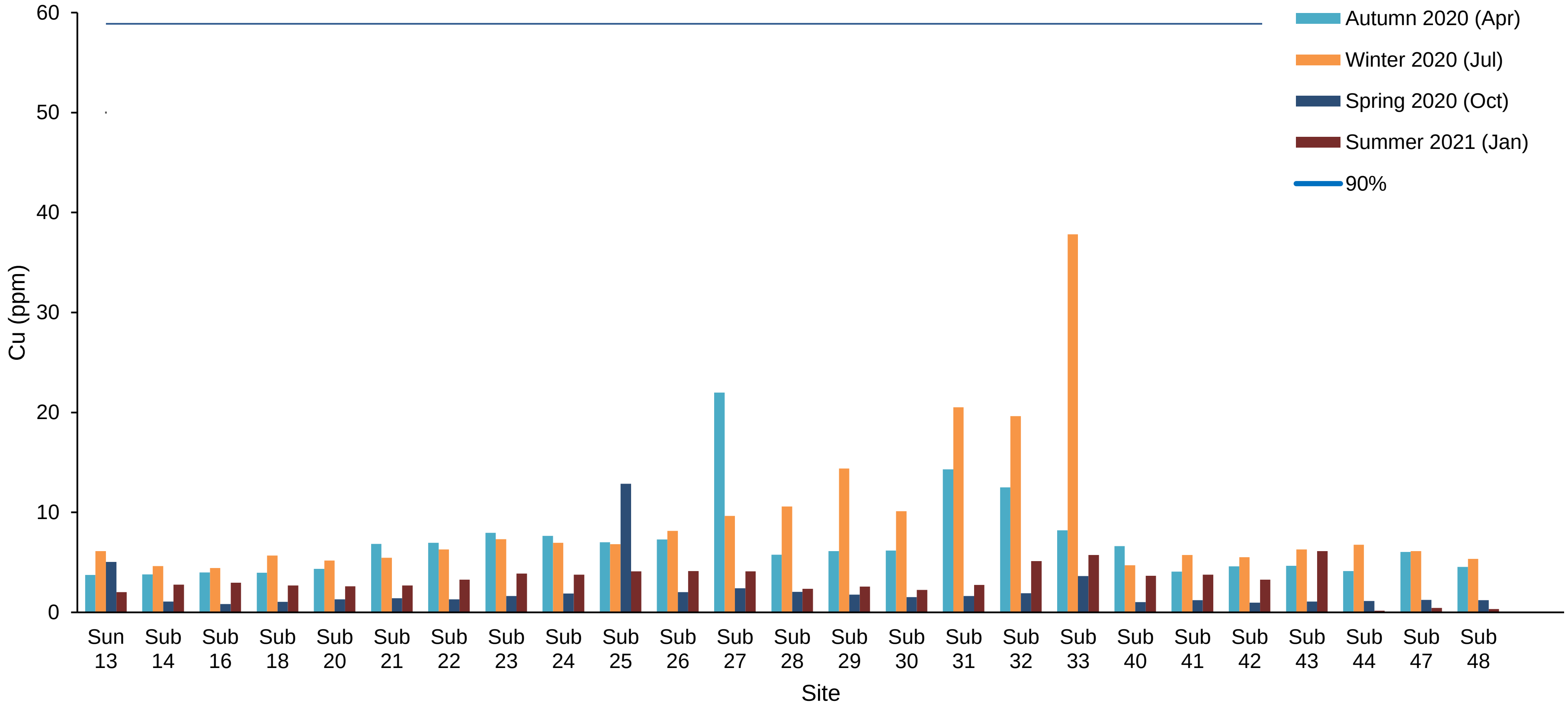

Figure 16: Concentration (ppm) of copper in subtidal sediments of impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

4.3.8 Mercury

Mercury concentrations started to increase in spring 2020 and have continued this trend in summer 2021, where most intertidal (**Figure 17**) and subtidal (**Figure 18**) concentrations were above the respective allowable thresholds stipulated in the CSMP. Elevated mercury concentrations have also been found in *Perna perna* mussels (section 7), indicating that the high mercury concentrations are not restricted to the sediments.

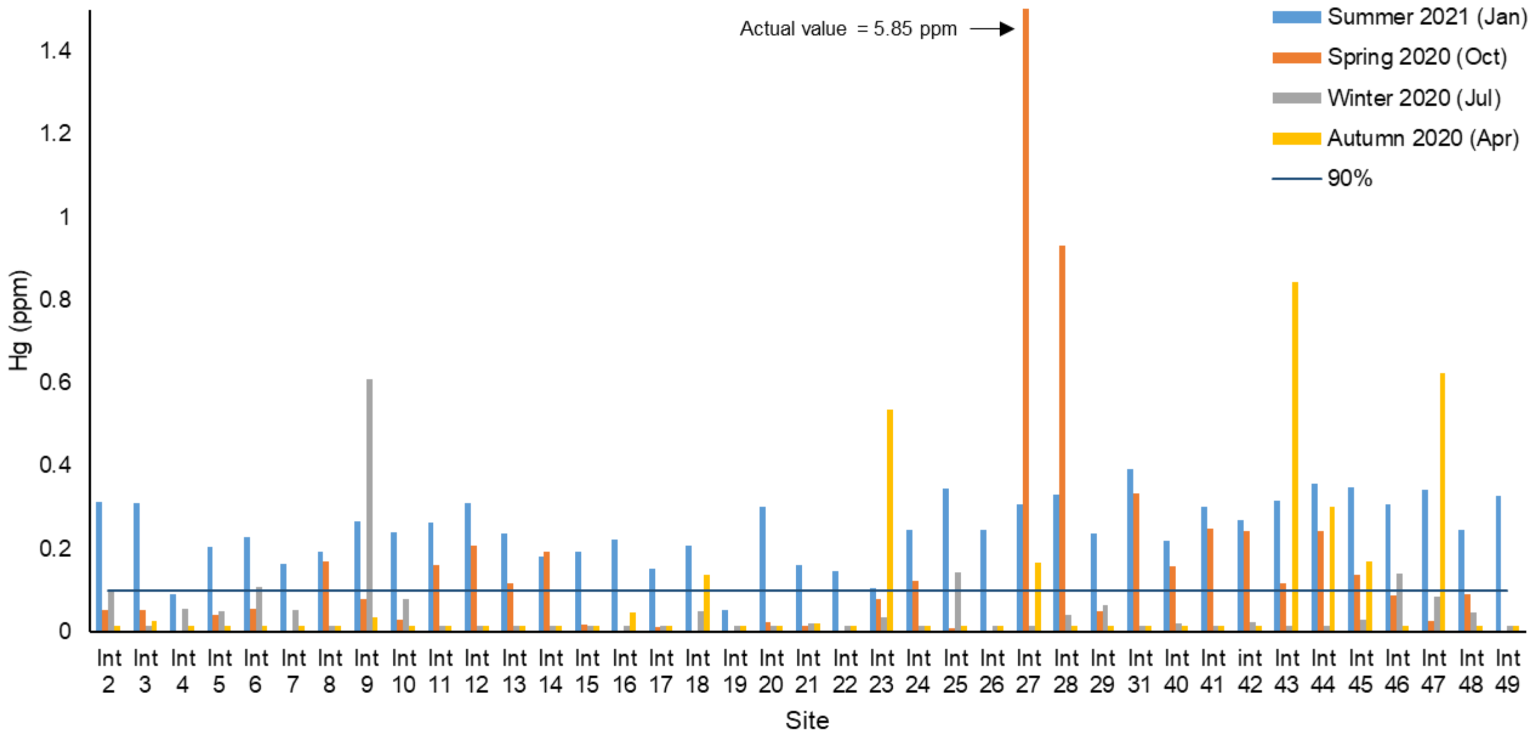

Figure 17: Concentration (ppm) of mercury in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Horizontal blue line: threshold maximum limit (90th percentile) from the CSMP baseline study. Note that the actual concentration at site Int 27 in spring is 5.85 ppm.

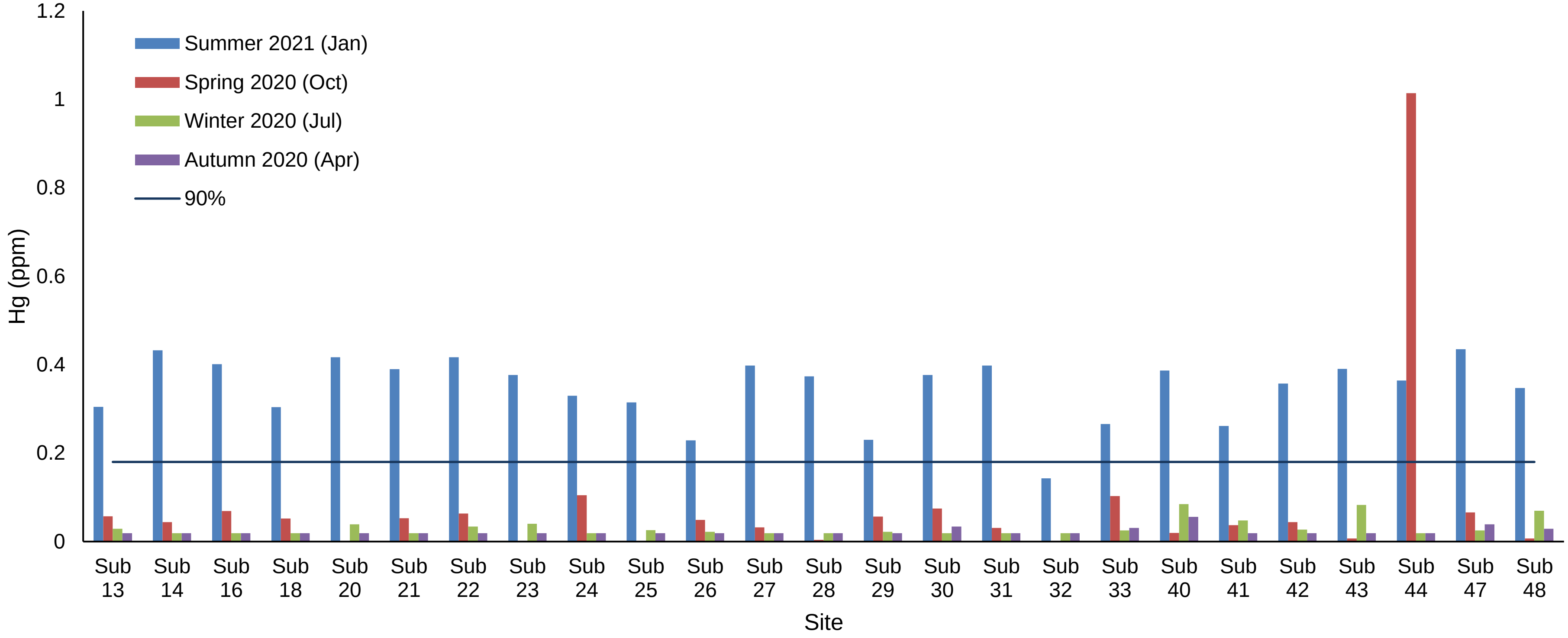

Figure 18: Concentration (ppm) of mercury in subtidal sediments at impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

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4.3.9 Lead

Apart from spring 2020, lead levels have been consistently below the maximum allowable values in intertidal and subtidal sediments (**Figure 19, Figure 20**).

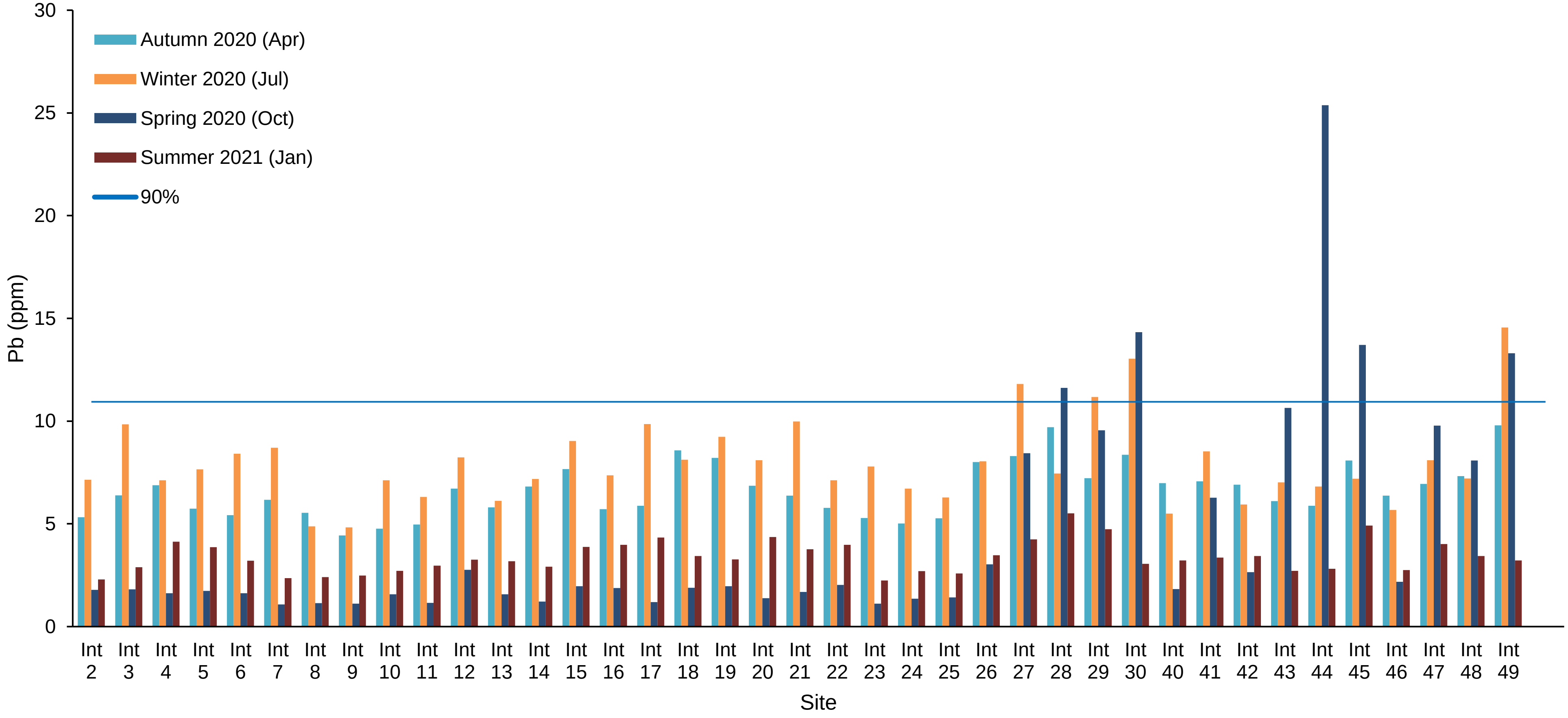

Figure 19: Concentration (ppm) of lead in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Blue horizontal line: CSMP 90th percentile maximum limit.

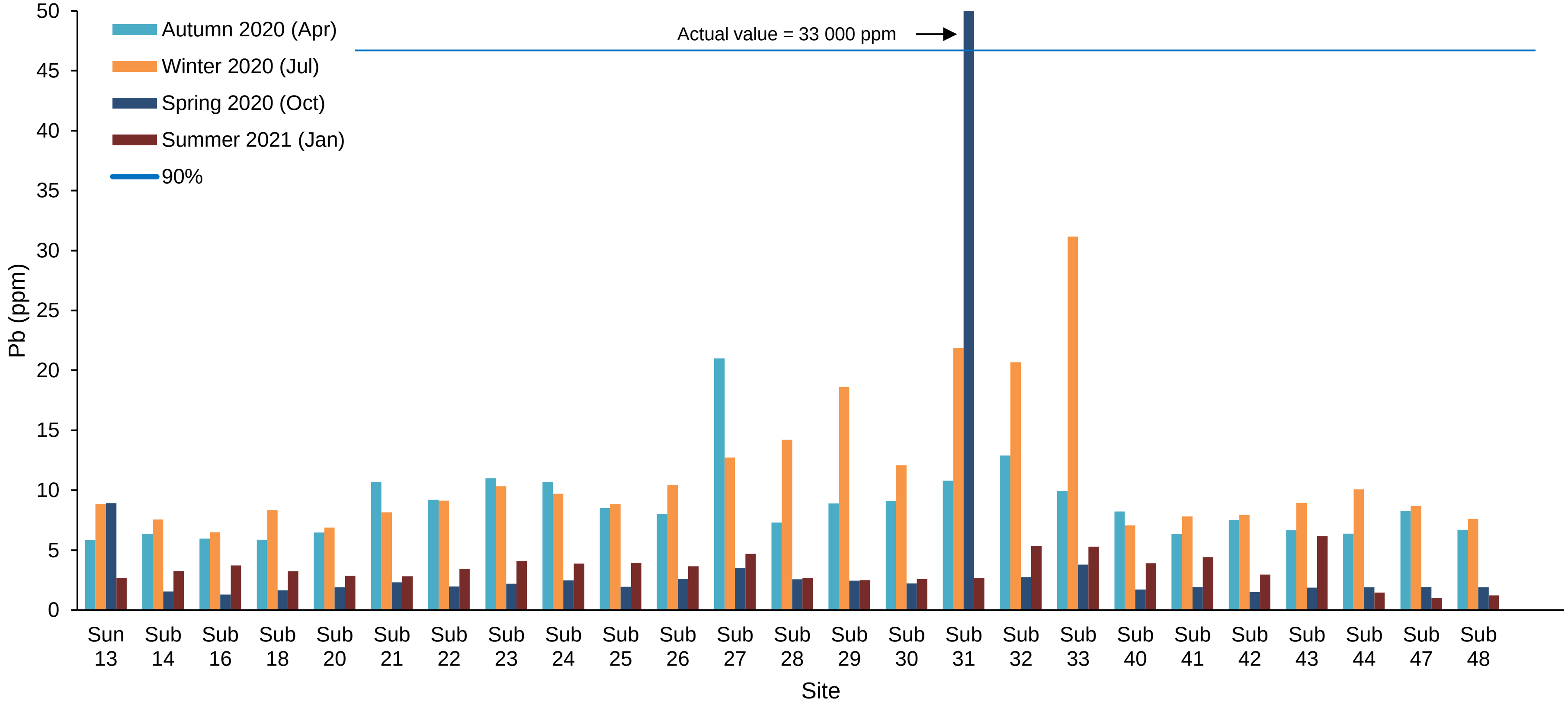

Figure 20: Concentration (ppm) of lead in subtidal sediments at impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Note that the actual value in spring for site Sub 31 is 33 000 ppm. Horizontal blue line: threshold maximum limit (90^{th} percentile) from the CSMP baseline study.

4.3.10 Nickel

Nickel concentrations recorded in the two most recent sampling events (summer 2021, spring 2020) have been some of the lowest thus far (**Figure 23, Figure 24**). All of these concentrations have been within allowable limits.

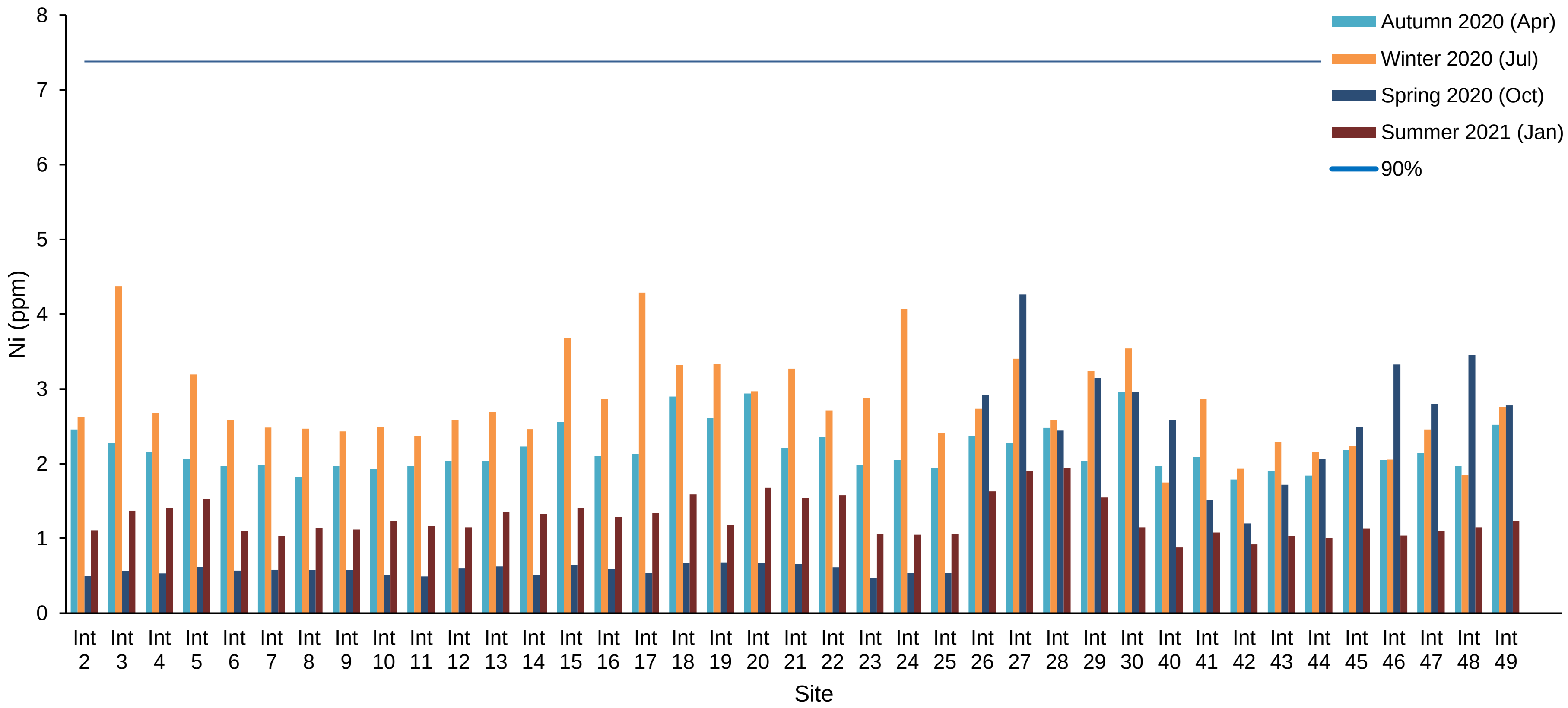

Figure 21: Concentration (ppm) of nickel in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

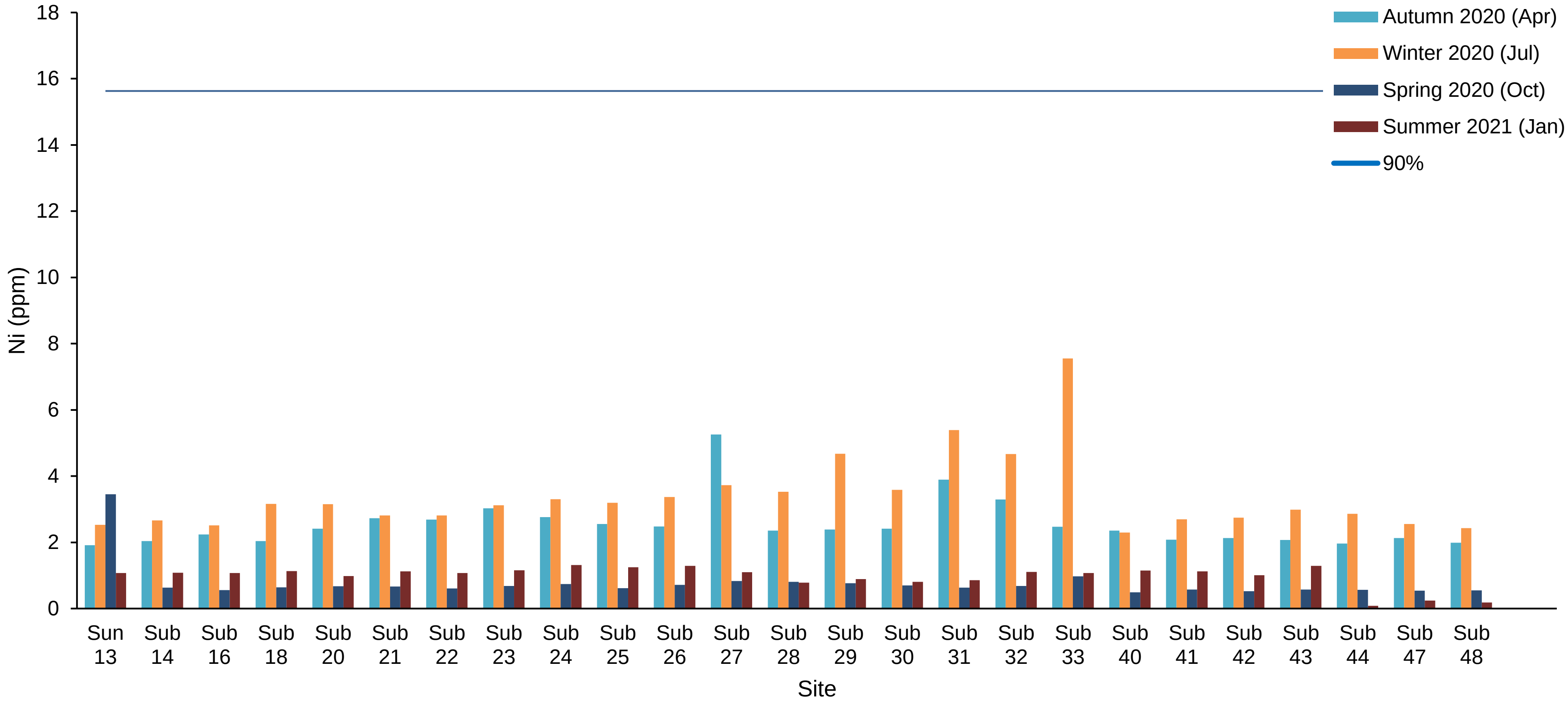

Figure 22: Concentration (ppm) of nickel in subtidal sediments at impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

4.3.11 Zinc

Zinc concentrations recorded in the two most recent sampling events (spring 2020, summer 2021) were overall lower than those recorded in autumn and winter 2020 (**Figure 23, Figure 24**). No clear visual trends have emerged from subtidal concentrations, but in intertidal sediments, zinc concentrations have been greater at impact sites Int 26 – Int 30, as with various other metals too.

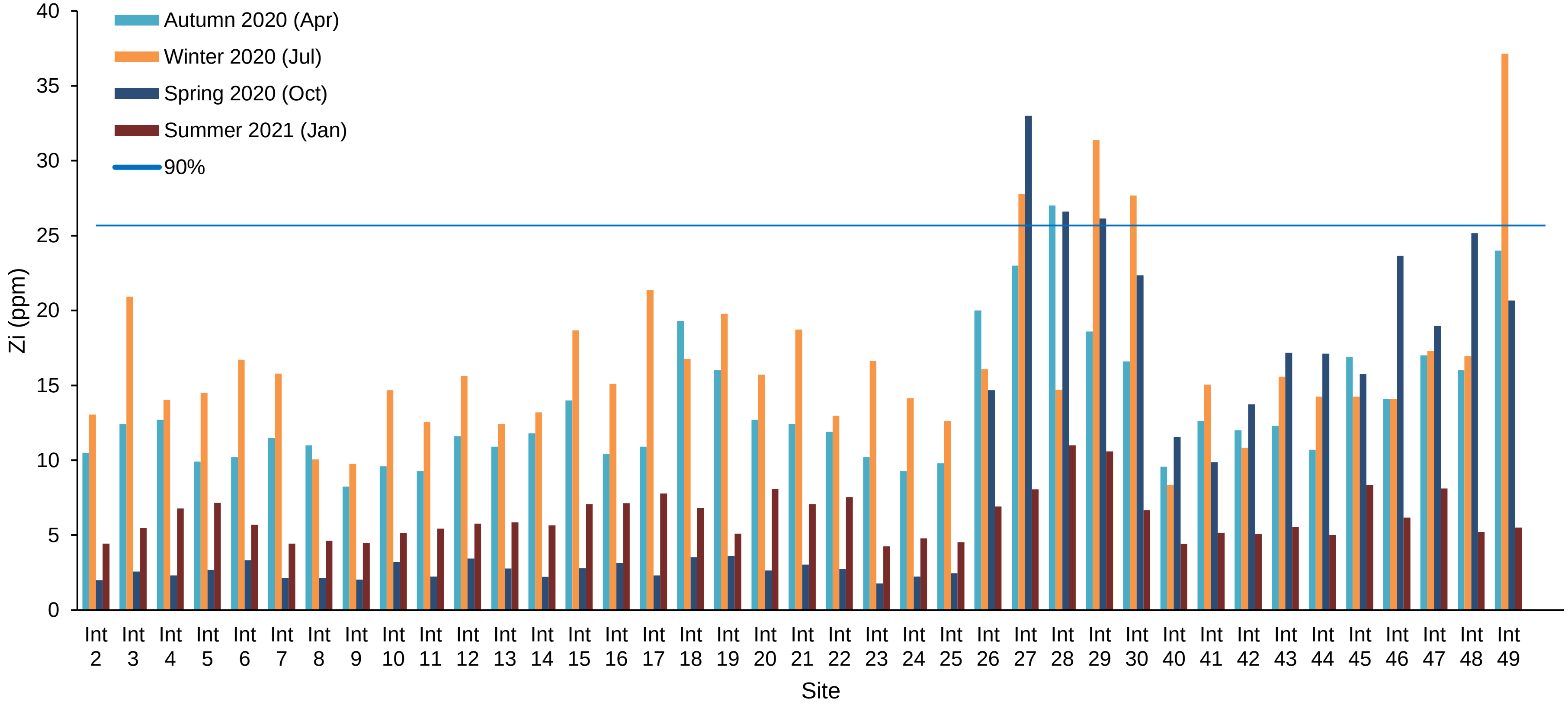

Figure 23: Concentration (ppm) of zinc in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

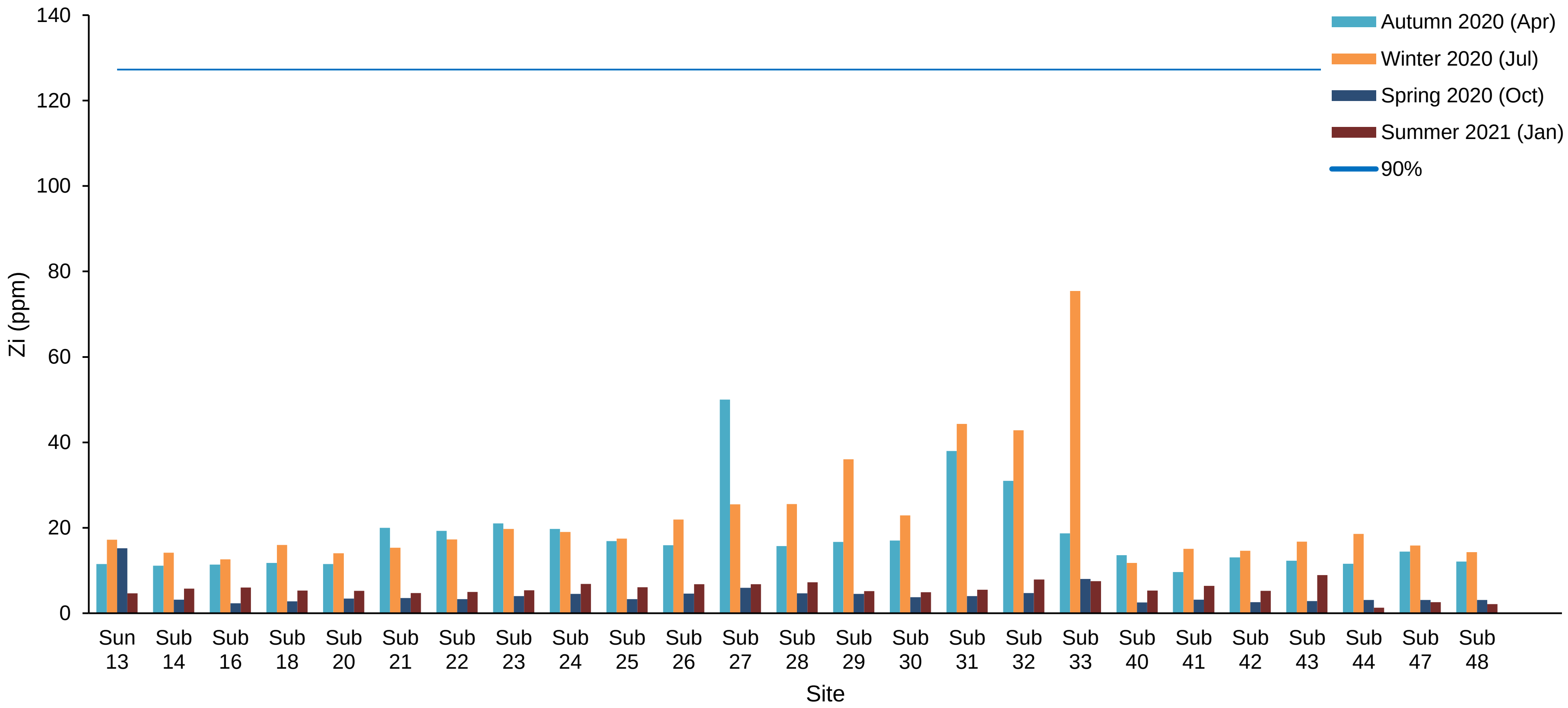

Figure 24: Concentration (ppm) of zinc in subtidal sediments at impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: Threshold maximum limit (90th percentile) from the CSMP baseline study.

4.3.12 Cobalt

Cobalt concentrations in intertidal sediments (**Figure 25**) also demonstrates peaks around sites Int 26 – Int 30, but have nonetheless remained under the maximum threshold value. Subtidal concentrations have been uniformly low (**Figure 26**).

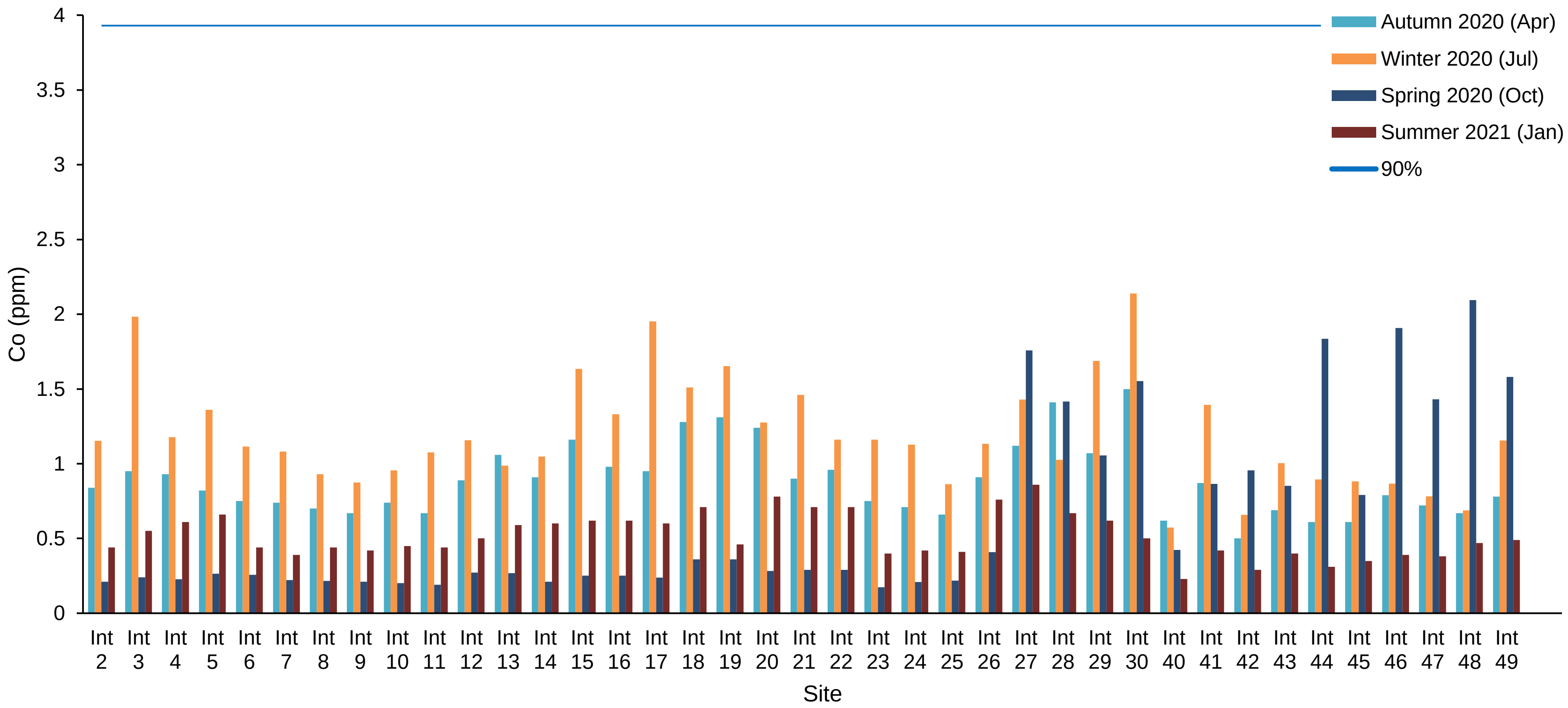

Figure 25: Concentration (ppm) of cobalt in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Blue horizontal line: threshold limit (90^{th} percentiles) from the CSMP baseline study.

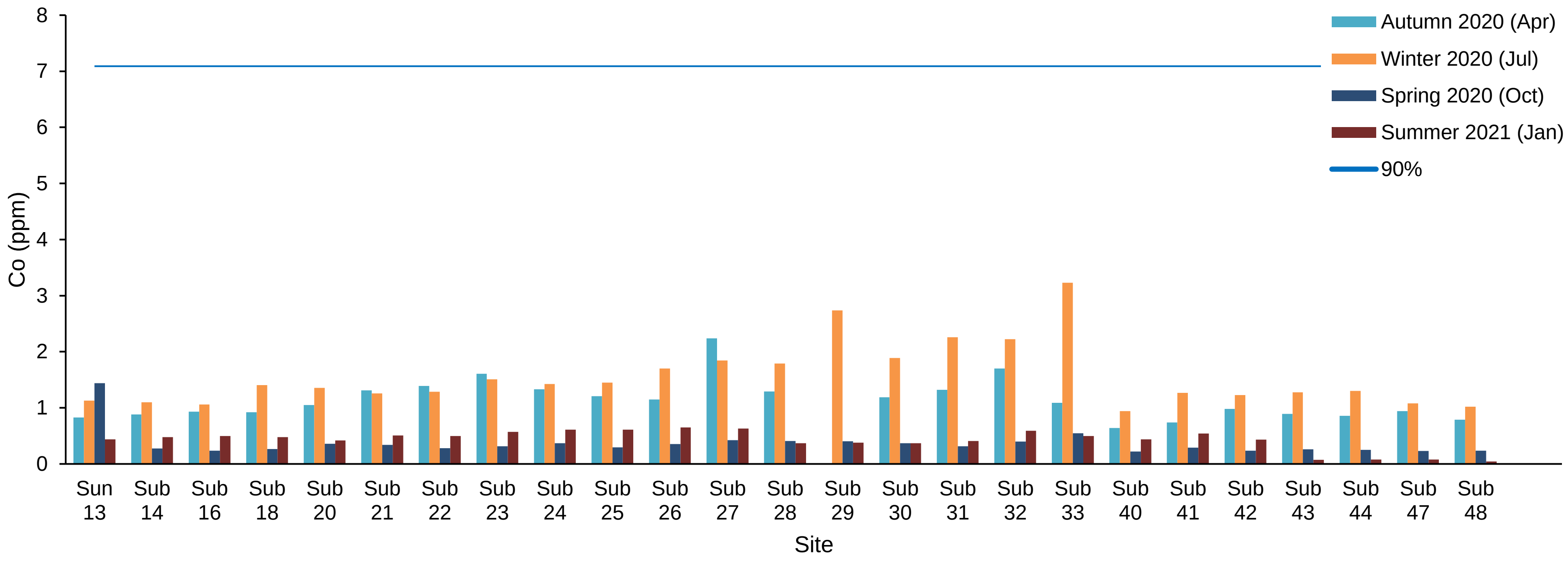

Figure 26: Concentration (ppm) of cobalt in subtidal sediments at impact (Sub 13 - 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

4.3.13 Iron

Apart from the baseline thresholds, no national prescribed ranges or limits have been set for iron concentrations in marine environments. The medians for all intertidal and subtidal sites were below the maximum CSMP threshold (**Figure 27**, **Figure 28**). Lower concentrations of iron were detected at control sites in intertidal and subtidal sediments.

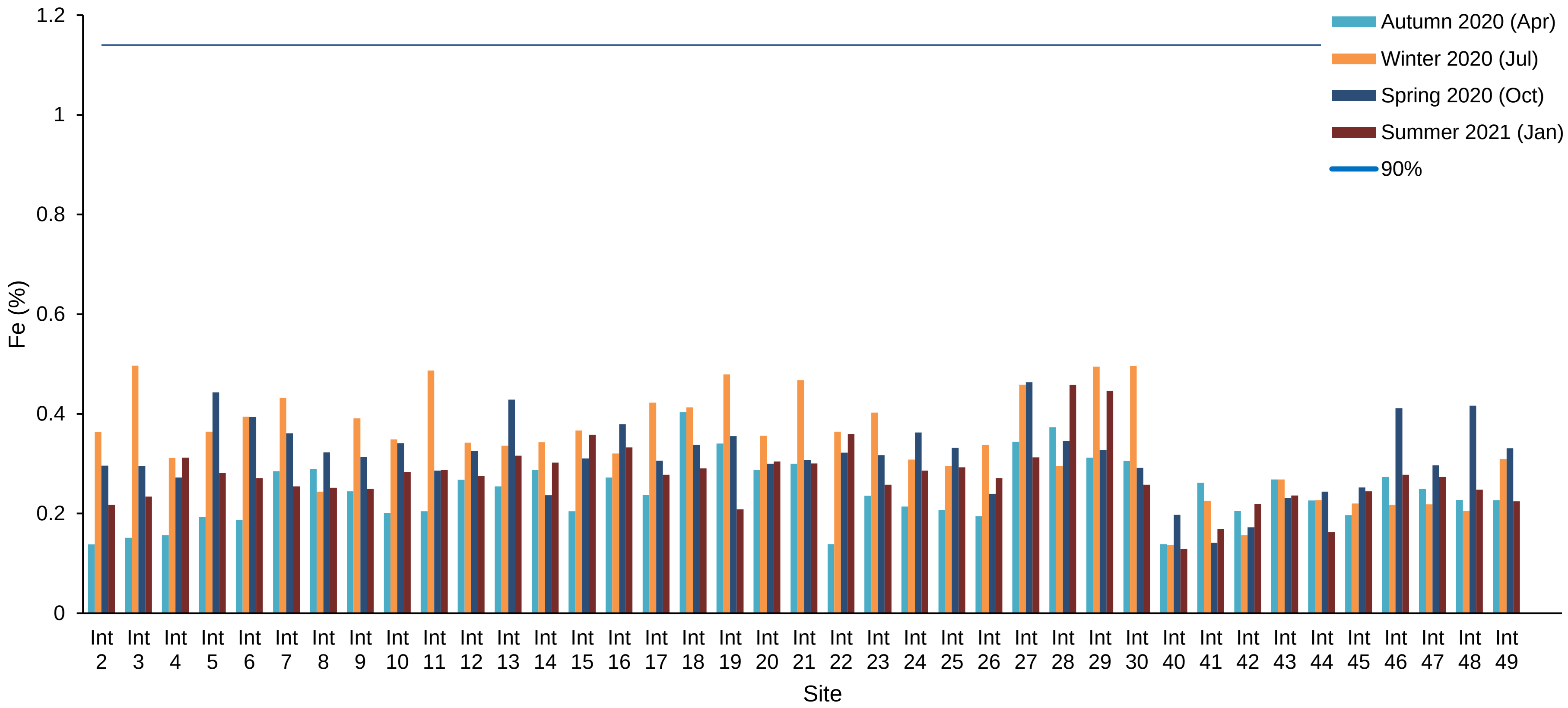

Figure 27: Iron percentage in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline report. Values are reported as percentages to enable comparisons with the baseline report.

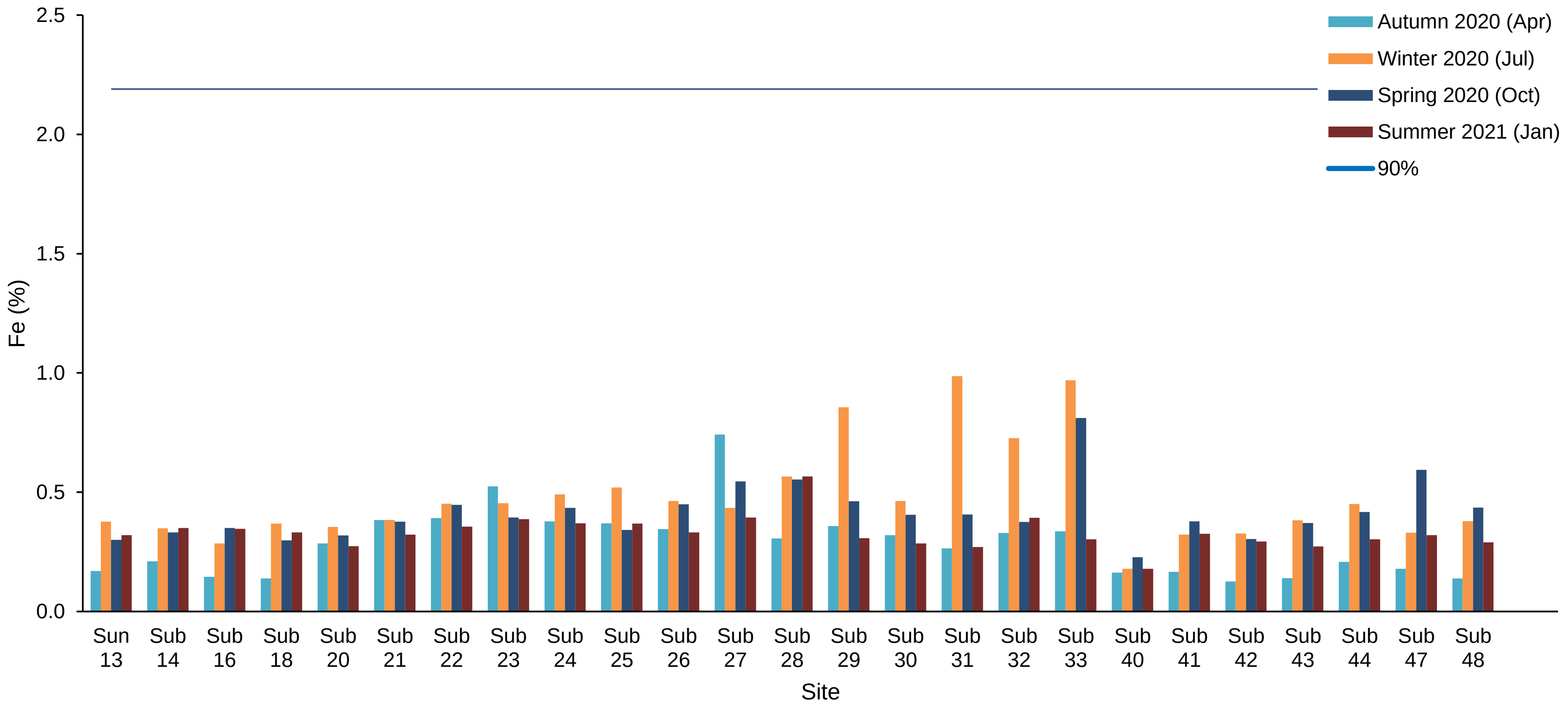

Figure 28: Iron percentage in subtidal sediments at impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline report. Values are reported as percentages to enable comparisons with the CSMP report.

4.3.14 Manganese

Median concentrations of manganese have been below the baseline maximum through sampling seasons thus far (**Figure 29**, **Figure 30**). The lowest concentrations of manganese in intertidal and subtidal sediments were recorded from control sites (northern bank).

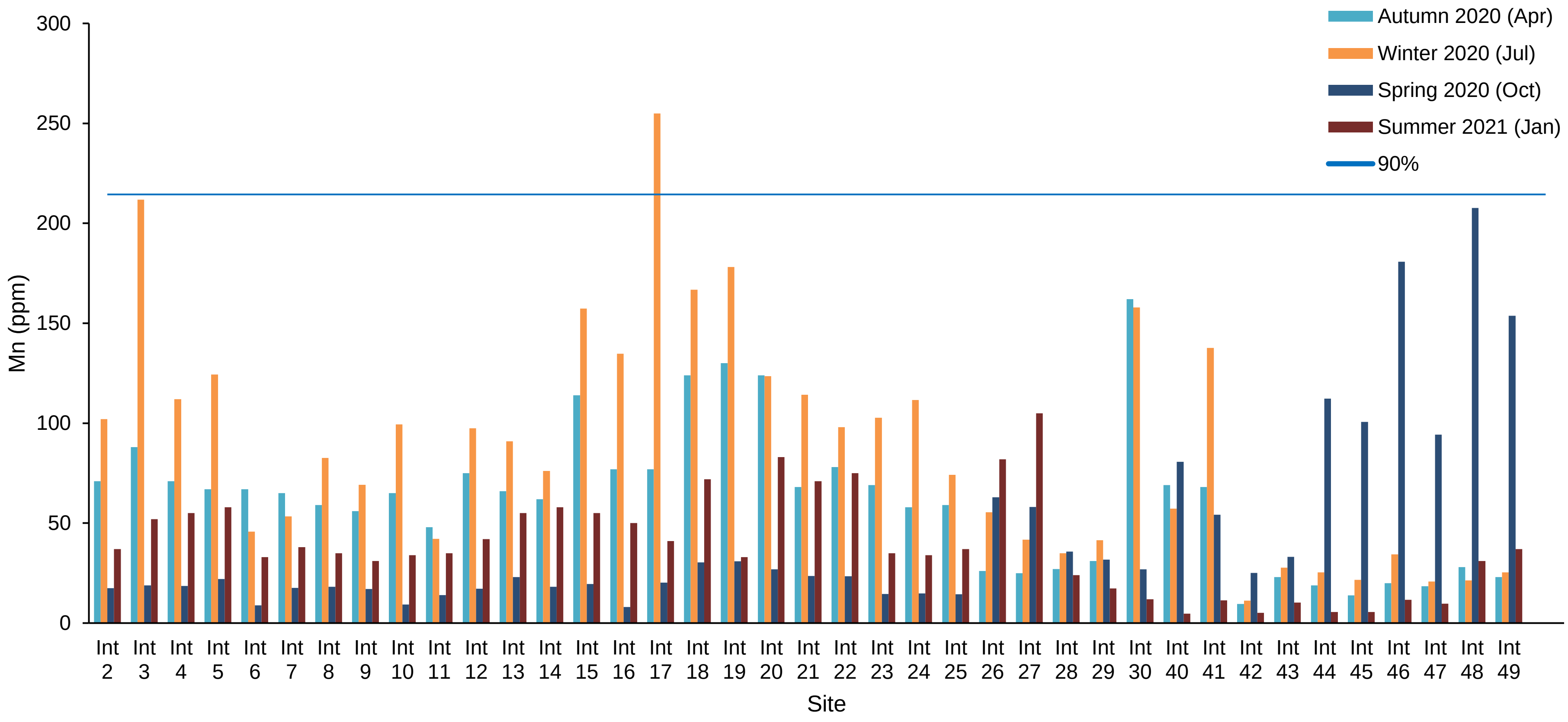

Figure 29: Concentration (ppm) of manganese in intertidal sediments at impact (Int 2 – Int 30) and control (Int 40 – 49) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

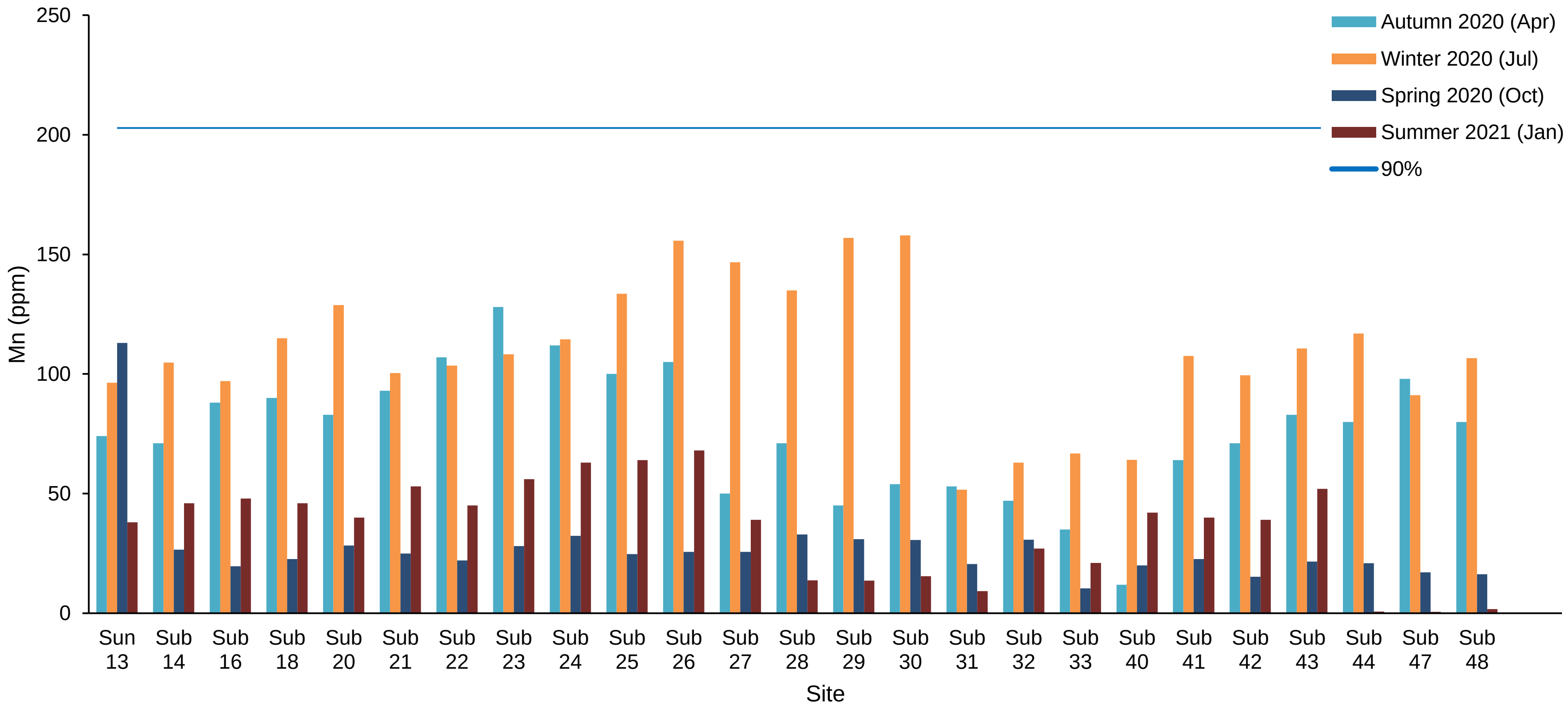

Figure 30: Concentration (ppm) of manganese in subtidal sediments at impact (Sub 13 – 33) and control (Sub 40 – 48) sites. Blue horizontal line: threshold maximum limit (90th percentile) from the CSMP baseline study.

4.4 Conclusion

Sediment monitoring is being undertaken at 64 sites in the intertidal (39 sites) and subtidal (25 sites) zones of the sandbanks within the Port of Durban. The majority of sediment characteristics align with what has been described in the baseline study and are within acceptable levels. In the most recent survey (summer 2021), the following parameters violated thresholds set in the baseline study: proportion of sand (too low; intertidal sediments), TOC content (too low; intertidal and subtidal sediments) and mercury concentrations (too high, intertidal and subtidal sediments).

The TOC content in intertidal and subtidal sediments have remained below the minimum allowable threshold for multiple seasons and indicates that the nutrient-deficiency in sediments is a persistent problem. This could be having effects on organisms such as benthic macrofauna that depend on such nutrients for basic physiological functioning.

In addition, the violation of maximum mercury concentrations in intertidal and subtidal sediments also represents a continued trend and is therefore at the stage where increased management attention is warranted. This is further stressed by the extremely elevated mercury concentrations recorded in *Perna perna* mussels (section 7), indicating that this problem is no longer restricted to the sediments and is affecting other biota as well.

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5 Benthic Macrofauna

5.1 Introduction

The term benthic macrofauna is used to describe the community of small (> 0.5 mm), mainly invertebrate organisms that live upon or within aquatic sandy and muddy substrata (Hauer & Resh, 2017). They play a significant role in the reworking of sediments and assist with enhancing sediment porosity (Goodnight, 1973). This process helps the exchange of oxygen and nutrients in substrates. Macrofaunal organisms are also an important food source for many marine and estuarine predators (Hauer & Resh, 2017) and are fed on by numerous fish, birds and invertebrates (França et al., 2011). Macrofaunal communities within estuaries often have important ecological linkages with neighbouring habitats as certain species from other areas depend on the health of these habitats for their survival (e.g. trophic subsidy) (Weinstein et al., 2005; França et al., 2011). Therefore, degradation or loss of these habitats and communities can have significant effects on ecologically connected environments.

It is important to monitor biological components of the ecosystem in addition to physico-chemical and eco-toxicological variables, as they provide a direct measure of the state of the ecosystem in space and time (O'Brien et al., 2016). Surveys of benthic macrofaunal communities are often done as part of environmental monitoring programmes and these organisms have come to represent a sort of 'bio-indicator' for the health of an aquatic environment. This is because these organisms are sensitive to changes in the surrounding environment (Pinto et al., 2009) and, because they are relatively non-mobile (Gray et al., 2002), they can provide an indication of localised impacts. If a pollution source is known (e.g. discharges, oil spills, dredging activities, other pollutants), it is possible to examine macrofaunal communities along a distance gradient from the pollution source in order to establish the extent of impact. In addition, because these organisms are short-lived, environmental changes will be reflected rapidly in their community compositions (Warwick, 1993).

Various factors can affect the composition of macrofaunal communities. This includes pollutants and environmental variables such as sediment grain size (Riera et al. 2013), brine discharges (Riera et al. 2012), dredging and trace metal concentrations (Ryu et al. 2011; Fonseco et al. 2020) and other pollutants (e.g. sewage (Riera et al. 2013)). Properties of macrofaunal communities that are often examined include abundance, species richness and diversity. Those that are close to a pollution source generally have lower diversity and the densities of different species may be determined by species-specific tolerances to specific pollutants (Pearson & Rosenberg, 1978).

Organic matter is one of the most important pollutants affecting marine life and it can lead to significant changes in community composition and abundance, particularly in semi-enclosed or closed bays such as the Port of Durban where water circulation is limited. High organic loading often results in eutrophication that can alter macrofaunal community dynamics such as growth rates. Resulting anoxic conditions can further drive complete exclusion of certain species based on specific respiratory requirements (Saunders et al., 2007).

The aim for monitoring benthic macrofaunal communities in the Port of Durban is to assess and monitor potential changes in intertidal and subtidal sandbank macrofaunal communities in response to the planned development activities in the Port. The use of dredging equipment to create an extension of the existing sandbanks will create additional shallow intertidal and subtidal sandbank habitats that will be expected to mimic the lost or existing ones, as has been demonstrated in mudflats (Ray, 2000) and saltmarsh (Streever, 2000) systems.

5.1.1 Benthic macrofauna threshold limits set in the Central Sandbank Mitigation Plan, 2017

Threshold (warning) levels have been established for the benthic macrofauna from the Central Sand Bank Mitigation Plan, 2017 (**Table 8**). If levels fall below these limits, recovery of invertebrate populations may be delayed and negative impacts on biota such as fish and birds in the port can be expected.

Table 8: Threshold (warning) levels of benthic macrofauna abundance (mean abundance/m^2) and species richness (number of species) for intertidal and subtidal communities (adapted from Clark et al., 2017).

	Spring	**Summer**	**Autumn**	**Winter**
Intertidal invertebrates				
Abundance (individuals/m^2)	162.4	209.6	277.6	204.3
Species richness (no. species)	4.0	5.2	6.4	5.6
Subtidal invertebrates				
Abundance (individuals/m^2)	232.0	256.0	232.0	176.0
Species richness (no. species)	7.2	8.0	7.2	6.4

5.2 Methodology

5.2.1 Sampling protocol

Benthic macrofauna samples were collected from the same 64 monitoring stations as for sediments and benthic microalgae along adjacent sandbanks (intertidal and subtidal samples) in the Port (**Figure 3**). Methods used in the baseline report (Clark et al., 2017) were also applied here. Intertidal samples were collected at spring low tide by inserting an 18 cm diameter corer into the sediment to a depth of 30 cm and transferring the contents to a 0.5 mm mesh cone sieve. At each intertidal sampling site, three core samples were taken and kept separate. Contents of the cores were transferred to mesh cones (0.5 mm^2 mesh size) that were agitated until all possible sediment have been removed. The remaining contents were transferred to honey jars and preserved in 90% ethanol. At each subtidal site, three samples were collected using a Van Veen Grab with a bite of 0.085 m^2. These samples were processed and preserved in the same way as intertidal samples. Subtidal stations had depths of 3 – 8m and were adjacent to sandbanks.

5.2.2 Measures of Diversity

Various measures can be used to assess spatial and/or temporal variation macrofaunal communities. For the purposes of this report, key results are given per habitat (intertidal habitats: central bank, northern bank; subtidal habitats: central bank, northern bank, little lagoon) as well as an overall estimates of intertidal and subtidal communities. The following measures were determined:

- taxonomic composition of each habitat (intertidal habitats: central bank, northern bank; subtidal habitats: central bank, northern bank, little lagoon),
- abundance,
- species richness,
- Shannon-Wiener diversity indices,
- statistical comparisons of overall community compositions and identification of key species

5.2.3 Statistical Analysis

For intertidal habitats, t-tests were used to determine whether there are statistically significant differences in mean abundance, species richness, and Shannon-Wiener diversity indices of communities inhabiting different areas within the Port. A t-test is a statistical test used to compare the means of two groups (e.g. the mean abundance of intertidal macrofauna in the central bank vs the northern bank). For subtidal habitats, similar comparisons were made but in this case a one-way ANOVA was used as this is the appropriate test to use when comparing more than two groups. In this case comparisons were made among communities of the central bank, little lagoon, and northern bank. Both t-tests and ANOVAs produces p-values, whereby a p-value smaller than 0.05 indicates that there is a statistically significant difference among the means of the groups compared. A p-value larger than 0.05 indicates that the groups compared do not differ significantly. These analyses were conducted in R (R Core Team, 2020).

Multivariate statistics can be used to determine whether there are significant differences in the compositions of communities across space/time. To do this, a PERMANOVA test was used. This test operates based on abundance and the presence/absence data of a species in a given habitat. Comparisons were made between intertidal macrofaunal communities inhabiting the central vs northern bank, and among subtidal communities inhabiting the central bank, little lagoon, and the northern bank. After assessing potential differences in communities inhabiting different areas in the Port, a SIMPER analysis was performed to determine which species distinguished the various communities. The results from this test also provides an indication of species most likely to drive differences (if they exist) among communities. These analyses were carried out through the PRIMER (v6) software.

5.3 Results

5.3.1 Key results

The CMSP baseline study stipulates minimum limits for parameters such as macrofauna abundance and species richness. These parameters are not to fall below their respective minimums during the construction phase of this project. All parameters in intertidal and subtidal habitats were substantially lower than the minimum thresholds specified for summer (**Table 9**) and demonstrate further declines from the last sampling event in spring 2020.

Table 9: Median macrofauna abundance and species richness in intertidal and subtidal impact and control stations as determined in the summer 2021 survey. Values printed in red violate the minimum 80%tile thresholds of the CSMP.

	80% limit	Median (overall)	Median (impact)	Median (control)
Intertidal				
Abundance	209.6	**39.2**	**65.5**	**19.65**
Species richness	5.2	**3**	**3**	**1.5**
Subtidal				
Abundance	256.0	**40**	**36**	**56**
Species richness	8.0	**5**	**4**	**7**

5.3.2 Intertidal communities

Abundance, species richness, and diversity

This summer, a total of 30 intertidal species were recorded, the majority of which were from the central bank (n = 27), with the northern bank having less than half of this number (n = 11). Abundance on the central bank was significantly greater than that of the northern bank ($T_{36.008}$= 3.3807, p = 0.0017), as was species richness ($T_{31.46}$ = 3.22, p = 0.0029) and Shannon-Weiner diversity indices ($T_{18.498}$ = 2.51, p = 0.0215) (**Table 10**, **Figure 31**). Three of the ten sites on the northern bank did not contain any animals, which may explain the observed differences between the two habitats.

Table 10: Mean (± standard error) species richness, abundance (per m^2) and Shannon-Wiener H' diversity indices of intertidal macrofaunal communities inhabiting the central and northern banks in spring 2020.

	Central Bank	**Northern Bank**	**Overall**
Abundance/m^2	84.02 (±16.6)	22.27 (±7.6)	68.18718 (±13.2)
Species richness	3.62 (±0.5)	1.5 (±0.4)	3.08 (±0.4)
Shannon-Wiener H'	0.64 (±0.1)	0.31 (±0.1)	0.57 (±0.1)

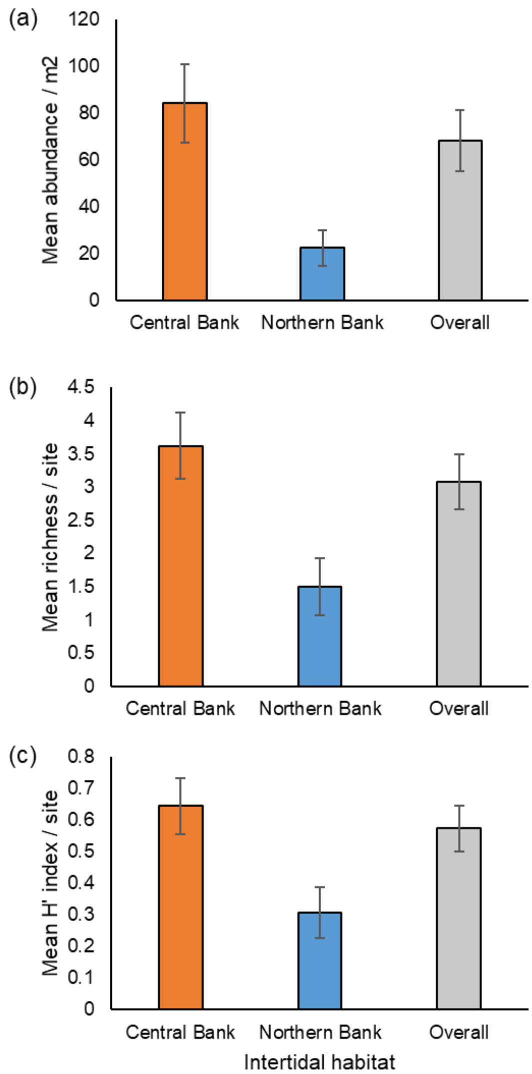

Figure 31: Mean (± standard error) (a) abundance, (b) species richness and (c) diversity of intertidal macrofaunal communities of the central and northern sandbanks.

Taxonomic composition

Both intertidal habitats were dominated by three classes: polychaetes, gastropods and bivalves (**Figure 32**). The large abundance of the moon shell *Polinices mamillia* drove the overall dominance of gastropods and glycerine worms *Glycera* spp. were the most abundant polychaetes. The most abundant bivalves in both habitats were the beaked clam *Eumarcia paupercula* and the lesser heart clam *Dosinia hepatica*. A notable observation from this season's survey is that the sand prawn *Callichirus kraussi* was not detected; usually a common intertidal species.

For the first time in this monitoring programme, the previously common sand prawn *Callichirus kraussi* was not detected from intertidal habitats.

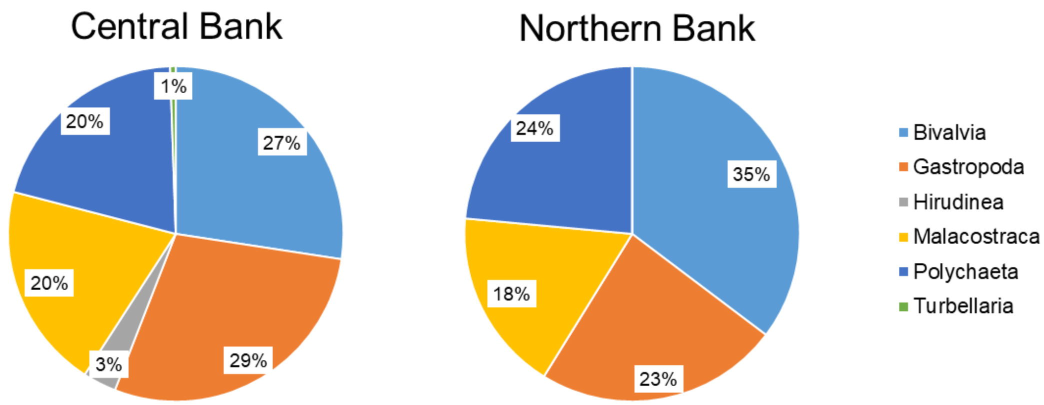

Figure 32: Percentage abundance of various macrofauna classes in communities on the central bank and northern bank

Comparisons among communities

There was no significant difference between the composition of communities inhabiting the central and northern bank (PERMANOVA, Pseudo-F = 1.6308, p = 0.115). This result could be driven by the fact that both habitats were dominated by few species (**Table 11**).

Table 11: Species that contributed up to 50% to overall similarity within intertidal habitats sampled (central bank, northern bank).

Species	Contribution (%)	Cumulative contribution (%)
Central Bank (average similarity = 15.27%)		
Polinices mamilla	30.33	30.33
Spiroplax spiralis	18.12	48.45
Glycera spp.	15.24	63.69
Northern Bank (average similarity = 4.30%)		
Eumarcia paupercula	61.37	61.37

5.3.3 Subtidal communities

Abundance, species richness, and diversity

A total of 41 species were detected from subtidal habitats, with an equal number of species detected from the central and northern banks (n = 26 for both habitats) and less from the little lagoon (n = 11). There were no significant differences in abundance across the three habitats ($F_2 = 0.79$, $p = 0.466$), but significant differences among species richness ($F_2 = 3.905$, $p = 0.035$) and Shannon-Weiner diversity indices ($F_2 = 3.762$, $p = 0.039$) were observed. Tukey HSD post hoc tests revealed that these results were driven by significant differences between the northern bank and the little lagoon ($p < 0.05$ in both cases) (**Table 12**, **Figure 33**). This is similar to the results from the previous survey (spring 2020).

Table 12: Mean (± standard error) abundance/m^2, species richness, and diversity (H' index) of subtidal macrofaunal communities inhabiting the central bank, little lagoon, northern bank and overall.

	Central Bank	Little Lagoon	Northern Bank	Overall
Abundance/m^2	48.4 (±9.8)	21.1 (±4.3)	60 (±7.5)	43.8 (±5.6)
Species richness	5.2 (±0.64)	3.1 (±0.4)	7.4 (±0.8)	5.3 (±0.5)
Shannon-Wiener H’	1.1 (±0.13)	0.7 (±0.09)	1.6 (±0.18)	1.1 (±0.1)

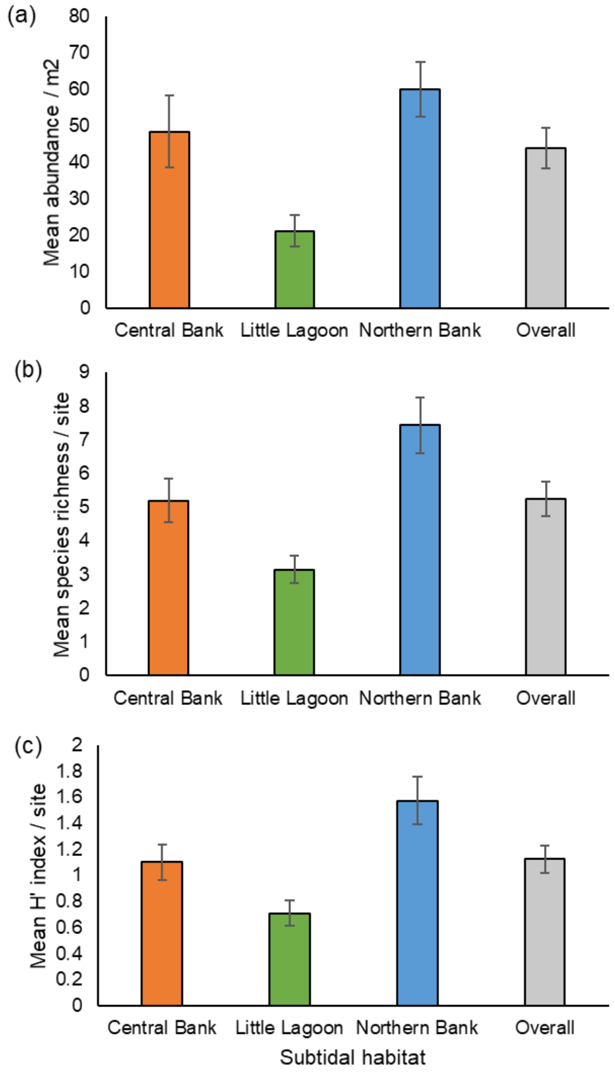

Figure 33: Mean (± standard error) (a) abundance, (b) species richness and (c) diversity of subtidal macrofaunal communities of the central bank, northern bank and little lagoon.

Taxonomic composition

The dominant organisms in subtidal habitats were polychaetes but malacostracans (crustaceans) also had a dominant abundance along the central and northern banks (**Figure 34**). The crustaceans with the greatest abundances in these sandbanks were the crimped cirolanid *Cirolana fluviatilis* and the amphipod *Grandidierella bonneroides*. Bivalves were most abundant in the little lagoon, with the lesser heart clam *Dosinia hepatica* and beaked clam *Eumarcia paupercula* the most abundant bivalve species, as in intertidal habitats.

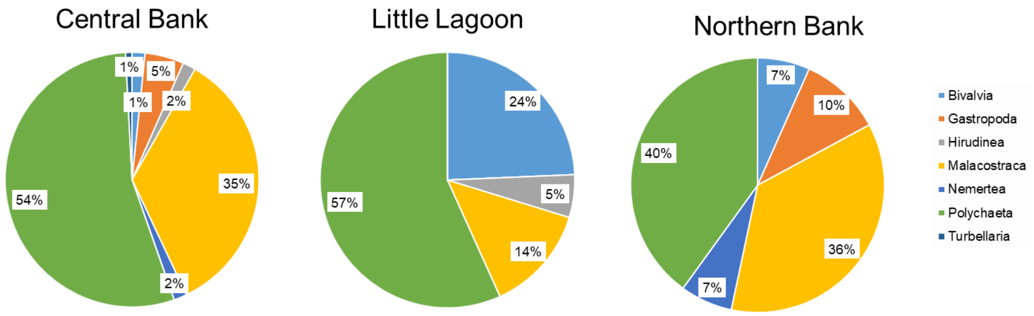

Figure 34: Percentage abundance of subtidal macrofauna classes in communities of the central bank, little lagoon and northern bank.

Comparisons among communities

There was a significant difference in the composition of subtidal communities (PERMANOVA, Pseudo-F = 2.7206, p = 0.001). Pair wise comparisons revealed that all three subtidal habitats differed significantly ($p < 0.05$) from each other. The SIMPER results further confirms the importance of crustaceans in the central and northern banks, but revealed that different crustacean species characterized these respective habitats (**Table 13**).

Table 13: Species that contributed up to 50% to overall similarity within subtidal habitats sampled (central bank, little lagoon, northern bank).

Species	Contribution (%)	Cumulative contribution (%)
Central Bank (average similarity = 23.58)		
Spiroplax spiralis	44.69	44.69
Cirolana fluviatilis	23.13	67.82
Little Lagoon (average similarity = 19.57)		
Spiroplax spiralis	38.58	38.58
Dosinia hepatica	25.06	63.64
Northern Bank (average similarity = 34.04)		
Grandidierella bonneroides	45.05	45.05
Nemertea	15.09	60.14

5.4 Conclusion

Concerning trends regarding macrofaunal biodiversity are starting to intensify. For another season, abundance and species richness and intertidal and subtidal communities did not meet the minimum thresholds stipulated in the CSMP. The overall abundance of these organisms was supposed to increase from spring but instead demonstrated a decrease. This is not related to the construction phase of this project, but this information is still a valuable reflection of the overall health of the Port ecosystem. It is possible that the impacts of the Umbilo river oil spill in October 2020 are reflected here. This, in combination with the continuous plastic pollution in the Port, is likely to affect these communities. Plastic debris that becomes inundated with sand can affect sediment porosity, a characteristic on which macrofaunal organisms depend (**Figure 35**).


Figure 35: Holes made by common sandprawn *Callichirus kraussi* through a plastic bag. (January 2021)

6 Benthic Microalgae (Microphytobenthos)

6.1 Introduction

Algae is a term used for a diverse group of microorganisms living in the ocean. Microalgae are photosynthetically active microorganisms. Benthic algae, also known as microphytobenthos, refers to microscopic, unicellular photoautotrophs that usually occur in the upper few centimeters of shelf sediments. Below this level, insufficient sunlight hampers their growth. Where the bottom is sandy or muddy the benthic algae cannot attach themselves as they have no roots. Benthic algae deliver major contributions to food webs and biogeochemistry in aquatic ecosystems, energy and cover for many other organisms (Christiansen et al., 2012). In this way, the productivity of the benthic algae in shallow waters directly or indirectly affects the efficiency of the entire marine ecosystem. Benthic microalgae are ubiquitous in aquatic areas where sunlight reaches the sediment surface. Although they are part of the microbial community already discussed, they deserve special attention because they are a very important component of benthic communities in shallow water systems (N-Uptake, 1999). Besides the fact that they contribute significantly to the primary productivity in sediments and pelagic habitats, they also have important trophic linkages with a variety of organisms, including macrofauna, birds and fish (Davis et al., 2015).

Like other single-celled "plant-like" organisms, they use energy gained from sunlight to transform carbon into organic matter via photosynthesis. They generally live in the top few millimeters to centimeters of aquatic sediment but may go deeper in sandy sediments when light availability is very high. In order to grow, benthic microalgae require nitrogen, phosphorus, and other micronutrients in addition to carbon dioxide. Much of the carbon they take up during photosynthesis is released as extracellular polymeric substances (EPS or "slime") into the sediment (Wolfstein & Stal, 2002). EPS plays an important role in sticking sediment particles together, which may increase sediment stabilization and, thereby, reducing resuspension. In addition, EPS is rapidly metabolized by the bacterial community.

Benthic microorganisms (microalgae and bacteria) are instrumental in controlling the exchange of nutrients, such as nitrogen and phosphorus, across the sediment-water interface (Paerl & Pinckney, 1996). Benthic microalgae in particular, may help to buffer the water column from eutrophication by storing nutrients that would otherwise be used by phytoplankton and bacteria in the water column. Nutrients used by benthic microalgae are derived not only from the water column but also from the sediments themselves as bacteria break down organic matter (Tengberg et al., 2003). Because of their location near the sediment surface, benthic microorganisms play a role in capping the sediments and reducing the release of nutrients to the overlying water column. Nutrients taken up by benthic microalgae and bacteria can be passed up the food chain, especially to meiofauna.

Microalgal communities in the Port of Durban occur on the sandbanks and bottom sediments as microphytobenthos and in the water column as phytoplankton. Microphytobenthos, however, is often suspended in the water column and can be as important as phytoplankton, particularly in turbid estuaries such as in the Port of Durban. Microphytobenthos play a vital and functional role in estuarine systems. As such, monitoring these communities is an important tool in the overall ecological health assessment of the Port ecosystem.

6.1.1 Benthic Microalgae Threshold Limits set in the Central Sandbank Mitigation Plan, 2017

Threshold (warning) levels have been established for benthic microalgae in the Central Sand Bank Mitigation Plan (CSMP) (Clark et al., 2017) (**Table 14**). According to the CSMP, the biomass of benthic microalgae, measured as the concentration of chlorophyll-a (ug/m^2) should not drop below the 20th percentile value of the median from baseline data, and should not rise above the 80th percentile of these data (**Table 14**). Comparisons are to be made separately for impact and control sites in intertidal and subtidal habitats. Intertidal impact sites are those located on the central bank (Int2 – Int31) and control sites are those on the northern bank (Int40 – Int49). Similarly, subtidal impact sites are those around the central bank and little lagoon (Sub13 – Sub33), while control sites are those around the northern bank (Sub40 – Sub48).

Table 14: Threshold (warning) levels of chlorophyll-a (µg/m^2) from intertidal and subtidal sediment samples across the four seasons in a year (adapted from Clark et al., 2017). Median levels measured at impact and control sites should not be lower than the 20th percentile values and not above the 80th percentile values.

	Spring	**Summer**	**Autumn**	**Winter**
Intertidal				
20%	6.3	7.7	1.4	0.6
Median	22.6	17.7	12.3	2.5
80%	47.7	66.4	43.7	21.6
Subtidal				
20%	1.5	6.6	1.6	1.1
Median	3.7	11.5	6.5	3.0
80%	8.2	21.2	26.8	8.3

6.2 Methodology

6.2.1 Sampling protocol

Benthic microalgae samples were collected from each of the 64 sediment monitoring sites and analyzed in accordance with methods prescribed by Pinckney and Zingmark (1993). Samples were collected by inserting a 20 mm vial directly into the sandbank sediment for intertidal samples, or into the top layer of sediment collected by an Ekman grab sampler for subtidal samples. From both habitats, a sample core of 40 mm in length was extracted and immediately sealed off with a plastic lid. Samples were immediately placed on ice in a dark container and transported to the laboratory for chlorophyll-a analysis.

6.2.2 Laboratory protocol

In the laboratory, the biomass of microalgae in the sediment samples was estimated as total chlorophyll (Chl-a) according to the methods of Whitney & Darley (1979), Dandonneau & Neveux (2002) and Seuront & Leterme (2006). Chlorophyll was extracted from the sediment samples through addition of 8 – 10 mL of 90% acetone. This mixture was then centrifuged for approximately 5 minutes at 8000rpm. For each sample, 1mL of the supernatant containing the chlorophyll was pipetted into microfuge tubes and analyzed using a Trilogy Turner Fluorometer™, which yielded results of chlorophyll-a concentrations in μgL^{-1} at each site. 1 - 2 drops of 1 M HCl was used to eliminate interference from degraded pigments that are common in sediment samples (Cahoon & Cooke, 1992).

6.3 Results

The median chl-a concentrations of control and impact sites in intertidal and subtidal habitats were within the allowable ranges (**Table 15**). As in previous seasons, subtidal chl-a concentrations were substantially lower than those of intertidal habitats. The greatest intertidal chlorophyll-a concentration was 57.89 $\mu g/m^2$ (Int49) at the Northern Bank (**Figure 36**). The greatest subtidal chlorophyll-a concentration of 23.38 $\mu g/m^2$ was recorded at station Sub27 in the Little Lagoon area (**Figure 37**).

Table 15: Median chlorophyll-a concentrations ($\mu g/m^2$) at intertidal and subtidal impact and control sites as measured in spring 2020. Values are not to drop below the 20% limit and not above the 80% limit. Values printed in red violate these limits.

	20% limit	80% limit	Median (overall)	Median (impact)	Median (control)
Intertidal					
Chl-a ($\mu g/m^2$)	7.7	66.4	28.59	22.54	38.30
Subtidal					
Chl-a ($\mu g/m^2$)	6.6	21.2	13.08	13.09	12.57

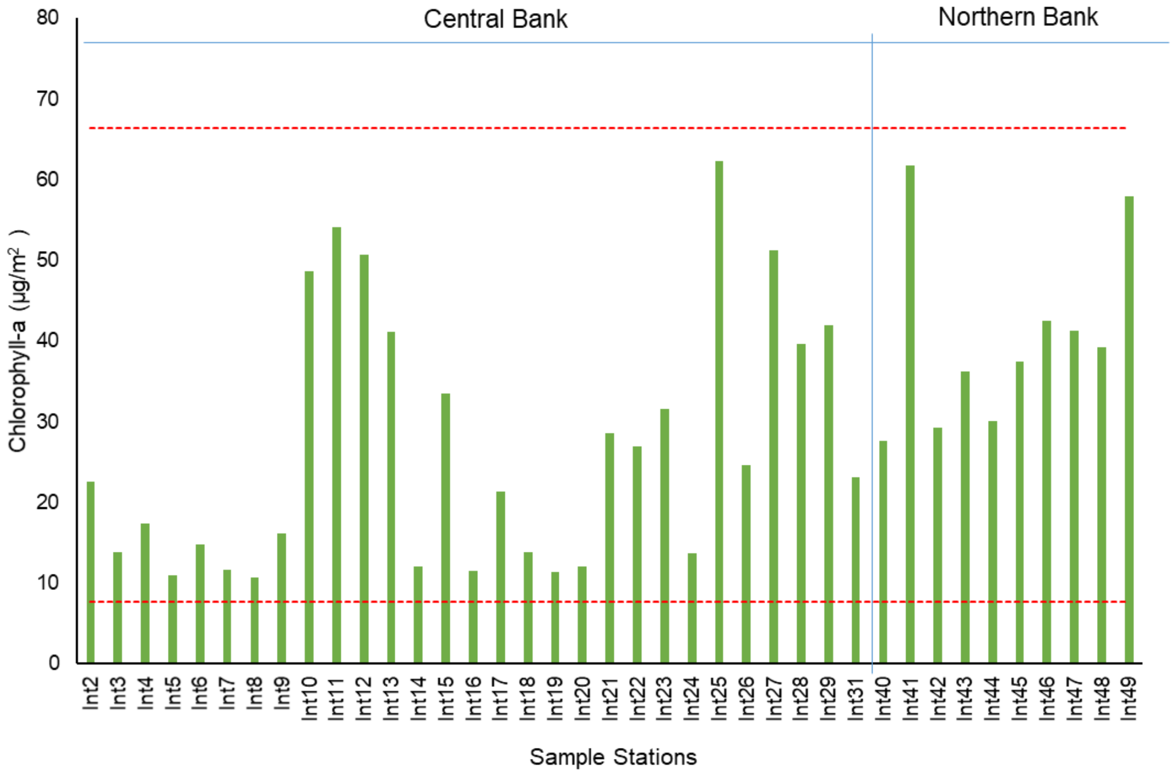

Figure 36: Chlorophyll-a concentrations (µg/m^2) in 39 intertidal monitoring stations in the Port of Durban, summer 2021. Impact sites = Int2 – Int31 (central bank), control sites = Int40 – Int49 (northern bank). Red dotted lines: 20%tile (7.7 µg/m^2) and 80%tile (66.4 µg/m^2) intertidal summer threshold limits stipulated in the CSMP.

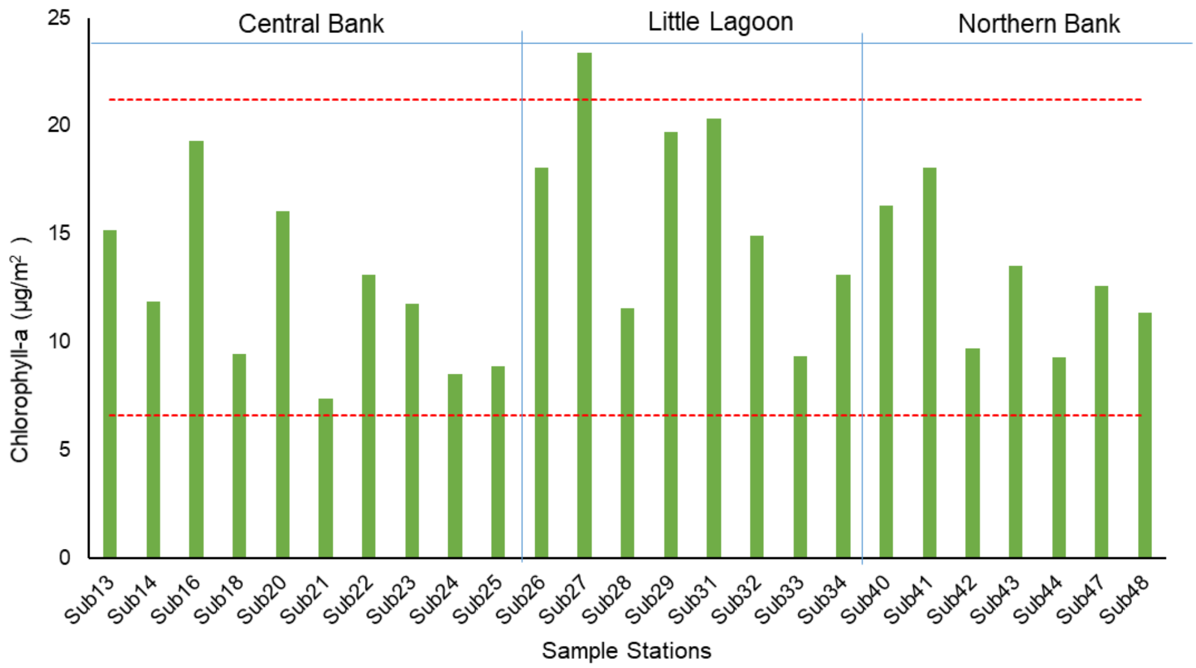

Figure 37: Chlorophyll-a concentrations (µg/m^2) in 25 subtidal monitoring stations in the Port of Durban, summer 2021. Impact sites = Sub13 – Sub34, control sites = Sub40 – Sub48. Red dotted lines: 20%tile (6.6 µg/m^2) and 80%tile (21.2 µg/m^2) subtidal summer threshold limits stipulated in the CSMP.

6.4 Conclusion

Chlorophyll-a and light availability are major determinants of benthic primary production (MacIntyre et al. 1996). Microphytobenthos may also contribute significantly to production in the water column when sediment is re-suspended by currents, upwelling or other forms of disturbance. These algae and cyanobacteria are an important food source for deposit-feeding and suspension-feeding macrofauna. An abundance of microphytobenthos can result in a greater diversity of species higher up the food chain and plays a significant role in system productivity and trophic dynamics.

The chlorophyll-a levels recorded in summer 2021 were greater than those recorded in spring 2020, which reflects a typical seasonal peak. The median chl-a levels at impact and control sites were within allowable ranges stipulated in the CSMP (Clark et al., 2017).

7 Biomonitoring using Mussels (*Perna perna*)

7.1 Introduction

Trace or heavy metals are persistent pollutants in aquatic ecosystems. They are all naturally occurring chemical elements, some of which (e.g. copper & zinc) are required by organisms in considerable quantities (Phillips, 1980). Aquatic organisms will normally accumulate essential trace metals that occur naturally in water. However, these metals can be toxic at greater concentrations (Rainbow, 1995). Anthropogenic activities and other naturally occurring geochemical processes may significantly increase the rates of mobilization of trace metals from the earth's crusts, which can lead to increases in their bioavailability in coastal waters through runoffs and wastewater discharge (Phillips, 1995).

Even though monitoring of heavy metal concentrations in sediments is more preferable when resolving analytical and temporal variability problems due to their accumulation in aquatic sediments, this method does not provide accurate information regarding their bioavailability to organisms inhabiting these environments. Measuring metal concentrations in the tissues of aquatic organisms appears to be the most suitable method for assessing eco-toxicity as the metals are frequently accumulated in high (easily measurable) concentrations and reflect a time-integrated measure of bioavailable metal levels (Rainbow, 1995).

Long-term pollution impacts on marine environments is increasingly being monitored through the assessment of contaminants that build up in marine biota. Filter feeding organisms such as mussels have been used successfully as bio-indicator organisms in environmental monitoring programs throughout the world (Kljaković-Gašpić et al. 2006, 2010). They are suitable indicators because they are abundant, widely distributed, sessile, tolerant of salinity changes, stress-resistant and can accumulate a wide range of contaminants (Phillips & Rainbow, 1993; Desideri et al., 2009; Kljaković-Gašpić et al., 2010). In addition, mussels can accumulate trace metals, hydrocarbons and pesticides in their flesh (Rainbow et al., 2006). As such, assessments of contaminant levels in mussel flesh can be used to detect pollution levels that may go unnoticed between pollution events or that may occur at chronically low levels that can be difficult to measure in the water column. Monitoring contaminant levels in mussels can therefore provide a reliable indication of water quality and spatial/temporal changes in bioavailable contaminant levels in the water column. For this purpose, the trace metal concentrations in mussels (*Perna perna*) throughout the Port of Durban are assessed.

7.1.1 Trace metal concentration guidelines for molluscs

Several guidelines are available regarding the acceptable concentrations of trace metals in animals such as molluscs (e.g. mussels) (**Table 16**). In addition, the CSMP (Clark et al. 2017) also provides local maximum thresholds specifically for *Perna perna* that should be assessed as part of this monitoring programme (**Table 17**). If levels exceed limits specified below, risks to health of people consuming shellfish and fish from the Port are likely to be elevated and negative impacts on biota such as invertebrates, fish and birds in the Port are likely.

Table 16: Established Guidelines for trace metals in molluscs in different countries including South Africa (maximum acceptable levels)

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Africa[1].	-	0.5	-	3.0	3.0	0.5
Canada[2]	70	2.5	150.0	1.0	2.0	-
Australia & NZ[3]	-	2.0	-	-	2.0	0.5
European Union[4]	-	1.5	-	-	1.0	0.5
Japan[5]	-	10.0	-	-	2.0	0.2
Switzerland[2]	-	1.0	-	-	0.6	0.5
Russia[6]	-	10.0	-	-	2.0	-
South Korea[2]	-	0.3	-	-	-	-
United States[7, 8]	-	1.7	-	-	4.0	-
China[9]	-	-	-	-	2.0	-
Brazil[10]	-	-	-	-	-	0-.5
Israel[10]	-	-	-	-	-	1.0

1. Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972)
2. Fish Products Standard Method Manual, Fisheries & Oceans, Canada (1995)
3. Food Standard Australia and New Zealand (website)
4. Commission Regulation (EC) No. 221/2002
5. Specifications and Standards for Foods. Food Additives, etc. Under the Food Sanitation Law JETRO (Dec 1999)
6. Food Journal of Thailand. National Food Institute (2002)
7. FDA Guidance Documents
8. Compliance Policy Guide 540.600
9. Food and Agricultural Import Regulations and Standards.
10. Fish Products Inspection Manual, Fisheries and Oceans, Canada, Chapter 10, Amend. No. 5 BR-1, 1995.

In addition to the national guidelines, local guidelines for trace metal concentrations in *P. perna* have also been established as part of the baseline study (**Table 17**).

Table 17: Threshold (warning) levels of trace metal concentrations for *Perna perna* from control and impact monitoring stations (adapted from Clark et al., 2017). Note that the concentration for mercury (Hg) is given as parts per billion and not parts per million as for other metals.

Trace metal	90^{th} Percentile
As (ppm)	3.61
Cd (ppm)	1.08
Co (ppm)	0.95
Cr (ppm)	8.44
Cu (ppm)	23.18
Fe (ppm)	800.11
Mn (ppm)	134.75
Ni (ppm)	5.60
Pb (ppm)	8.95
Zn (ppm)	223.88
Hg (ppb)	293.06

7.2 Methodology

As per the CSMP, mussels (*Perna perna*) must be collected from 16 channel buoys adjacent to the sandbanks in the Port (**Figure 38**). Sites 11, 12, 14, 16, 18 – 21 have been designated as impact sites, and sites 8 –10, 13, 15, 17, 22 and 23 are control sites. In this survey, mussels could be collected from 14 channel buoys (2 buoys did not contain any mussels). Mussels collected were placed on ice in plastic containers and transported to a SANAS accredited analytical laboratory for trace metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) analyses. Trace metal concentrations are contrasted against the 90th percentile maximum threshold levels prescribed in the CSMP (Clark *et al*., 2017) and against the maximum legal limits prescribed for each contaminant in shellfish for human consumption in South Africa, as stipulated by the Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972). Where threshold values have not been specified in national legislation, those adopted by other countries were employed.

Figure 38: Locations of channel buoys for brown mussel (*Perna perna*) biomonitoring in the Port of Durban. Impact sites: 11, 12, 14, 16, 18 – 21; Control sites: 8 – 10, 13, 15, 17, 22 and 23.

7.3 Results

The majority of trace metal concentrations in mussels collected from the 14 channel buoy stations (2 buoys lacked mussels) were within the established national guidelines and consumable threshold levels for South Africa and other countries of the world (**Table 18**). However, the median concentrations of mercury at impact and control sites exceeded the CSMP maximum as well as the national maximum (**Table 19**).

Table 18: Median concentrations of trace metals in *Perna perna* collected throughout the Port of Durban in summer 2021. Medians are given for all sites, impact (site 11, 12, 14, 16, 18-21) and control (site 8, 9, 10, 15, 17, 22). Values printed in red exceed the 90th percentile threshold of the CSMP. National Guideline levels are given for reference to other work. Note that the concentrations for mercury are given as part per million and not parts per billion.

Metal (mg/kg)	90th percentile	National guideline level	Median (all sites)	Median (impact sites)	Median (control sites)
Aluminium	--	--	44.34	44.07	44.34
Arsenic	3.61	3	1.16	1.12	1.24
Cadmium	1.08	3	0.02	0.02	0.02
Copper	23.18	70	3.07	3.08	3.07
Cobalt	0.95	--	0.16	0.16	0.15
Chromium	8.44	--	1.85	1.89	1.79
Manganese	134.75	--	34.67	34.03	34.67
Nickel	5.6	--	1.97	2.04	1.85
Lead	8.95	0.5	1.28	1.10	1.48
Zinc	223.88	150	23.12	21.63	26.79
Mercury	0.293	0.5	**10.36**	**20.77**	**9.08**
Iron	800.11	--	58.21	58.81	58.21

Table 19: Raw laboratory data of trace metal concentrations in brown mussels (*Perna perna*) collected during the summer 2021 survey from 14 channel buoys (control and impact sites) adjacent to the sandbanks in the Port of Durban. Concentrations that exceed the baseline guideline values are printed in red.

Trace Metal (mg/kg)	**Control Sites**						**Impact Sites**							
	Site 8	**Site 9**	**Site 10**	**Site 15**	**Site 17**	**Site 22**	**Site 11**	**Site 12**	**Site 14**	**Site 16**	**Site 18**	**Site 19**	**Site 20**	**Site 21**
Aluminium	28.22	89.35	60.45	80.54	11.96	14.39	15.42	78.32	63.37	19.64	7.54	24.77	97.87	67.88
Arsenic	1.49	1.21	1.28	1.43	1.03	0.74	1.12	1.36	1.03	1.12	1.41	0.88	1.49	0.44
Cadmium	0.06	0.02	0.03	0.03	0.02	0.01	0.02	0.02	0.01	0.01	0.03	0.06	0.04	0.02
Copper	2.95	3.01	3.13	3.20	3.30	1.64	4.10	3.39	3.40	2.76	1.78	2.70	3.46	1.84
Cobalt	0.20	0.12	0.17	0.39	0.12	0.13	0.16	0.15	0.32	0.17	0.07	0.20	0.20	0.14
Chromium	1.89	1.86	1.72	1.92	1.63	1.63	1.69	2.22	2	1.69	1.85	1.72	1.94	2.29
Manganese	51.15	22.50	28.91	61.59	40.43	20.87	41.01	42.14	41.62	26.41	13.99	57.63	27.06	17.13
Nickel	1.71	1.69	1.94	2.06	2.22	1.74	2.14	2.12	1.96	2.14	1.70	1.17	2.59	1.90
Lead	1.37	1.47	1.54	1.00	1.96	1.48	2.75	1.18	1.03	0.14	1.57	0.99	1.19	0.58
Zinc	29.70	24.22	20.34	29.36	35.43	17.29	40.36	22.72	19.06	23.52	18.28	41.89	20.54	9.79
Mercury	**9.78**	**21.49**	**10.94**	**6.16**	**8.39**	**5.56**	**8.87**	**35.12**	**23.24**	**5.24**	**23.50**	**18.30**	**29.54**	**6.21**
Iron	40.89	111.08	75.53	104.71	29.71	29.63	37.32	105.90	83.85	38.85	24.70	36.96	78.77	91.81

7.4 Conclusion

Biomonitoring of mussels is an important tool for the assessment of pollution levels and indices of when action is required to maintain good water quality. All metals, apart from mercury, were below maximum baseline concentrations. Median mercury concentrations at control and impact sites demonstrated a 30-fold and 70-fold exceedance of the baseline guidelines, respectively. This is a substantial increase from the concentrations quantified in the previous sampling event (October 2020) (**Figure 39**) and represents a serious health risk for animals and humans.

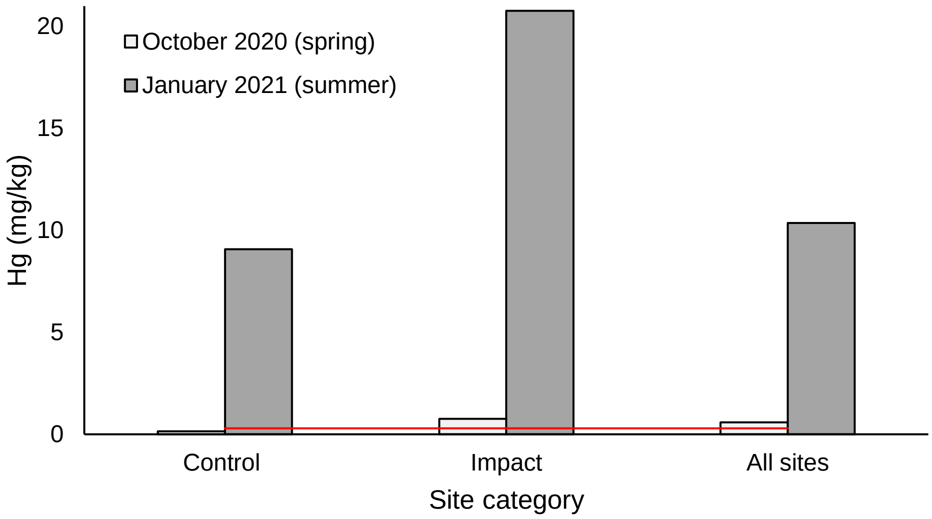

Figure 39: Visual comparison between mercury concentrations (mg/kg) quantified in October 2020 (previous sampling event) and January 2021 (most recent sampling event). Red line = baseline threshold value (0.29306 mg/kg).

Bioaccumulation of trace metals in mussels take place over long periods, so the specific driver behind these elevated mercury concentrations will be difficult to pinpoint. Mercury can enter the marine environment through various sources, including agricultural run-off, waste from manufacturing electrical equipment, mine tailings and the burning of fossil fuels (DWAF 1995). The crude oil spill that occurred in the Umbilo river in October 2020 and/or the increased effluent and storm water runoff into the Port associated with the rainy season may be potential drivers. Nonetheless, this in an important problem that needs to be urgently addressed by Port management authorities.

8 Fish

8.1 Introduction

Fish communities in the Port of Durban have been described as very diverse in past research conducted in the 1950s, where around 186 fish species were recorded (Day & Morgan, 1956). During this time, the most common species included *Terapon jarbua*, *Mugil cephalus*, *Liza dumerili*, *Ambassis dussumieri* and *Leiognathus equulus*. Many of these species are recognised as being dependent on estuaries, and the Bay was revealed as an important nursery areas for these and other economically important marine fish species. To this end, the shallow sandbanks and the little lagoon area specifically have been described as especially valuable nursery habitats (Cyrus & Forbes, 1996; Forbes & Demetriades, 2003).

More recent fish surveys in the Port by Angel and Clark (2008) and Newman et al. (2008) recorded far fewer species, at 29 and 34 species respectively. Most of the species either are listed as “Least Concern” on the IUCN Red List (2013) or have not been assessed. In these studies, the most abundant species have always been the Bald Glassy (*Ambassis dussumieri*), a small species that often dominates abundance but not biomass.

8.1.1 Threshold limits set in the Central Sand Bank Mitigation Plan, 2017

The CSMP study stipulated various thresholds applicable to fish monitoring. According to this study, the median values of fish abundance, biomass and species richness are not to drop below the 80th percentile of the season-specific baseline median value (**Table 20**). If levels drop below limits specified, recovery of these faunal components in the Port may be delayed.

Table 20: Threshold (warning) levels to be adopted for fish abundance (no. ind./haul), biomass (g/haul) and species richness (no. species/haul) for the impact monitoring stations (adapted from Clark et al., 2017).

	Spring	Summer	Autumn	Winter
Abundance				
Median	15.2	31.6	408.7	255.3
80%	19.0	39.5	510.9	319.2
Biomass				
Median	175.2	252	711.15	2126.1
80%	219	315	888.9	2657.6
Species richness				
Median	4	4.4	5.2	4.8
80%	5.0	5.5	6.5	6.0

8.2 Methodology

8.2.1 Sampling protocol

The nearshore fish community in the Port of Durban was sampled using a beach seine net of 30m length, 2m depth and a stretched mesh size of 12mm. Seine netting was conducted at 14 stations along the margins of the main sandbank areas in the Port (**Figure 40**). The net was deployed from a small fishing boat 30 – 50m from the shore during daylight hours. All fish caught in the net at each station were identified, enumerated, weighed and measured – and where possible, returned to the estuary alive. All species caught were also classified using an adaption of Whitfield's (1994) estuarine fish classification system. Four broad categories were used: marine, estuarine dependent, estuarine resident and freshwater species.

Figure 40: Location of fish sampling stations in the Port of Durban are in yellow. The black pins indicate additional sampling sites that will be included after the construction of the Berth to monitor recovery of the sandbank.

Sites where fish surveys are conducted are further divided into impact and control sites (**Table 21**).

Table 21: Classification of impact and control sites for fish surveys in the Port of Durban.

Habitat	Site	Treatment
Central bank	6	Impact
Central bank	7	Impact
Central bank	8	Impact
Central bank	9	Impact
Central bank	10	Impact
Little lagoon	11	Impact
Little lagoon	12	Impact
Little lagoon	13	Control
Little lagoon	14	Control
Northern bank	19	Control
Northern bank	20	Control
Northern bank	21	Control
Northern bank	22	Control
Northern bank	23	Control

8.2.2 Statistical Analyses

Multivariate analyses were conducted using PRIMER (v6) where fish abundance data were subjected to a fourth root transformation to reduce the weight of abundant species and to achieve a balance of contribution between the rare and most common species. All analyses were performed using Bray-Curtis similarities of the fourth root abundance data. A non-metric multidimensional scaling (MDS) ordination technique was used to separate fish communities based on their similarity in species composition. Analysis of Similarity (ANOSIM) was also performed to statistically estimate the degree of similarity among fish communities. This test produces a p-value which, when smaller than 0.05 indicates a significant difference between the fish communities that inhabit the different sandbanks.

8.3 Results

8.3.1 Key results

The median fish abundance (49 individuals / haul) in summer 2021 for all sites (impact and control combined) was greater than the baseline minimum of 39.5 individuals / haul for summer. However, median biomass (130.2 g) and species richness (2) were below the minimum allowable thresholds of the CSMP. Furthermore, when considering data from control and impact sites separately, it appears as though the median abundance, biomass and species richness was lower at impact versus control sites (**Table 22**).

Table 22: Median values of fish community dynamics at impact and control sites identified during the summer 2021 survey. Values given alongside 80th percentile thresholds stipulated in CSMP baseline study. Values printed in red violate CSMP threshold guidelines.

Parameter	80% limit (CSMP)	Median Overall	Median Impact	Median Control
Abundance	39.5	49	**1.5**	81
Biomass	315	**130.2**	**51.15**	**151.84**
Species richness	5.5	**2**	**1**	**2**

Additional data of fish communities at the three habitats are provided below (**Table 23**). While these data are not meant to be used to assess compliance against the CSMP thresholds, it still offers interesting insights regarding fish communities in the main habitats in the Port. In this survey, the little lagoon had the greatest abundance, species richness and biomass out of the three habitats.

Table 23: Median values of fish community dynamics for three sandbank habitats in the Port of Durban as surveyed in spring 2020. Note that the groupings of these sites are not the same as those of impact and control sites.

Parameter	80% limit (CSMP)	Central bank	Little lagoon	Northern bank
Abundance	39.5	2	156	67
Biomass	315	42.3	176.48	130.2
Richness	5.5	1	6	2

8.3.2 Catch Composition

A total of 1211 fish (~ 2.5 kg) representing 18 species were caught in summer 2021. No fish were caught at three impact sites (site 8, 9 and 12) despite multiple hauls at these sites. The total catch was, as in previous seasons, dominated by Bald Glassy (*Ambassis dussumieri*) that contributed around 91% to the overall abundance of fish caught. Other common species detected include Silver Silago *Sillago sihama* (1.07% in number; 0.24% by mass), River Bream

Acanthopagrus berda (1.07% in number; 0.78% by mass), Groovy Mullet *Liza dumerilii* (0.74% in number; 34.16% by mass) and the Dory Snapper *Lutjanus fulviflamma* (0.25% in number; 0.44% by mass) (**Table 24, Table 25, Figure 41, Figure 42**).

Table 24: Abundance of fish species caught overall (all sites) and at control and impact sites in spring 2020.

Common name	Species	All sites	Control	Impact
Bald Glassy	*Ambassis gymnocephalus*	1104	1069	35
Bartailed Flathead	*Platycephalus indicus*	1	1	0
Black-eyed Puffer	*Arthron nigropunctatus*	3	3	0
Dory Snapper	*Lutjanus fulviflamma*	3	2	1
Dusky Kob	*Argyrosomus japonicus*	2	2	0
Groovy Mullet	*Liza dumerilii*	9	6	3
Largetooth Flounder	*Pseudorhombus arsius*	1	1	0
Piggy Grunter	*Pomadasys olivaceum*	1	1	0
Pony Slimy	*Leiognathus equula*	7	7	0
River Bream	*Acanthopagrus berda*	13	13	0
Salmon spp.	*Oncorhynchus spp.*	10	10	0
Sand Steenbras	*Lithognathus mormyrus*	7	5	2
Shad	*Pomatomus saltatrix*	6	6	0
Shadow Goby	*Yongeichthys nebulosus*	2	2	0
Silver Silago	*Sillago sihama*	13	13	0
Spotted Grunter	*Pomadasys commersonnii*	2	1	1
Springer	*Elops machnata*	24	24	0

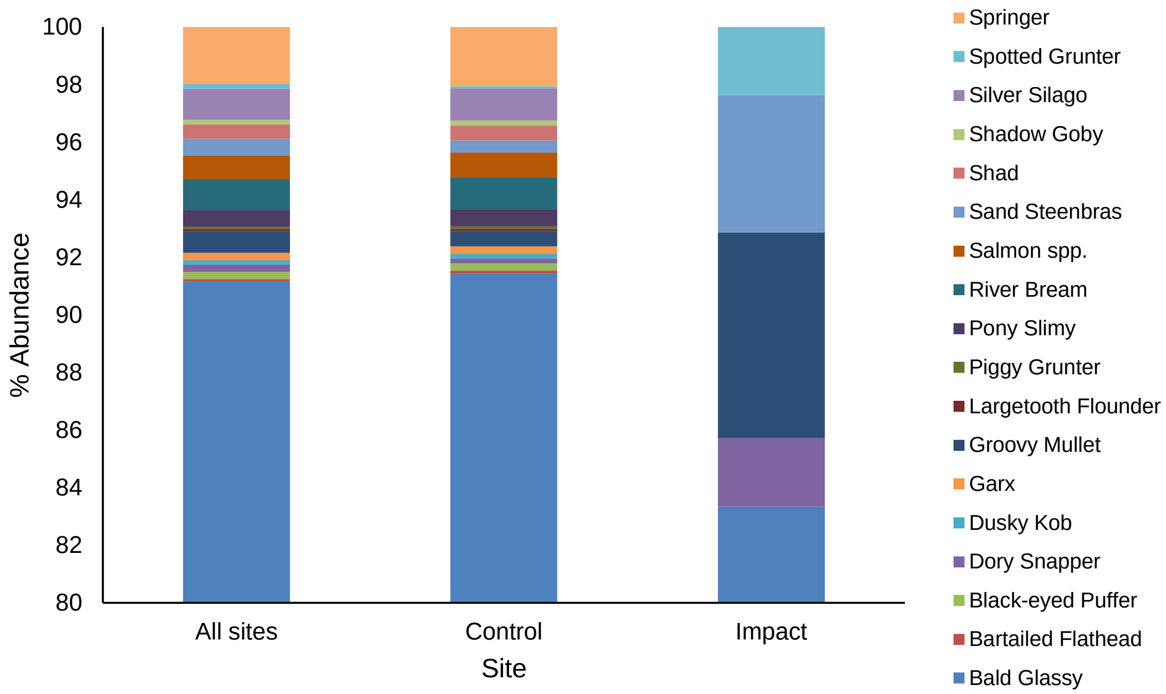

Figure 41: Relative abundance (%) of fish species caught overall (all sites) and at impact and control sites. Note that the y-axis starts at 80%.

Species that dominated by mass include Bald Glassy, Groovy Mullet and Spotted Grunter (**Table 25, Figure 42**).

Table 25: Mass (g) of fish species caught overall (all sites) and at control and impact sites in spring 2020.

Common name	Species	All sites	Control	Impact
Bald Glassy	*Ambassis gymnocephalus*	1192.32	1154.52	37.8
Bartailed Flathead	*Platycephalus indicus*	40	40	0
Black-eyed Puffer	*Arthron nigropunctatus*	50	50	0
Dory Snapper	*Lutjanus fulviflamma*	11	9.5	1.5
Dusky Kob	*Argyrosomus japonicus*	3	3	0
Groovy Mullet	*Liza dumerilii*	851.5	571.5	280
Largetooth Flounder	*Pseudorhombus arsius*	1.5	1.5	0
Piggy Grunter	*Pomadasys olivaceum*	1.5	1.5	0
Pony Slimy	*Leiognathus equula*	130	130	0
River Bream	*Acanthopagrus berda*	19.5	19.5	0
Salmon spp.	*Oncorhynchus spp.*	15	15	0
Sand Steenbras	*Lithognathus mormyrus*	10.5	7.5	3
Shad	*Pomatomus saltatrix*	9	9	0
Shadow Goby	*Yongeichthys nebulosus*	6.38	6.38	0
Silver Silago	*Sillago sihama*	6	6	0
Spotted Grunter	*Pomadasys commersonnii*	117	100	17
Springer	*Elops machnata*	24	24	0

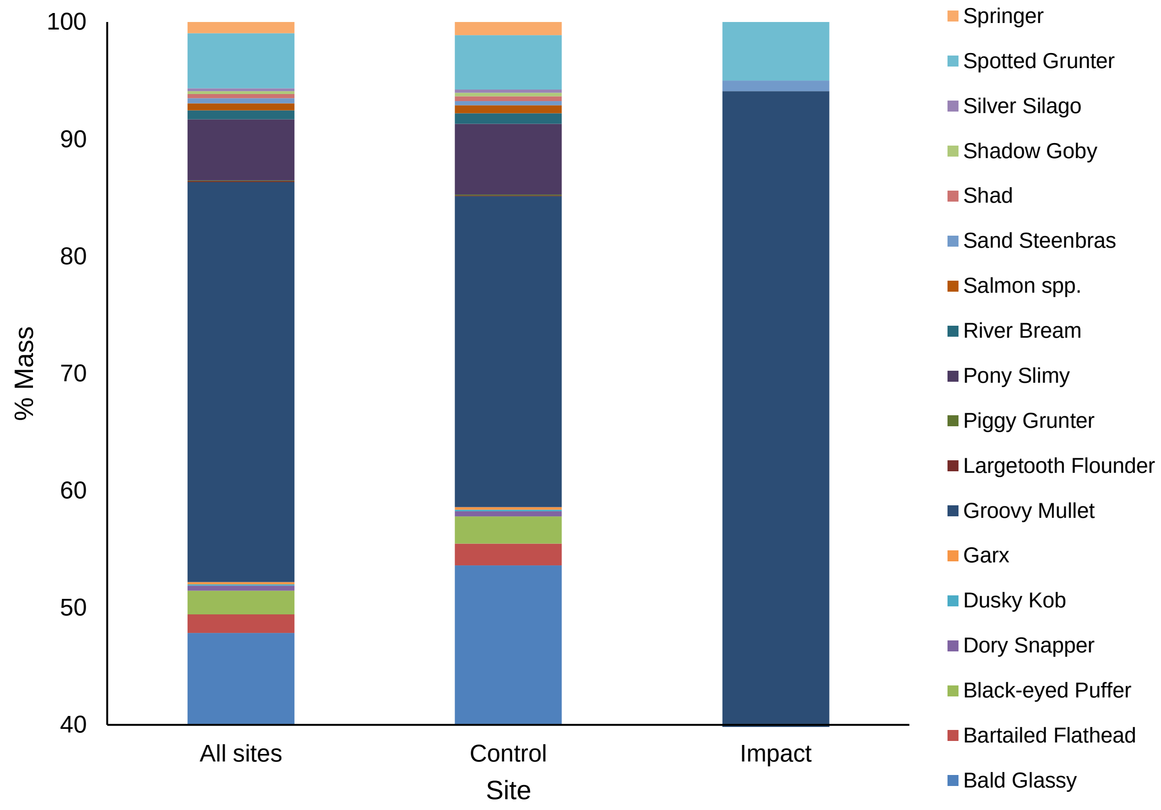

Figure 42: Relative mass (%) of fish species caught overall (all sites) and at impact and control sites. Note that the y-axis starts at 40%.

8.3.3 Spatial Patterns and Species Richness

The fish community around the Northern Bank had the greatest species richness (n = 11), followed by the Little Lagoon (n = 10) and Central Bank (n = 5). Fish communities around the Little Lagoon have had the lowest species richness in previous seasons too. Species richness of the Central Bank decreased by nearly 50% from the previous survey (spring 2020), which is most likely attributable to the fact that no fish were caught at multiple Central Bank sites.

8.3.4 Multivariate Analyses

Species diversity trends as indicated by the Shannon-Weiner diversity index (H') for all fish monitoring sites are given below (**Table 26**). Species diversity was greatest at site 23 (H' = 0.9223) in the Northern Bank area and lowest at sites 7, 10, 11 and 20 (with H' = 0.0000 each respectively) in across the sandbanks. As in previous seasons, ANOSIM analyses of fish community composition indicated that fish communities found around the three habitats did not differ significantly ($p > 0.05$).

Table 26: Shannon-Weiner H' indices of fish communities surveyed at 11 monitoring stations within the Port of Durban in summer 2021.

Central bank		***Little lagoon***		***Northern bank***	
Site	**H' index**	**Site**	**H' index**	**Site**	**H' index**
6	0.4423	11	0.0000	19	0.2445
7	0.0000	13	0.7240	20	0.0000
10	0.0000	14	0.8770	21	0.2635
				22	0.2556
				23	0.9223

8.3.5 Estuarine Association in Fish Communities

Estuarine associations of marine and estuarine fish species have been well-described by Whitfield (1994), especially species that live and breed in estuaries (referred to as estuarine resident species). Estuarine dependent species, on the other hand, are marine fishes that breed at sea but whose juveniles show varying degrees of dependency of estuaries. In summer 2021, catches were dominated by the estuarine resident species (mainly Bald Glassy), followed by estuarine dependent species.

8.4 Conclusion

Overall, the median fish abundance of all sites combined and of control sites were the only measures that did not violate the CSMP guideline values. Species richness and biomass were below the minimum allowable limit at impact and control sites. As in previous seasons, the dominant species caught was Bald Glassy. Construction had not yet commenced at the time of this survey, so these data can be viewed as complimentary to the baseline data. Importantly, the fact that species richness continues to be low indicates that fish communities in the Port are at risk of becoming homogenized and losing important species.

9 Birds

9.1 Introduction

The natural habitats within Durban Bay have long been transformed and replaced by infrastructure associated with harbour developments. The original tidal flats, mangrove forests, and other littoral vegetation have vastly been reduced and replaced by open water areas and concrete Berths. According to Allan et al. (1999), bird abundance and diversity dropped to 30% of that recorded in 1965 and avifaunal health of the Port was rated as poor in the 2011 National Biodiversity Assessment, due to substantial habitat loss and poor prey abundance and diversity (Driver et al., 2012).

The aim of the avifaunal monitoring programme prior to construction, was to determine the spatial and seasonal variability in avifaunal community structure. The monitoring must be continued during the construction phases to assess the impacts and effectiveness of the mitigation measures implemented during construction. This also forms part of the avifaunal monitoring programme recommended in the Bay of Natal Estuarine Management Plan (ERM/MER, 2012 and 2015), which proposes monthly surveys of birds on the intertidal, shallow subtidal, and mangrove habitats of the Bay.

9.2 Methodology

9.2.1 Sampling protocol

The monitoring programme has been designed to align with the long-term monitoring already being conducted by the Durban Natural Science Museum (Allan et al., 1999; McInnes et al., 2005; Allan, 2012). The methodology followed that defined in the CSMP (Clark et al., 2017).

Five natural and semi-natural habitats have been identified in 20 sampling areas in Durban Bay (**Figure 43**), which will be monitored during the construction phase:

- Centre Bank and Little Lagoon (Bayhead North, MW West, MW East, CT West, CT East, FW North, FW South and Centre Bank Roost)
- Northern Sand Banks (Yacht Basin, Fish Wharf East and Fish Wharf West)
- Muddy/mangrove habitat (Sporting Bodies, Pelican Island, Bayhead West, Bayhead Central)
- Island View Sandbank
- Open Water (Harbour East, West, North and Harbour Mouth)

Figure 43: Aerial view of Durban Bay (Port of Durban) with 20 bird survey areas.

Individual birds of each species are counted and recorded within this series of monitoring sections by circumnavigating the inner periphery of the Port on a motorised vessel once per month at spring-low tide between 08h30 and 12h30. Counts of birds are conducted by at least two observers with the aid of binoculars. To avoid double counting, observers count birds to the right of the vessel and flying overhead from the front only.

9.2.2 Statistical analyses

Data collected during December 2020, January and February 2021 (summer) are included in this reporting period. Data have been collated and used to characterise overall taxonomic composition, community structure, abundance, species richness and diversity, and compared to the baseline / preconstruction situation. Diversity indices were used as a measure of species richness and evenness to define community structure and diversity. The Shannon-Wiener diversity index (H') and the Pielou's evenness index (J') were calculated for each habitat type.

9.3 Results

9.3.1 Key results

As in spring 2020, bird abundance and species richness were below the allowable minimum thresholds in each month (**Table 27**). These declines are not related to the construction phase of this project as construction has not yet commenced. Instead they are most likely attributable to other anthropogenic drivers or natural fluctuations. For example, extremely heavy rainfall was experienced in the area just prior to the January 2021 count. As a result, the water table in the harbour was unusually high and the amount of exposed area on the sand and mud flats for birds to feed on was less than usual.

In addition, the degree of plastic pollution on the sand banks is ever increasing, even more so following the heavy rains in January. The litter affects feeding opportunities for birds both in the water (for piscivorous species) and on the sandbanks (for invertebrate feeders). Field workers are also experiencing increased difficulty with bird counts among the accumulating plastic litter on all of the sand banks that form part of the study area (**Figure 44**).

Table 27: Comparison with threshold levels of bird numbers and species richness recorded for Central Bank and Little Lagoon in the Durban harbour over the sampling period for all bird species. Values in red violate threshold limits.

	December	January	February
CSMP threshold			
Total # species	24	24	24
Total # individuals	884	1019	1000
Dec '20 - Feb '20			
Total # species	**18**	**18**	**16**
Total # individuals	**782**	**574**	**716**

Figure 44: Accumulating plastic pollution on the Central Bank where monthly bird counts are conducted.

9.3.2 Avian community composition

A total of 3 539 individual birds, representing 42 species were recorded during the three-month spring sampling period (December 2020 – January 2021). The largest proportion was counted at the Centre Bank and Little Lagoon (2 027 birds), which is in line with the overall findings of the baseline study.

As during the baseline surveys, waders and wading birds comprised the largest proportion, more than half of the total number of species recorded, consisting of 14 species (33%) and 9 species (21%) respectively (**Figure 45**). This was followed by cormorants, darters, pelicans and terns, each comprising 4 species.

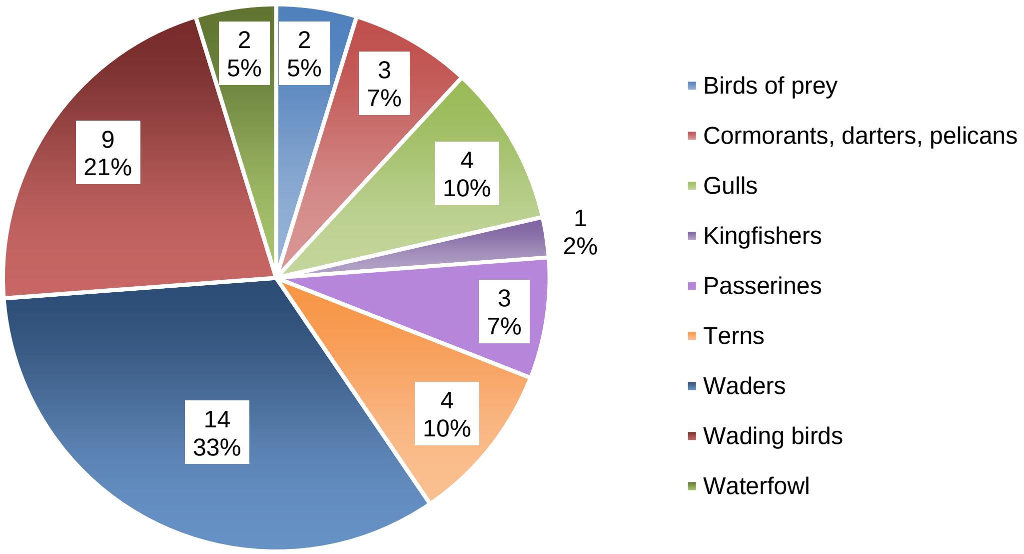

Figure 45: Number of bird species (number, percentage) per taxonomic group recorded during monthly counts from December 2020 – January 2021.

In terms of feeding guilds, piscivores (fish eaters) and invertebrate feeders made up the largest proportion of bird species recorded over the three-month sampling period, each contributing 18 species (43%) and 16 species (38%) respectively (**Figure 46**). This is also comparable to the baseline scenario where piscivores and invertebrate feeders comprised the largest proportion of birds observed over the sampling period.

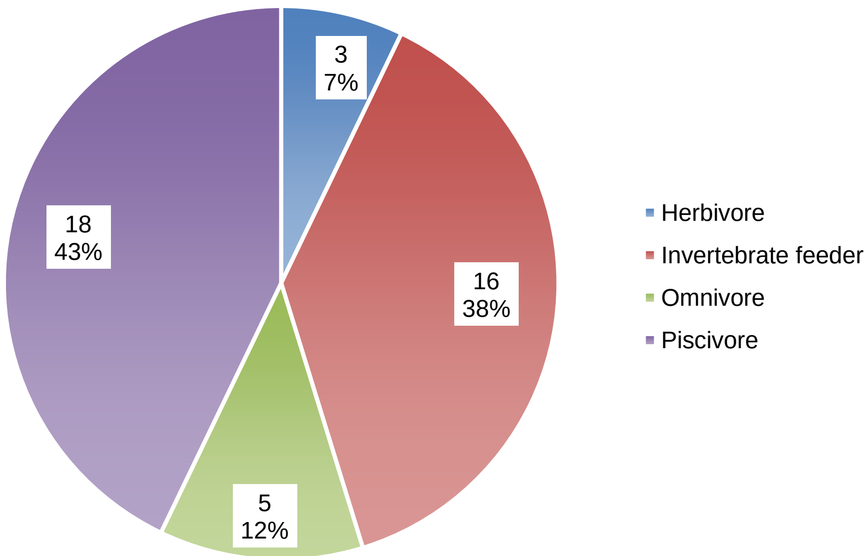

Figure 46: Composition of feeding guilds (total number of species) recorded during monthly counts from December 2020 - January 2021.

The avifauna typically found in Durban harbour can be divided into eight different taxonomic orders (**Table 28**). The most species-rich group of birds recorded during the three-month period were the Charadriiformes (waders, gulls and terns) comprising 22 of the 42 species recorded (52.4%). Within this group are the migratory waders and terns, which make up the highest number of migratory species (11 and 3 species respectively) recorded in the sampling period. Migratory species made up 38.1% of the total species recorded.

Table 28: Taxonomic composition of common water associated birds in the Durban harbour over the three-month sampling period (December 2020 - January 2021)

Bird Group	**Order**	**No. of SA Resident Species**	**No. of Migrant Species**
Birds of prey	Falconiformes	1	1
Cormorants, darters, pelicans	Pelecaniformes	3	
Gannets	Suliformes	0	
Gulls	Charadriiformes	4	
Kingfishers	Coraciiformes	1	
Passerines (swallows, martins, wagtails)	Passeriformes	2	1
Terns	Charadriiformes	1	3
Waders	Charadriiformes	3	11
Wading birds (herons, egrets, ibises)	Ciconiiformes	9	
Waterfowl (ducks, geese)	Anseriformes	2	
	Total	**26**	**16**

9.3.3 Avian Species Abundance, Richness and Diversity

Of the five habitats identified within the Durban harbour, the Central Bank and Little Lagoon had the greatest number of birds (2 072) compared to Open Water (301), the Northern Bank (438), and Mangroves (699) during the three-moth sampling period (**Figure 47**). The Central Bank and Little Lagoon had the greatest number of birds on a monthly basis, followed by the Mangroves then Open Water (**Figure 48**). Only 29 birds were recorded at Island View in this three-month period. Similar results were recorded during previous seasons and the baseline study, where the greatest numbers of birds were recorded from the Central Bank intertidal flats, and Island view had significantly lower bird abundance than all other sites. This is not surprising given that the Central Bank provides important feeding and roosting habitat for seabirds when exposed. It is also relatively isolated from harbour activities compared with other intertidal flats in the harbour so may present the most undisturbed and attractive site to the birds. However, there is a growing concern that the degree of plastic pollution accumulating in this habitat might negatively affect avian communities.

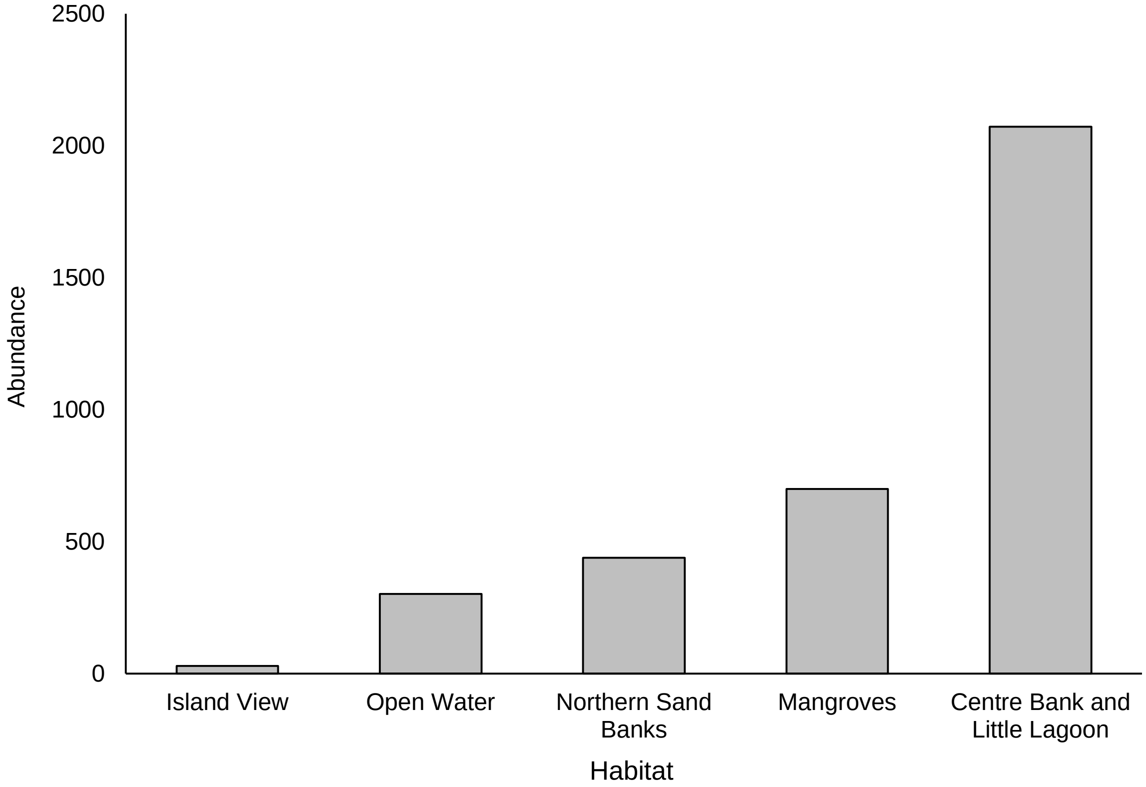

Figure 47: Total bird abundance per habitat recorded during monthly counts from December 2020 - January 2021.

The number of birds recorded during the 2020/2021 summer sampling period (3,539) was relatively higher than the number recorded during the 2020 spring sampling period (3,008). The increase in number of birds recorded signifies the last of the arrivals of migrant species to the area. On a monthly basis, the Centre Bank and Little Lagoon recorded the highest number of birds, followed by the Mangroves (**Figure 48**).

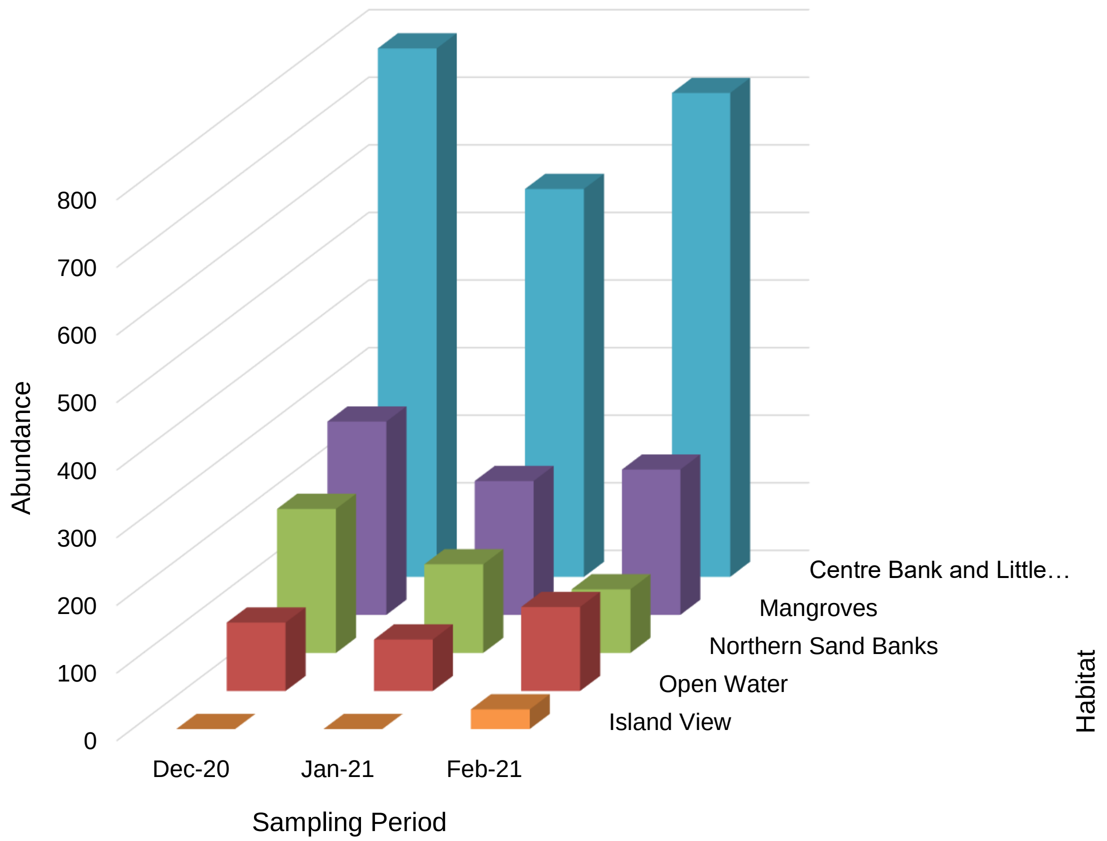

Figure 48: Total bird abundance per habitat recorded per month during counts from December 2020 – January 2021.

While species richness (S) is purely a count of the number species present, species diversity provides more information about the community composition. Species diversity takes the relative abundance into account and therefore provides information about rarity and commonness of species in a community (Stirling and Wilsey, 2001). Species diversity for the bird communities in the Durban harbour is represented here by the Shannon Wiener Index (H'), which calculates diversity based on both abundance and evenness of the species present. Evenness in this case is represented by Pielou's evenness index (J') and is constrained between zero and one. A higher number (i.e. closer to one) signifies a more even community, while a smaller number (i.e. closer to zero) suggests that the community is dominated by a few species (Stirling and Wilsey, 2001).

The greatest avian diversity was found at the Mangroves (2.279) followed by Central Bank and Little Lagoon (1.914) and Open Water habitat (2.357). The Mangroves had the greatest species richness (S = 28) followed by the Central Bank, Little Lagoon and then Open Water. This reflects the value of this habitat and it is also the only protected natural area in the Port (McInnes et al., 2005).

Open Water habitat displayed the highest evenness of species (J' = 0.74) followed by the Mangroves (J' = 0.68) and Centre Bank (J' = 0.68) (**Table 29**). The centre Bank is often visited by flocking species that have high numbers of individuals using the area for roosting and feeding, while the open water has an array of species that are mostly recorded utilising buoys and other harbour infrastructure to roost on.

As found in the baseline surveys, the Island View and the Northern Bank had considerably lower diversity index values than the other habitats (**Table 29**), which is most likely attributable to the higher levels of modification and human activity common in these areas.

Table 29: Avifaunal species richness, diversity and evenness per habitat in the Durban harbour over the winter sampling period

Habitat	Species Richness (S)	Species Diversity (H')	Species Evenness (J')
Centre Bank and Little Lagoon	24	1.914	0.60
Mangroves	28	2.279	0.68
Open Water	24	2.357	0.74
Northern Sand Banks	19	0.790	0.27
Island View	3	0.398	0.36

9.4 Conclusion

The largest proportion of birds was counted at the Central Bank and Little Lagoon during the three-moth sampling period, but species richness was greatest at the Mangroves. Similar results were reported in the baseline study. The Central Bank provides important feeding and roosting (including shelter from the wind) habitat for seabirds when exposed. The Mangroves provide important natural habitat and is the only protected natural area in the Port. Possibilities for potential refuge sites, include the sandbanks at the Bayhead 'Natural Heritage' site, Fish Wharf opposite the Central Sandbank, and the smaller Yacht Basin, however to get full protection of these areas and to limit human disturbance will be difficult.

The sandbanks are not used for breeding by birds due to the transient nature of the intertidal flats (i.e. they become submerged at high tide every day), and many of the species utilising the sandbanks are non-breeding migrants. No nests or breeding birds are therefore at risk by the development at this time.

As found during the baseline surveys, waders and wading birds (mostly utilising the centre bank intertidal flats) were most abundant, more than half of the total number of species recorded during the three-month period. Within this group are the migratory waders and terns, which make up the highest number of migratory species recorded in the sampling period. Migratory species made up 38.1% of the total species recorded highlighting the importance of managing the timing of disturbance to the centre bank during construction, with migratory season beginning in October and ending (based on previous studies) in April.

Piscivores (fish eaters) and invertebrate feeders made up the largest proportion of birds recorded in the three-month sampling period. The vast amount of litter in the harbour can impact on feeding opportunities for birds both in the water (for piscivorous species) and on the sandbanks (for invertebrate feeders). It is recommended that as an additional mitigation strategy for the approaching construction phase, the harbour is cleaned of litter on a regular basis, especially after heavy rainfall.

Monthly bird counts and species richness for the Central Bank and Little Lagoon over the sampling period December 2020 to February 2021 were once again lower than the threshold values stipulated in the in the CSMP. As the construction phase for this project had not continued over the past year and a half, the lower values may be attributable to other anthropogenic or natural drivers. However, it is concerning that bird counts and species richness are below allowable levels for another sampling season and indicates that intensified management / mitigation measures need to be implemented.

10 General Conclusion

10.1 Water quality

Physico-chemical water quality parameters have been within levels characteristic of a typical marine environment. A substantial drop in salinity levels were observed which is likely driven by the rainy season and greater influx of freshwater into the Port. The greatest turbidity levels were recorded close to the mangroves and the western bank. Overall, all results demonstrated typical seasonal patterns and are in line with the results from the baseline study.

10.2 Sediment characteristics

Medium to fine sand dominated intertidal and subtidal sediments and the total proportions of sand in the intertidal zone were slightly lower than recommended in the CSMP baseline study. Intertidal and subtidal TOC content have similarly remained below minimum allowable levels and is indicative of a system with very low nutrients. All trace metals, apart from mercury were below threshold maximum values. Mercury concentrations continued to increase from the previous sampling season (spring 2020).

10.3 Benthic macrofauna

A total of 30 intertidal and 41 subtidal macrofaunal species were identified in summer 2021. The median abundance and species richness in both zones were substantially lower than the minimum thresholds stipulated in the CSMP. These trends demonstrate further decreases from spring, where it should have increased. While it is complicated to discern the exact drivers behind these concerning trends, known factors such as the oil spill in October 2020 and severe plastic pollution are likely candidates.

10.4 Benthic microalgae

Microalgae, measured in this case as the concentration of chlorophyll-a, is important in its role as primary producers and the concentration thereof play crucial roles in the flow of energy throughout the aquatic food web. As in previous seasons, intertidal habitats had greater concentrations of chl-a than subtidal habitats. The overall concentrations of chl-a concentrations were greater in summer than in spring and is reflective of a typical seasonal peak. Importantly, the median chl-a concentrations of all habitat were within allowable limits set in the CSMP.

10.5 Biomonitoring using mussels (*Perna perna*)

Assessment of trace metal concentrations in aquatic animals such as mussels is often used as an indication of the trace metal bioavailability in a habitat. In this regard, brown mussels (*Perna perna*) that grow on channel buoys across the Port of Durban are used. Mussels collected from 14 channel buoys had trace metal concentrations below the baseline thresholds for all metals apart from mercury. Mercury concentrations demonstrated stark increases from the previous seasons and are at concerning levels for animal and human health.

10.6 Fish

Fish abundance at control sites were above the minimum threshold, but this was not the case at impact sites. Species richness and biomass at all sites were below the respective minimum values. The fact that species richness continued to be low from the previous season is indicative of biodiversity loss and needs to be closely monitored.

10.7 Birds

Spring bird monitoring was conducted from December 2020 – January 2021. Avian species richness and abundance were below the threshold minimum values in all three months, as was also the case in the previous season (spring 2020). There are various potential factors that may explain these declines, including the severe degree of plastic pollution in the Port of Durban. Marine birds often mistake plastic for food and feed it to their chicks that cannot digest plastic. The Central Bank, a key roosting habitat for birds, has progressively become covered in plastic debris. This problem needs to be urgently addressed by Port management authorities.

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