Coastal water quality of Bonaire, St. Eustatius, and Saba during a period of restricted tourism

T0 monitoring October-December 2020

Author: E.M. Foekema

With input from:
Roxanne-Liana Francisca (STINAPA)
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Wageningen University &
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Contents

Summary

The traveling restrictions during the Covid-19 pandemic in 2020 and 2021 created a unique possibility to measure water quality parameters along the coasts of the Dutch Caribbean Islands with minimised anthropogenic pressure resulting from tourism. Such a baseline dataset could serve as a reference for future measurements of the monitoring parameters during periods without traveling restrictions, allowing the determination of the impact of the presence of tourists on the local water quality.

Rijkswaterstaat contracted STINAPA Bonaire and the Caribbean Netherlands Science Institute (CNSI) to collect water samples along the coasts of Bonaire (STINAPA), and Saba and St. Eustatius (CNSI) in the period October – December 2020. The samples were stored frozen until transport to the Netherlands where they were analysed by the NIOZ for nitrogen, phosphorous, and total organic carbon. Wageningen Marine Research combined the results in the current report and formulated recommendations for future monitoring of coastal water quality at the Dutch Caribbean Islands.

Although a wide range of samples was collected, especially in Bonaire and St. Eustatius, the number of samples per site was too low to obtain statistical power in the observations.

Nonetheless, the first insights were achieved as follows:

- The Bonaire locations generally showed lower nitrogen and phosphate concentrations in 2020 than during a sampling campaign in 2012/13.
- In water samples collected at St Eustatius the inorganic nutrient concentrations ranged from low impacted at positions more remote from the shore to high affected at specific shallow positions.
- At Saba no evident indications were found for negatively affected water quality. However, the dataset was minimal and covered only a small part of the coastline.
- The available dataset suggests that the NH4-DIN ratio could be a good indicator of a disturbed nutrient balance in the coastal water.

And following future directions are recommended:

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- Extending the dataset in the future with more time points and additional analyses will facilitate more in-depth data interpretation. Recommendations for future monitoring projects are to work according to strict protocols regarding selecting parameters, sample identification, sampling procedure, additional data collection (e.g. weather conditions prior to sampling), sample storage, and data storage.
- In addition it could be considered to build local analytical capacity in the Dutch Caribbean for samples from future monitoring projects, which at least allows a safe and secure sample processing and storage until transport to specific facilities abroad.

1 Introduction

During the Covid-19 pandemic, global traveling was restricted for substantial periods in the years 2020 and 2021, and as a result, the number of tourists visiting the Dutch Caribbean Islands was strongly reduced. This created a unique possibility to measure water quality parameters along the coasts of these islands with minimized anthropogenic pressure resulting from tourism to create a baseline. Collecting coastal water provides a snapshot concentration in time, thus, a valuable dataset as presented here could serve as a reference for future measurements during periods without traveling restrictions, allowing the evaluate the impact of tourism on the local water quality.

Rijkswaterstaat contracted STINAPA Bonaire and the Caribbean Netherlands Science Institute (CNSI) to collect water samples along the coasts of Bonaire (STINAPA), and Saba and St. Eustatius (CNSI). The samples were stored frozen until transported to the Netherlands and analysed by the institute NIOZ. Wageningen Marine Research was asked to combine the results in the current report and formulate recommendations for future monitoring of coastal water quality in the Dutch Caribbean Islands.

2 Sample collection

The water samples were collected in the period October – December 2020, as presented in the figures and tables below. Where possible water samples were collected at three depths; surface (0.5m), around 5 m and around 10 m. More details about the sampling can be found in the field reports of STINAPA (2021) and CNSI (2021).

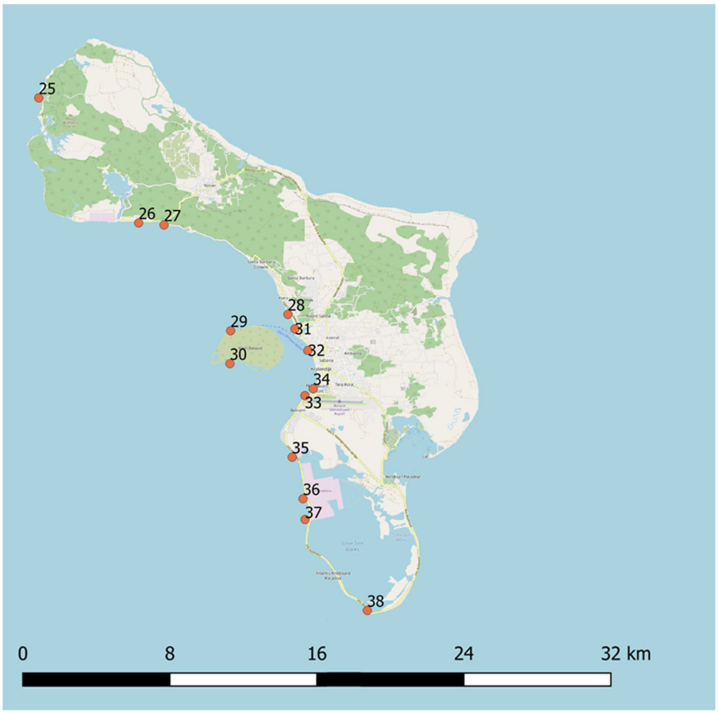

Figure 1 *Overview of positions at Bonaire that STINAPA sampled. See Table 1 for details.*

Table 1 *Locations at Bonaire where STINAPA collected water samples during two sampling rounds. Numbers correlate with positions shown in Figure 1.*

Nr on map	Bonaire	Position		Round 1	Round 2
25	Playa Funchi	12°16'56.30"N	68°24'54.33"W	23 Oct '20	8 Dec'20
26	No-Dive Reserve	12°13'11.52"N	68°21'54.74"W	23 Oct '20	8 Dec'20
27	Karpata	12°13'7.79"N	68°21'9.14"W	23 Oct '20	8 Dec'20
28	Cliff	12°10'27.04"N	68°17'26.36"W	23 Oct '20	8 Dec'20
29	Ebo's Special	12° 9'57.60"N	68°19'9.42"W	23 Oct '20	8 Dec'20
30	South Bay	12° 8'58.51"N	68°19'10.63"W	23 Oct '20	8 Dec'20
31	Front Porch	12°10'1.13"N	68°17'13.81"W	25 Oct '20	9 Dec'20
32	Playa Lechi	12° 9'22.38"N	68°16'50.16"W	25 Oct '20	9 Dec'20
33	Airport	12° 8'0.97"N	68°16'55.79"W	25 Oct '20	9 Dec'20
34	18th Palm	12° 8'13.50"N	68°16'40.92"W	25 Oct '20	9 Dec'20
35	Angel City	12° 6'10.32"N	68°17'18.78"W	25 Oct '20	9 Dec'20
36	Salt Pier	12° 4'55.53"N	68°16'59.18"W	25 Oct '20	9 Dec'20
37	Tori's reef	12° 4'18.30"N	68°16'55.50"W	25 Oct '20	9 Dec'20
38	Red Slave	12° 1'34.67"N	68°15'3.67"W	25 Oct '20	9 Dec'20

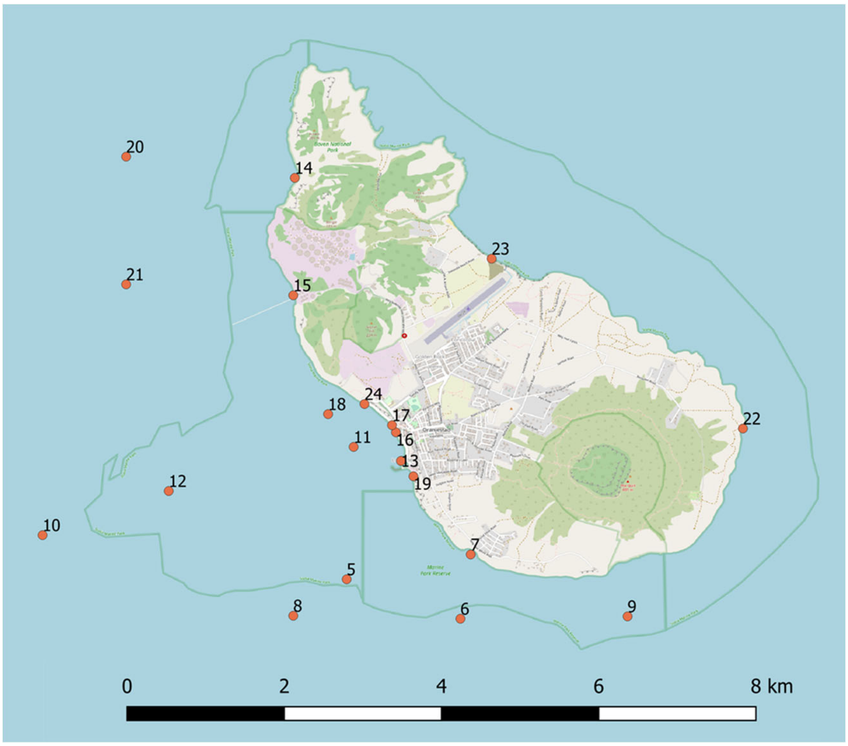

Figure 2 *Overview of positions at St Eustatius that CSNI sampled. See Table 2 for details.*

Table 2 *Locations at St Eustatius where CSNI collected water samples during three sampling rounds. Numbers correlate with positions shown in Figure 4.*

Nr on map	St. Eustatius	Position		Round 1	Round 2	Round 3
5	Charly Brown	17° 27' 52" N	62° 59' 37" W	28 Oct'20		15 Dec'20
6	Drop Off	17° 27' 35" N	62° 58' 48" W	28 Oct'20		15 Dec'20
7	Kay Bay	17° 28' 2.67" N	62° 58' 43.58" W	28 Oct'20		15 Dec'20
8	Lagoon	17° 27' 36.28" N	63° 0' 0" W	28 Oct'20		15 Dec'20
9	White Wall	17° 27' 36" N	62° 57' 36" W	28 Oct'20		15 Dec'20
10	Blue Ocean	17° 28' 11" N	63° 01' 48" W		18 Nov'20	15 Dec'20
11	Double wreck	17° 28' 49" N	62° 59' 34" W		18 Nov'20	15 Dec'20
12	Flat	17° 28' 30" N	63° 0' 53.66" W		18 Nov'20	15 Dec'20
13	Harbour	17° 28' 42.98" N	62° 59' 13.62" W		18 Nov'20	15 Dec'20
14	Jenkins bay	17° 30' 44.86N	62° 59' 59.35" W		18 Nov'20	15 Dec'20
15	Nustar	17° 29' 54.28" N	63° 0' 0" W		18 Nov'20	15 Dec'20
16	Old gin house	17° 28' 55.28" N	62° 59' 15.78" W		18 Nov'20	15 Dec'20
17	Scubaqua	17° 28' 58.35" N	62° 59' 17.46" W		18 Nov'20	15 Dec'20
18	Stenapa reef	17° 29' 3.12" N	62° 59' 45" W		18 Nov'20	15 Dec'20
19	Stuco	17° 28' 36.33" N	62° 59' 8.24" W		18 Nov'20	15 Dec'20
20	West Jenkin's	17° 30' 54" N	63° 01' 12" W		18 Nov'20	15 Dec'20
21	West Nustar	17° 29' 59" N	63° 01' 12" W		18 Nov'20	15 Dec'20
22	Corre Corre	17° 28' 56.91" N	62° 56' 46.29" W		19 Nov'20	15 Dec'20
23	Dump	17° 30' 10.07" N	62° 58' 34.54" W		19 Nov'20	15 Dec'20
24	Smoke Alley	17° 29' 7.46" N	62° 59' 29.33" W			15 Dec'20

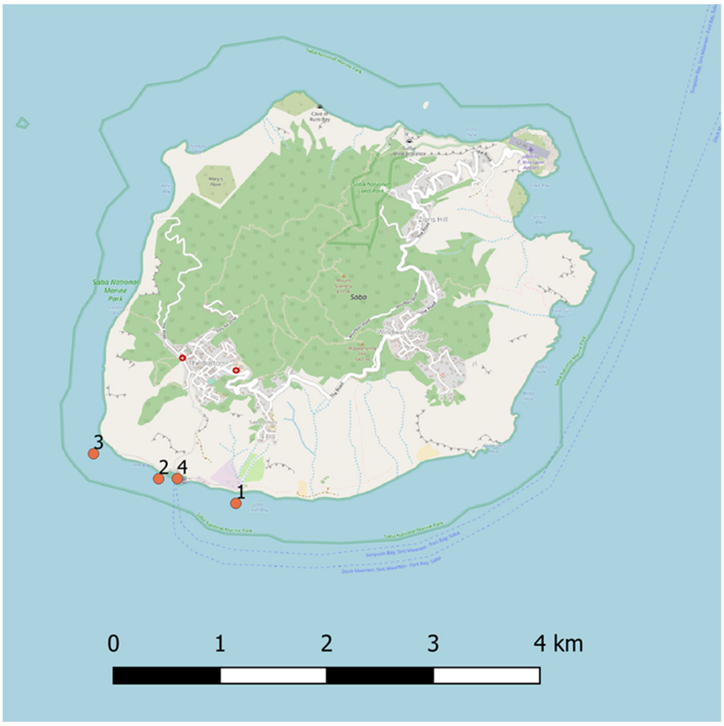

Figure 3 *Overview of positions at Saba that CSNI sampled. See Table 3 for details.*

Table 3 *Locations at Saba where CSNI collected water samples during a single sampling round. Numbers correlate with positions shown in Figure 5.*

Nr on map	Saba	Position		Round 1
1	Stone Crusher	63°14’47.17”N	17°36’50.19”W	18 Oct'20
2	Pipe	63°15’11.72”N	17°36’58.01”W	18 Oct'20
3	Harbour	63°15'5.79"N	17°36'58.05"W	18 Oct'20
4	Beach	63°15’32.41”N	17°37’5.97”W	18 Oct'20

3 Analytical Methods

Below is a brief overview of the colorimetric methods used by NIOZ (Texel, the Netherlands) to analyse the samples. For details about the analyses, we refer to the methodological references given.

Ortho-Phosphate (PO_4) reacts with ammonium molybdate at pH 1.0, and potassium antimonyltartrate is used as a catalyst. The yellow phosphate-molybdenum complex is reduced by ascorbic acid and forms a blue reduced molybdophosphate-complex measured at 880nm (Murphy & Riley, 1962).
Ammonium (NH_4) reacts with phenol and sodiumhypochlorite at pH 10.5 to form an indo-phenolblue complex. Citrate is used as a buffer and complexant for calcium and magnesium at this pH. The blue colour is measured at 630nm (Koroleff, 1969 and optimised by W. Helder and R. de Vries, 1979).
Nitrate plus Nitrite (NO_3+NO_2) is mixed with an imidazol buffer at pH 7.5 and reduced by a copperised cadmium column to Nitrite. The Nitrite is diazotated with sulphanylamide and naphtylethylene-diamine to a pink coloured complex and measured at 550nm. Nitrate is calculated by subtracting the Nitrite value measured on the Nitrite channel from the 'NO3+NO2' value (Grasshoff et al, 1983).
Nitrite (NO_2) is diazotated with sulphanylamide and naphtylethylene-diamine to form a pink coloured complex measured at 550nm (Grasshoff et al, 1983).
The method detection limits (MDL) were calculated using the standard deviation of ten samples containing 2% of the highest standard used for the calibration curve and multiplied with the student's value for n=10, thus being 2.82. (MDL = Std Dev of 10 samples x 2.82).

Table 4 *Quality assurance data for the analyses performed on the samples; Method Detection Limits (MDL), measuring range, and standard deviation at representative concentrations (Data provided by Jan van Ooijen, NIOZ).*

	MDL (µM/L)	Full-scale measuring ranges (µM/L)	Standard deviation
PO_4	0.007	1.505	1.9% (at 0.364 µM/L)
NH_4	0.010	10.05	2.5% (at 1.705 µM/L)
NO_3+NO_2	0.012	11.51	0.6% (at 4.102 µM/L)
NO_2	0.003	1.505	3.5% (at 0.086 µM/L)

4 Results and discussion

The following paragraphs show the results of the sampling for the three Islands. Some individual datapoints form high outliers compared to the rest of the data. It cannot be excluded that these values are affected by any form of contamination of the sample. However, it is also possible that these values are indicative for inhomogeneous distribution of the measured component at the moment of sampling. The data set consists of many individual samples that vary in time, position and water depth, which makes it hard to identify if a value is reliable or not. For that reason all measured values are included in this report. When in future monitoring programs a more solid database is collected it will be possible to assess the value of the outliers statistically.

The dataset will be described in paragraphs per Island below on the bases of summarising graphs. The individual data points are presented per timepoint, position, and sampling depth in graphs that are included in Annexes 1 to 3 for Bonaire, St. Eustatius and Saba respectively. The complete raw dataset is included in Annex 4 to 6.

4.1 Arbitrary reference location

Including an open ocean reference sample is a prerequisite for quality assurance and control for chemical water quality collection in coastal waters. However, during the present sampling campaign no open ocean water was sampled that could serve as a reference far from the influence of the Islands. Of all locations sampled, the position ‘Blue Ocean’ at St. Eustatius (position 10 in Figure 4) was the most remote from land. For that reason, this position was used as an arbitrary reference location in this report. Although without further analysis, it is not sure that this position is a good representative for levels detected in the open ocean for all three islands. Unfortunately in the water samples collected at this position only inorganic nutrients were analysed, therefore no ‘reference values’ for TOC and TN are available.

Position ‘Blue Ocean’ was sampled twice in November and December 2020, respectively, at three different depths. The results of the individual analyses are presented in Table 5. Differences between the individual samples were relatively small except in November 2020 at 0.5 m depth, which contained two to three times higher concentrations of inorganic nutrients than the other samples. Since it is unclear if these outlying values were due to contamination of the sample or reflect the real situation at the moment of sampling, they were not excluded from the dataset. As a consequence, the maximum of the ranges that were used as a reference in this report can be an overestimation of the actual water quality at position ‘Open Ocean’. It should be noted that the PO_4 concentration that was measured (0.107 µmol/L) at position ‘Blue Ocean’ in November 2020 at 0.5 m depth exceeds the threshold (0.07 µmol/L) that is set in the Nature Environmental Policy Plan (NEPP), while all other samples were below this threshold. This again, raises questions about the suitability of the such an arbitrary reference location.

Table 5 *Results of the analysis of the water samples collected at position 'Blue Ocean' near St. Eustatius, which was arbitrarily selected as reference location. The range (minimum-maximum) of these values is plotted as arbitrary reference value in the data graphs presented below and in the annexes.*

name	date	Depth	PO_4	NH_4	NO_3+NO_2	DIN	N:P ratio	NH_4:DIN
Blue Ocean	Nov/20	0.5	0.107	0.30	0.07	0.37	3.5	0.80
Blue Ocean	Nov/20	5	0.031	0.14	0.02	0.16	5.3	0.85
Blue Ocean	Nov/20	10	0.041	0.11	0.02	0.13	3.1	0.84
Blue Ocean	Dec/20	0.5	0.024	0.13	0.02	0.14	6.0	0.87
Blue Ocean	Dec/20	5	0.017	0.09	0.01	0.11	6.2	0.88
Blue Ocean	Dec/20	10	0.017	0.10	0.03	0.13	7.4	0.79
Minimum			0.02	0.09	0.01	0.11	3.09	0.79
Maximum			0.11	0.30	0.07	0.37	7.41	0.88

4.2 Bonaire

The samples collected at Bonaire were analysed for the nutrients, ammonium (NH_4), nitrite (NO_2) and nitrate (NO_3) that together form total dissolved inorganic nitrogen (DIN), phosphate (PO_4), and for Total nitrogen (TN), and total organic carbon (TOC).

In all water samples the dissolved inorganic phosphate concentrations were below the environmental threshold level of 0.07 µmol/L, with one exception at position 'Cliff' (*Figure 4*). This single sample was collected in December 2020 at 10 m depth and contained 0.14 µmol PO_4/L (see Annex 1), while in the other three samples 10 times lower concentrations were measured. That one of these samples was taken at the same time and same depth suggests that the outlying value is less reliable. With this exception, the 75 percentile values at all sample positions are below the minimum value at the arbitrary reference location. Impact of the Island is therefore not evident. Phosphate concentrations in all samples from position 'South Bay' are remarkably low.
Finally, the dataset does not contain clear indications that phosphate concentrations were related with water depth or moment of sampling.

Relative to the data collected by Slijkerman *et al* in 2012/13 (*Figure 5*) phosphate concentrations were in general lower in 2020.

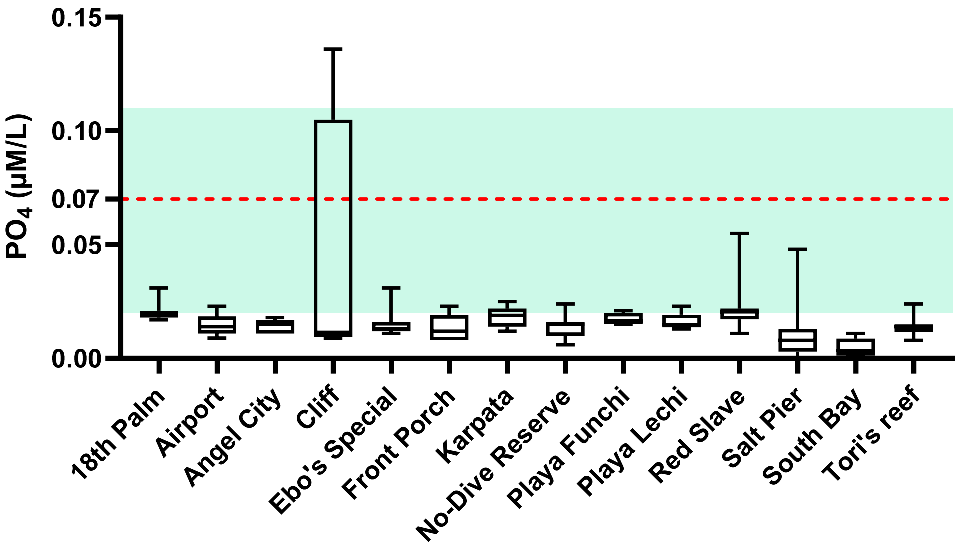

Figure 4 *Disolved inorganic phosphate (PO_4) concentrations in all watersampes collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The red dotted line indicates the NEPP threshold level (NEPP 2020). The green field indicates the range of the measured values at the arbitrairy reference position 'Blue Ocean' at St. Eustatius.*

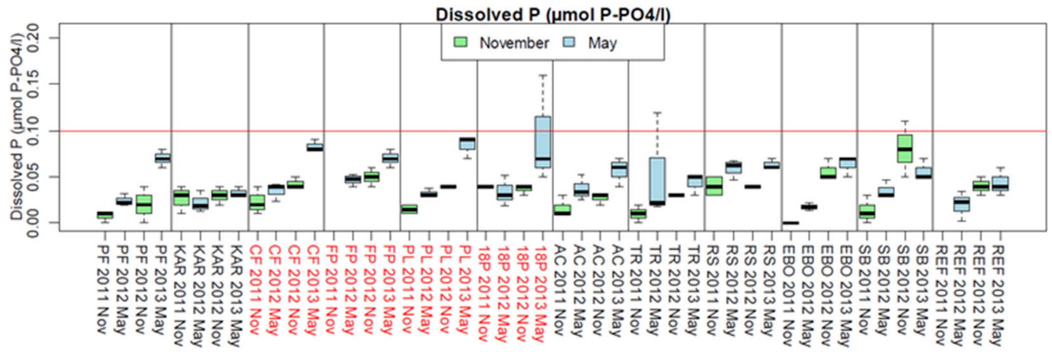

Figure 19 *Dissolved phosphate (PO_4) concentrations (µmol/l) at three different sampling moments in 2012 and 2013 in two months (November and May) at 12 locations. Locations are North-south ordered, except for Ebo's Special, South Bay and the offshore reference (coming last). Red line represents the environmental threshold concentration for phosphate, being 0.1 µmol/l.*

Figure 5 *Disolved inorganic phosphate (PO_4) concentrations at locations in Bonaire in 2012-2013, as determined by Slijkerman et al 2013. Note that the environmental treshold concentration (red line) has been lowered since 2013.*

The average concentrations of total dissolved inorganic nitrogen (DIN) remained below the environmental threshold value of 1 µmol/L (NEPP 2020) at all Bonaire positions (*Figure 6*). But at positions 'Cliff' and 'Ebo's Special' this threshold felt within the 25-75 percentile of the datasets. Individual samples from positions '18th Palm', 'Airport', 'Salt Pier', and 'South Bay' contained unexpected high concentrations of ammonium (NH_4), that might indicate inhomogeneous mixing of the water column at these positions, but could also be due to contamination of the sample.

Except for positions 'Playa Funchi' and 'Playa Lechi', the maximum value of the arbitrary reference was exceeded by most of the samples from all positions. No clear relations between concentrations and water depth or sampling moment could be established from this dataset.

In comparison with the dataset of Slijkerman et al (2013) the phosphate concentrations were in general lower in 2020, this is especially the case for the locations 18th Palm and 'Angel City' ('18P' and 'AC' in *Figure 7*), that showed elevated values in 2012-2013.

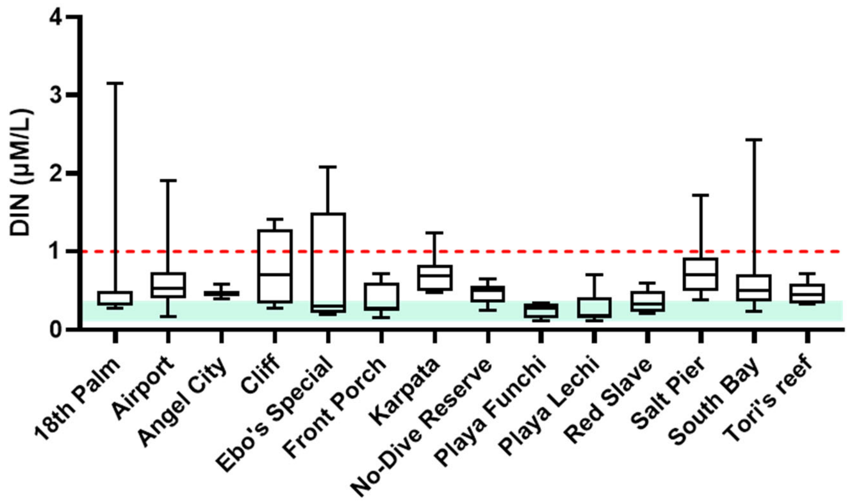

Figure 6 *Total dissolved inorganic nitrogen (DIN) concentrations in all watersampes collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The red dotted line indicates the NEPP threshold level (NEPP 2020). The green field indicates the range of the measured values at the arbitrairy reference position 'Blue Ocean' at St. Eustatius.*

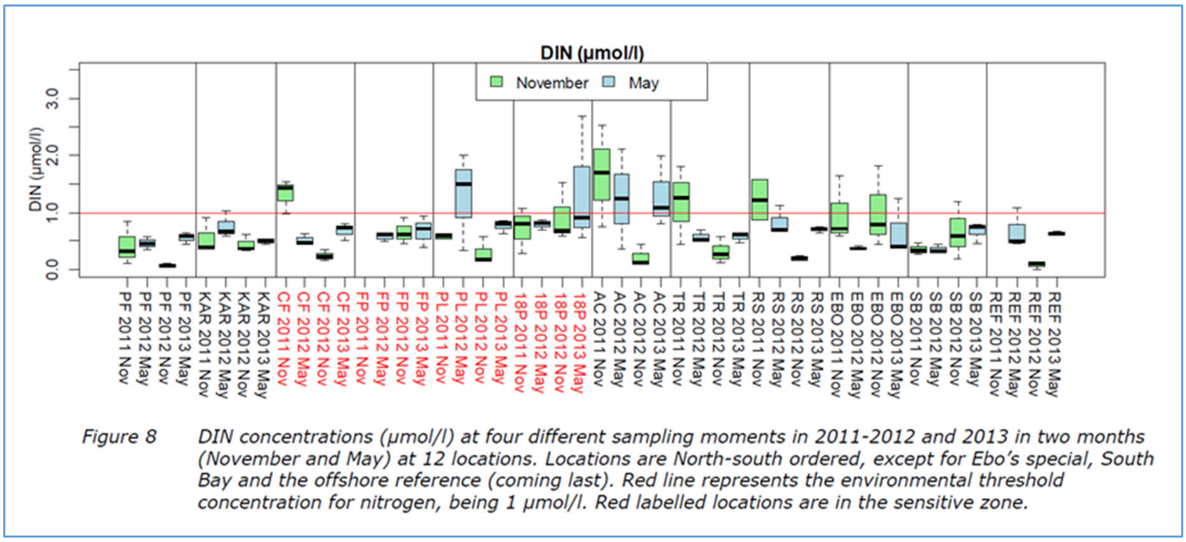

Figure 7 *Total dissolved inorganic nitrogen (DIN) concentrations at locations in Bonaire in 2012-2013, as determined by Slijkerman et al 2013.*

Total nitrogen concentrations varied around 5 µmol/L in all samples, without substantial differences between positions (Figure 8). In one sample from position 'Karpata' 19 µmol/L was measured, which could make this single value less reliable. Total nitrogen was not measured at the arbitrary reference position, nor by Slijkerman et al (2013). Since there is also no solid environmental threshold defined, we plotted an indicative blue reference line in at 2 µmol/L in Figure 8 and in all TN-figures to follow.
This 2 µmol/L is based on the added environmental thresholds for dissolved inorganic nitrogen (DIN) and particulate organic nitrogen (PON), that are both set at 1 µmol/L (NEPP 2020). This reference however does not take dissolved organic nitrogen into account and therefore need to be considered with cautions.

The concentrations of total nitrogen that were detected in 2020 were at the lower range of the concentrations measured in 2012-2013 (*Figure 9*).

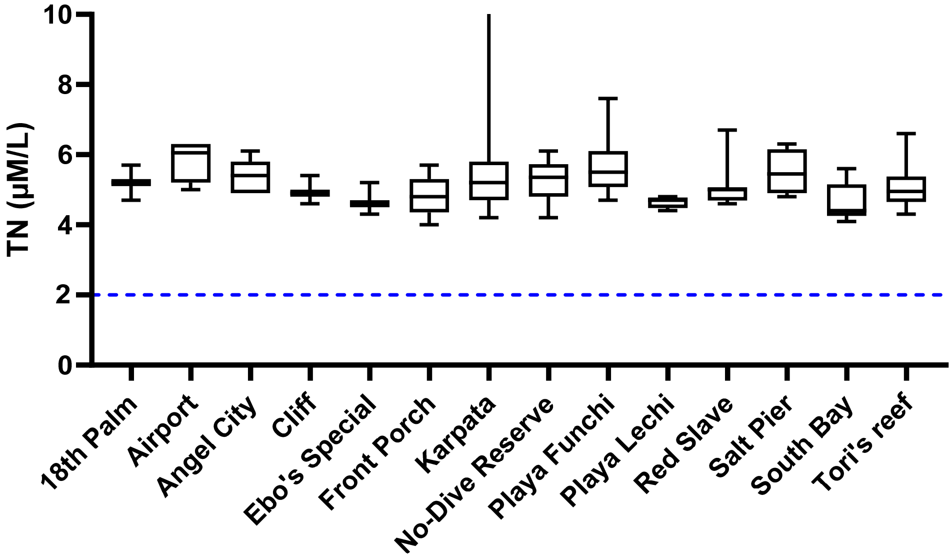

Figure 8 *Total nitrogen (TN) concentrations in all watersampes collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The dotted blue line serves as a reference that is defined by adding the environmental threshold values for dissolved inorganic nitrogen (DIN) and Particulate organic nitrogen (PON), but that does not take dissolved organic nitrogen (DON) into account.*

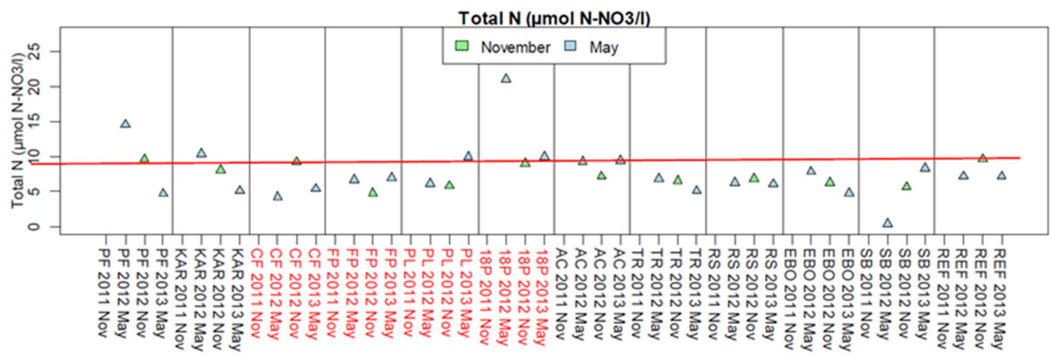

Figure 15 *Total nitrogen concentrations (µmol/l) at three different sampling moments in 2012 and 2013 in two months (November and May) at 12 locations. Locations are North-south ordered, except for Ebo's special, South Bay and the offshore reference (coming last).*

Figure 9 *Total nitrogen (TN) concentrations at locations in Bonaire in 2012-2013, as determined by Slijkerman et al 2013. The red line indicates the 80 percentile of all values.*

The fraction of ammonium (NH_4) in total inorganic nitrogen in the water samples at the arbitrary reference position ranged from 0.79 to 0.88. At all Bonaire positions this ratio was on average lower. Only at position 'Playa Lechi' the average felt just within the range of the reference position. For positions '18th Palm', 'Airport', 'Angel City', 'Front Porch', 'Karpata', and 'No-Dive Reserve' the 25-75 percentile was substantially lower than the reference value. This could indicate that these positions are more impacted by additional nitrogen sources in the form of nitrate/nitrite, that may have a terrestrial origin.

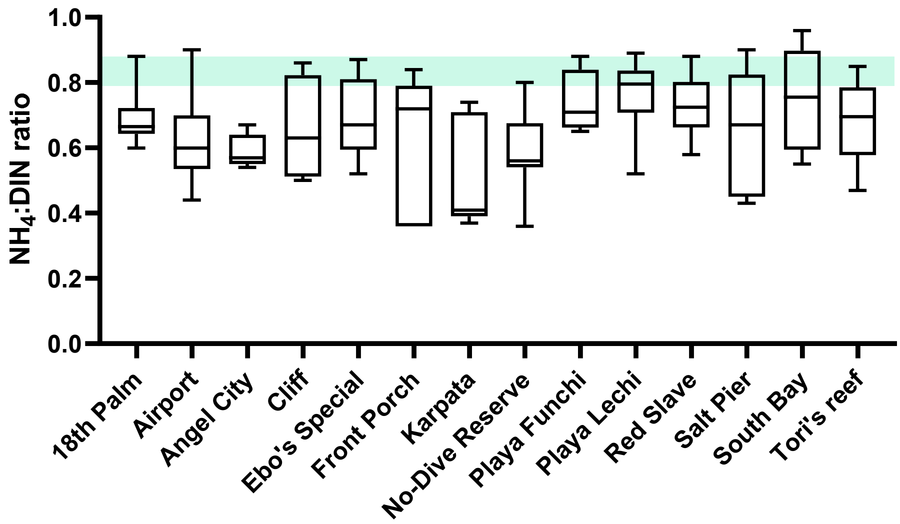

Figure 10 *The fraction ammonium in total inorganic Nitrogen (DIN) in all watersampes collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The green field indicates the range of the measured values at the arbitrairy reference position 'Blue Ocean' at St. Eustatius.*

The nitrogen-phosphorous ratios showed large differences between positions (*Figure 11*), with some extremely high values at positions 'Salt Pier' and 'Tori's Bay', that were driven by low phosphate concentrations. When looked at in more detail (*Figure 11*a), it is clear that the ratio of the arbitrary reference position is exceeded at all Bonaire positions. The lowest ratios were found at positions 'Playa Funchi', 'Playa Lechi' and 'Red Slave' where none of the samples exceeded the ratio of 30, suggesting that at these positions nitrogen is the limiting nutrient for primary production (Slijkerman et al 2013), which is more pronounced the case at the arbitrary reference location.

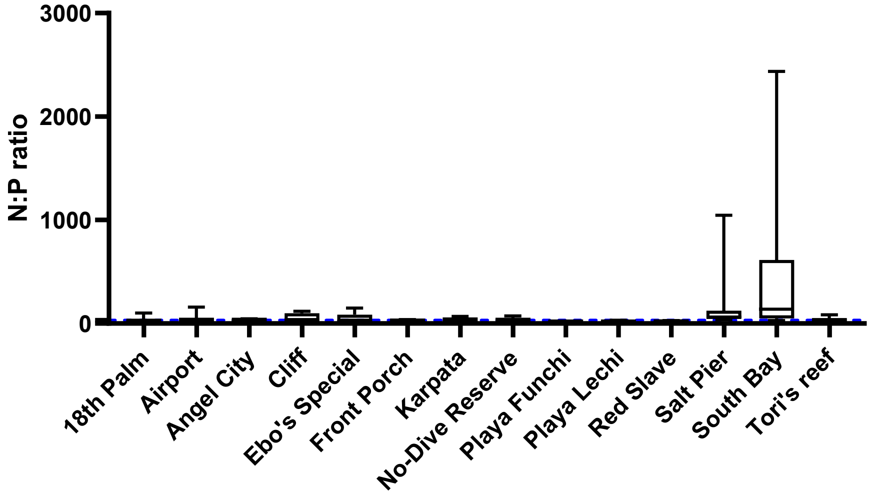

Figure 11 *Inorganic nitrogen (N) : phosphous (P) ratio in all watersampes collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'.*

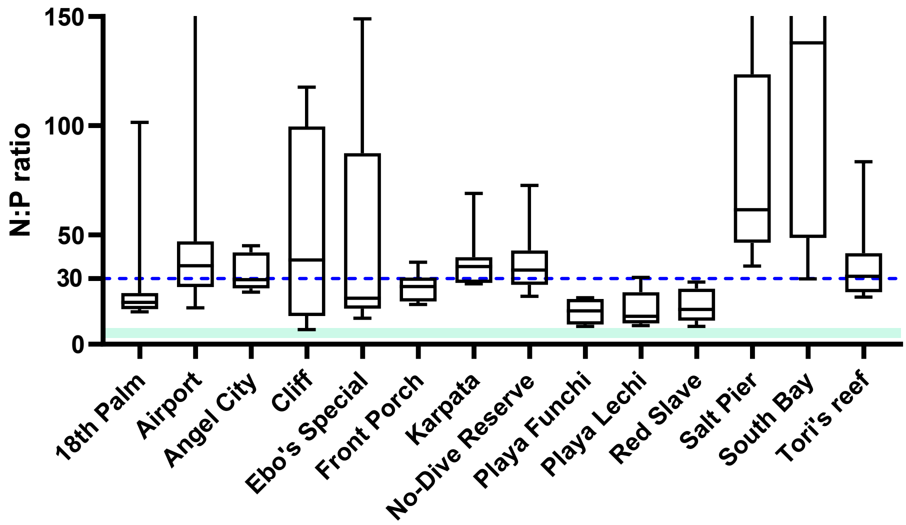

Figure 11a *Detail of Inorganic nitrogen (N) : phosphous (P) ratio in all watersampes collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. Below the dotted blue line nitrogen can be considered the limiting factor for algal development. The green field indicates the range of the measured values at the arbitrairy reference position 'Blue Ocean' at St. Eustatius.*

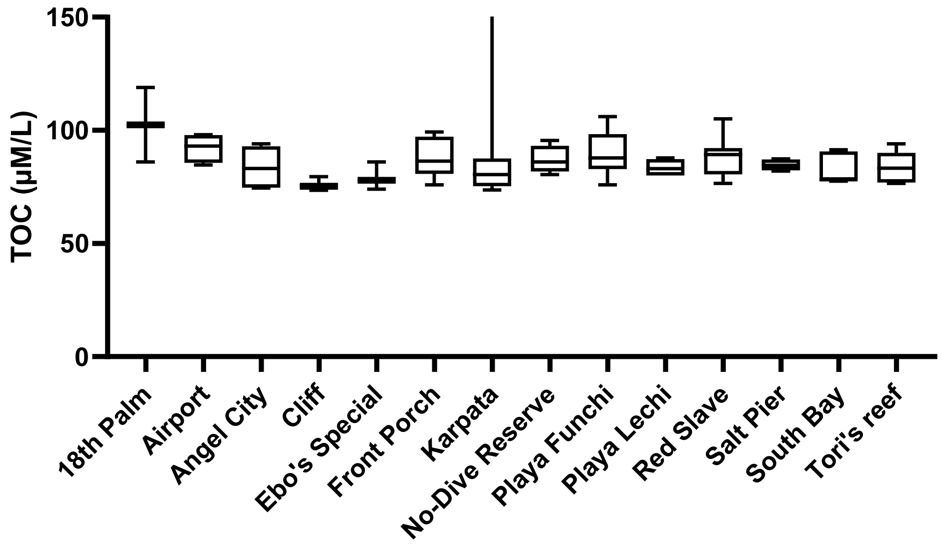

Figure 12 *Total organic carbon (TOC) concentrations in all watersampes collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'.*

The average concentrations of total organic carbon (TOC) varied around 80 µmol/L at most locations. In one single sample from position 'Karpata' a value of 250 µmol/L was detected. It is unclear if this forms a reliable value or is due to sample contamination. Average TOC concentrations were slightly higher at positions 18th Palm and Airport, but substantial differences between positions were not detected.

4.3 St. Eustatius

The samples collected at St Eustatius were analysed for the nutrients, ammonium (NH_4), nitrite (NO_2) and nitrate (NO_3) that together form total dissolved inorganic nitrogen (DIN), and phosphate (PO_4).

The majority of the water samples that were collected at St. Eustatius contained phosphate concentrations that felt within the range of the arbitrary reference position, and remained below the environmental threshold level of 0.07 µmol/L (*Figure 13*). At positions 'Drop off' and 'Smokey Alley' phosphate concentrations were extremely low in all samples. The highest average concentrations were detected at positions 'Nustar' and 'Stuco'. At position 'Nustar' samples were collected at 0.5 and 5 m water depth; high phosphate concentrations were found in both the October samples, while in the water samples that were collected in December the threshold level for phosphate was not exceeded. Position 'Stuco', that was only sampled at 0.5 m depth, showed relatively high phosphate concentrations around 0.15 µmol/L both during the October and the December.

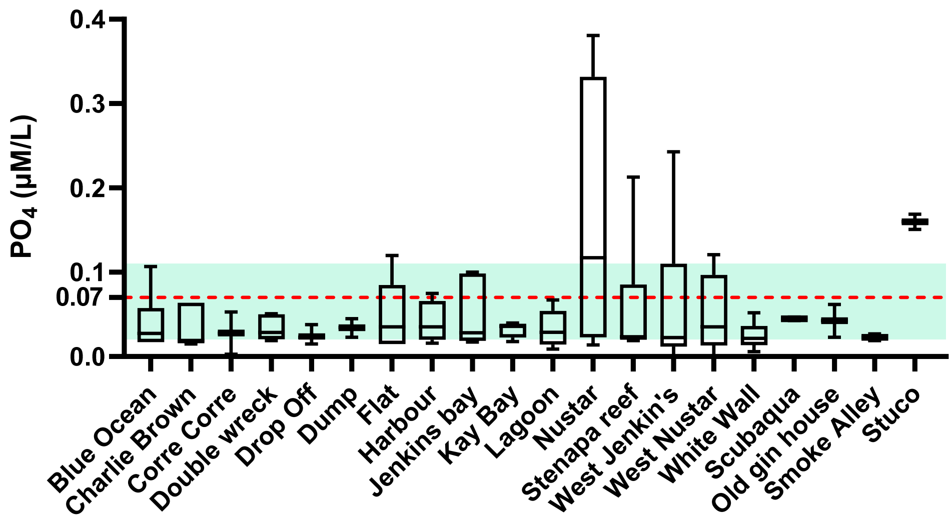

Figure 13 *Disolved inorganic phosphate (PO_4) concentrations in all water samples collected between October and December 2020 at St. Eustatius. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The red dotted line indicates the NEPP threshold level (NEPP 2020). The green field indicates the range of the measured values at the arbitrary reference position 'Blue Ocean'.*

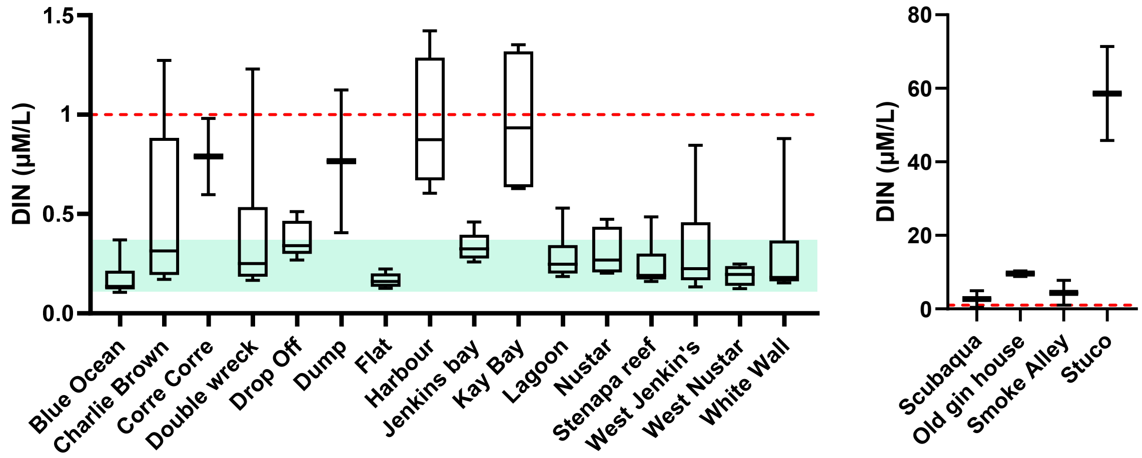

Figure 14 *Total dissolved inorganic nitrogen (DIN) concentrations in all water samples collected between October and December 2020 at St. Eustatius. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The red dotted line indicates the NEPP threshold level (NEPP 2020). The green field indicates the range of the measured values at the arbitrary reference position 'Blue Ocean' at St. Eustatius.*

Dissolved inorganic nitrogen concentrations showed a large variation between the St. Eustatius positions (*Figure 14*). Although the average values at most positions remained within the range of the arbitrary reference position, at some positions all samples exceeded this range. In case of positions 'Corre corre', 'Dump', 'Harbour' and 'Kay Bay' this resulted in partial exceedance of the environmental threshold level of 1 µmol/L. However, much higher concentrations up to 10 µmol/L were detected in samples from positions 'Scubaqua', 'Smoke Alley' and 'Old Gin House', while at position Stuco the average concentration was even around 60 µmol/L. All these four positions were only sampled at 0.5 m depth, so the dataset is limited to 2 samples per position collected in October and December respectively. With exception of position 'Old Gin House' the DIN concentrations in the water samples collected in December were considerably higher than in those collected in October (see Annex 2 for details). In all cases the high DIN concentrations in the mentioned four positions were steered by high nitrate/nitrite concentrations. This is clearly reflected by the fraction of ammonia that is extremely low at positions 'Stuco' and 'Old Gin House', and strongly reduced at positions ' Scubaqua' and 'Harbour' (*Figure 15*). The fact that positions 'Blue Ocean', 'Flat', 'West Jenkins' and 'West Nustar' have the highest NH_4-DIN ratio, and are the most remote from the island, suggests that this ratio is a good indicator for 'Island influence', most likely related to the influx of nitrate from sources at land.

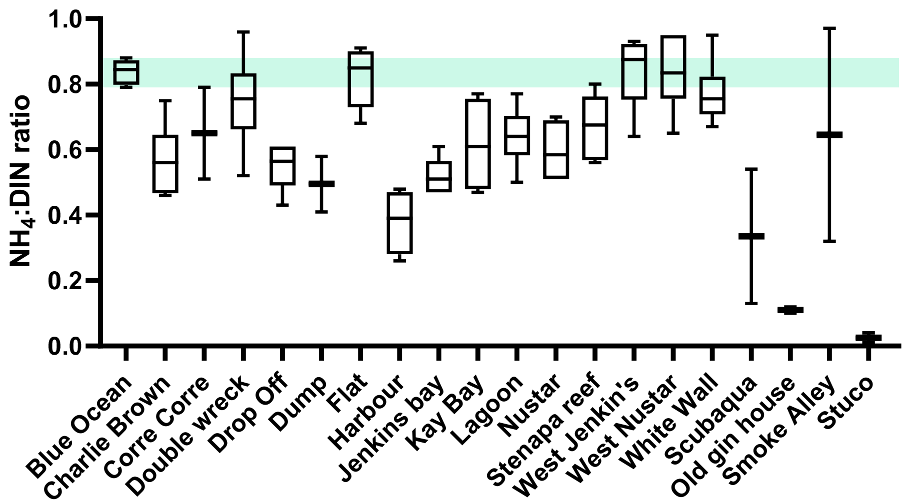

Figure 15 *Fraction ammonium in total inorganic Nitrogen (DIN) in all water samples collected between October and December 2020 at Bonaire. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The green field indicates the range of the measured values at the arbitrary reference position 'Blue Ocean'.*

As a result of the high nitrogen concentrations also the N:P ratio shifts at locations discussed above (*Figure 16*). Also at some other positions the N:P ratio reaches values above 30 that suggest that algal production is not limited by nitrogen availability.

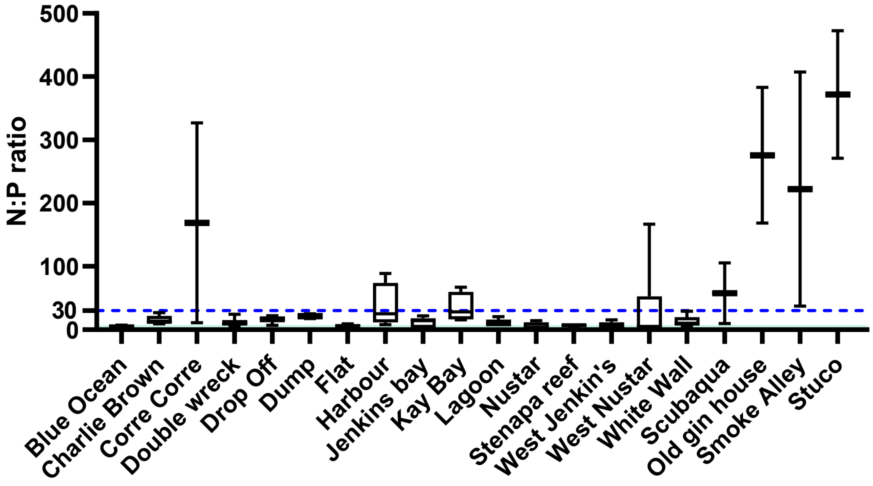

Figure 16 *Inorganic nitrogen (N) : phosphous (P) ratio in all water samples collected between October and December 2020 at St. Eustatius. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. Below the dotted blue line nitrogen can be considered the limiting factor for algal development.*

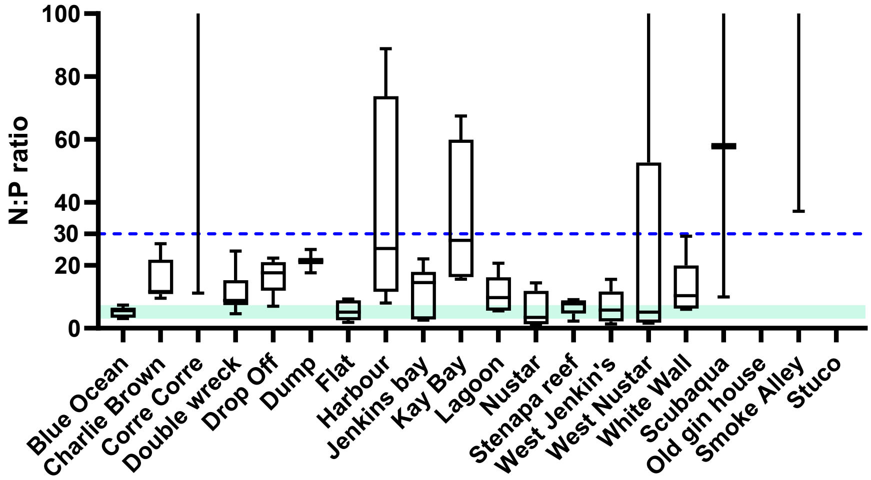

Figure 16a *(Detail) Inorganic nitrogen (N) : phosphorus (P) ratio in all water samples collected between October and December 2020 at St. Eustatius. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. Below the dotted blue line nitrogen can be considered the limiting factor for algal development.*

4.4 Saba

Saba was only sampled at four positions, and only in October 2020. Since only 2 or 3 samples per position were collected, the dataset is too small for a good evaluation. The samples were analysed for the nutrients, ammonium (NH_4), nitrite (NO_2) and nitrate (NO_3) that together form total dissolved inorganic nitrogen (DIN), and phosphate (PO_4).

Dissolved phosphorous concentrations were at all positions in the range of the arbitrary reference position, and below the environmental threshold level of 0.07 µmol/L (*Figure 17*). Inorganic nitrogen concentrations were at all positions higher that at the arbitrary reference position, but did not exceed the environmental threshold level of 1 µmol/L, except at position 'Harbour' (*Figure 18*). Here only samples were collected at 0.5 and 5 m water depth and the surface water sample contained relatively high concentrations of ammonium. As only these two samples were available it is not possible to indicate the reliability of the outcome of the analysis.

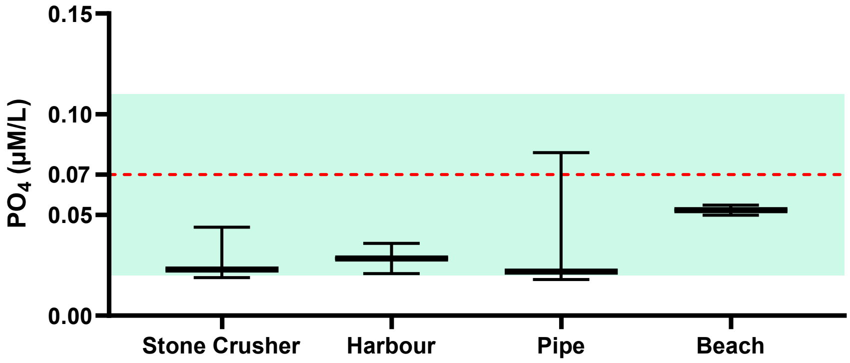

Figure 17 *Disolved inorganic phosphate (PO_4) concentrations in all water samples collected in October 2020 at Saba. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The red dotted line indicates the NEPP threshold level (NEPP 2020). The green field indicates the range of the measured values at the arbitrary reference position 'Blue Ocean' at St. Eustatius.*

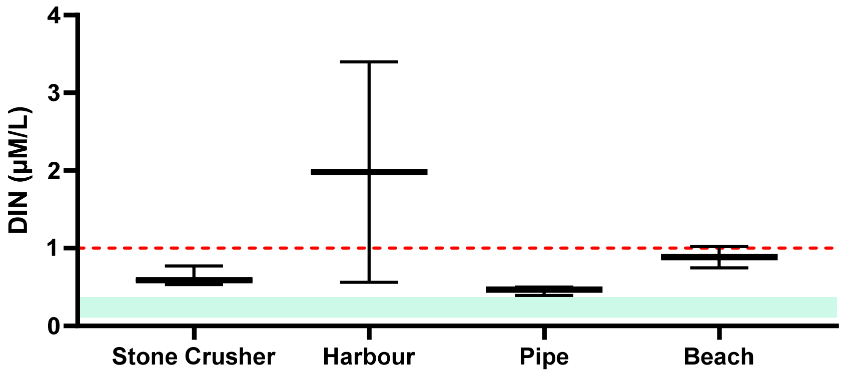

Figure 18 *Total dissolved inorganic nitrogen (DIN) concentrations in all water samples collected in October 2020 at Saba. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The red dotted line indicates the NEPP threshold level (NEPP 2020). The green field indicates the range of the measured values at the arbitrary reference position 'Blue Ocean' at St. Eustatius.*

The N:P ratio of position 'Harbour' is subject to the same doubts. At the other positions the ratio is elevated compared with the arbitrary reference position, but still in the range where nitrogen availability can be expected to limit primary production, according to Slijkerman et al 2013.
The fraction of ammonium in inorganic nitrogen is at all positions close to the arbitrary reference position. Only at position 'Pipe' this ratio seems a bit lower.

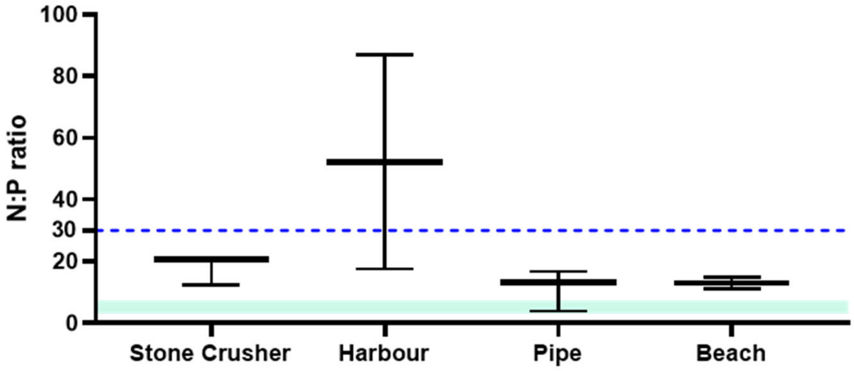

Figure 19 *Inorganic nitrogen (N) : phosphous (P) ratio in all water samples collected in October 2020 at Saba. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. Below the blue dotted line it may be expected that nitrogen becomes the limiting factor for primary production. The green field indicates the range of the measured values at the arbitrary reference position 'Blue Ocean' at St. Eustatius.*

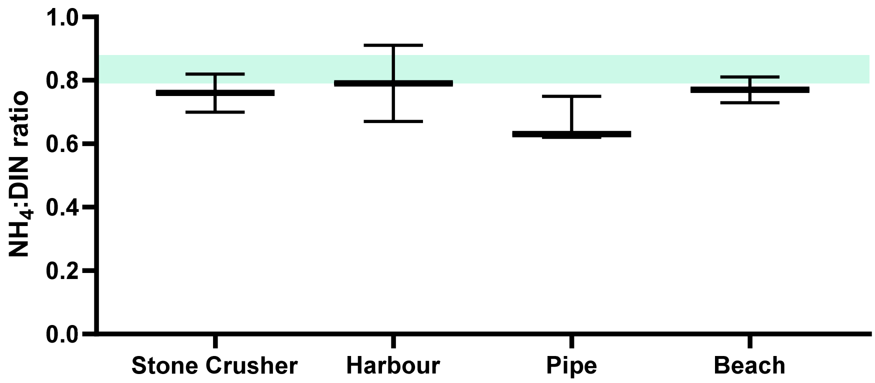

Figure 20 *Fraction ammonium in total inorganic Nitrogen (DIN) in all water samples collected in October 2020 at Saba. Box-Whisker plots show mean as horizontal line, 25-75 percentile as box, and minimum and maximum values as 'error bars'. The green field indicates the range of the measured values at the arbitrary reference position 'Blue Ocean'.*

5 Conclusions and recommendations

5.1 Data evaluation

The dataset presented in this report reveals interesting first insights in the water quality around the Dutch Caribbean islands. Although samples were collected at many positions at especially Bonaire and St. Eustatius, the number of samples per position in general was limited. Extending the dataset in the future will facilitate more in depth data interpretation. It will for instance give more insight if outlying values indicate inhomogeneous water mixing at the sampling locations, or problems with contamination or analyses of the samples.

A general relation between water quality and sampling depth for all positions could not be established, and for individual positions the datasets were too small for such analyses.

Since the dataset did not include a clear reference location, 'Blue Ocean' at St. Eustatius was used as such, as this position was the most remote from any of the Islands. The low nitrogen concentrations with a high proportion of ammonia indeed suggested low external input at this position, this was also the case with the phosphate concentrations in most of the 'Blue Ocean' water samples although in one of the six samples higher concentrations were detected. Due to the small dataset it cannot be concluded that this was a unreliable value. No measurements of TOC and TN were available from this position, thus, no reference concentrations were available for these variables. For future monitoring programs it is advised always to include at least one open ocean location that can serve as a real reference, and to analyse the complete set of variables in the samples from this position.

With the limitations mentioned above in mind, some observations can however already be extracted from the present dataset:

- In general the Bonaire locations showed lower nitrogen and phosphate concentrations in 2020 than during the sampling in 2012/13 by Slijkerman *et al*. This could be the results of reduced tourism due to Covid restrictions in 2020, or indicate a general improvement of water quality. This should become clear with future monitoring. Environmental threshold values for nitrogen and phosphorous were somewhat exceeded in individual Bonaire samples, but none of the positions showed constant exceedance. However, the impact of currents and weather events should be included within the interpretation of such data. Furthermore, a prolonged monitoring will provide the information how often the proposed thresholds have been exceeded to evaluate whether anthropogenic pollution causes a serious health threat to the coastal environment with its coral reef ecosystems.

- In water samples collected at St Eustatius only inorganic nutrients were measured. Samples were included from low land-based anthropogenic impacts, for example, at positions more remote from the shore ('Blue Ocean', 'Flat', 'West Jenkins' and 'West Nustar') to high impacted locations at shallow positions ('Stuco', 'Old Gin House', ' Scubaqua' and 'Harbour'). This impact was most clearly indicated by the low fraction of NH_4 in DIN, most likely the result of influx of land-based nitrogen in the form of nitrate. At several positions this influx seemed related to the moment of sampling with substantially higher nitrate concentrations in December than in October. This could be related to differences in weather conditions and/or land use between the moments of sampling, but within the scope of this report such more in-depth analyses of the data were not performed.

- At Saba no evident indications were found for negatively affected water quality, however the dataset was very limited, and covered only a small part of the coast line.

- The available dataset suggests that especially the NH4-DIN ratio could be a good indicator of a disturbed nutrient balance in the coastal water.

5.2 Recommendations for future monitoring

5.2.1 Technical recommendations

First of all it is essential that a clear and workable protocol for sampling, storage, transport and analyses is being prepared for the individual islands and strictly followed. Particularly, this protocol should emphasize on correct sample labelling. This is best done by giving each sample as unique code that refers to location, depth, moment of sampling (date, time), whether it is a pure or filtered sample, and if it is a replicate sample.

Sampling positions are now only described as the main position and the water depth where the sample was collected. It is advised to bring a field GPS during sampling and to mark the exact positions where each sample was collected as well.

5.2.2 Future monitoring recommendations

The dataset of the 2020 sampling campaign holds no indication that water quality is strongly related to water depth. However, the dataset is not solid enough to conclude that the water column is homogenously mixed. It is therefore recommended to continue the sampling at these depths for a few years, and then to evaluate the necessity for each individual position.

Also to identify a temporal impact on the pollution concentrations need to be further evaluated with a more extended sampling strategy. In addition data should be collected about the weather conditions, especially rainfall, and incorporated during data analysis.

To allow good comparison between locations it is advised that a set of variables is selected that will be analysed in all samples that are being collected, including at least one open ocean reference location. For the selection of the set of variables Foekema et al 2021 can be used as guidance.

It is recommended that the parties involved in this and future monitoring projects in the Dutch Caribbean decide on central storage of the collected (raw) data, both with respect to place and format.

After a relatively long and unsuccessful search for an appropriate (more) local laboratory, it was decided to ship the samples to the Netherlands for the nutrient analyses. Shipping frozen samples always holds the risk of loss of quality, especially when traveling takes longer than expected. For future more regular monitoring the option could be considered to build local analytical capacity for these samples, the minimum requirement however is that at each island facilities are available that allow proper pre-treatment and storage of samples so that no quality is lost during storage. Such a facility should at least include freezers, drying ovens, and appropriate storage room for preservation liquids.

5.2.3 Future reporting recommendations

In this report the interpretation of the dataset was restricted as well as the visualisation of the results. For future reports it is recommended that monitoring data are presented in maps per island showing the values per sampling position. When, in the future, the volume of the datasets allows statistical models can be used to explore relationships between different variables.

6 References

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STINAPA -Francisca R.L.- (2021): Veldrapport water monstering voor nulmeting waterkwaliteit Bonaire. STINAPA report number: 202101-01

7 Quality Assurance

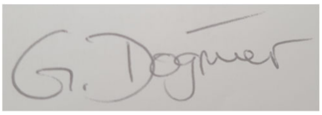
Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

Justification

Report C026/22
Project Number: 431 51001 60

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: G Dogruer
Researcher

Signature: 

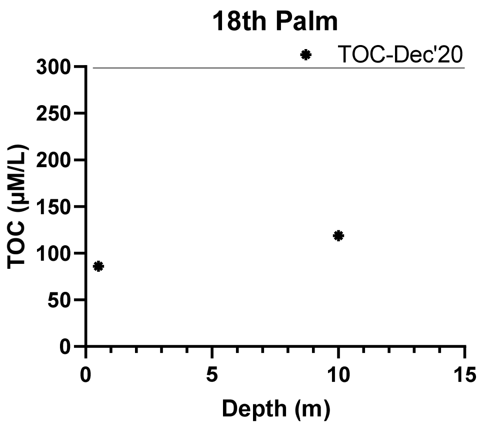
Date: 19 May 2022

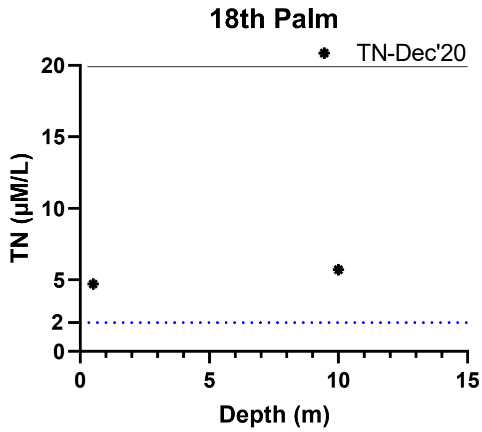
Approved: drs. J Asjes
Manager integration

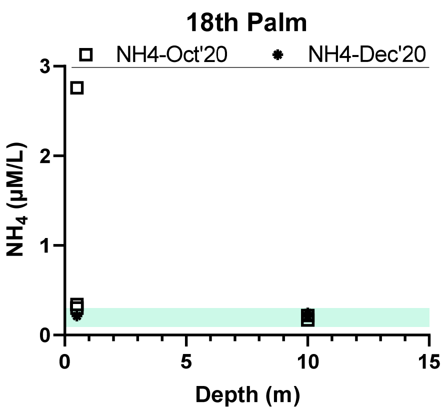
Signature: 

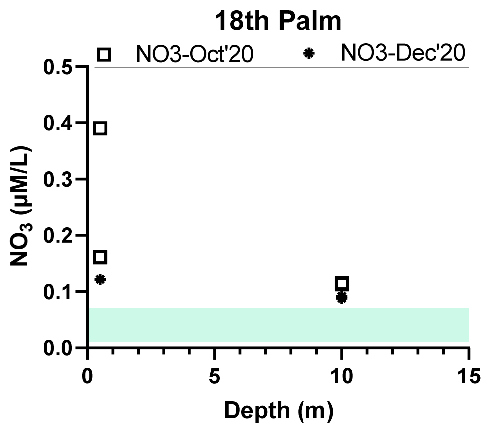
Date: 19 May 2022

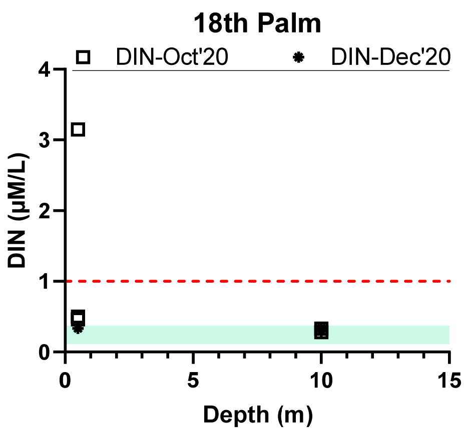
ANNEX 1: Individual datapoints Bonaire

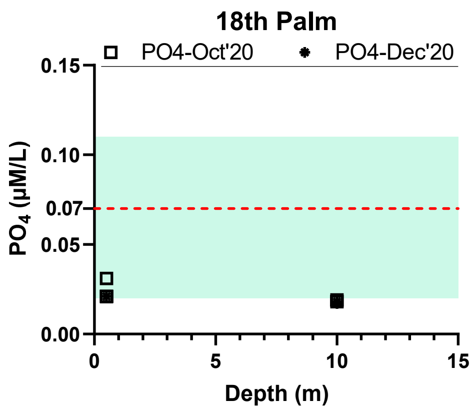


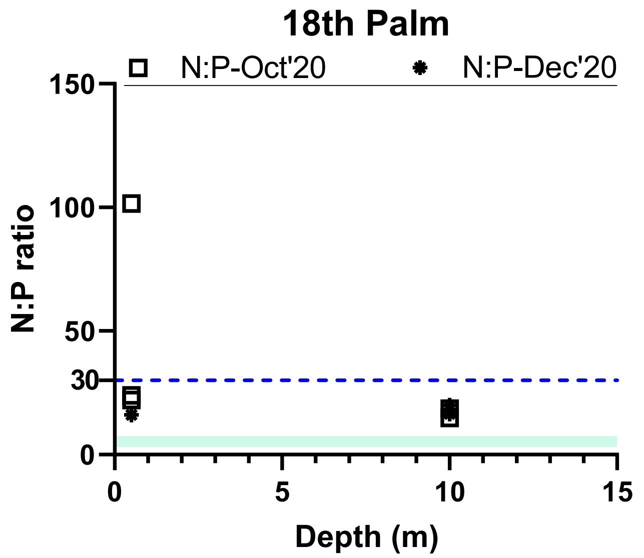








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N:P-Dec'20
N:P ratio
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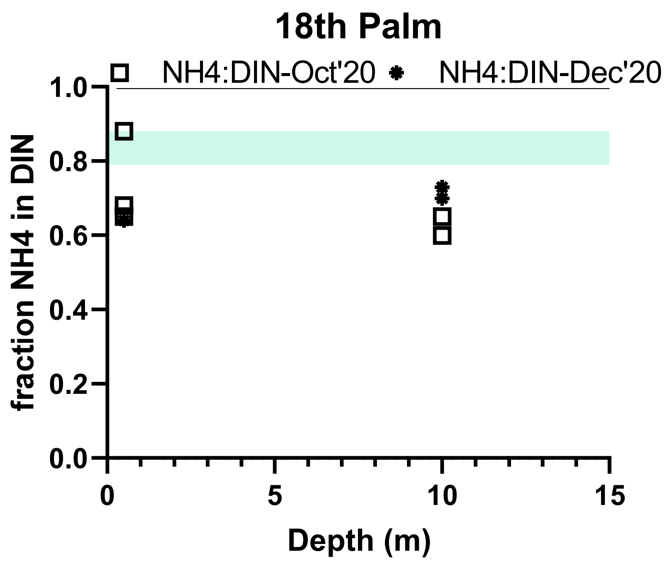
100
50
30
0
0
5
10
15
Depth (m)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NH4:DIN-Dec'20
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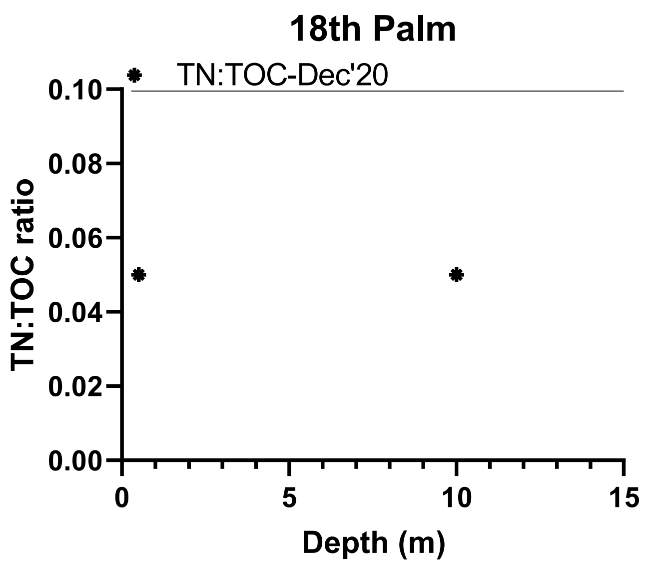
5
10
15
Depth (m)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0.00
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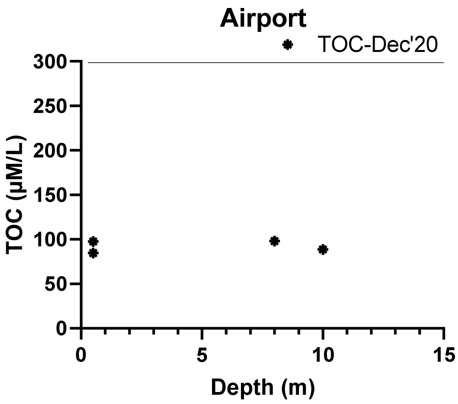
5
10
15
Depth (m)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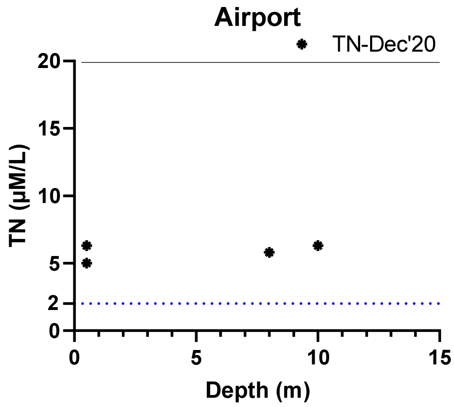
Depth (m)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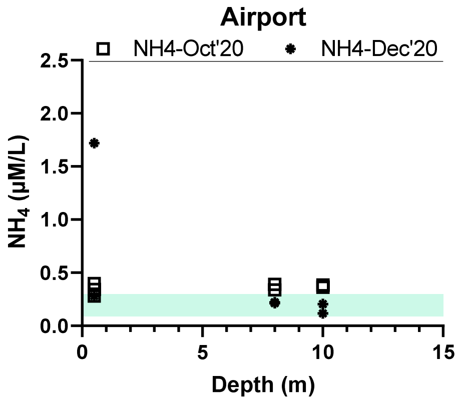
Depth (m)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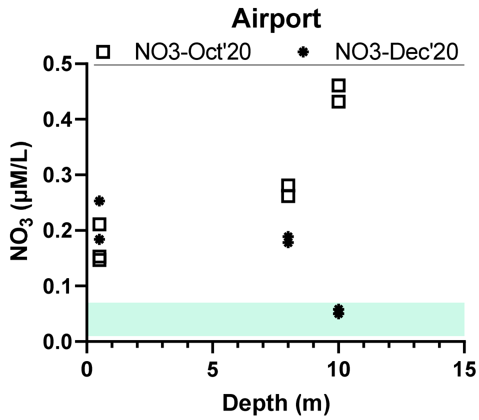
0
5
10
15
Depth (m)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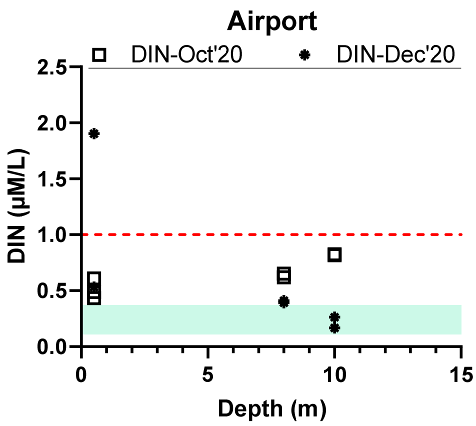
5
10
15
Depth (m)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5
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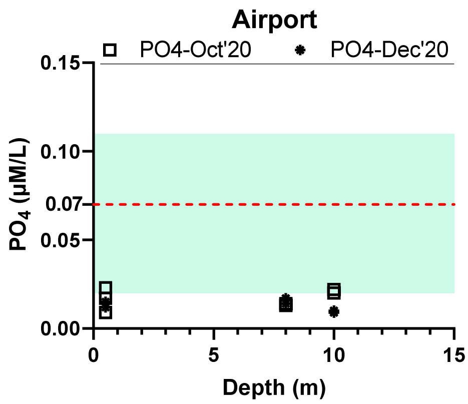
Depth (m)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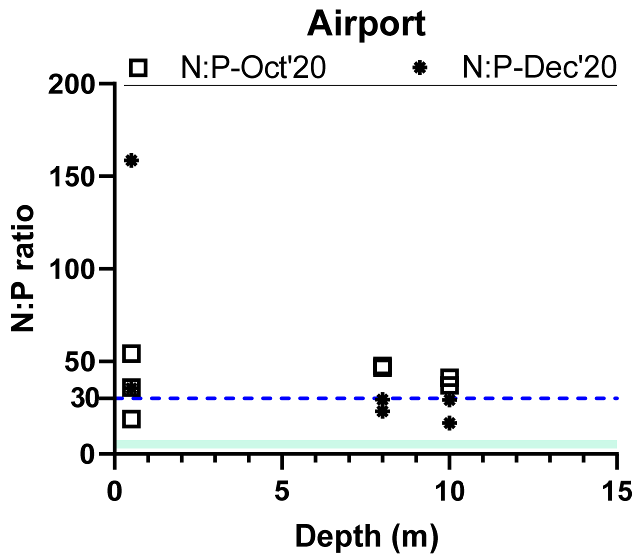
Depth (m)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N:P-Dec'20
N:P ratio
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100
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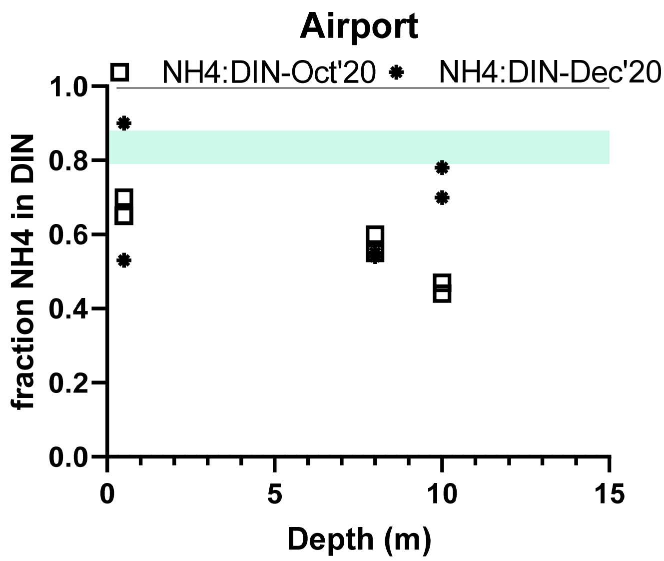
0
5
10
15
Depth (m)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NH4:DIN-Dec'20
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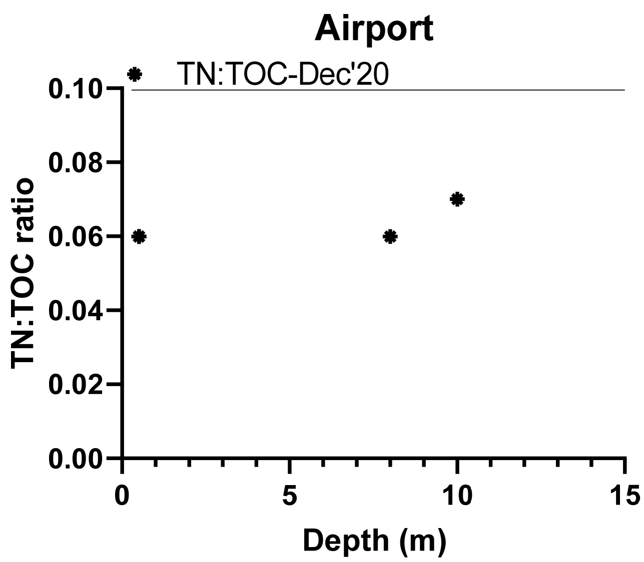
Depth (m)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TN:TOC ratio
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0.00
0
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10
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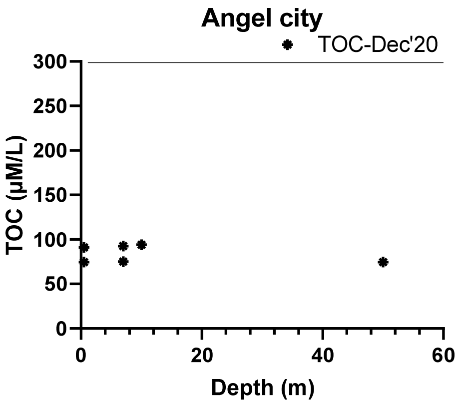
Depth (m)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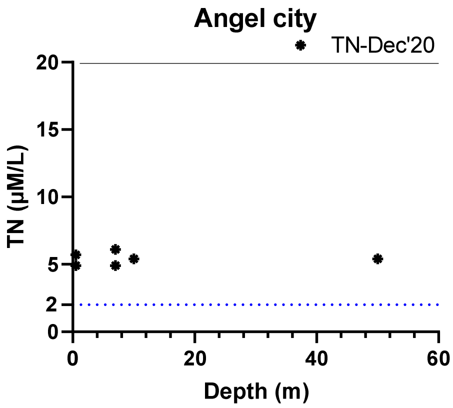
Depth (m)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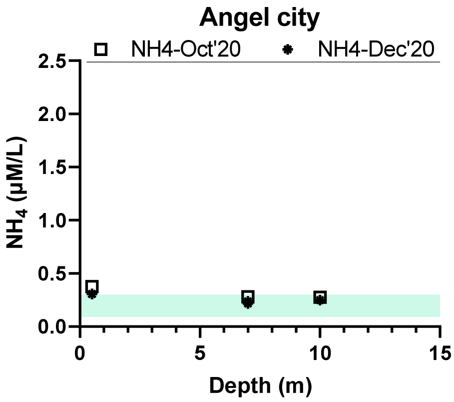
Depth (m)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NH4-Dec'20
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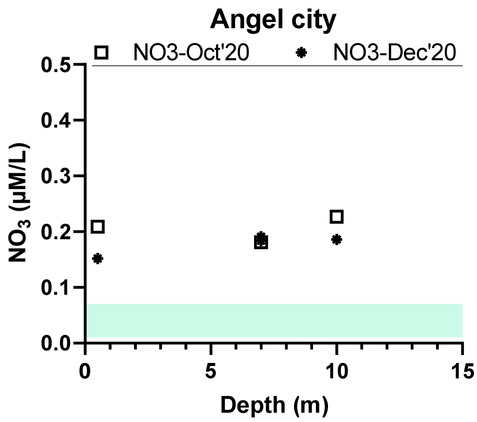
0
5
10
15
Depth (m)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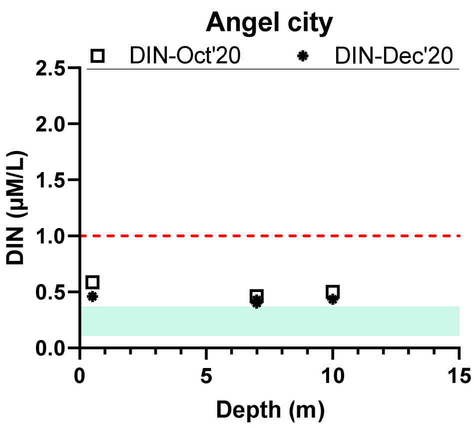
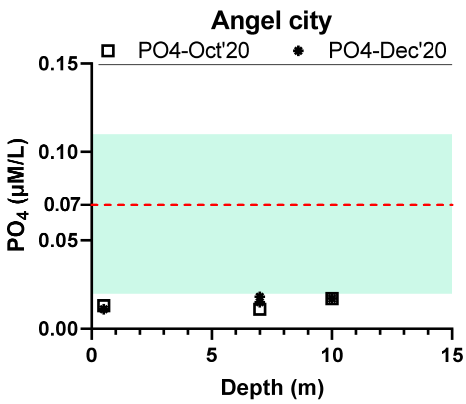
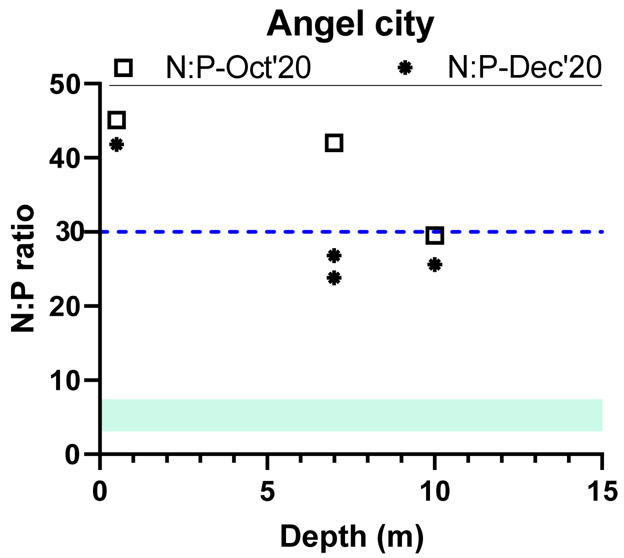
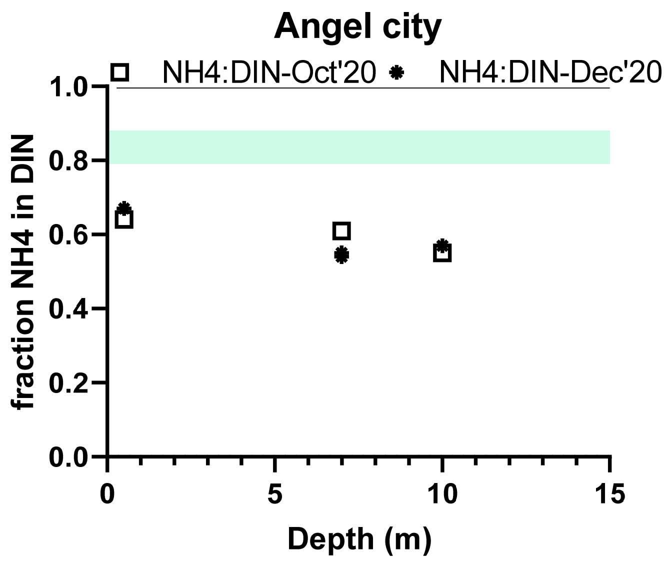
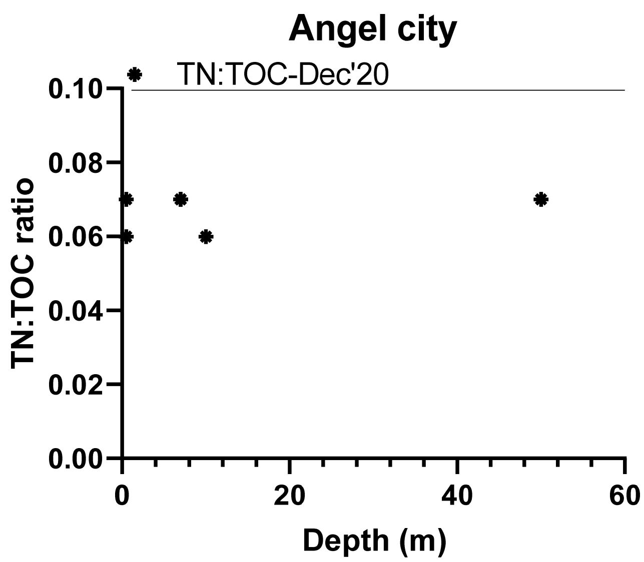
5
10
15
Depth (m)

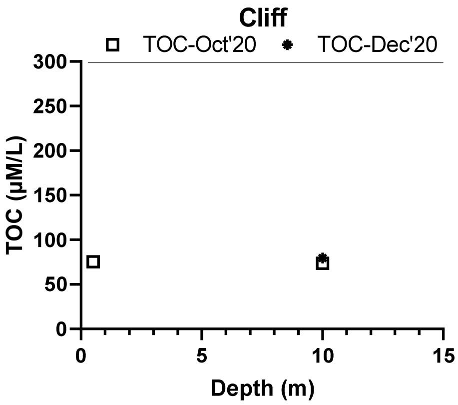

Angel city
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

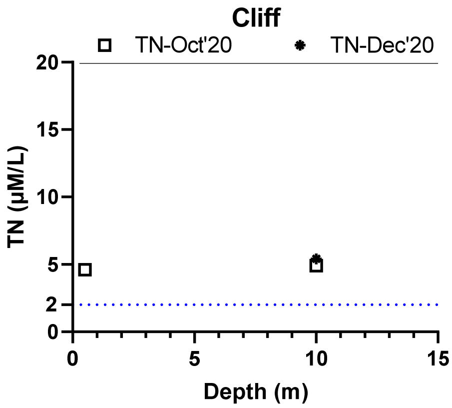

Angel city
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

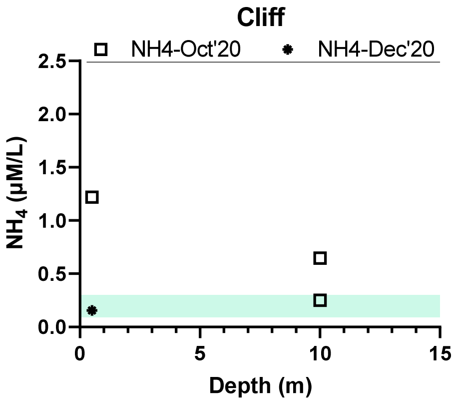

Angel city
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

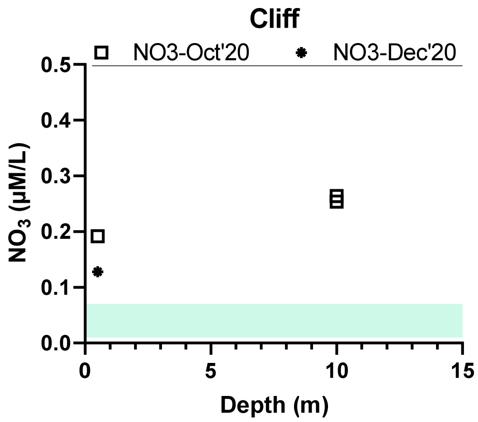

Angel city
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

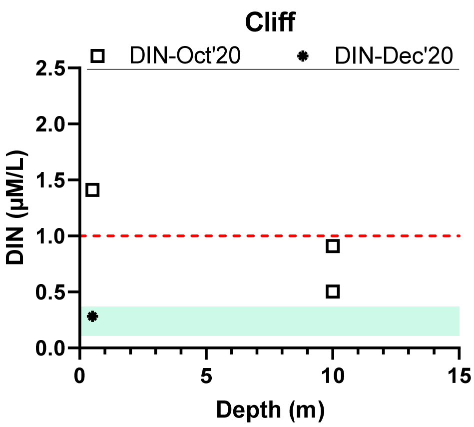

Angel city
TN:TOC-Dec'20
TN:TOC ratio
Depth (m)

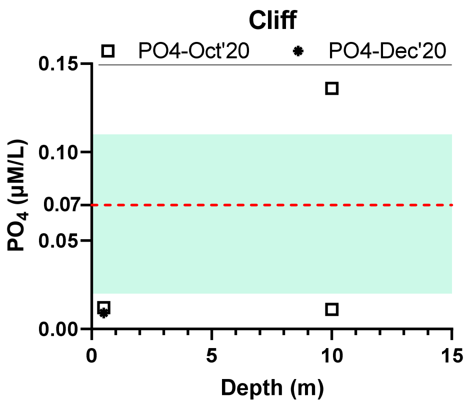

Cliff
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)

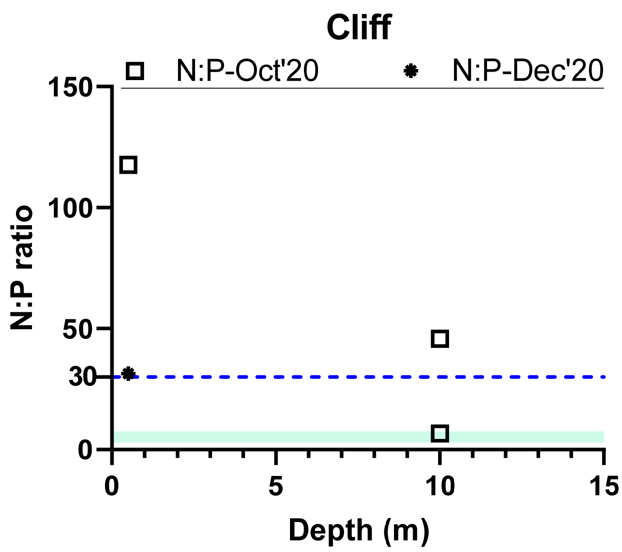

Cliff
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)

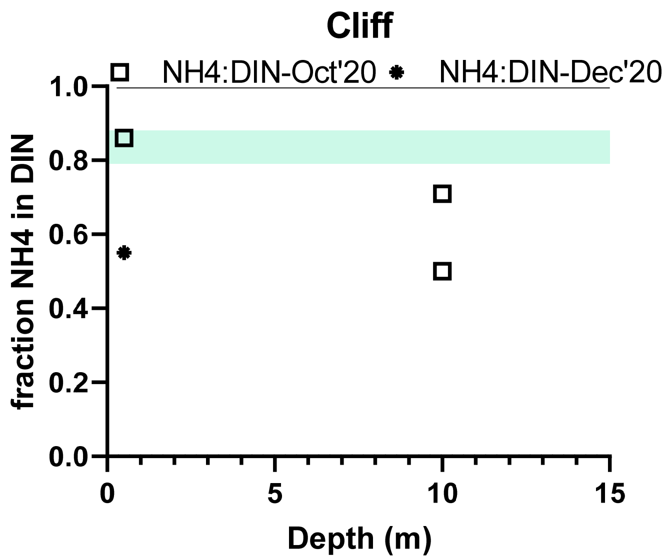

Cliff
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

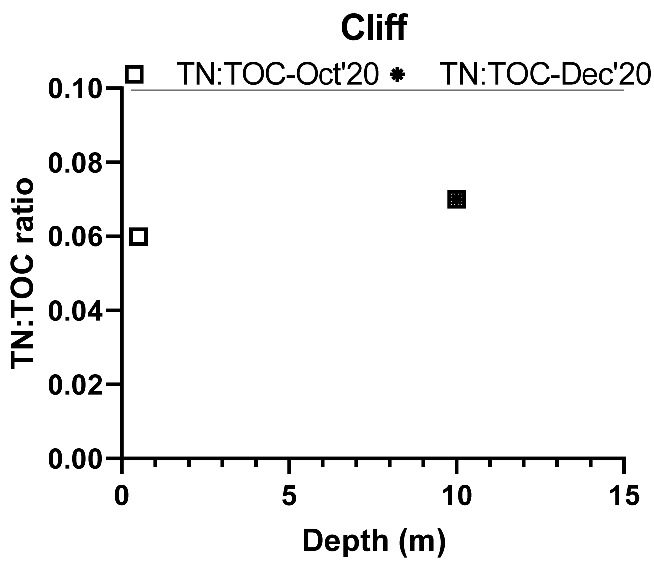

Cliff
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

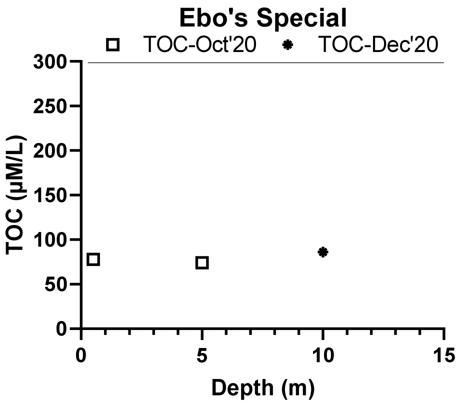

Cliff
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

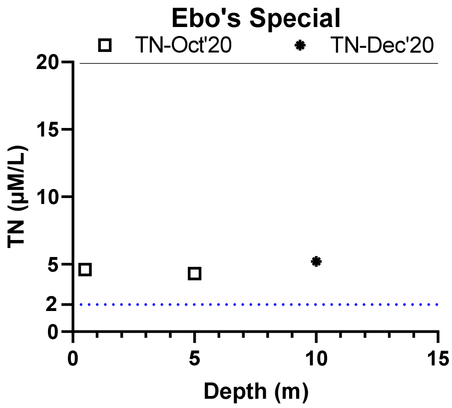

Cliff
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

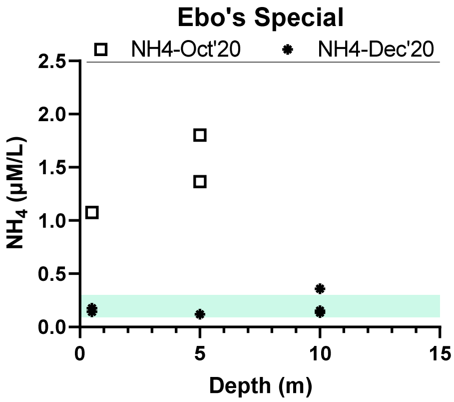

Cliff
N:P-Oct'20
N:P-Dec'20
N:P ratio
150
100
50
30
0
0
5
10
15
Depth (m)

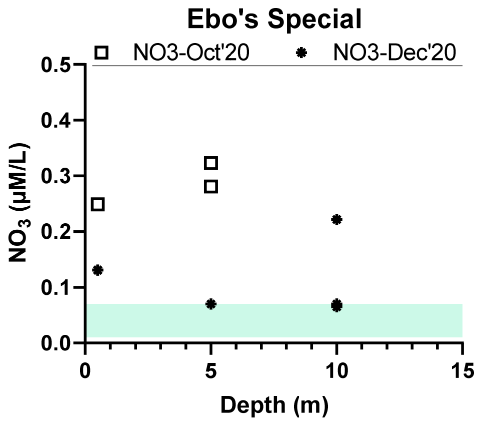

Cliff
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

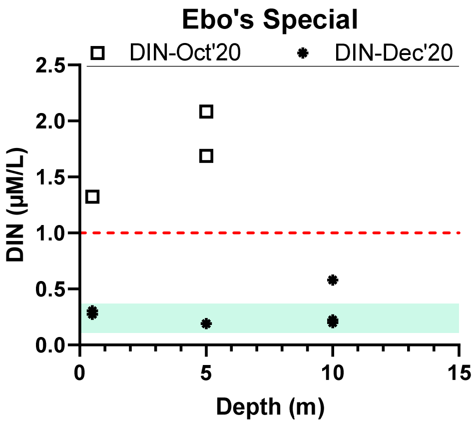

Cliff
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
Depth (m)

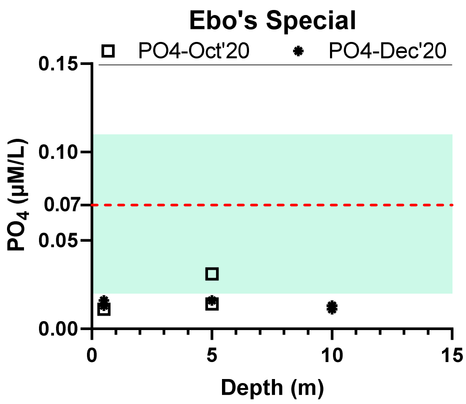

Ebo's Special
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)
0
50
100
150
200
250
300
0
5
10
15

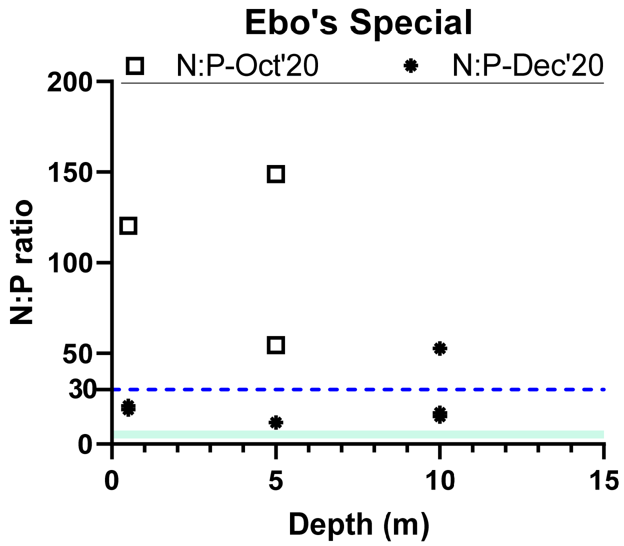

Ebo's Special
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)
0
2
5
10
15
20
0
5
10
15

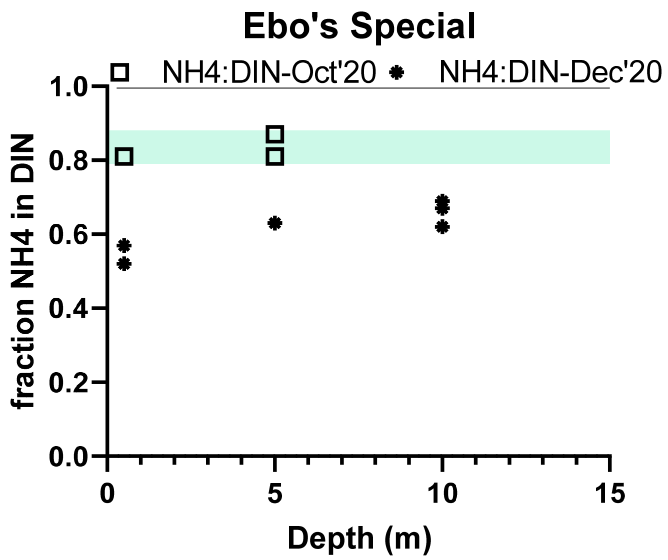

Ebo's Special
NH4-Oct'20
NH4-Dec'20
NH_4 (µM/L)
Depth (m)
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15

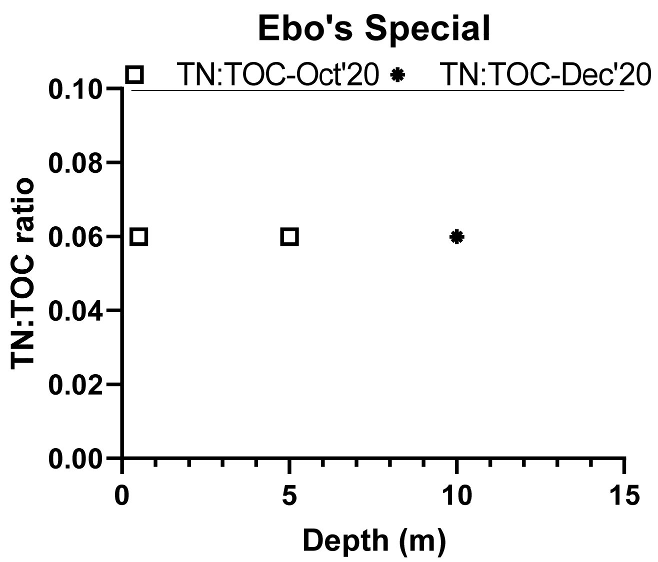

Ebo's Special
NO3-Oct'20
NO3-Dec'20
NO_3 (µM/L)
Depth (m)
0.0
0.1
0.2
0.3
0.4
0.5
0
5
10
15

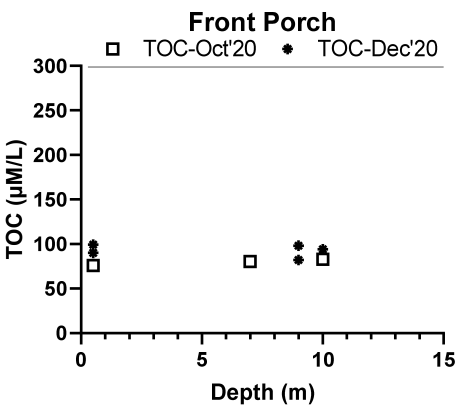

Ebo's Special
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15

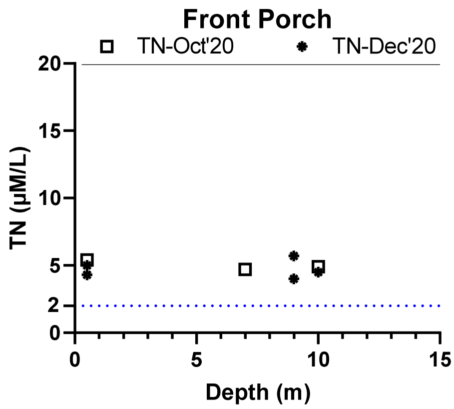

Ebo's Special
PO4-Oct'20
PO4-Dec'20
PO_4 (µM/L)
Depth (m)
0.00
0.05
0.07
0.10
0.15
0
5
10
15

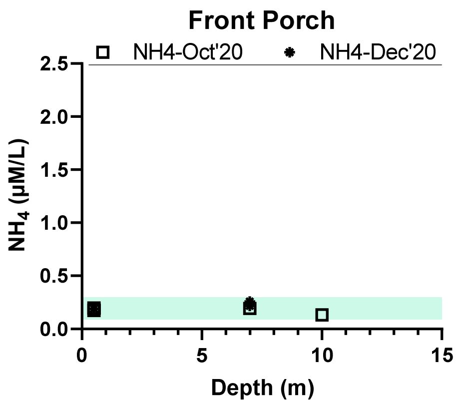

Ebo's Special
N:P-Oct'20
N:P-Dec'20
N:P ratio
200
150
100
50
30
0
0
5
10
15
Depth (m)

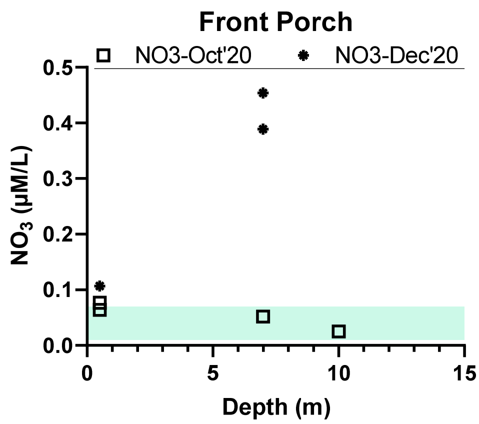

Ebo's Special
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

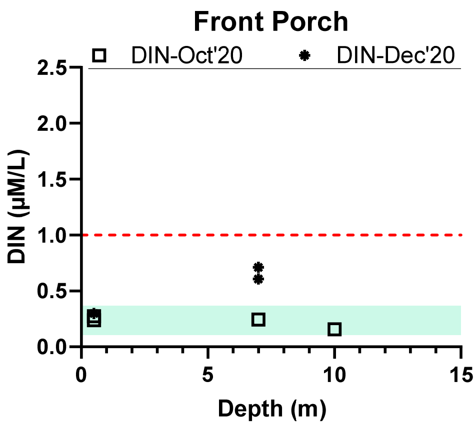

Ebo's Special
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
Depth (m)

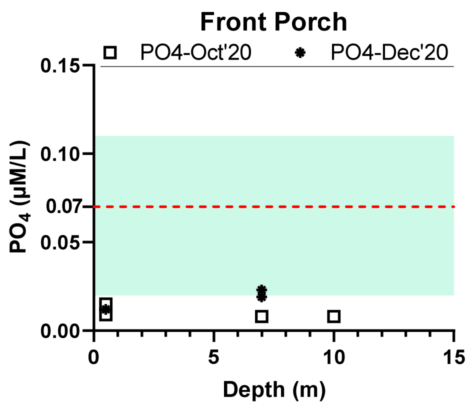

Front Porch
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)

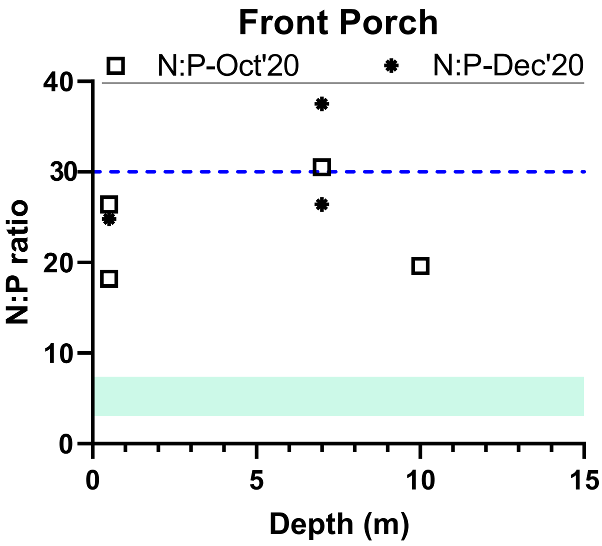

Front Porch
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)

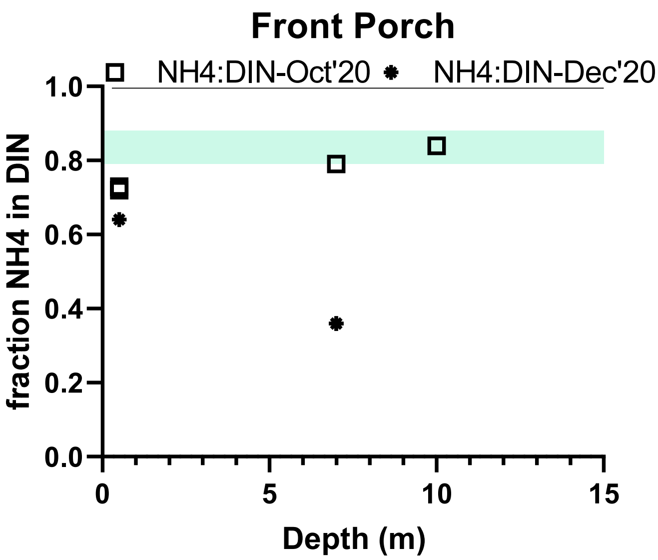

Front Porch
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

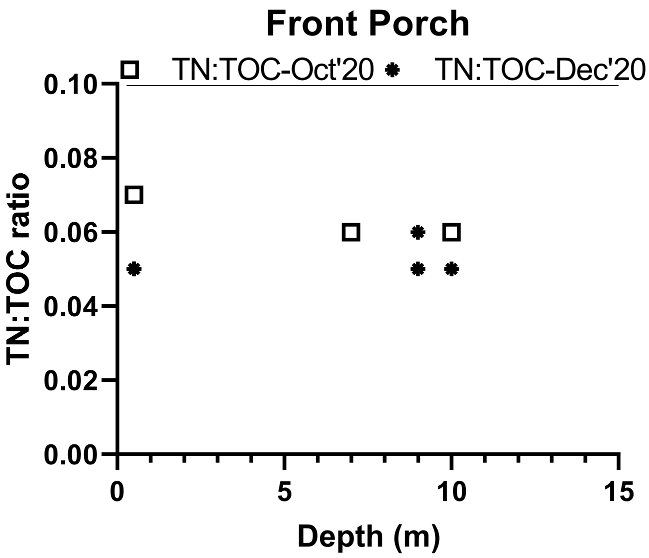

Front Porch
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

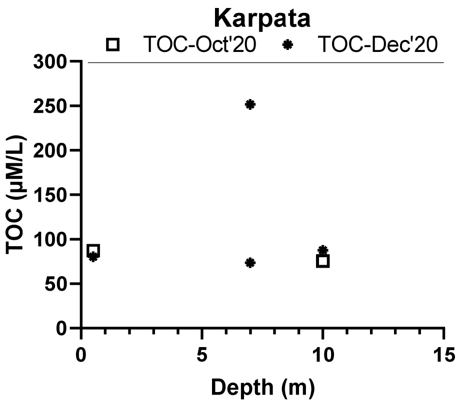

Front Porch
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

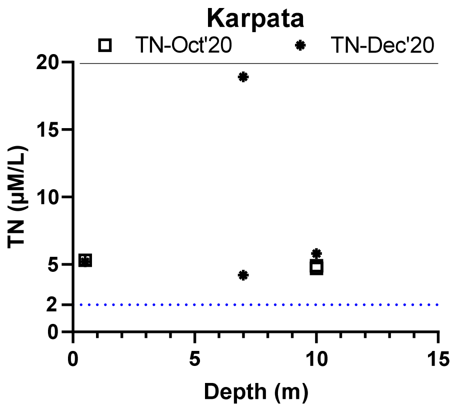

Front Porch
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

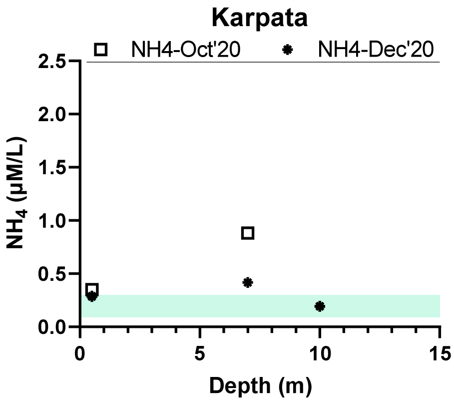

Front Porch
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)
0
10
20
30
40
0
5
10
15

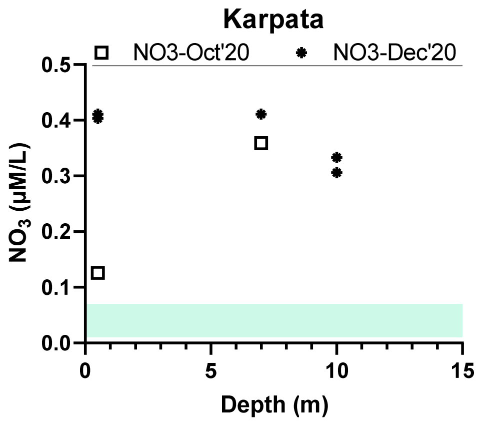

Front Porch
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15

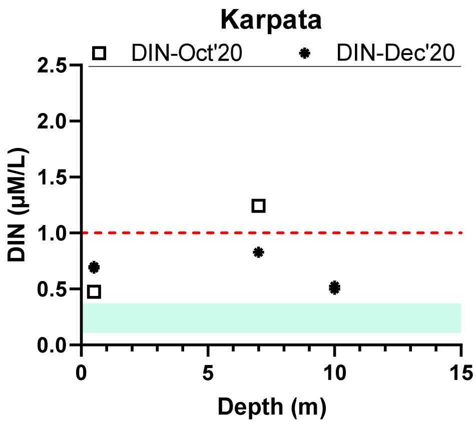

Front Porch
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
Depth (m)
0.00
0.02
0.04
0.06
0.08
0.10
0
5
10
15

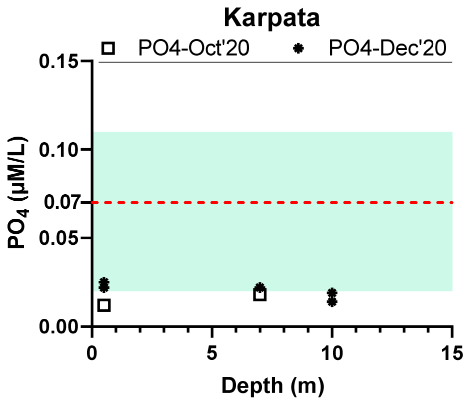

Karpata
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)

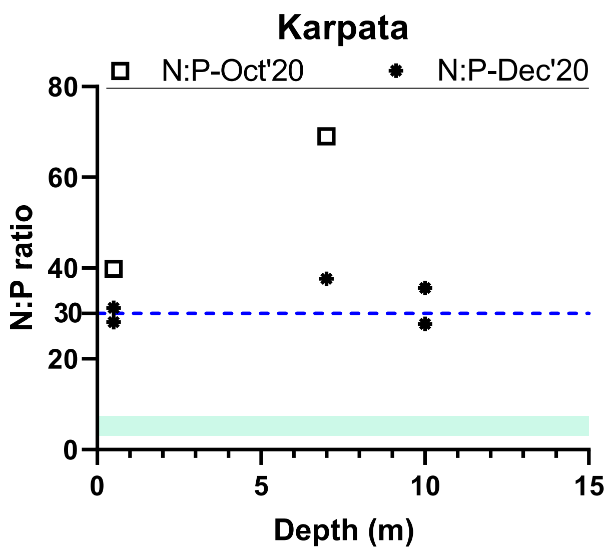

Karpata
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)

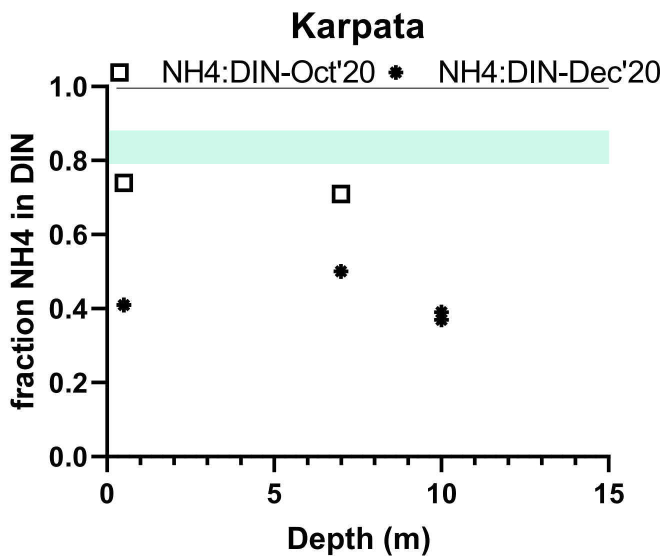

Karpata
NH4-Oct'20
NH4-Dec'20
NH_4 (µM/L)
Depth (m)

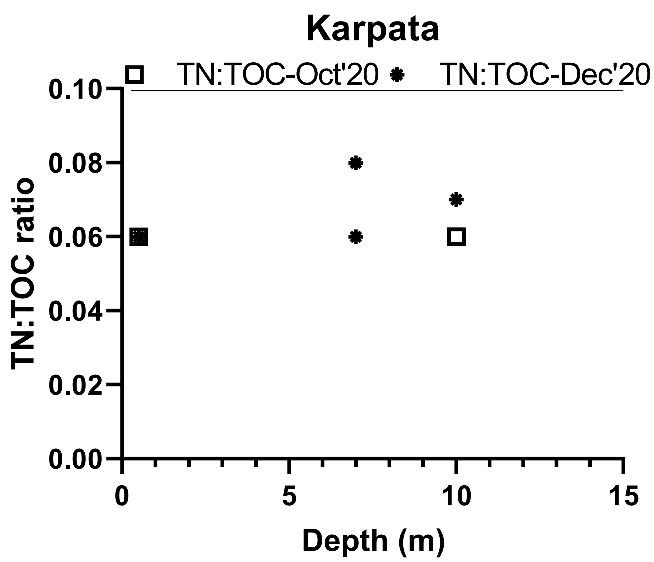

Karpata
NO3-Oct'20
NO3-Dec'20
NO_3 (µM/L)
Depth (m)

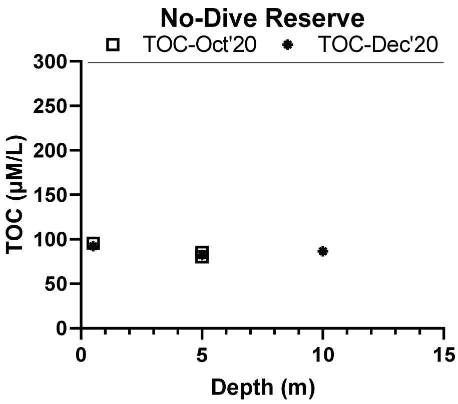

Karpata
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

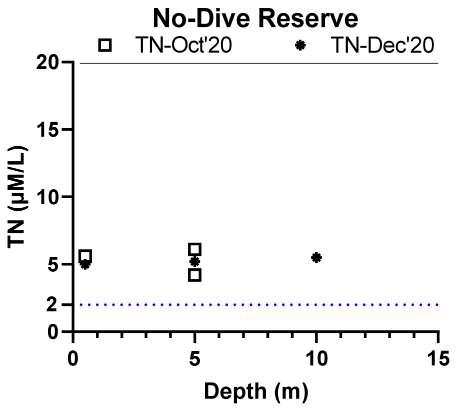

Karpata
PO4-Oct'20
PO4-Dec'20
PO_4 (µM/L)
Depth (m)

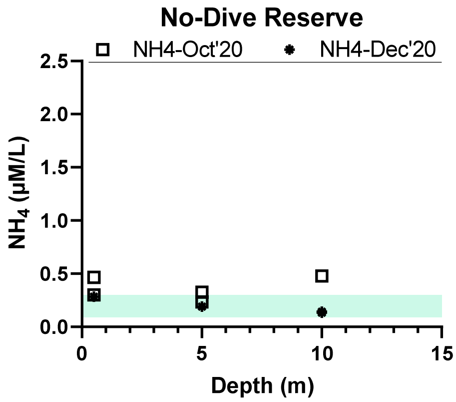

Karpata
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

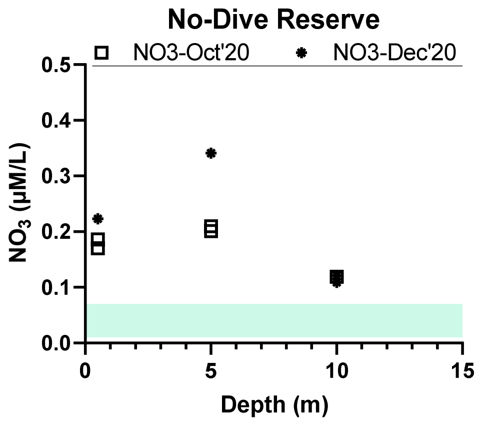

Karpata
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

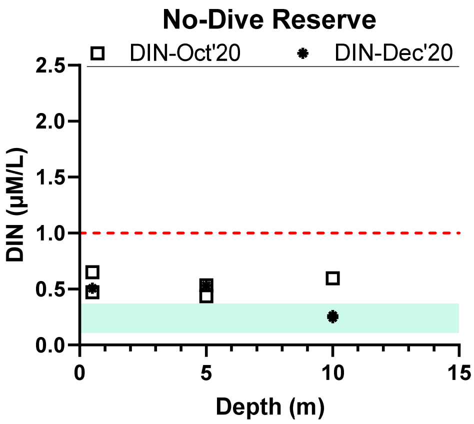

Karpata
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
Depth (m)

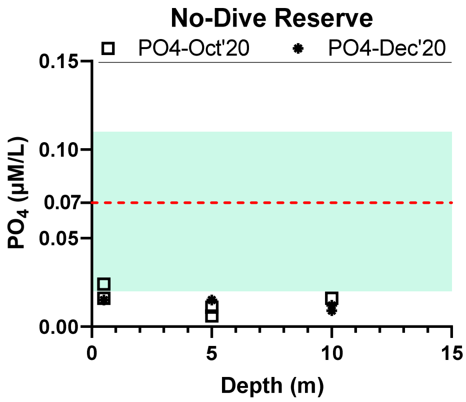

No-Dive Reserve
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)

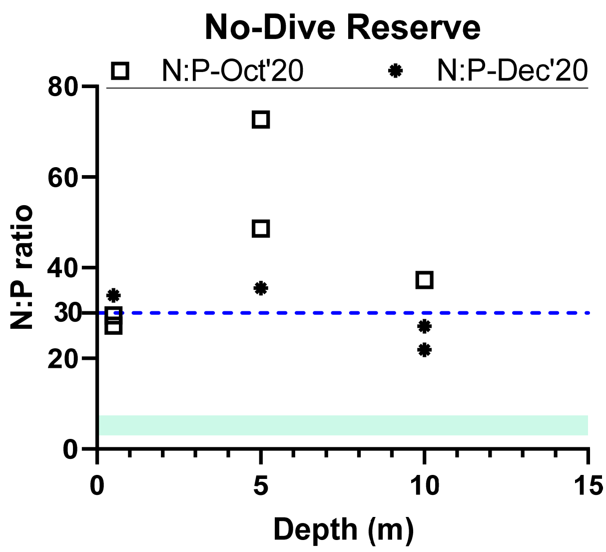

No-Dive Reserve
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)

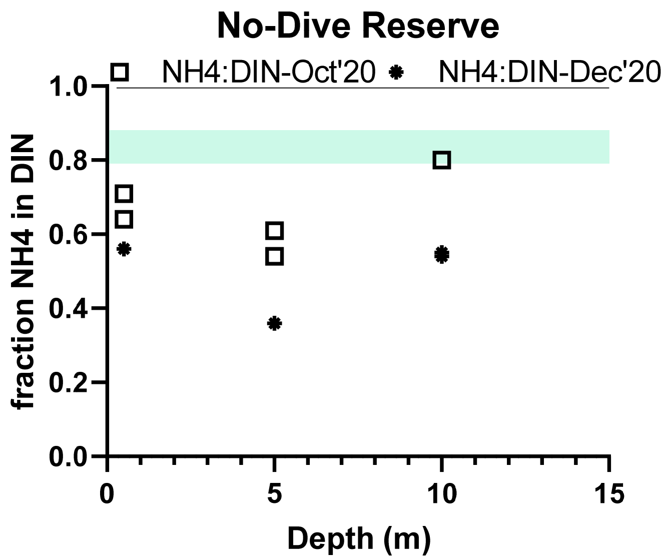

No-Dive Reserve
NH4-Oct'20
NH4-Dec'20
NH_4 (µM/L)
Depth (m)

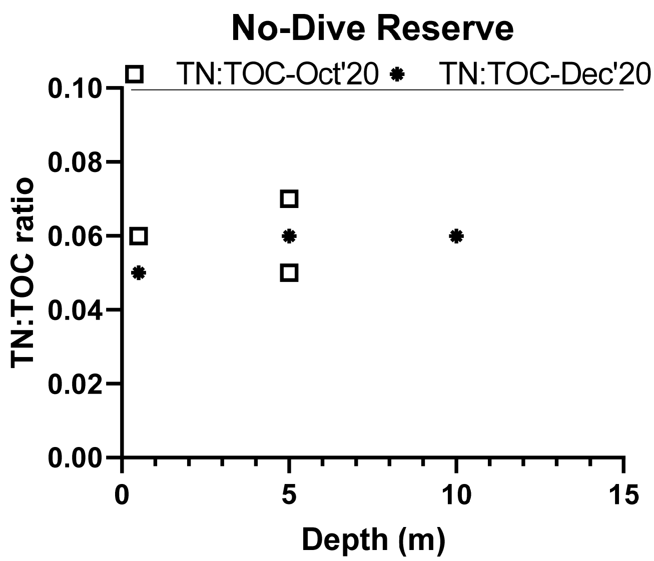

No-Dive Reserve
NO3-Oct'20
NO3-Dec'20
NO_3 (µM/L)
Depth (m)

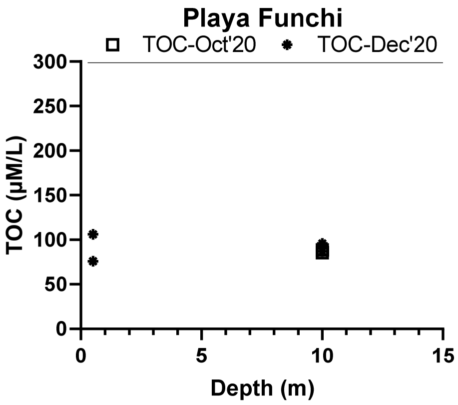

No-Dive Reserve
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

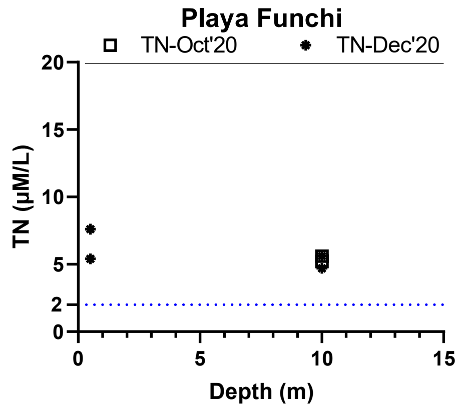

No-Dive Reserve
PO4-Oct'20
PO4-Dec'20
PO_4 (µM/L)
Depth (m)

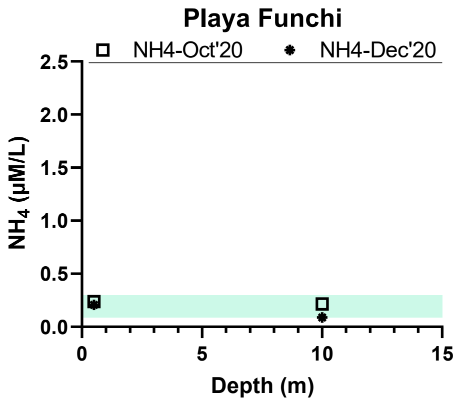

No-Dive Reserve
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

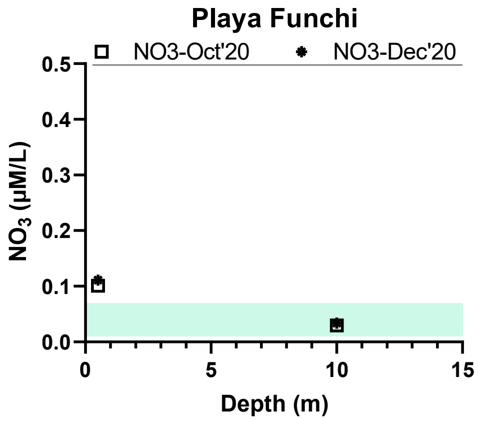

No-Dive Reserve
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

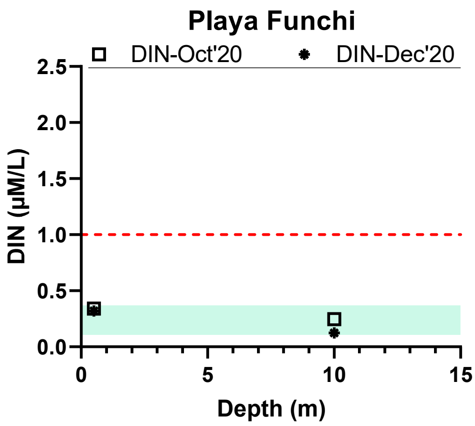

No-Dive Reserve
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
Depth (m)

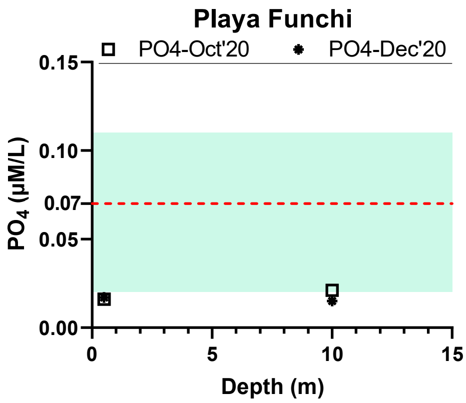

Playa Funchi
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)

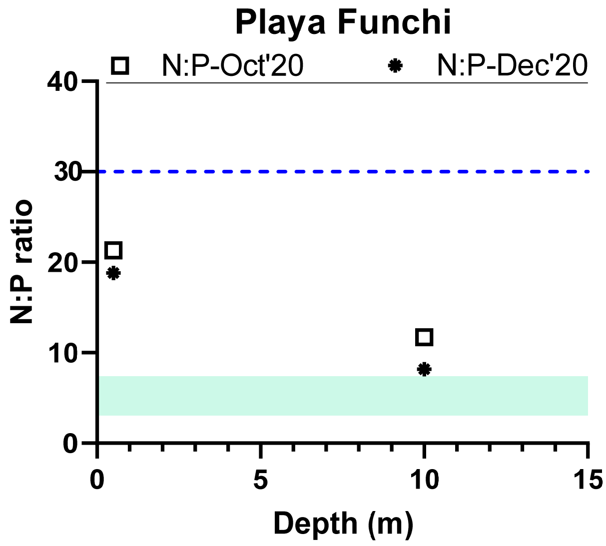

Playa Funchi
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)

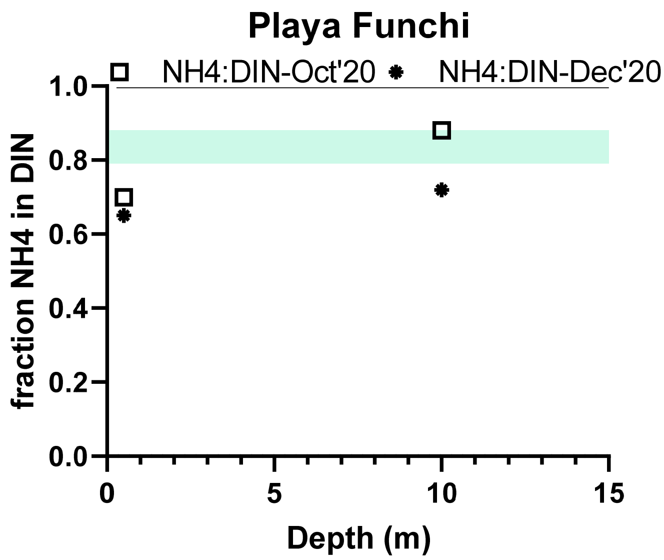

Playa Funchi
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

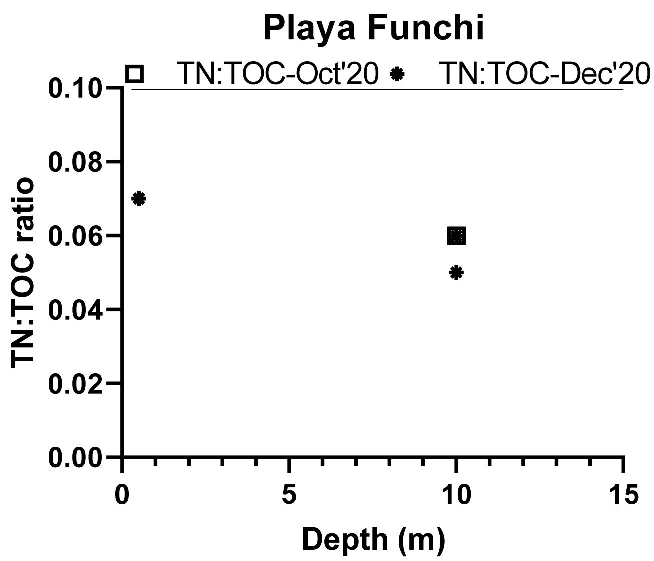

Playa Funchi
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

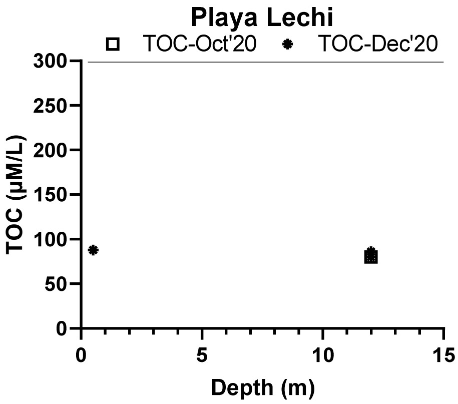

Playa Funchi
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

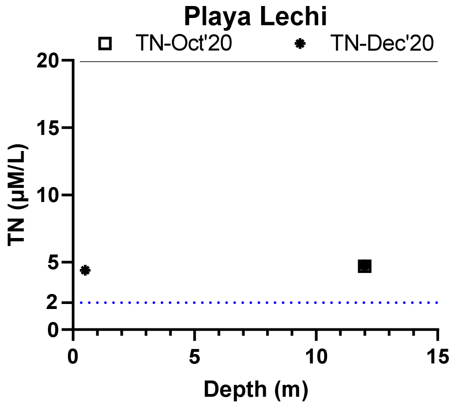

Playa Funchi
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

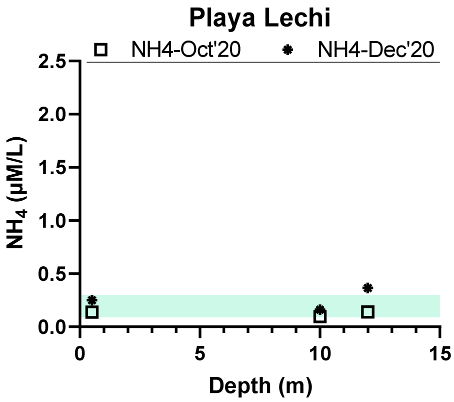

Playa Funchi
N:P-Oct'20
N:P-Dec'20
N:P ratio
40
30
20
10
0
0
5
10
15
Depth (m)

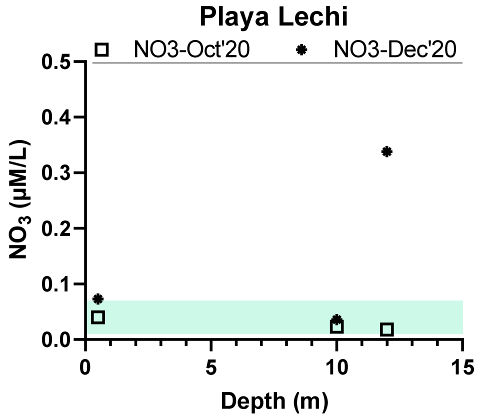

Playa Funchi
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

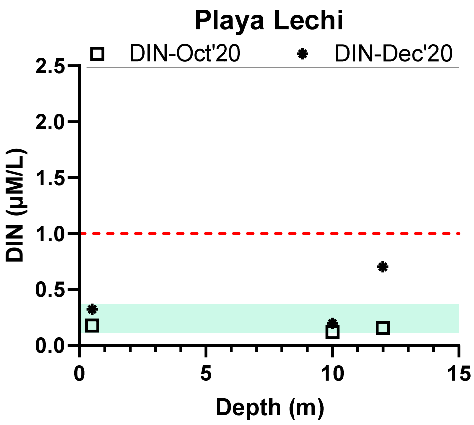

Playa Funchi
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
Depth (m)

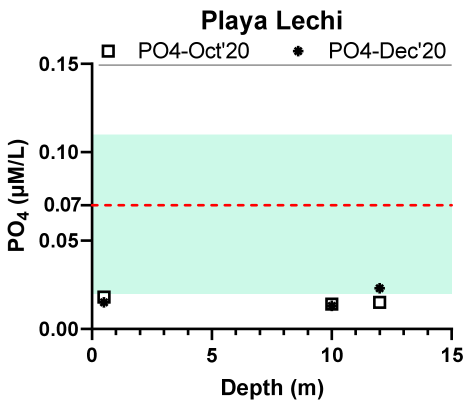

Playa Lechi
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)

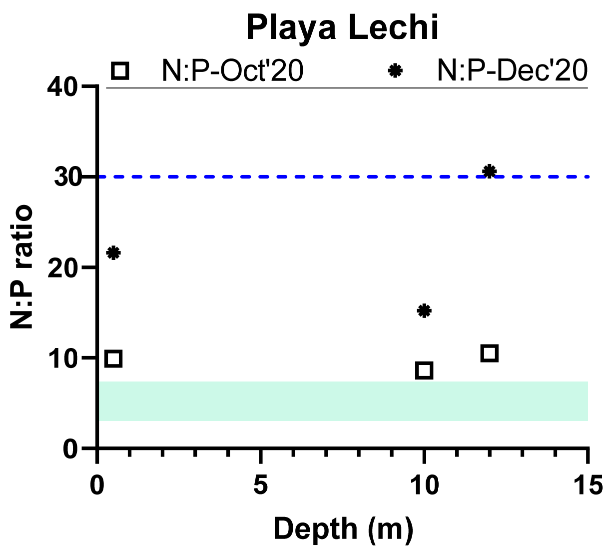

Playa Lechi
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)

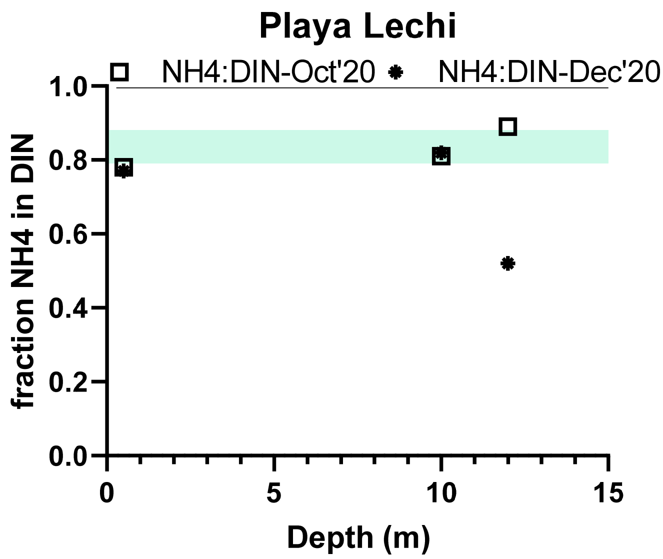

Playa Lechi
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

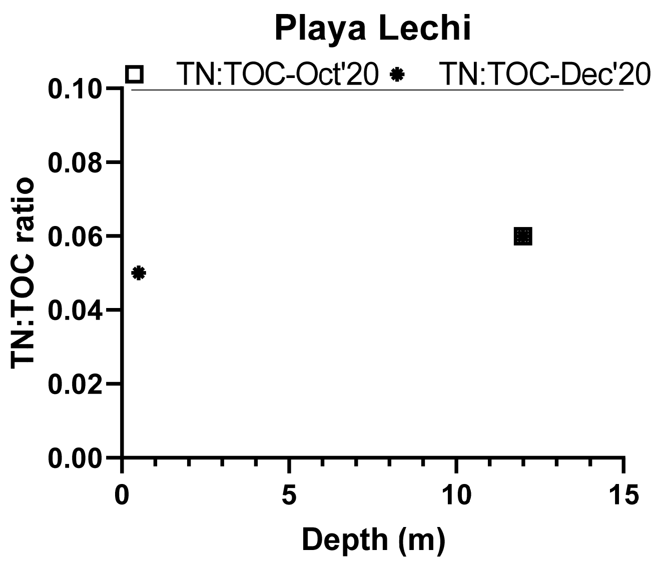

Playa Lechi
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

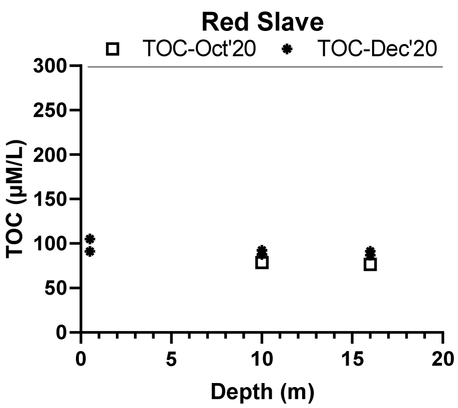

Playa Lechi
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

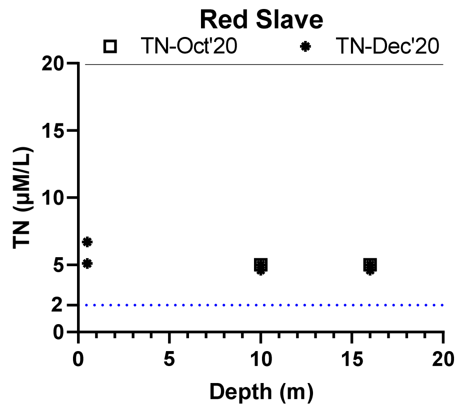

Playa Lechi
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

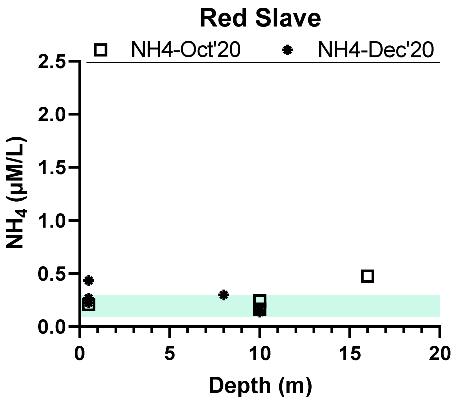

Playa Lechi
N:P-Oct'20
N:P-Dec'20
40
30
20
10
0
N:P ratio
0
5
10
15
Depth (m)

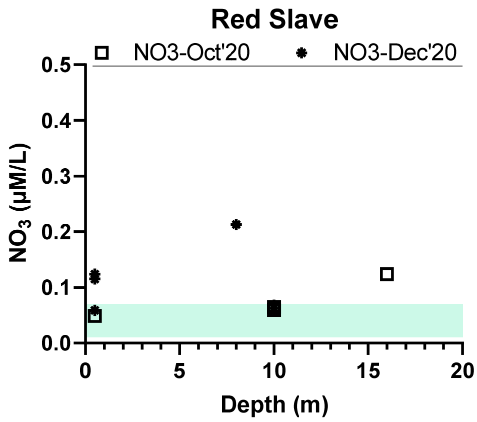

Playa Lechi
NH4:DIN-Oct'20
NH4:DIN-Dec'20
1.0
0.8
0.6
0.4
0.2
0.0
fraction NH4 in DIN
0
5
10
15
Depth (m)

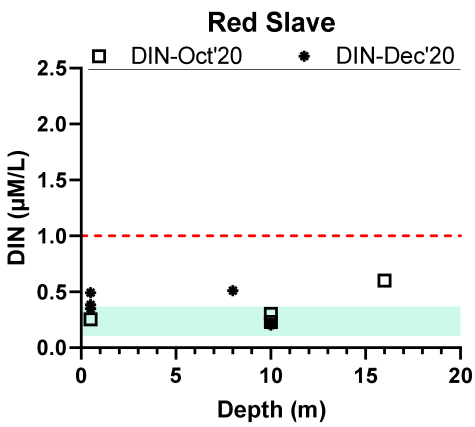

Playa Lechi
TN:TOC-Oct'20
TN:TOC-Dec'20
0.10
0.08
0.06
0.04
0.02
0.00
TN:TOC ratio
0
5
10
15
Depth (m)

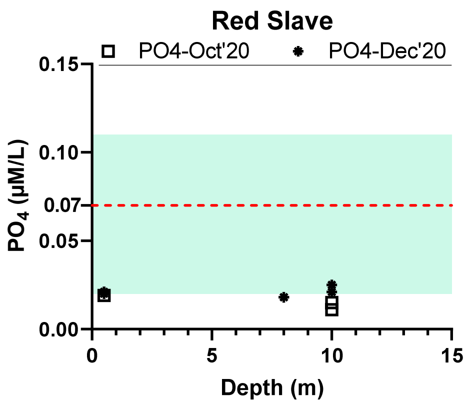

Red Slave
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
Depth (m)

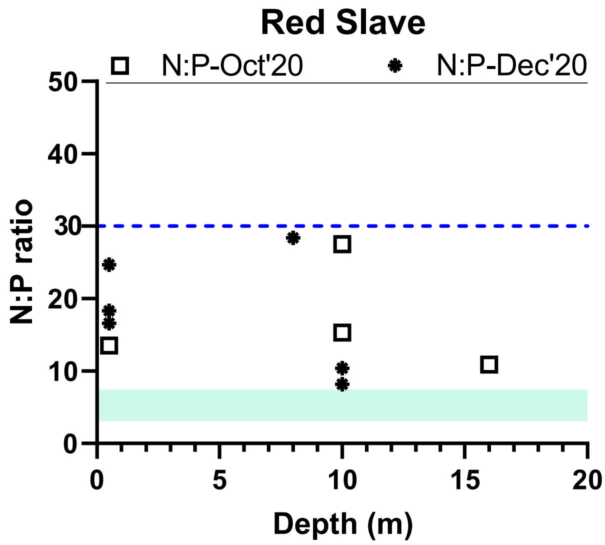

Red Slave
TN-Oct'20
TN-Dec'20
TN (µM/L)
Depth (m)

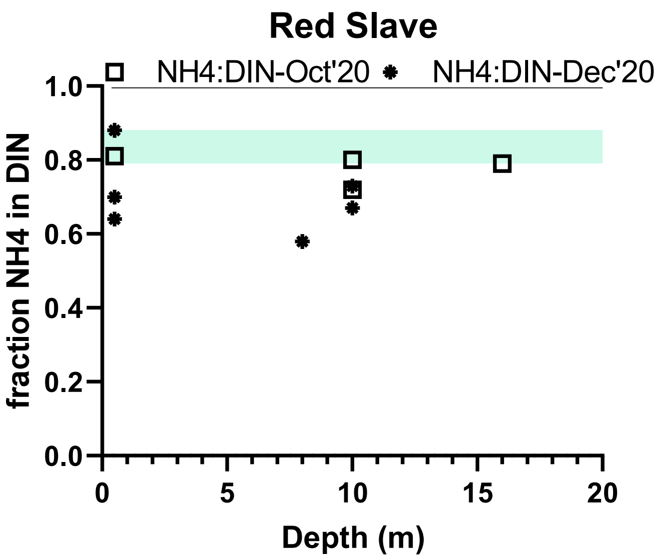

Red Slave
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

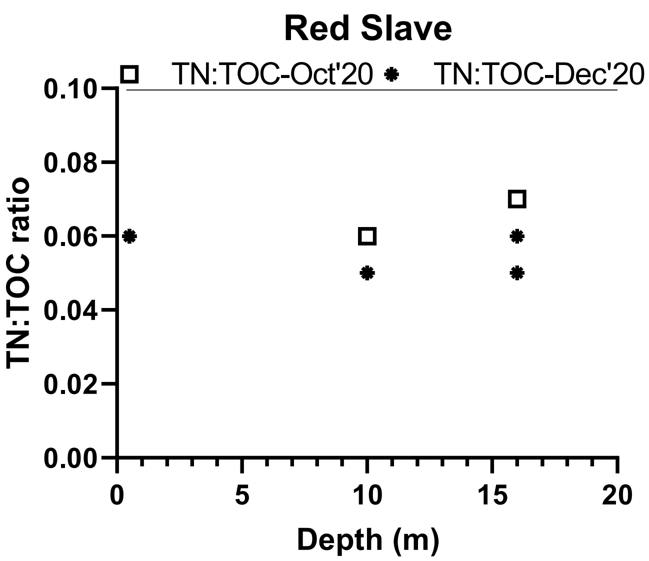

Red Slave
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

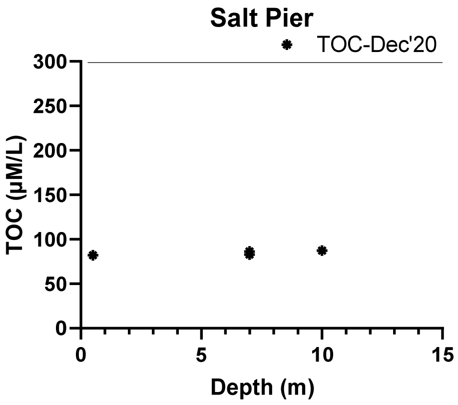

Red Slave
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)


Red Slave
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

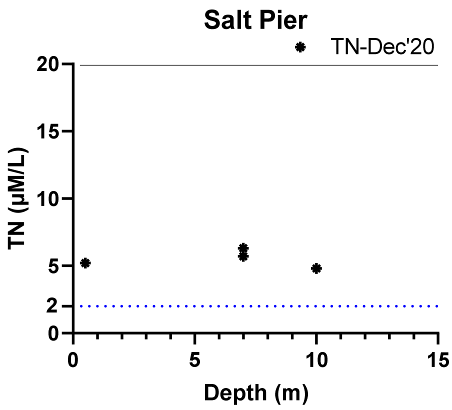

Red Slave
N:P-Oct'20
N:P-Dec'20
N:P ratio
50
40
30
20
10
0
0
5
10
15
20
Depth (m)


Red Slave
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Depth (m)

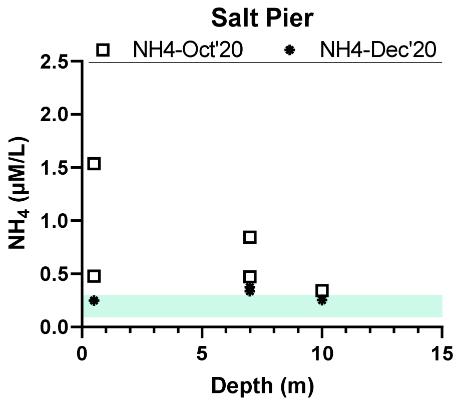

Red Slave
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
20
Depth (m)



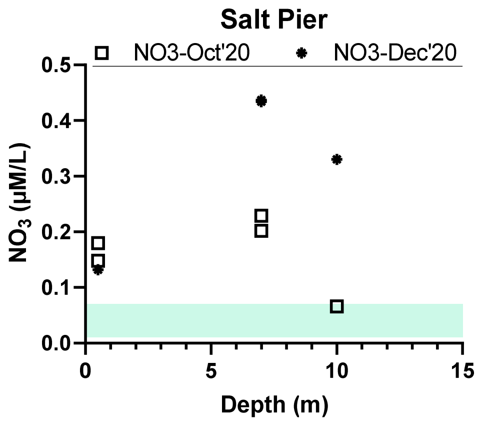
Salt Pier
TOC-Dec'20
TOC (µM/L)
Depth (m)



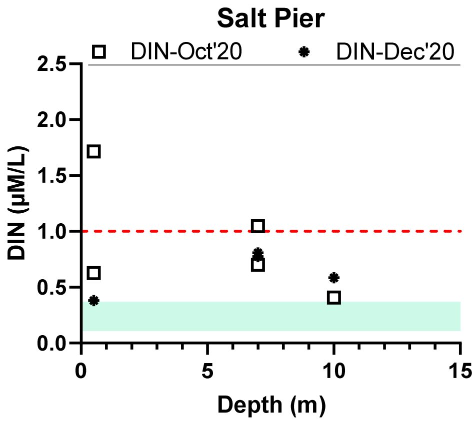
Salt Pier
TN-Dec'20
TN (µM/L)
Depth (m)



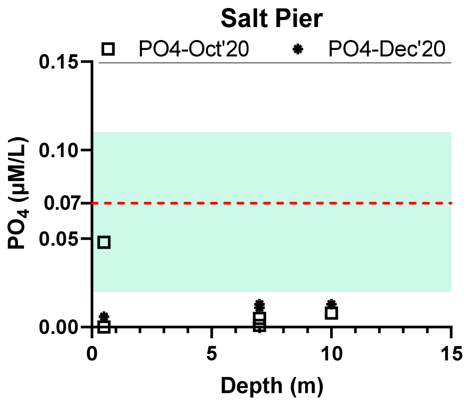
Salt Pier
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)



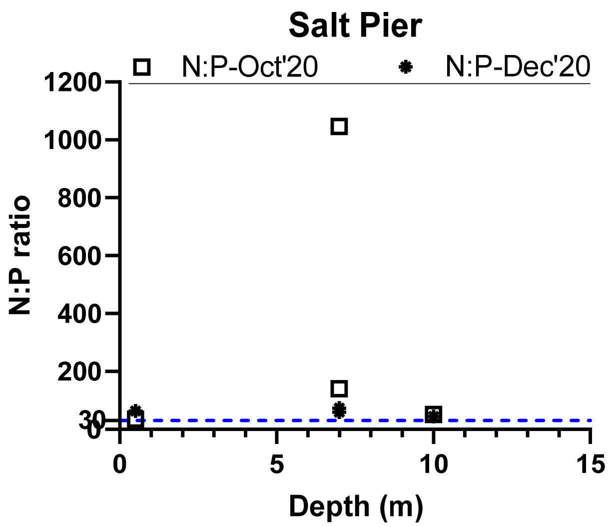
Salt Pier
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

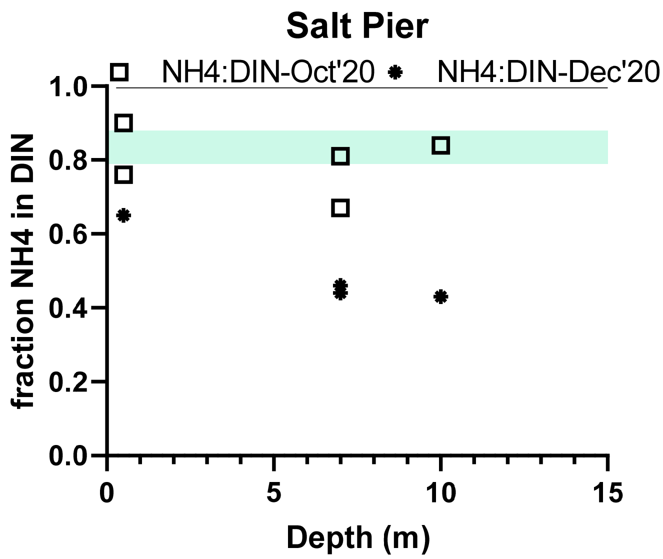


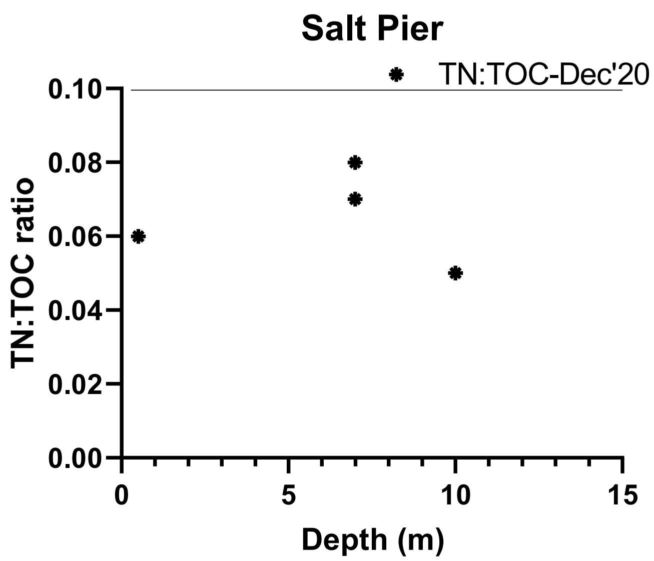
Salt Pier
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

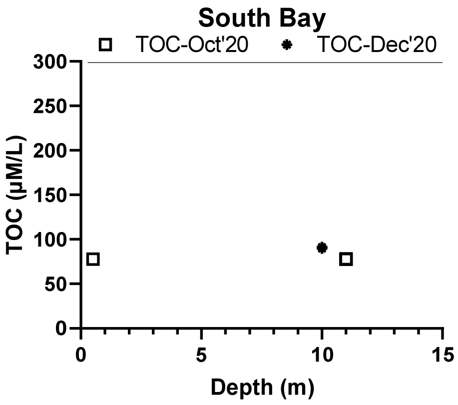


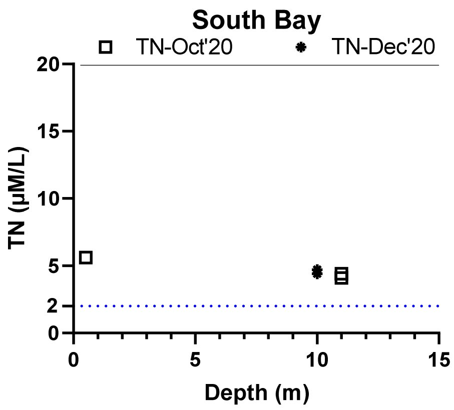
Salt Pier
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

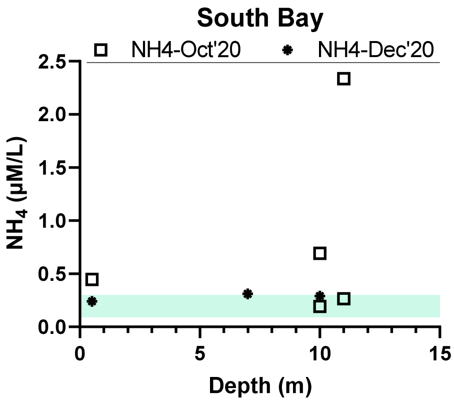

Salt Pier
N:P-Oct'20
N:P-Dec'20
N:P ratio
1200
1000
800
600
400
200
30
0
0
5
10
15
Depth (m)

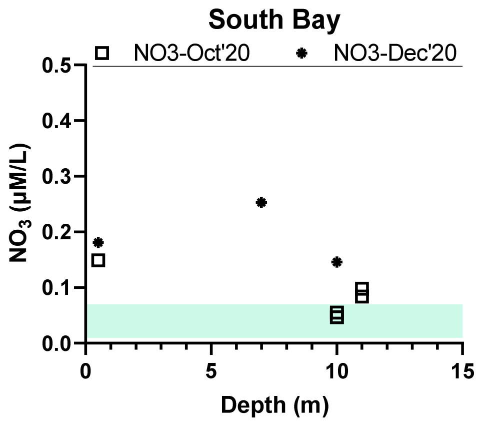

Salt Pier
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

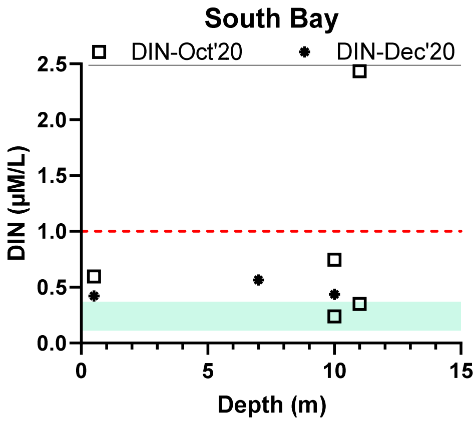

Salt Pier
TN:TOC-Dec'20
TN:TOC ratio
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
Depth (m)

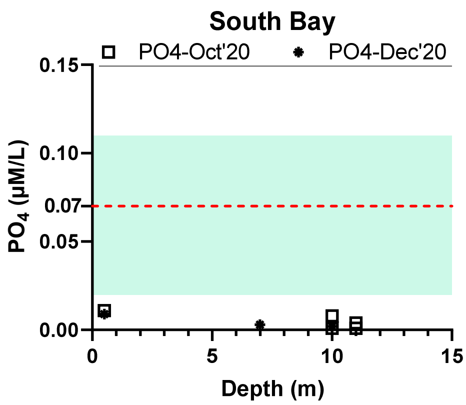

South Bay
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
300
250
200
150
100
50
0
0
5
10
15
Depth (m)

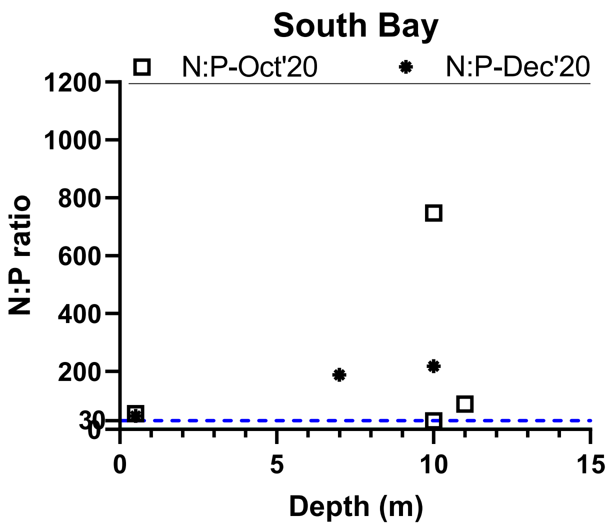

South Bay
TN-Oct'20
TN-Dec'20
TN (µM/L)
20
15
10
5
2
0
0
5
10
15
Depth (m)

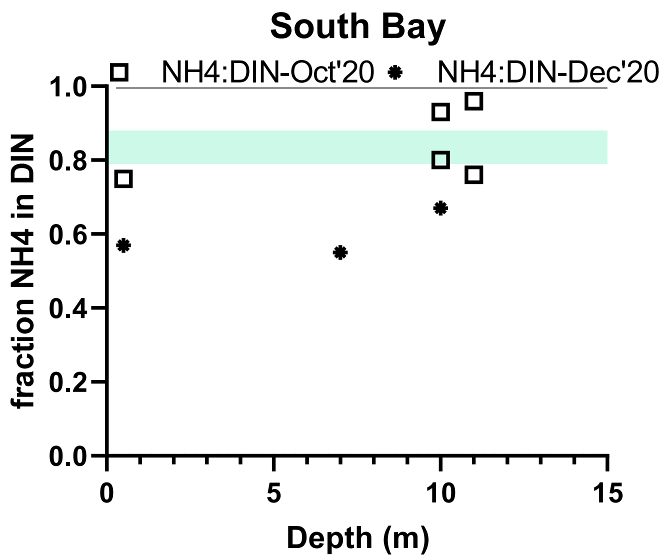

South Bay
NH4-Oct'20
NH4-Dec'20
NH_4 (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

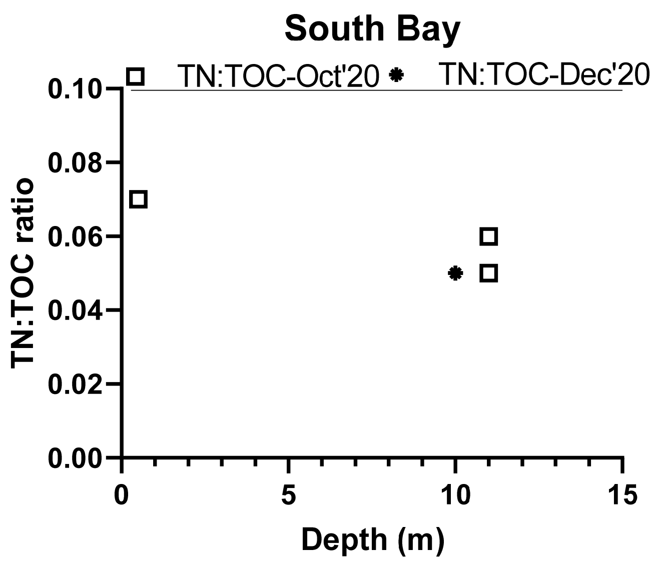

South Bay
NO3-Oct'20
NO3-Dec'20
NO_3 (µM/L)
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)

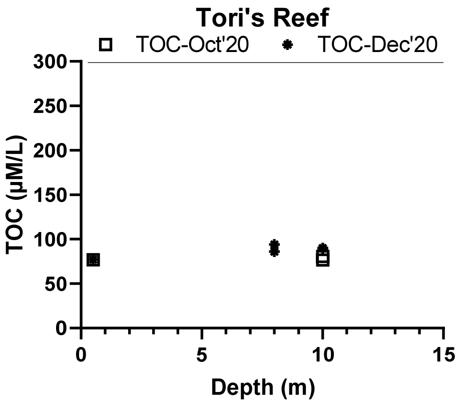

South Bay
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

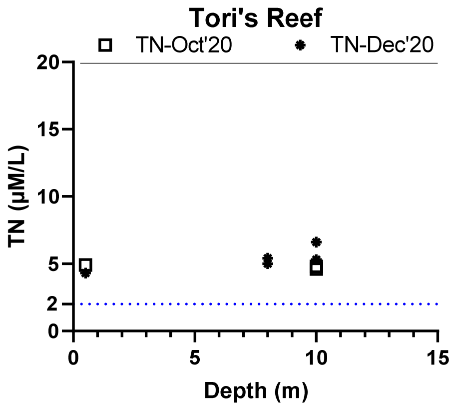

South Bay
PO4-Oct'20
PO4-Dec'20
PO_4 (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

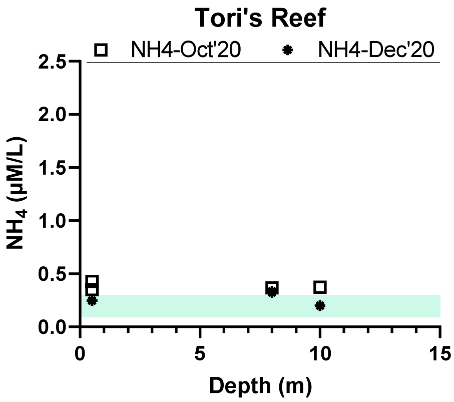

South Bay
N:P-Oct'20
N:P-Dec'20
1200
1000
800
600
400
200
30
0
N:P ratio
0
5
10
15
Depth (m)

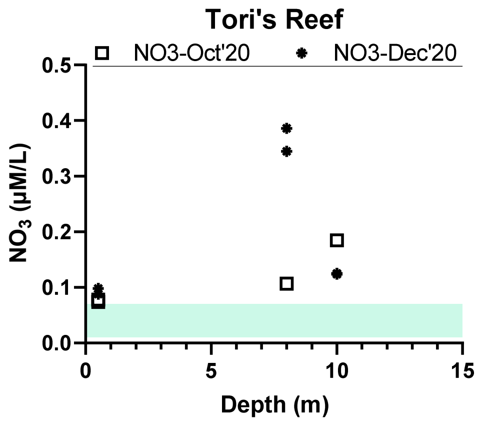

South Bay
NH4:DIN-Oct'20
NH4:DIN-Dec'20
1.0
0.8
0.6
0.4
0.2
0.0
fraction NH4 in DIN
0
5
10
15
Depth (m)

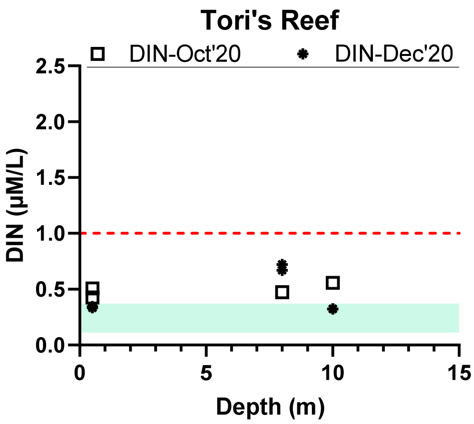

South Bay
TN:TOC-Oct'20
TN:TOC-Dec'20
0.10
0.08
0.06
0.04
0.02
0.00
TN:TOC ratio
0
5
10
15
Depth (m)

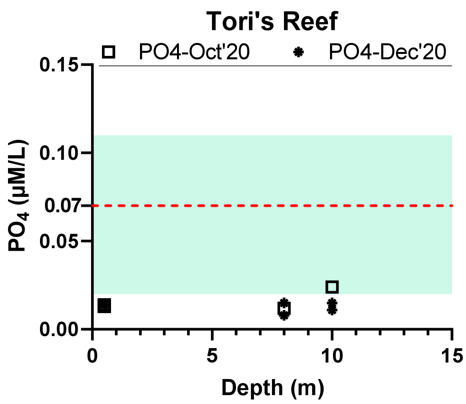

Tori's Reef
TOC-Oct'20
TOC-Dec'20
TOC (µM/L)
300
250
200
150
100
50
0
0
5
10
15
Depth (m)

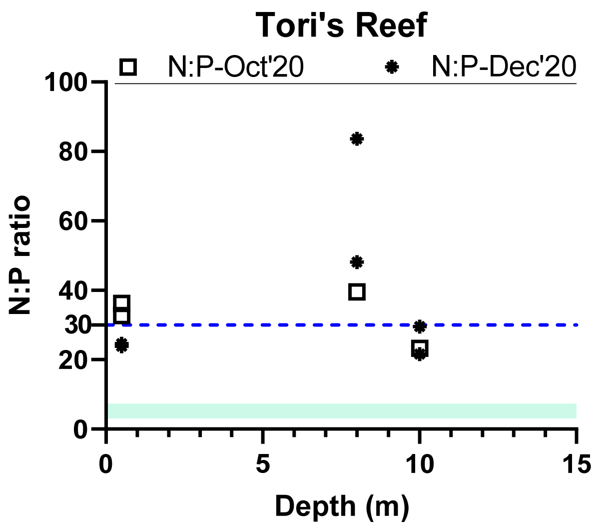

Tori's Reef
TN-Oct'20
TN-Dec'20
TN (µM/L)
20
15
10
5
2
0
0
5
10
15
Depth (m)

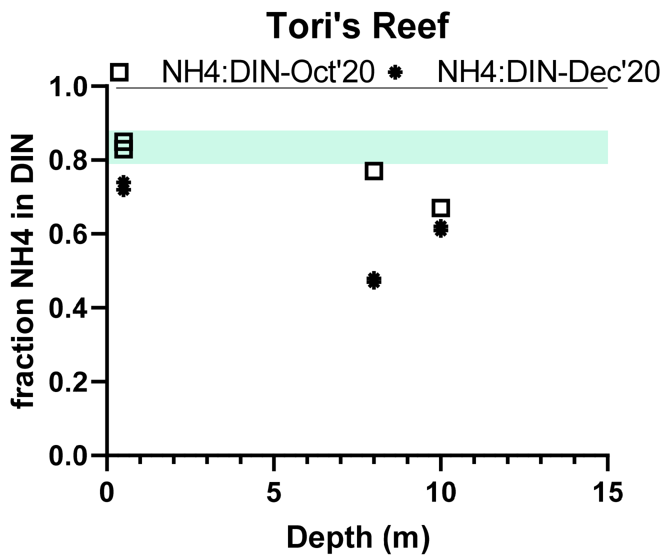

Tori's Reef
NH4-Oct'20
NH4-Dec'20
NH_4 (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

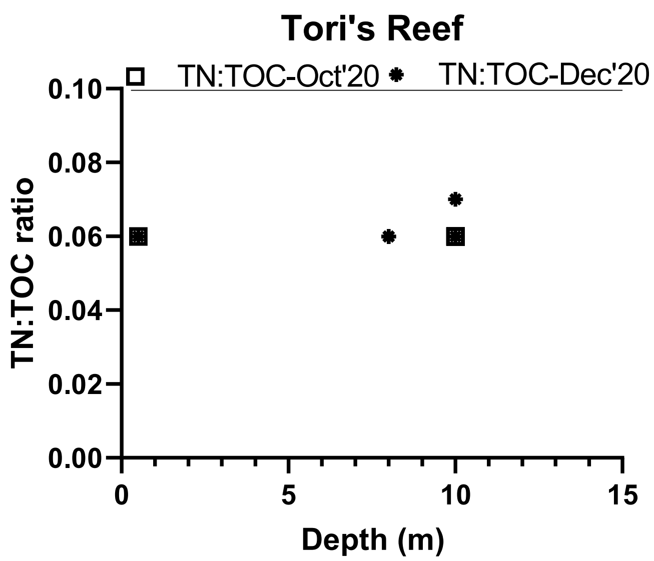

Tori's Reef
NO3-Oct'20
NO3-Dec'20
NO_3 (µM/L)
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)


Tori's Reef
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

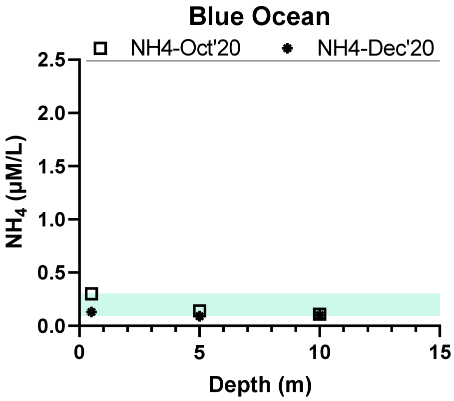

Tori's Reef
PO4-Oct'20
PO4-Dec'20
PO_4 (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

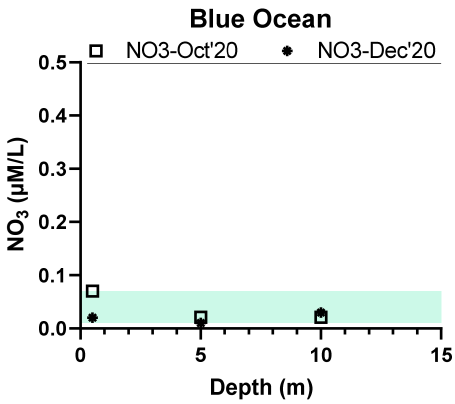

Tori's Reef
N:P-Oct'20
N:P-Dec'20
N:P ratio
100
80
60
40
30
20
0
0
5
10
15
Depth (m)

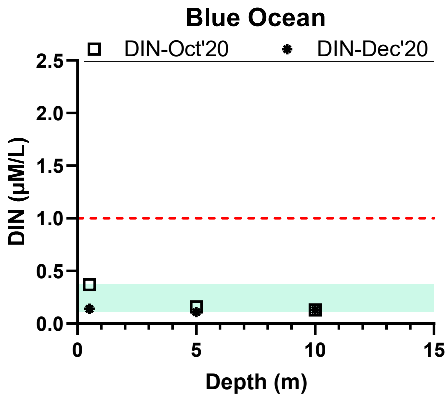

Tori's Reef
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

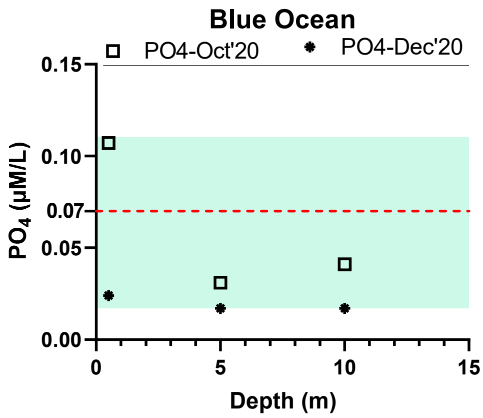

Tori's Reef
TN:TOC-Oct'20
TN:TOC-Dec'20
TN:TOC ratio
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
Depth (m)

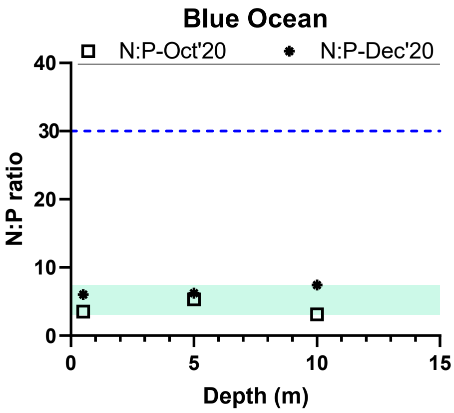
ANNEX 2: Individual datapoints St. Eustatius

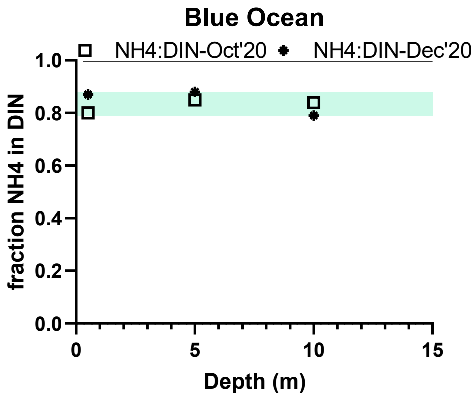


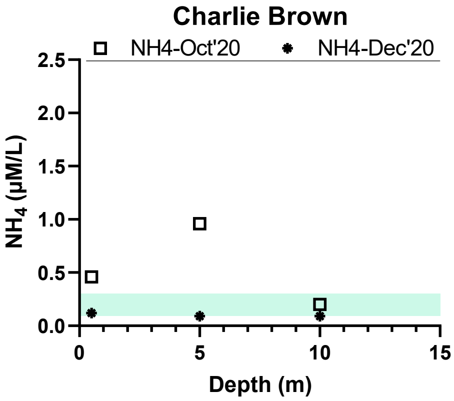


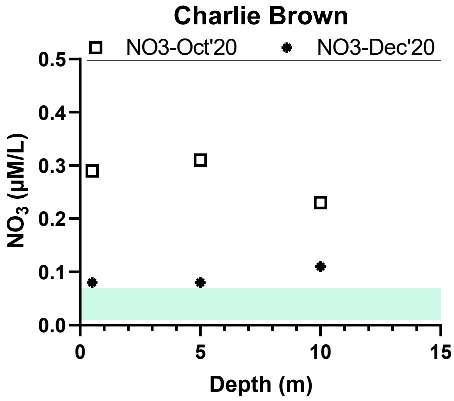


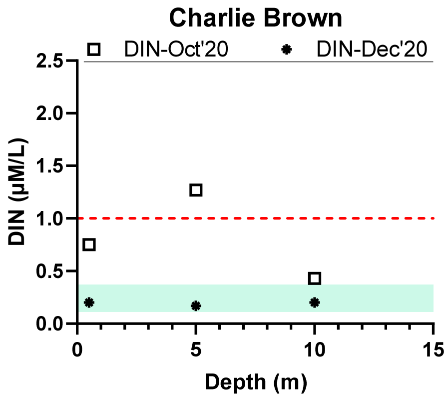


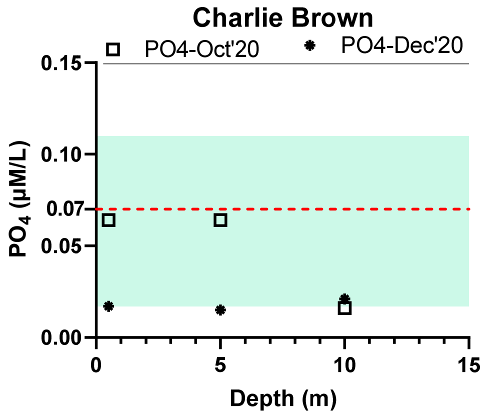


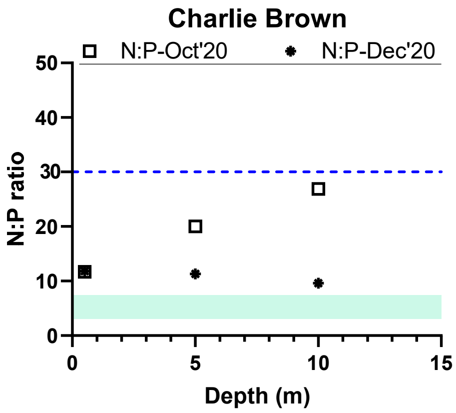


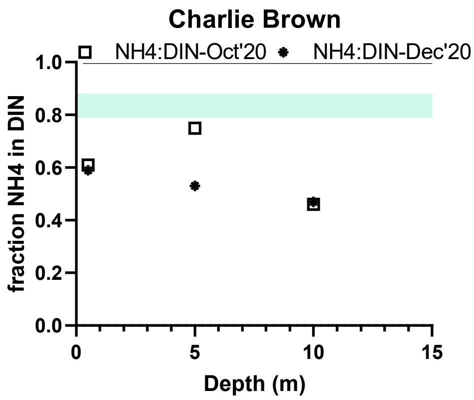

Charlie Brown
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

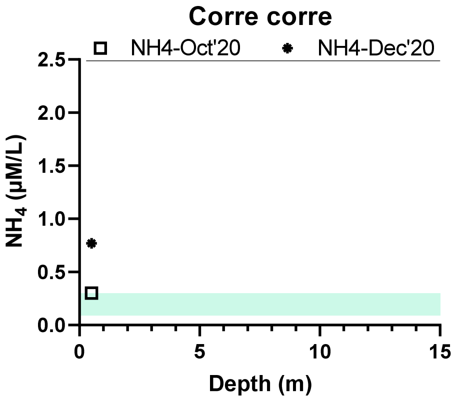

Charlie Brown
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

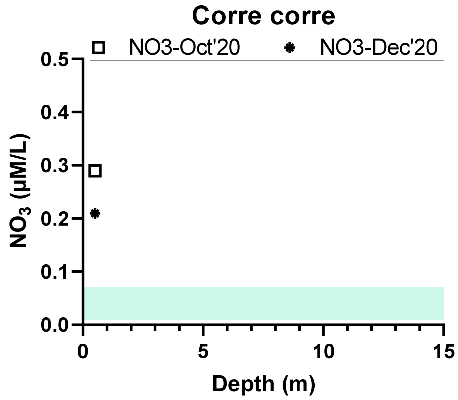

Charlie Brown
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

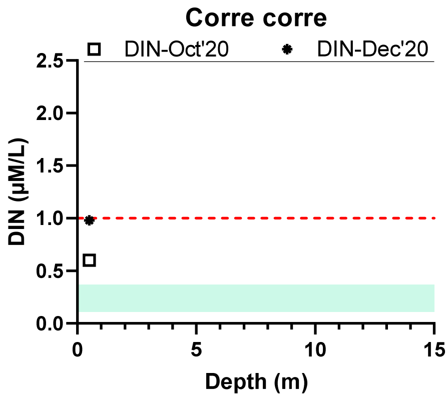

Charlie Brown
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

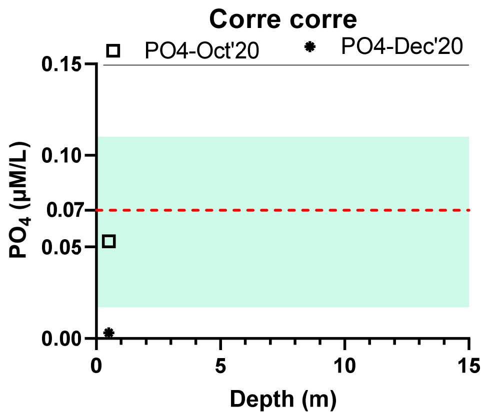

Charlie Brown
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

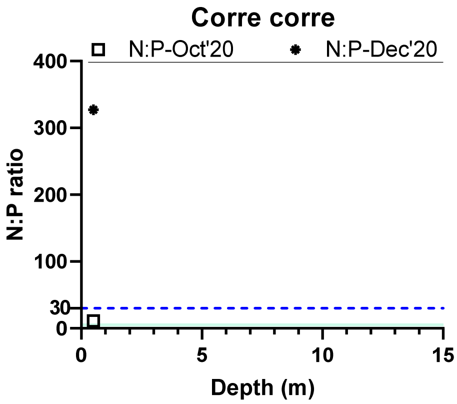

Charlie Brown
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

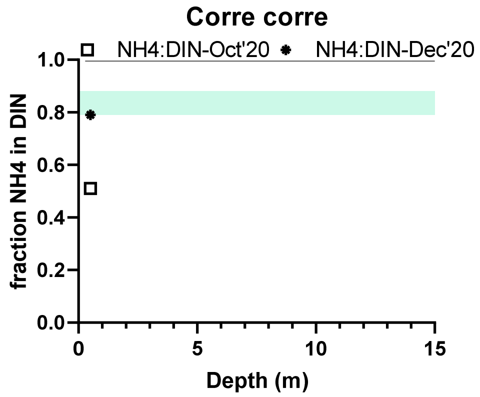

Corre corre
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

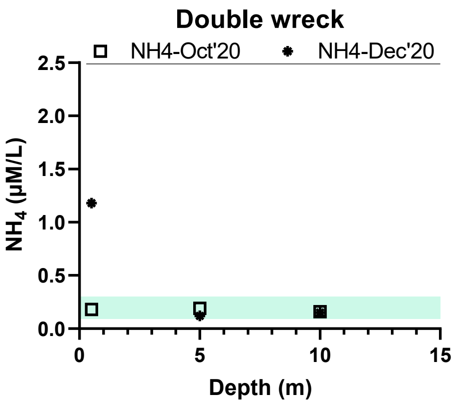

Corre corre
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)

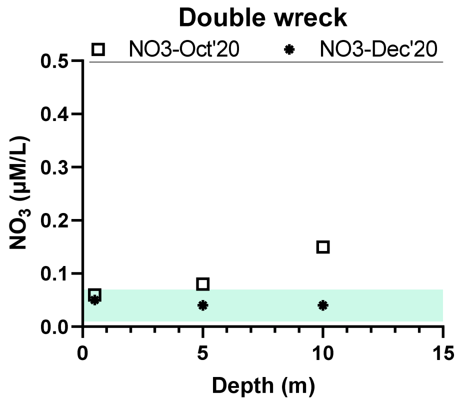

Corre corre
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

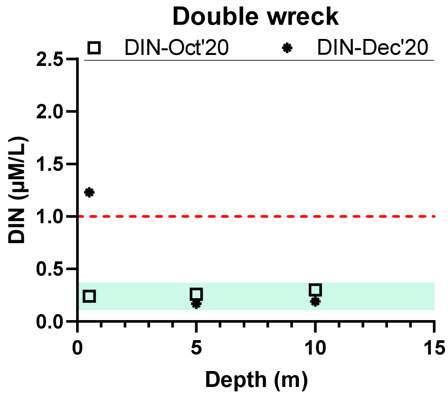

Corre corre
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

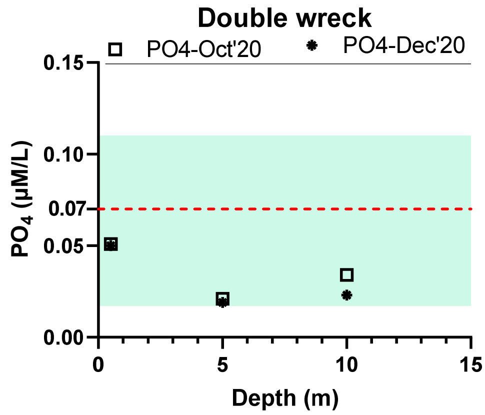

Corre corre
N:P-Oct'20
N:P-Dec'20
N:P ratio
400
300
200
100
30
0
0
5
10
15
Depth (m)

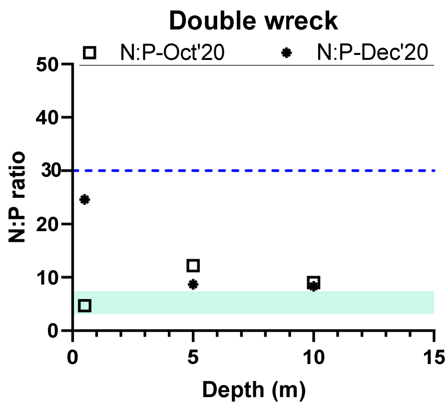

Corre corre
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

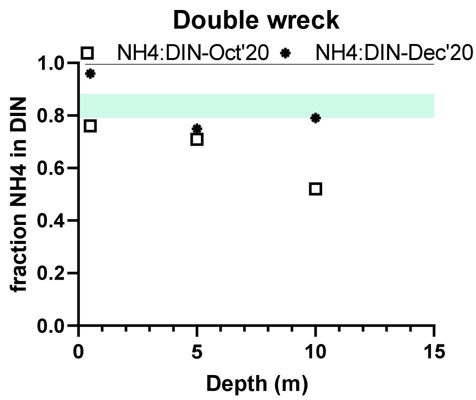

Double wreck
NH4-Oct'20
NH4-Dec'20
NH₄ (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

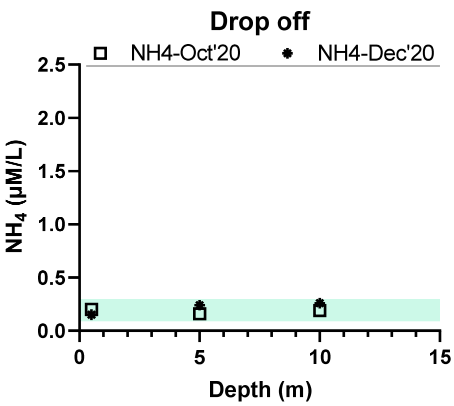

Double wreck
NO3-Oct'20
NO3-Dec'20
NO₃ (µM/L)
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)

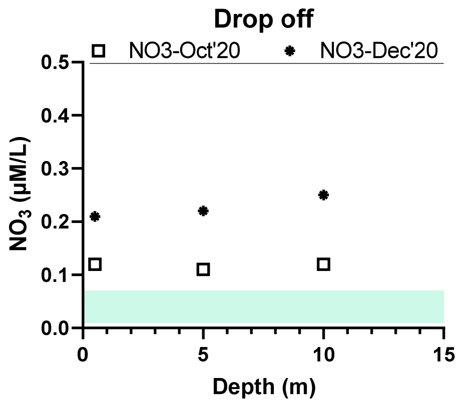

Double wreck
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

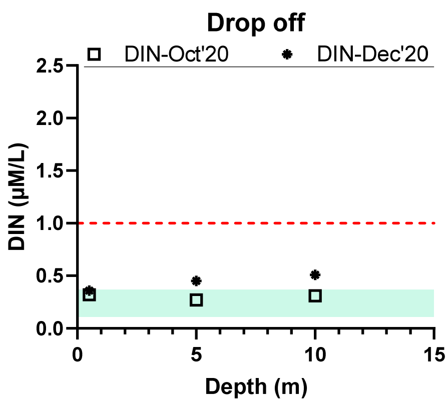

Double wreck
PO4-Oct'20
PO4-Dec'20
PO₄ (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

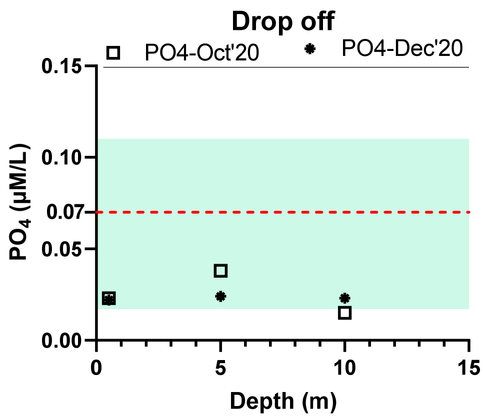

Double wreck
N:P-Oct'20
N:P-Dec'20
N:P ratio
50
40
30
20
10
0
0
5
10
15
Depth (m)

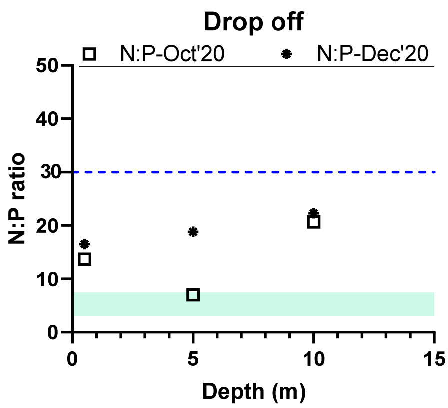

Double wreck
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

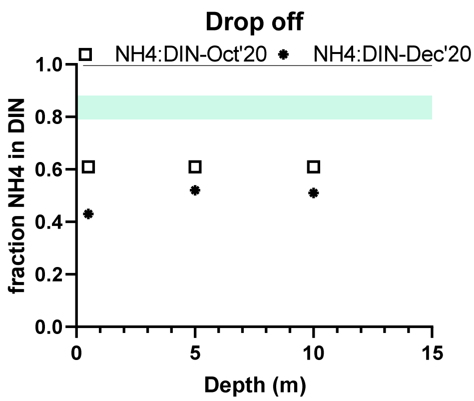

Drop off
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

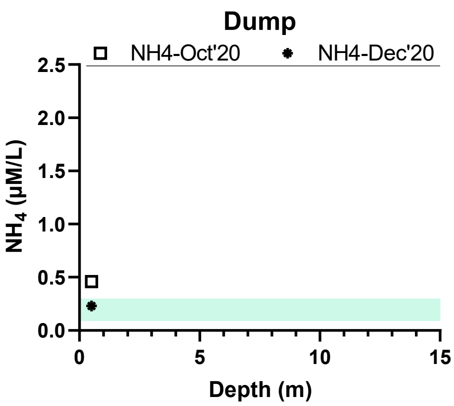

Drop off
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

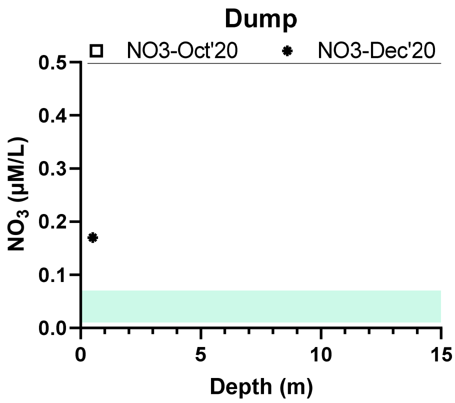

Drop off
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

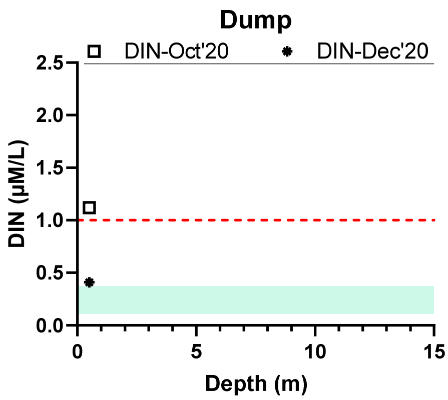

Drop off
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

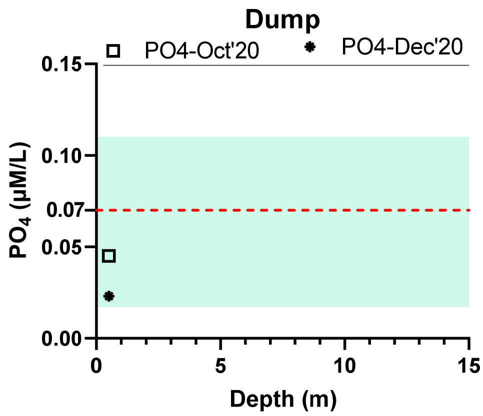

Drop off
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

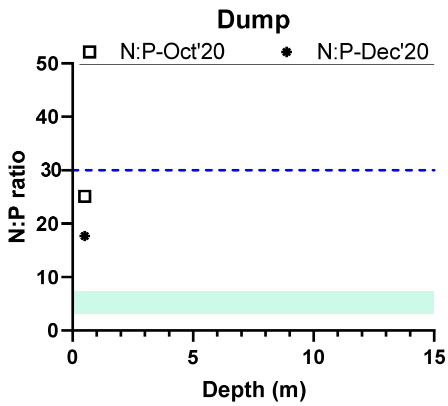

Drop off
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

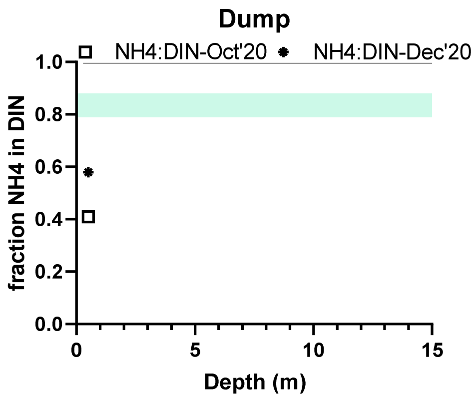

Dump
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

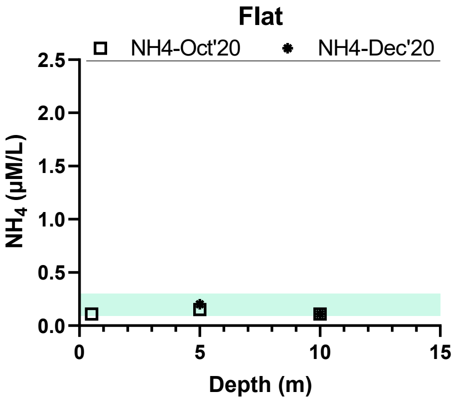

Dump
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

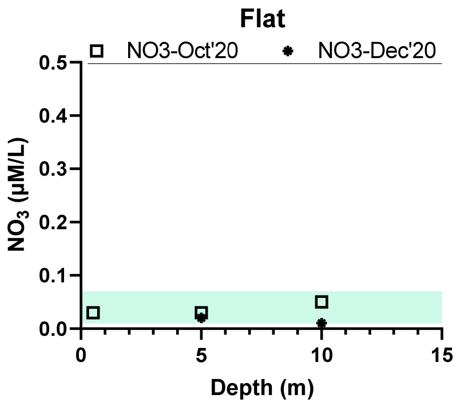

Dump
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

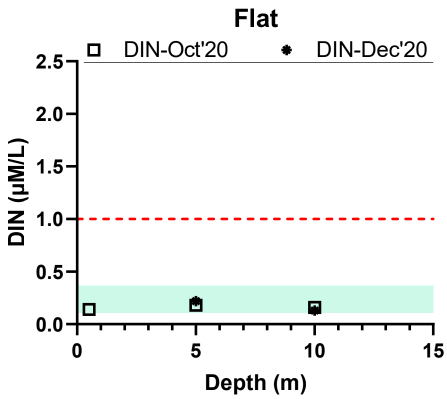

Dump
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

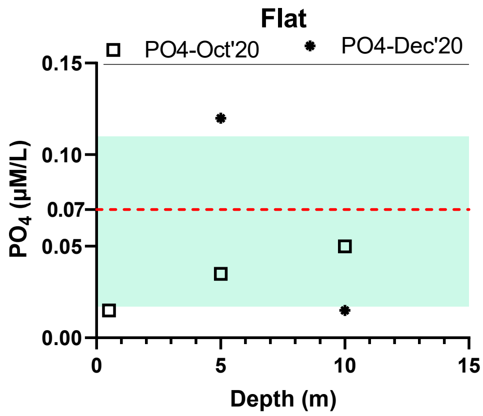

Dump
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

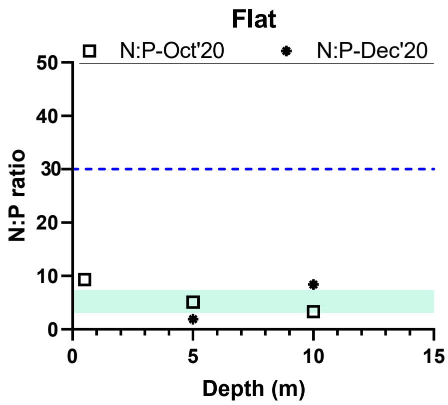

Dump
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

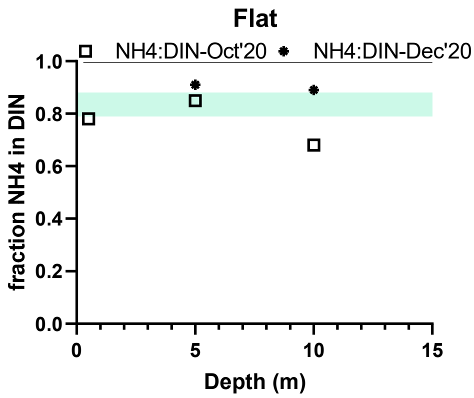

Flat
NH4-Oct'20
NH4-Dec'20
NH$_4$ (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

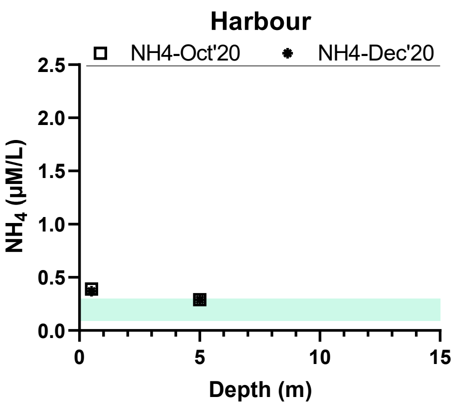

Flat
NO3-Oct'20
NO3-Dec'20
NO$_3$ (µM/L)
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)

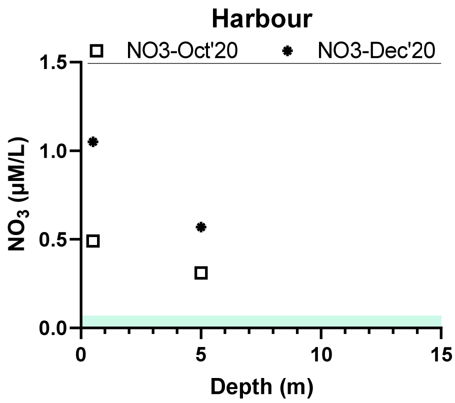

Flat
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

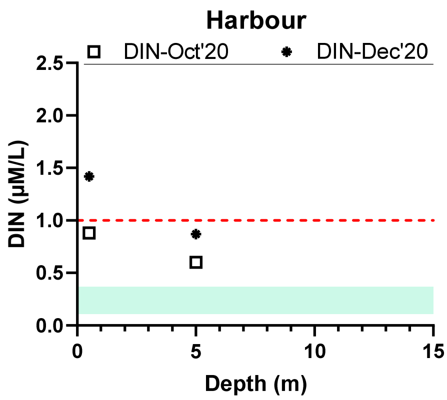

Flat
PO4-Oct'20
PO4-Dec'20
PO$_4$ (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

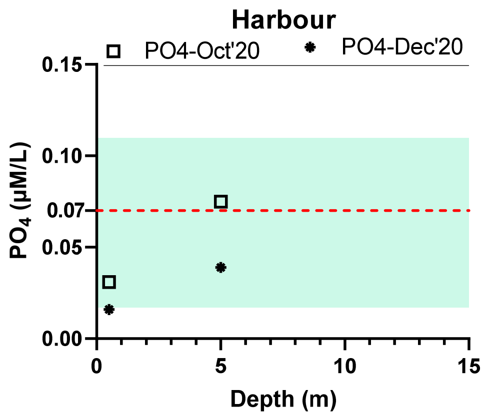

Flat
N:P-Oct'20
N:P-Dec'20
N:P ratio
50
40
30
20
10
0
0
5
10
15
Depth (m)

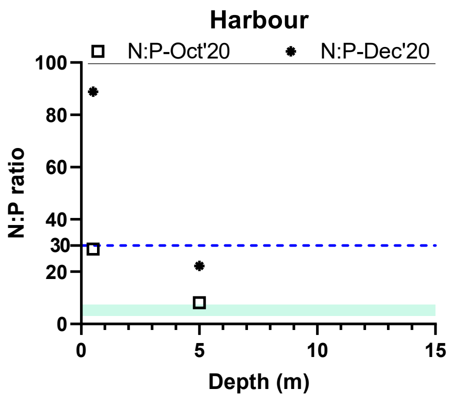

Flat
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

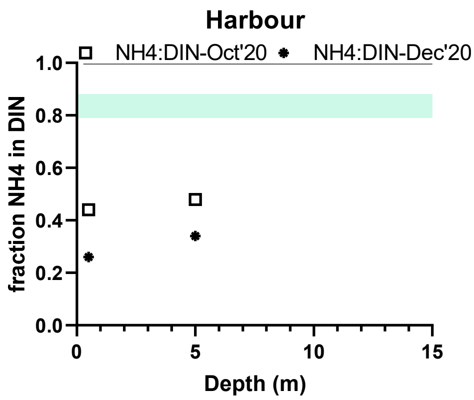

Harbour
NH4-Oct'20
NH4-Dec'20
NH_4 (µM/L)
Depth (m)

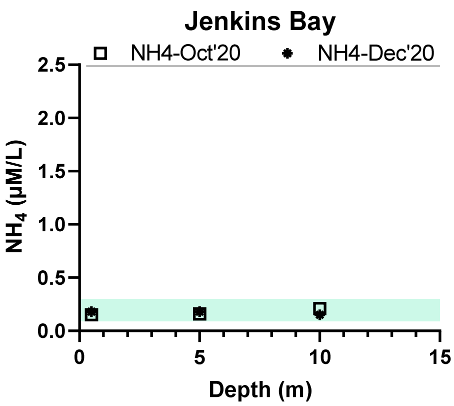

Harbour
NO3-Oct'20
NO3-Dec'20
NO_3 (µM/L)
Depth (m)

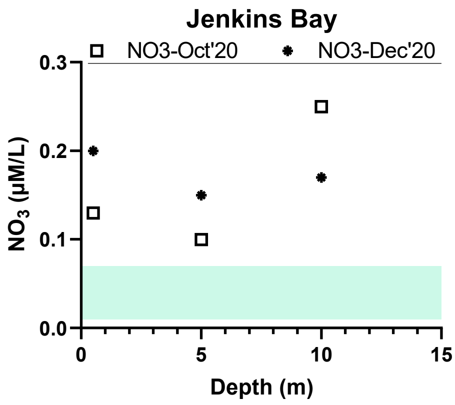

Harbour
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

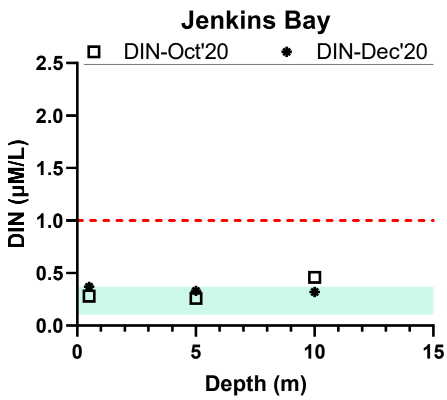

Harbour
PO4-Oct'20
PO4-Dec'20
PO_4 (µM/L)
Depth (m)

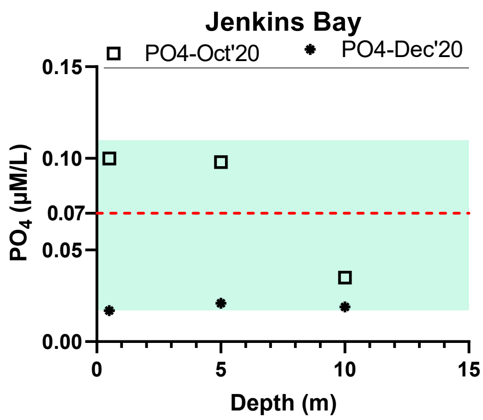

Harbour
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

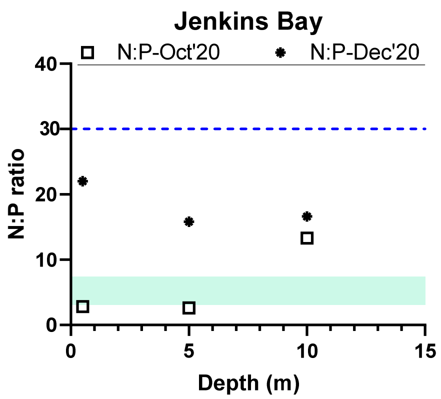

Harbour
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

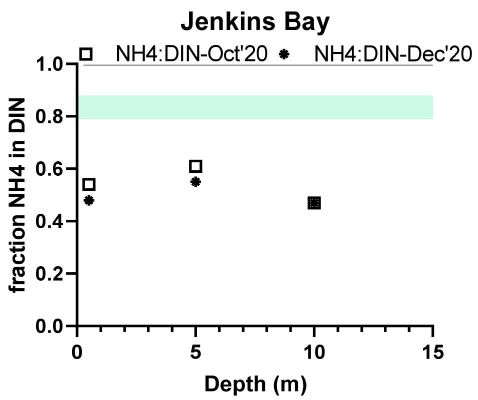

Jenkins Bay
NH4-Oct'20
NH4-Dec'20
NH_4 (µM/L)
Depth (m)

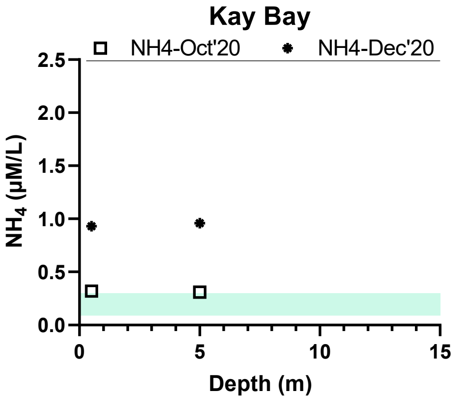

Jenkins Bay
NO3-Oct'20
NO3-Dec'20
NO_3 (µM/L)
Depth (m)

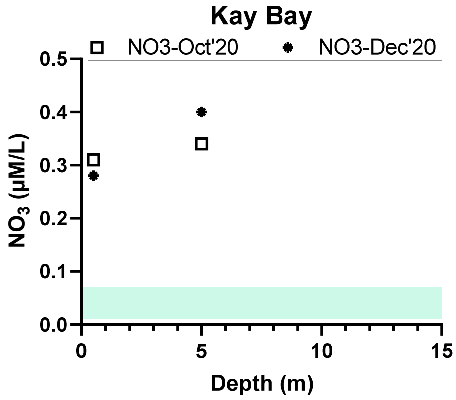

Jenkins Bay
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

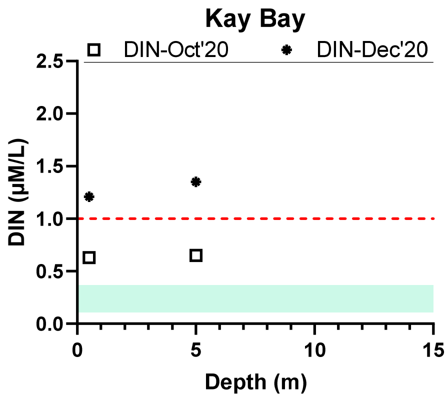

Jenkins Bay
PO4-Oct'20
PO4-Dec'20
PO_4 (µM/L)
Depth (m)

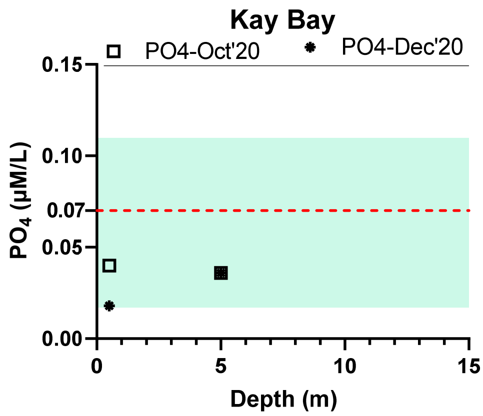

Jenkins Bay
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

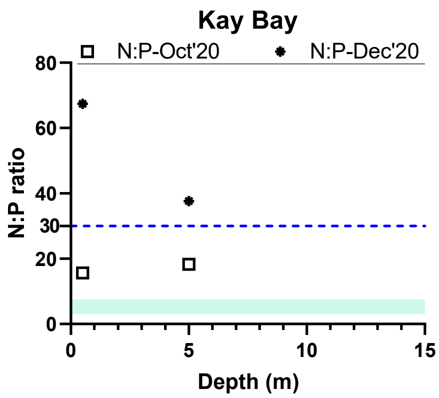

Jenkins Bay
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

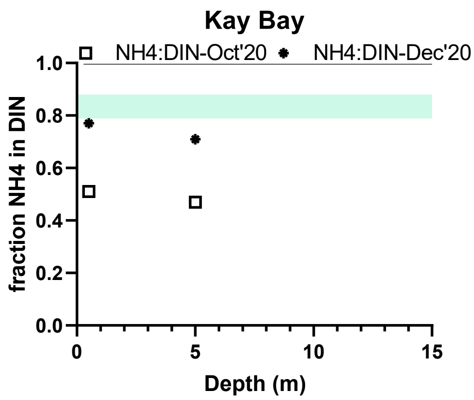

Kay Bay
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
Depth (m)

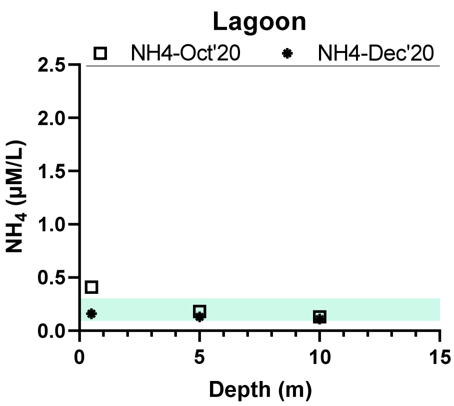

Kay Bay
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
Depth (m)

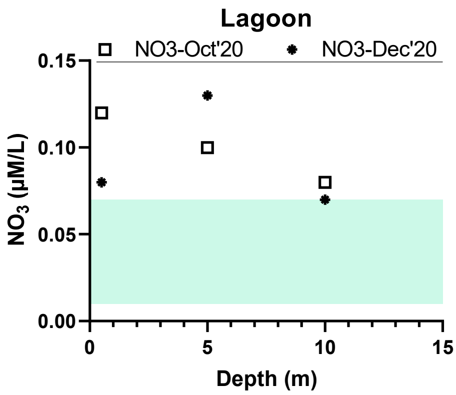

Kay Bay
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

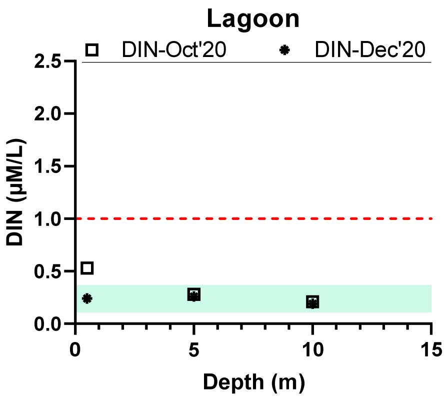

Kay Bay
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
Depth (m)

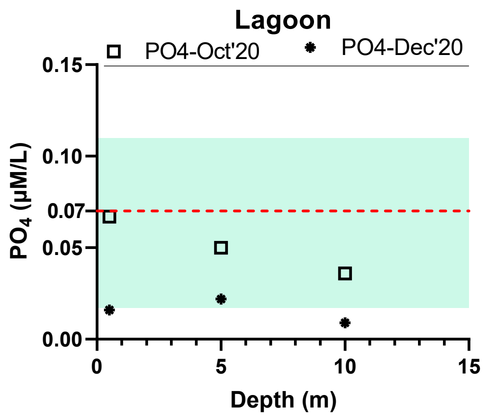

Kay Bay
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

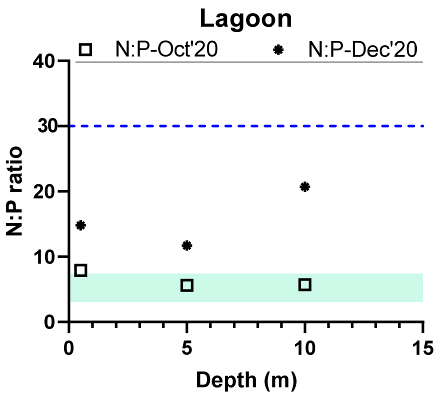

Kay Bay
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

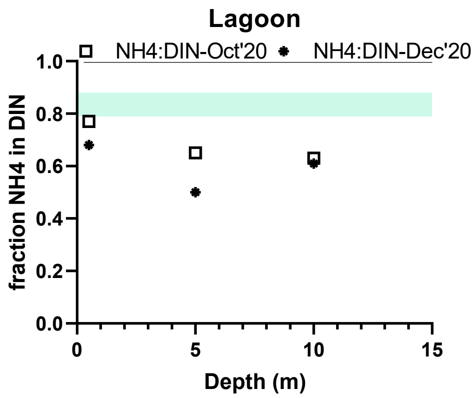

Lagoon
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

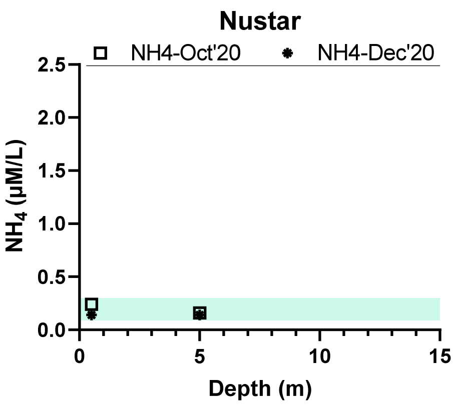

Lagoon
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
0.15
0.10
0.05
0.00
0
5
10
15
Depth (m)

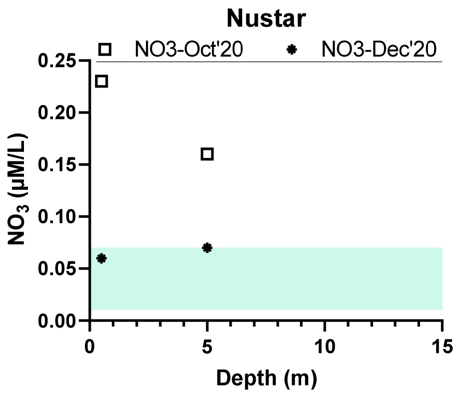

Lagoon
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

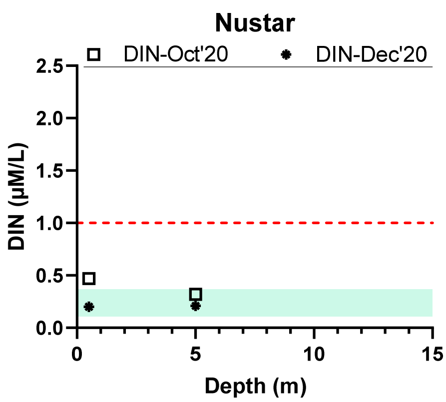

Lagoon
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

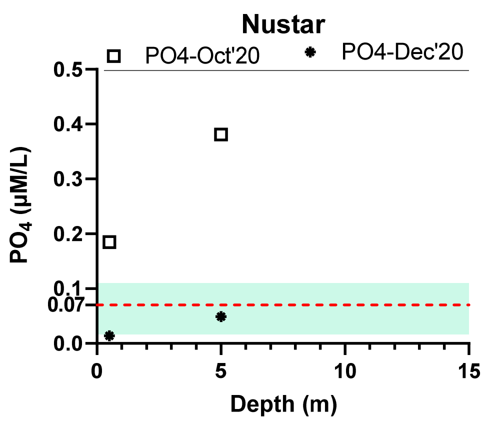

Lagoon
N:P-Oct'20
N:P-Dec'20
N:P ratio
40
30
20
10
0
0
5
10
15
Depth (m)

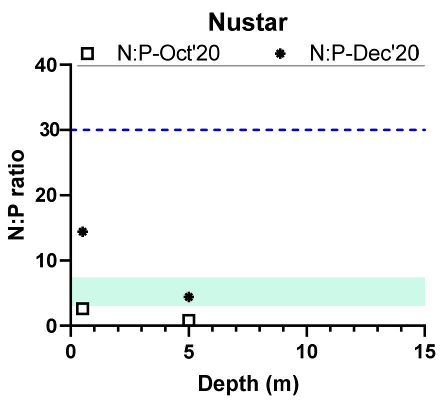

Lagoon
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

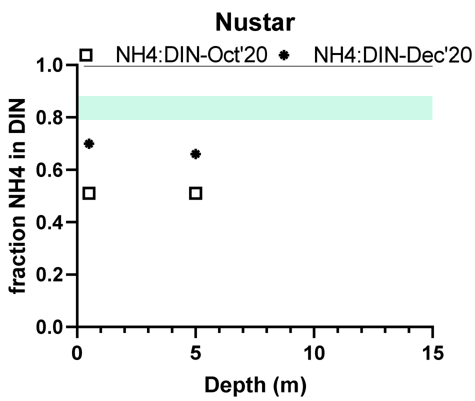

Nustar
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

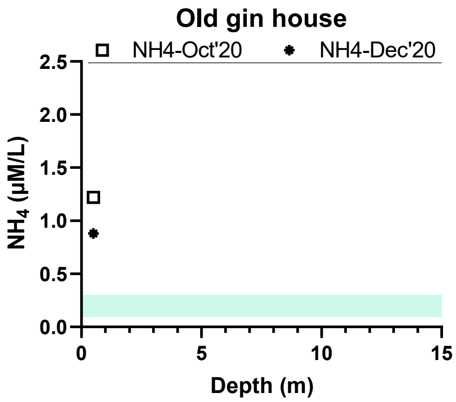

Nustar
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
Depth (m)

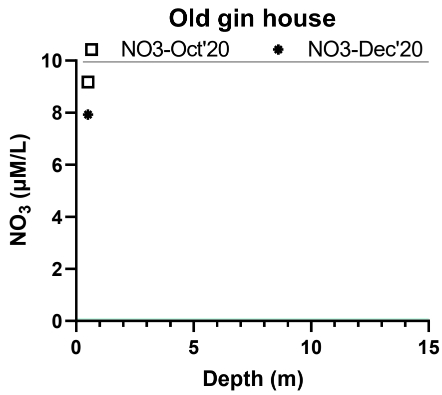

Nustar
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

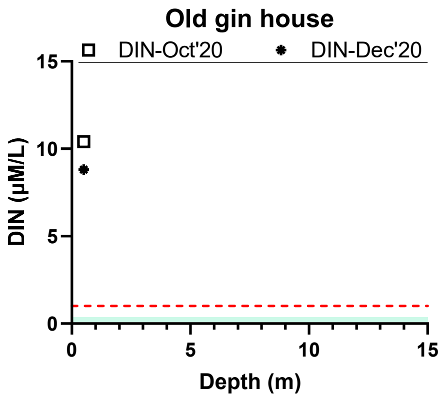

Nustar
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
0.5
0.4
0.3
0.2
0.1
0.07
0.0
0
5
10
15
Depth (m)

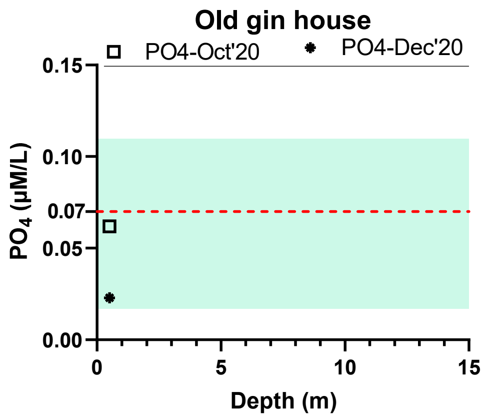

Nustar
N:P-Oct'20
N:P-Dec'20
N:P ratio
40
30
20
10
0
0
5
10
15
Depth (m)

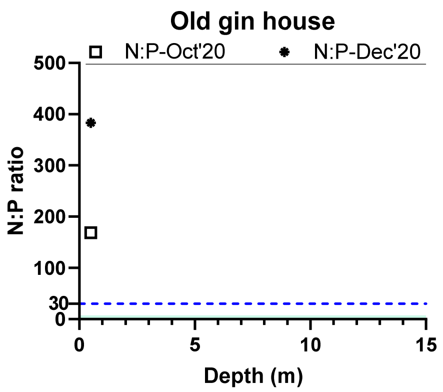

Nustar
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

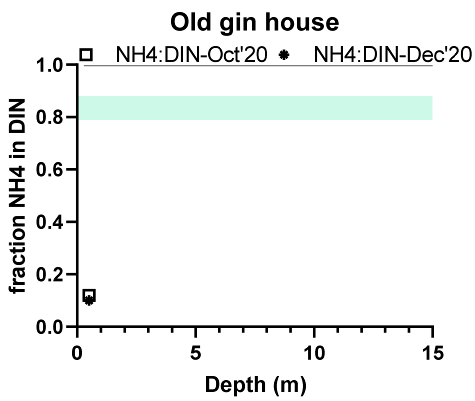

Old gin house
NH4-Oct'20
NH4-Dec'20
NH$_4$ (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

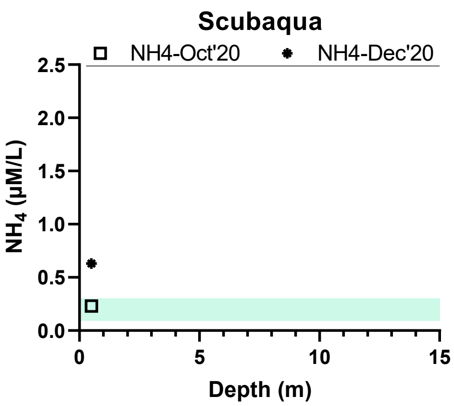

Old gin house
NO3-Oct'20
NO3-Dec'20
NO$_3$ (µM/L)
10
8
6
4
2
0
0
5
10
15
Depth (m)

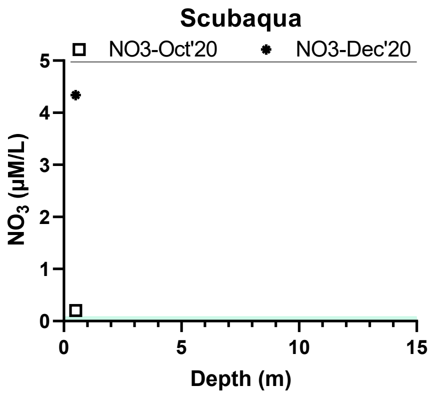

Old gin house
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
15
10
5
0
0
5
10
15
Depth (m)

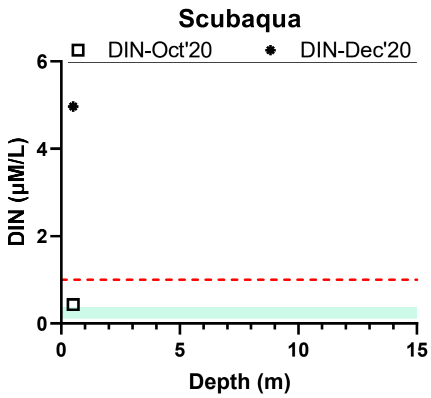

Old gin house
PO4-Oct'20
PO4-Dec'20
PO$_4$ (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

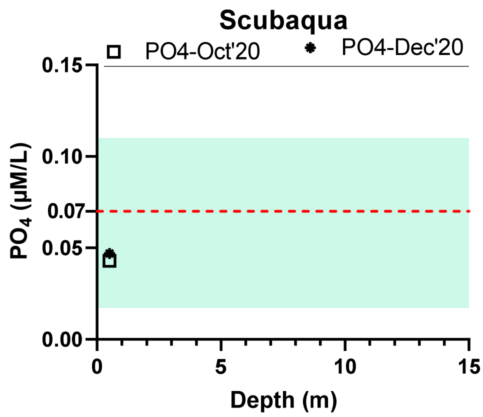

Old gin house
N:P-Oct'20
N:P-Dec'20
N:P ratio
500
400
300
200
100
30
0
0
5
10
15
Depth (m)

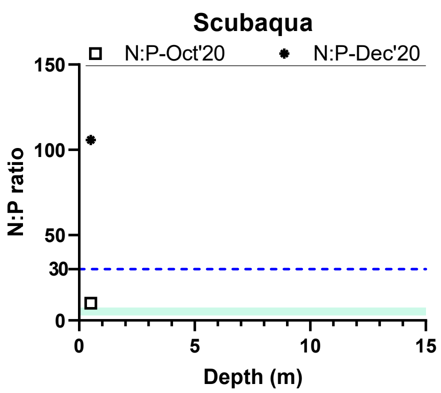

Old gin house
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

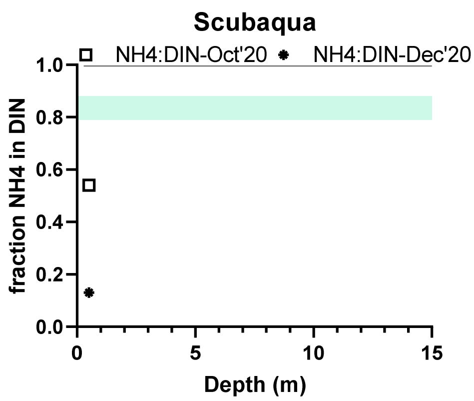

Scubaqua
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

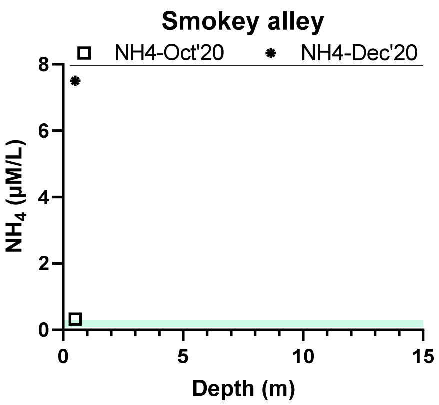

Scubaqua
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
5
4
3
2
1
0
0
5
10
15
Depth (m)

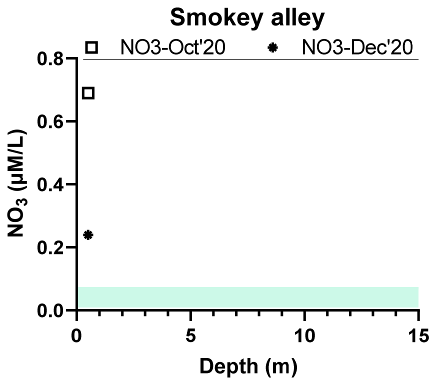

Scubaqua
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
6
4
2
0
0
5
10
15
Depth (m)

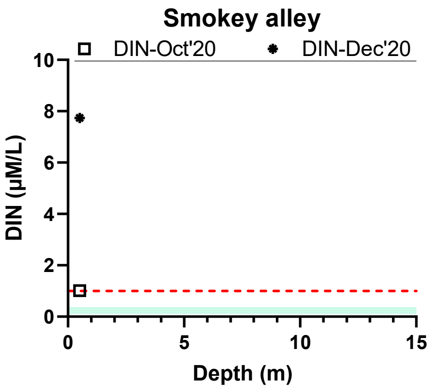

Scubaqua
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

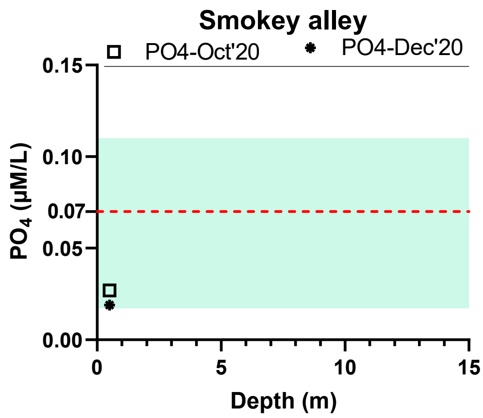

Scubaqua
N:P-Oct'20
N:P-Dec'20
N:P ratio
150
100
50
30
0
0
5
10
15
Depth (m)

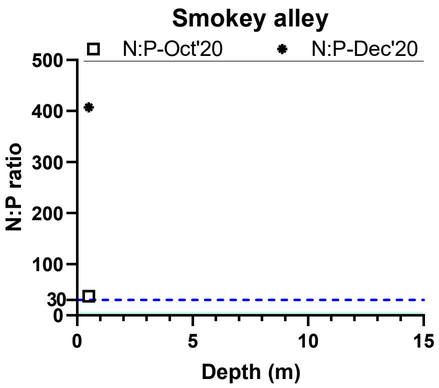

Scubaqua
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

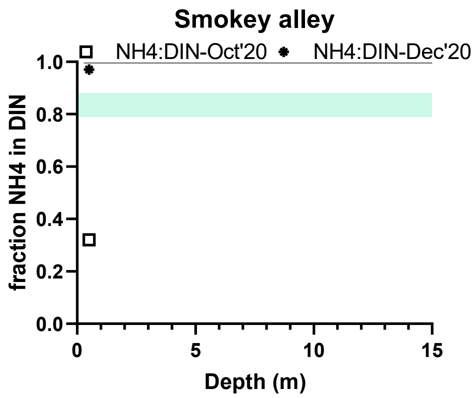

Smokey alley
NH4-Oct'20
NH4-Dec'20
NH4 (µM/L)
0
2
4
6
8
0
5
10
15
Depth (m)

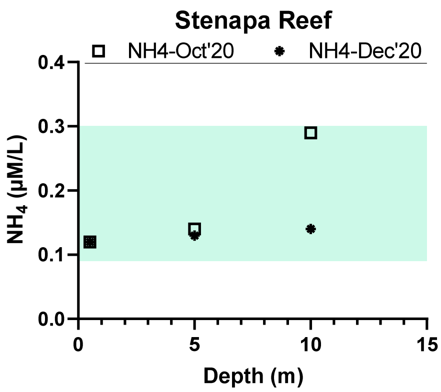

Smokey alley
NO3-Oct'20
NO3-Dec'20
NO3 (µM/L)
0.0
0.2
0.4
0.6
0.8
0
5
10
15
Depth (m)

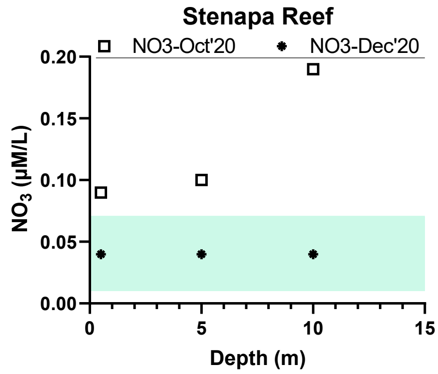

Smokey alley
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
0
2
4
6
8
10
0
5
10
15
Depth (m)

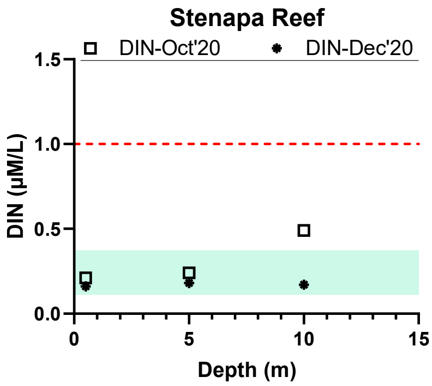

Smokey alley
PO4-Oct'20
PO4-Dec'20
PO4 (µM/L)
0.00
0.05
0.07
0.10
0.15
0
5
10
15
Depth (m)

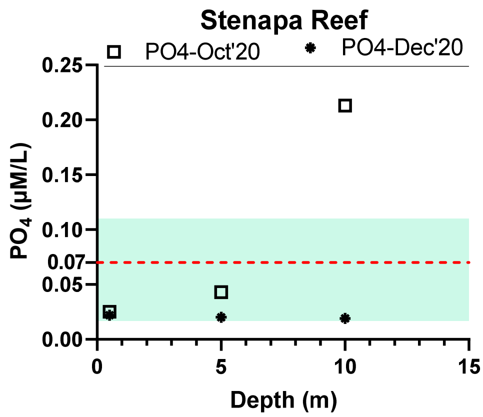

Smokey alley
N:P-Oct'20
N:P-Dec'20
N:P ratio
0
30
100
200
300
400
500
0
5
10
15
Depth (m)

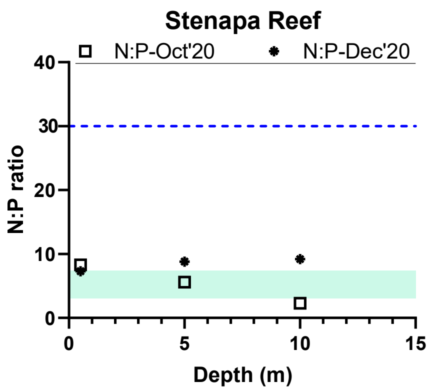

Smokey alley
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
Depth (m)

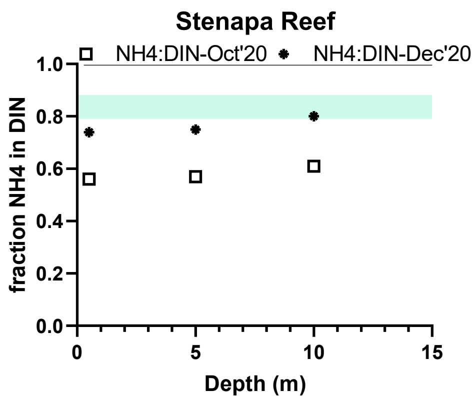

Stenapa Reef
NH4-Oct'20
NH4-Dec'20
NH$_4$ (µM/L)
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)

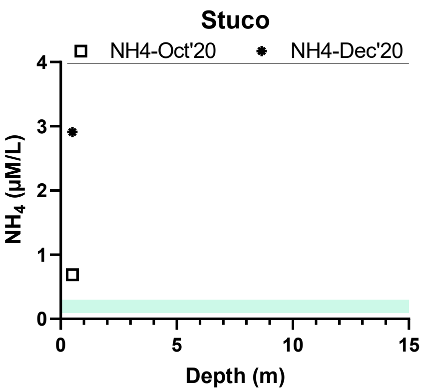

Stenapa Reef
NO3-Oct'20
NO3-Dec'20
NO$_3$ (µM/L)
0.20
0.15
0.10
0.05
0.00
0
5
10
15
Depth (m)

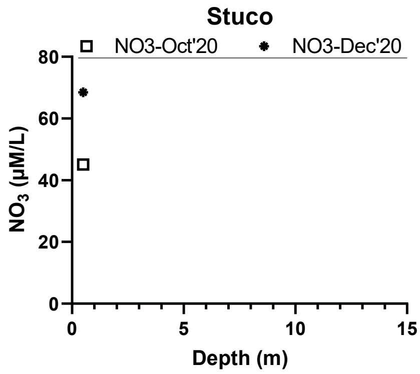

Stenapa Reef
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
1.5
1.0
0.5
0.0
0
5
10
15
Depth (m)

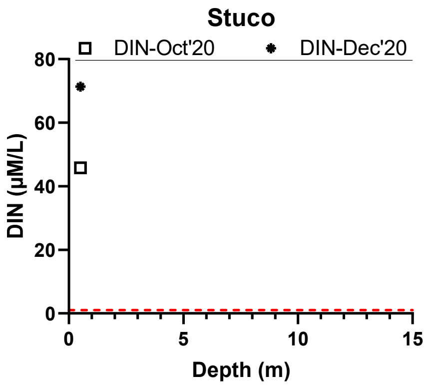

Stenapa Reef
PO4-Oct'20
PO4-Dec'20
PO$_4$ (µM/L)
0.25
0.20
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

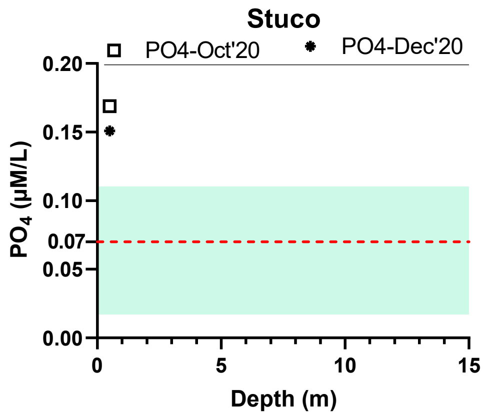

Stenapa Reef
N:P-Oct'20
N:P-Dec'20
N:P ratio
40
30
20
10
0
0
5
10
15
Depth (m)

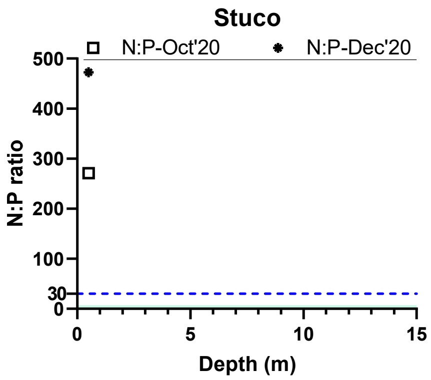

Stenapa Reef
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

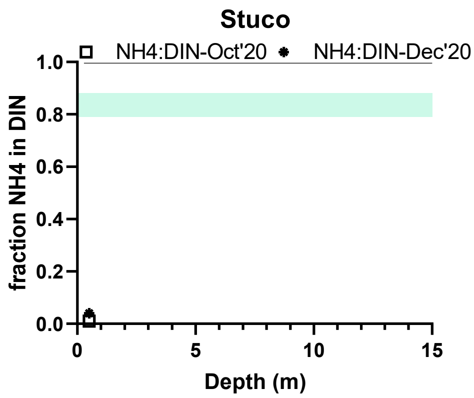

Stuco
NH4-Oct'20
NH4-Dec'20
NH₄ (µM/L)
Depth (m)

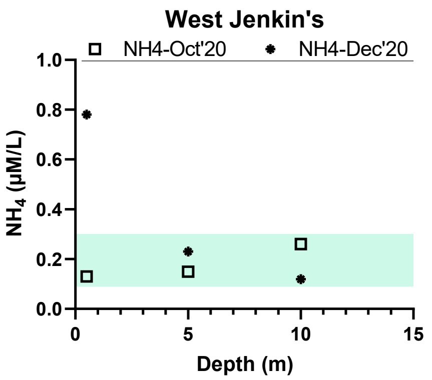

Stuco
NO3-Oct'20
NO3-Dec'20
NO₃ (µM/L)
Depth (m)

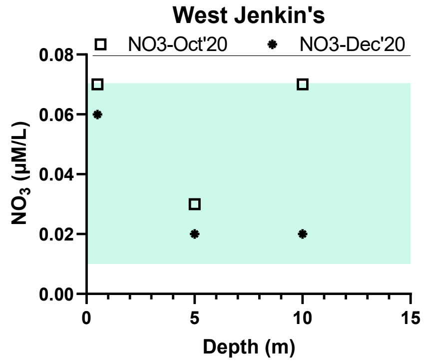

Stuco
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

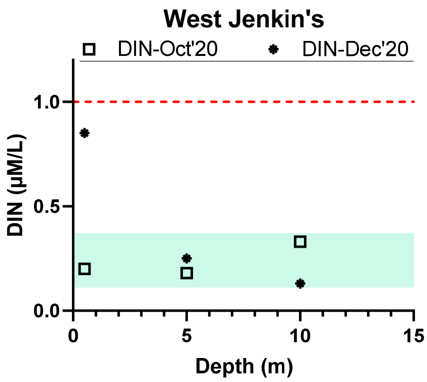

Stuco
PO4-Oct'20
PO4-Dec'20
PO₄ (µM/L)
Depth (m)

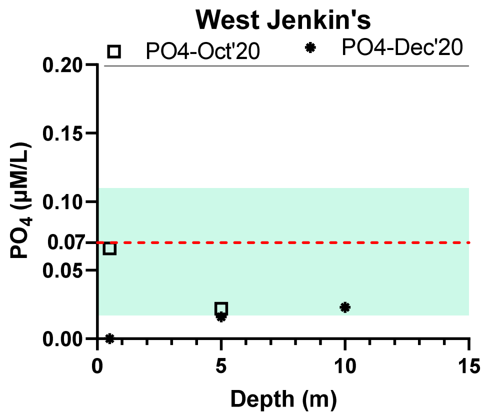

Stuco
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

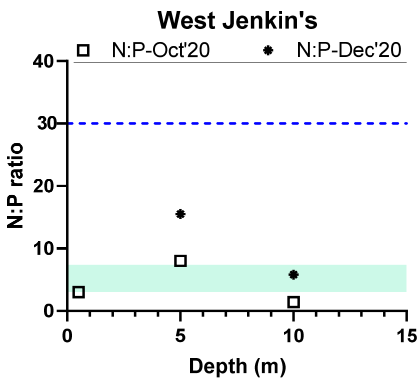

Stuco
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

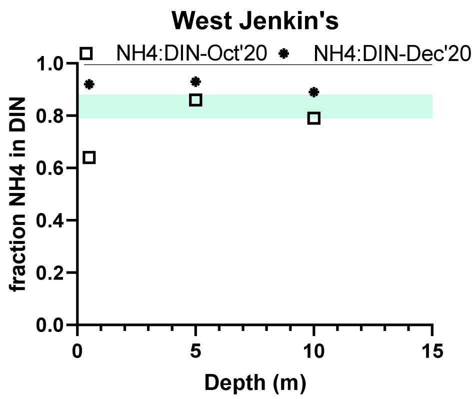

West Jenkin's
NH4-Oct'20
NH4-Dec'20
NH$_4$ (µM/L)
Depth (m)

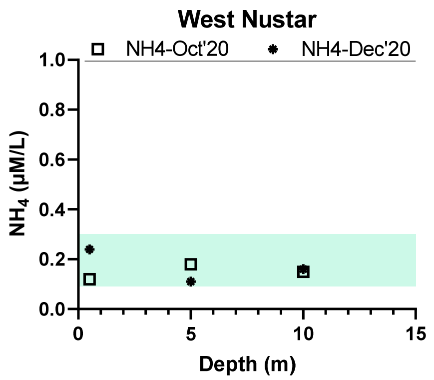

West Jenkin's
NO3-Oct'20
NO3-Dec'20
NO$_3$ (µM/L)
Depth (m)

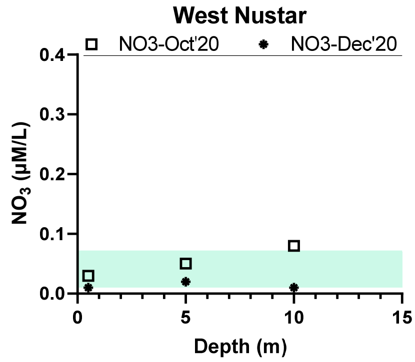

West Jenkin's
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
Depth (m)

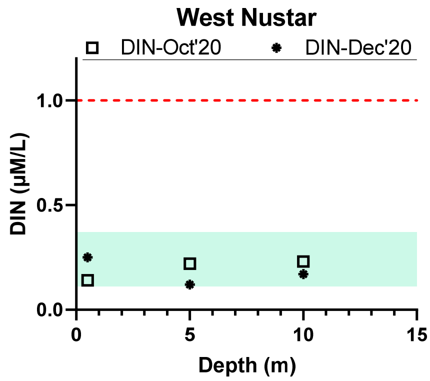

West Jenkin's
PO4-Oct'20
PO4-Dec'20
PO$_4$ (µM/L)
Depth (m)

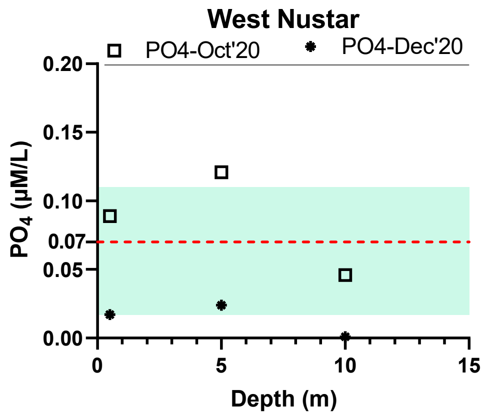

West Jenkin's
N:P-Oct'20
N:P-Dec'20
N:P ratio
Depth (m)

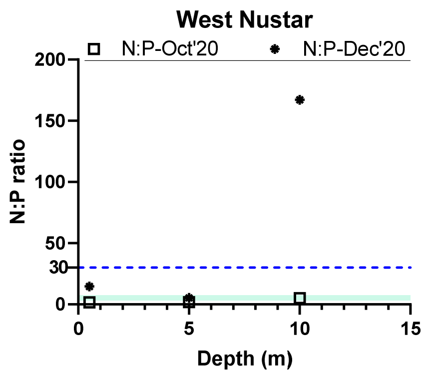

West Jenkin's
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
Depth (m)

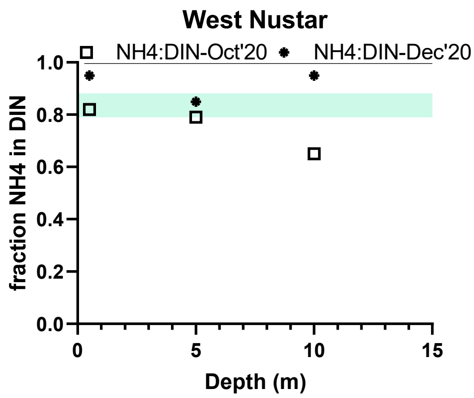

West Nustar
NH4-Oct'20
NH4-Dec'20
NH$_4$ (µM/L)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

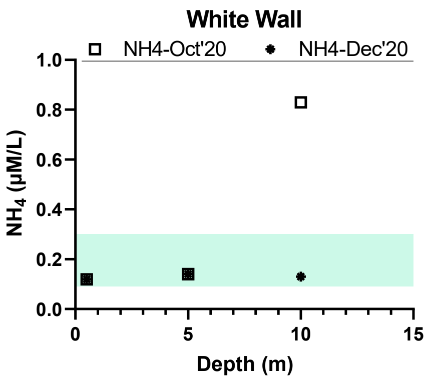

West Nustar
NO3-Oct'20
NO3-Dec'20
NO$_3$ (µM/L)
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)

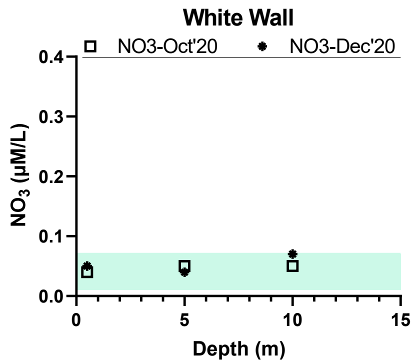

West Nustar
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
1.0
0.5
0.0
0
5
10
15
Depth (m)

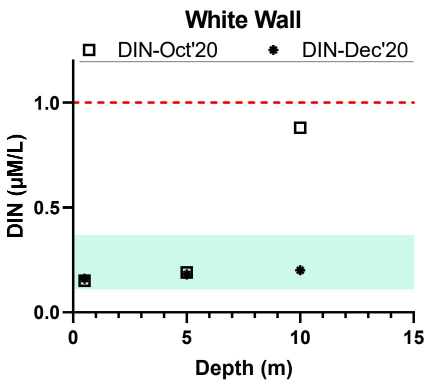

West Nustar
PO4-Oct'20
PO4-Dec'20
PO$_4$ (µM/L)
0.20
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

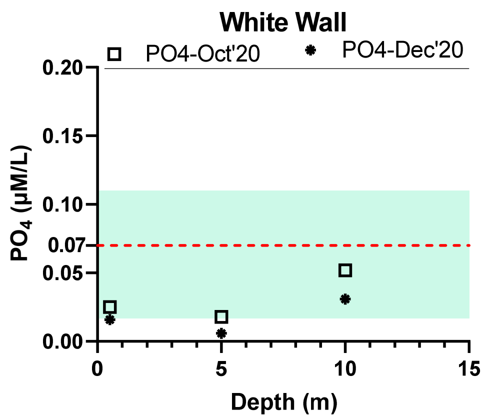

West Nustar
N:P-Oct'20
N:P-Dec'20
N:P ratio
200
150
100
50
30
0
0
5
10
15
Depth (m)

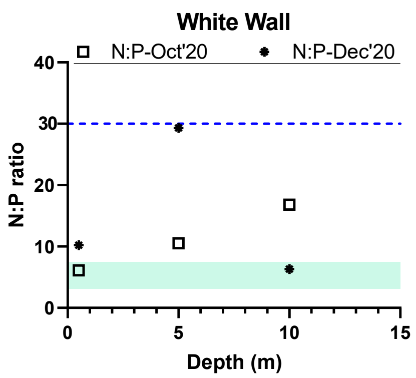

West Nustar
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

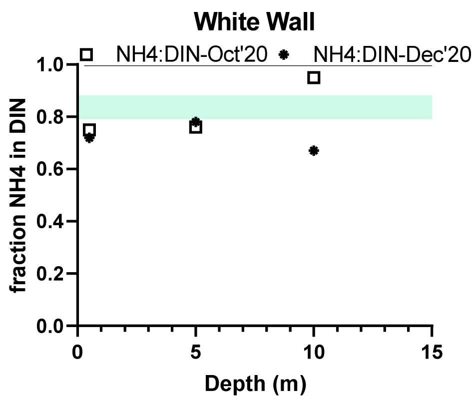

White Wall
NH4-Oct'20
NH4-Dec'20
NH$_4$ (µM/L)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)


White Wall
NO3-Oct'20
NO3-Dec'20
NO$_3$ (µM/L)
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Depth (m)

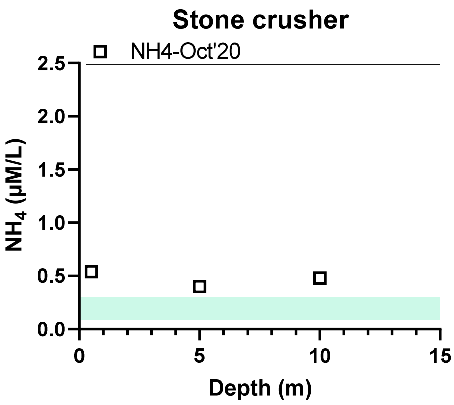

White Wall
DIN-Oct'20
DIN-Dec'20
DIN (µM/L)
1.0
0.5
0.0
0
5
10
15
Depth (m)

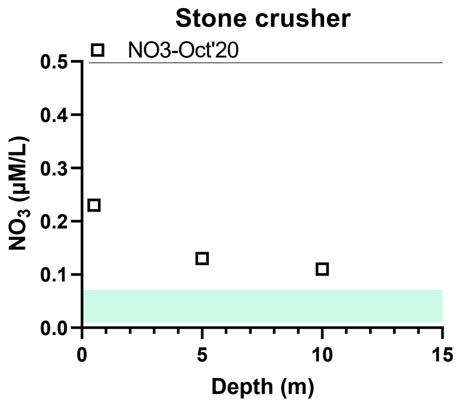

White Wall
PO4-Oct'20
PO4-Dec'20
PO$_4$ (µM/L)
0.20
0.15
0.10
0.07
0.05
0.00
0
5
10
15
Depth (m)

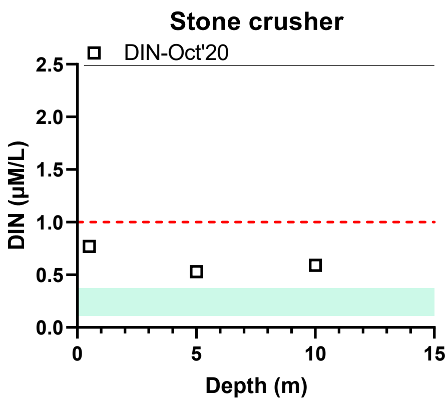

White Wall
N:P-Oct'20
N:P-Dec'20
N:P ratio
40
30
20
10
0
0
5
10
15
Depth (m)

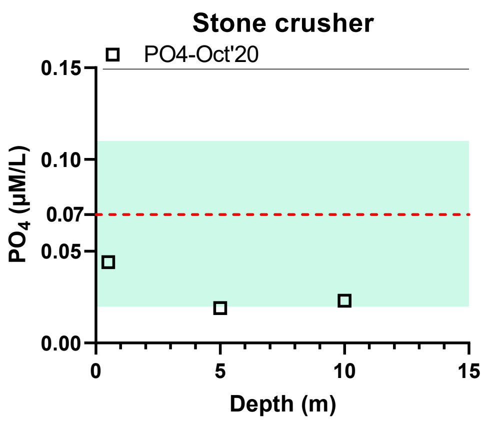

White Wall
NH4:DIN-Oct'20
NH4:DIN-Dec'20
fraction NH4 in DIN
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Depth (m)

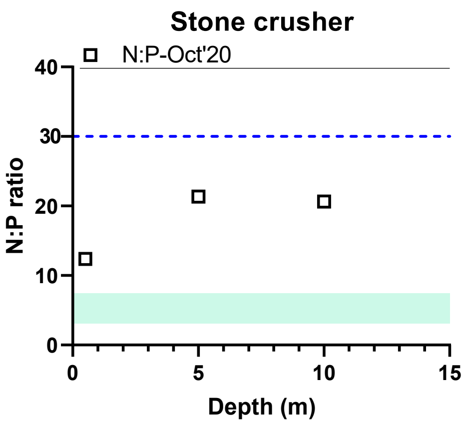
ANNEX 3: Individual datapoints Saba

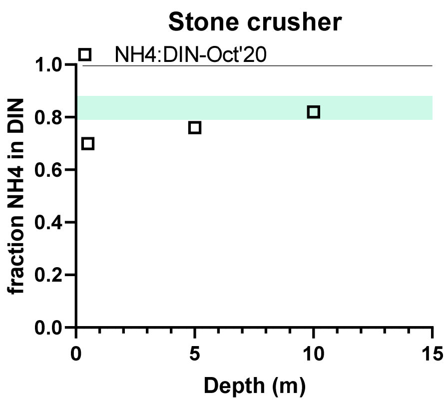


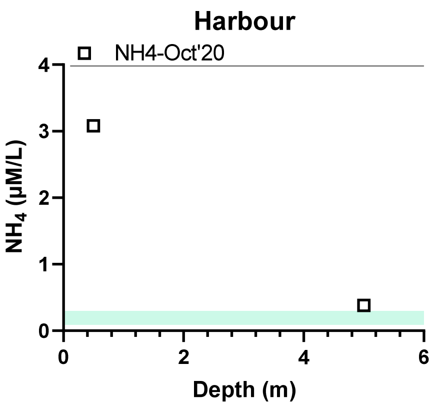


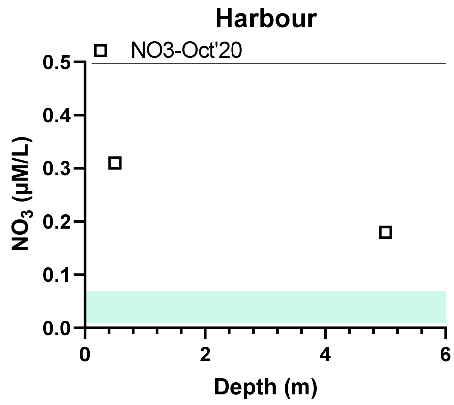


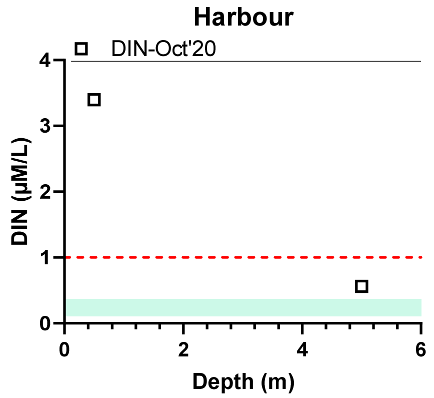


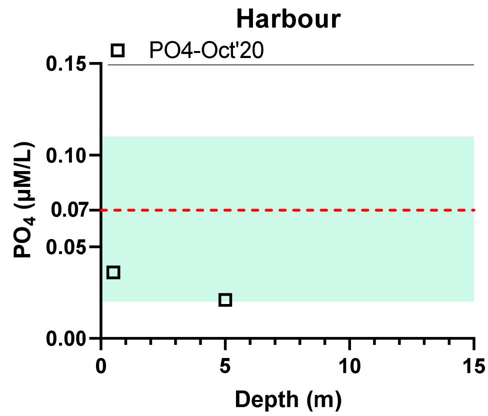


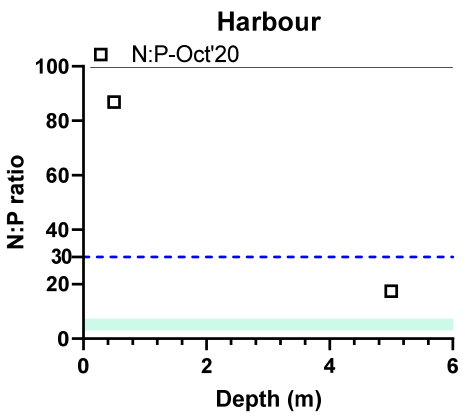


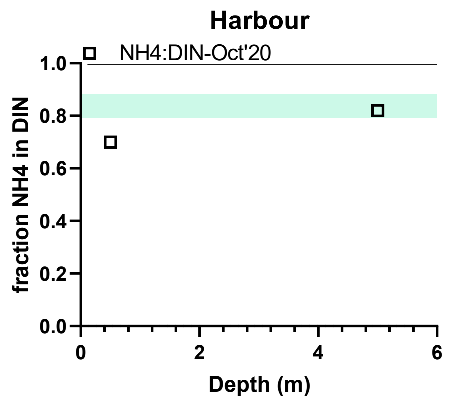

Harbour
NH4-Oct'20
NH4 (µM/L)
Depth (m)
0
1
2
3
4
0
2
4
6

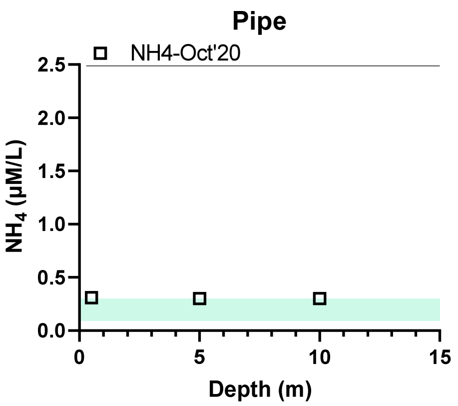

Harbour
NO3-Oct'20
NO3 (µM/L)
Depth (m)
0.0
0.1
0.2
0.3
0.4
0.5
0
2
4
6

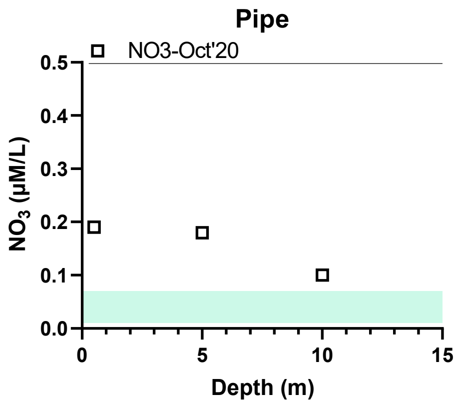

Harbour
DIN-Oct'20
DIN (µM/L)
Depth (m)
0
1
2
3
4
0
2
4
6

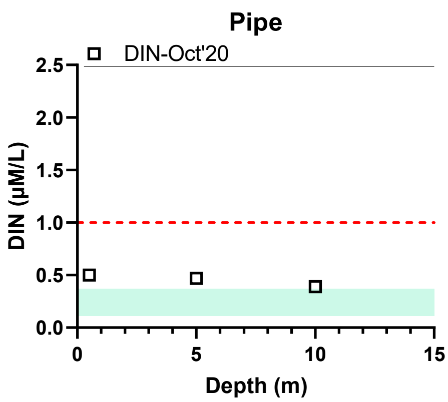

Harbour
PO4-Oct'20
PO4 (µM/L)
Depth (m)
0.00
0.05
0.07
0.10
0.15
0
5
10
15

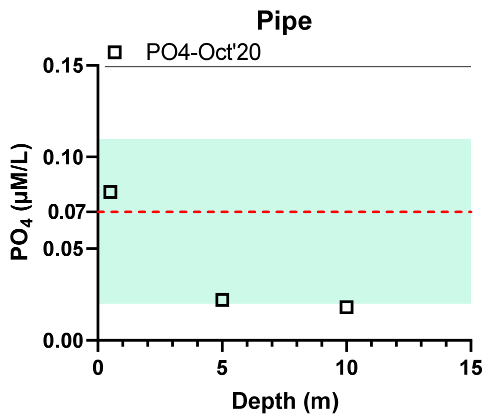

Harbour
N:P-Oct'20
N:P ratio
Depth (m)
0
20
30
40
60
80
100
0
2
4
6

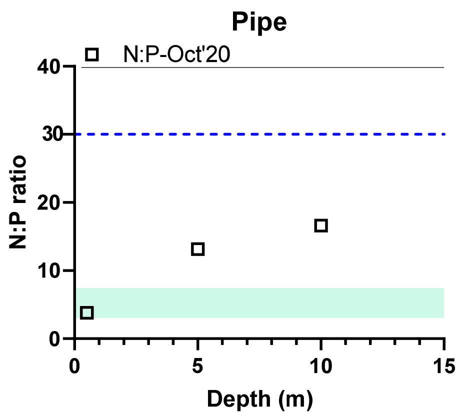

Harbour
NH4:DIN-Oct'20
fraction NH4 in DIN
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
0
2
4
6

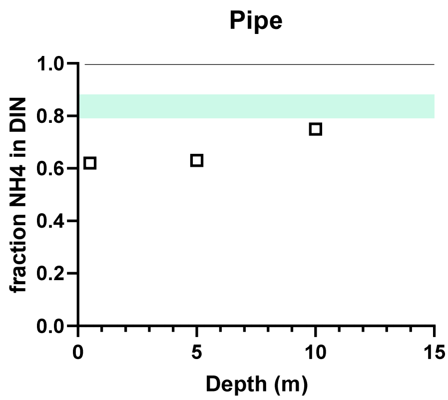

Pipe
NH4-Oct'20
NH4 (µM/L)
Depth (m)

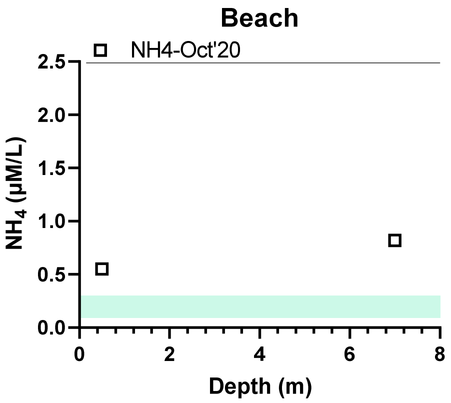

Pipe
NO3-Oct'20
NO3 (µM/L)
Depth (m)

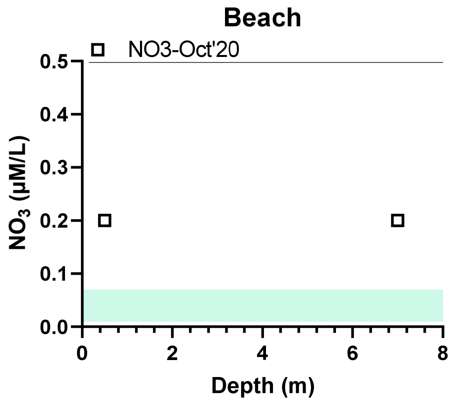

Pipe
DIN-Oct'20
DIN (µM/L)
Depth (m)

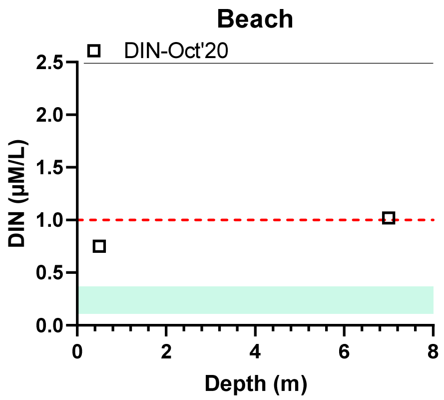

Pipe
PO4-Oct'20
PO4 (µM/L)
Depth (m)

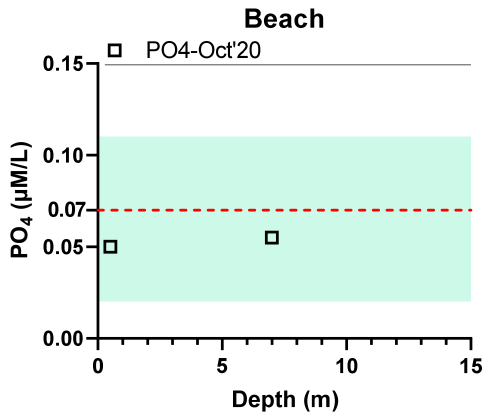

Pipe
N:P-Oct'20
N:P ratio
Depth (m)

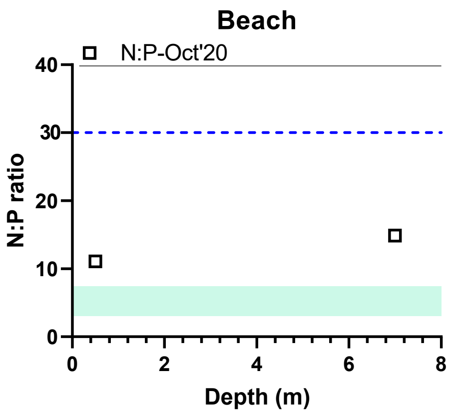

Pipe
fraction NH4 in DIN
Depth (m)

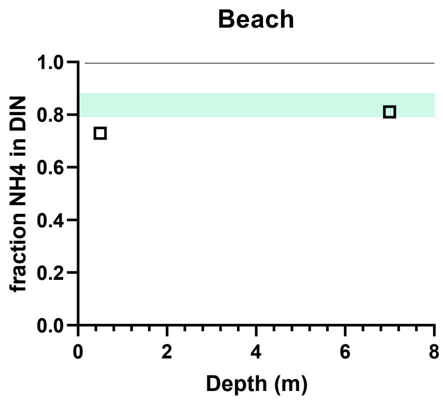

Beach
NH4-Oct'20
NH4 (µM/L)
Depth (m)


Beach
NO3-Oct'20
NO3 (µM/L)
Depth (m)


Beach
DIN-Oct'20
DIN (µM/L)
Depth (m)


Beach
PO4-Oct'20
PO4 (µM/L)
Depth (m)


Beach
N:P-Oct'20
N:P ratio
Depth (m)


Beach
fraction NH4 in DIN
Depth (m)

ANNEX 4: Raw data Bonaire

	Depth	PO4		NH4		NO3+NO2		Inorg N		TN		TOC	
Name	m	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20
18th Palm	0.5	0.021		0.302		0.161		0.463					
18th Palm	0.5	0.021		0.341		0.161		0.502					
18th Palm	0.5	0.031		2.759		0.39		3.149					
18th Palm	0.5		0.021		0.213		0.122		0.335		4.7		86
18th Palm	10	0.019		0.169		0.113		0.282					
18th Palm	10	0.018		0.218		0.115		0.333					
18th Palm	10		0.017		0.246		0.092		0.338		5.7		118.9
18th Palm	10		0.018		0.208		0.088		0.296				
Airport	0.5	0.023		0.281		0.153		0.434					
Airport	0.5	0.017		0.399		0.211		0.61					
Airport	10	0.022		0.385		0.432		0.817					
Airport	10	0.02		0.364		0.461		0.825					
Airport	8	0.014		0.391		0.262		0.653					
Airport	8	0.013		0.338		0.281		0.619					
Airport	0.5	0.009		0.342		0.147		0.489					
Airport	10		0.01		0.117		0.05		0.167		6.3		88.7
Airport	8		0.014		0.222		0.189		0.411		5.8		98.1
Airport	0.5		0.015		0.28		0.253		0.533		5		84.7
Airport	0.5		0.012		1.719		0.184		1.903		6.3		97.5
Airport	8		0.017		0.214		0.178		0.392				
Airport	10		0.009		0.205		0.058		0.263				
Angel City	10	0.017		0.275		0.227		0.502					
Angel City	7	0.011		0.281		0.181		0.462					
Angel City	0.5	0.013		0.377		0.209		0.586					
Angel City	7		0.015		0.218		0.184		0.402		6.1		92.5
Angel City	10		0.017		0.249		0.186		0.435		5.4		94
Angel City	7		0.018		0.237		0.191		0.428		4.9		75.1
Angel City	0.5		0.011		0.308		0.152		0.46		4.9		74.6
Angel City	0.5										5.7		91.2
Angel City	50										5.4		74.7
Cliff	10	0.011		0.25		0.254		0.504		4.9		73.5	
Cliff	0.5	0.012		1.22		0.192		1.412		4.6		75.3	
Cliff	10	0.136		0.646		0.264		0.91					
Cliff	0.5		0.009		0.155		0.128		0.283				
Cliff	10										5.4		79.5
Ebo's Special	0.5	0.011		1.075		0.249		1.324		4.6		77.9	
Ebo's Special	5	0.031		1.365		0.323		1.688		4.3		74	
Ebo's Special	5	0.014		1.804		0.281		2.085					
Ebo's Special	10		0.013		0.154		0.07		0.224		5.2		86
Ebo's Special	5		0.016		0.12		0.07		0.19				
Ebo's Special	10		0.013		0.134		0.065		0.199				
Ebo's Special	0.5		0.016		0.175		0.131		0.306				
Ebo's Special	0.5		0.013		0.142		0.131		0.273				
Ebo's Special	10		0.011		0.359		0.222		0.581				
Front Porch	10	0.008		0.132		0.025		0.157		4.9		82.8	
Front Porch	0.5	0.015		0.196		0.077		0.273		5.4		75.9	
Front Porch	7	0.008		0.192		0.052		0.244		4.7		80.4	
Front Porch	0.5	0.009		0.174		0.064		0.238					
Front Porch	0.5		0.012		0.191		0.107		0.298		5		99.3
Front Porch	7		0.023		0.218		0.389		0.607				
Front Porch	7		0.019		0.258		0.454		0.712				
Front Porch	0.5										4.3		90
Front Porch	9										5.7		98.2
Front Porch	9										4		82.2
Front Porch	10										4.5		94
Karpata	0.5	0.012		0.351		0.126		0.477		5.3		87.1	
Karpata	7	0.018		0.883		0.359		1.242					
Karpata	10									4.7		75.3	
Karpata	10									4.9		75.6	
Karpata	10		0.019		0.194		0.333		0.527		5.8		87.6
Karpata	0.5		0.025		0.291		0.411		0.702		5.2		80.4
Karpata	7		0.022		0.417		0.411		0.828		4.2		73.7
Karpata	0.5		0.022		0.284		0.403		0.687				
Karpata	10		0.014		0.192		0.306		0.498				
Karpata	7										18.9		251.7

	Depth	PO4		NH4		NO3+NO2		Inorg N		TN		TOC	
Name	m	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20
No-Dive Reserve	0.5	0.016		0.302		0.17		0.472		5.6		95.6	
No-Dive Reserve	5	0.011		0.325		0.21		0.535		6.1		85.3	
No-Dive Reserve	5	0.006		0.235		0.201		0.436		4.2		80.4	
No-Dive Reserve	0.5	0.024		0.466		0.186		0.652					
No-Dive Reserve	10	0.016		0.478		0.119		0.597					
No-Dive Reserve	10		0.009		0.135		0.109		0.244		5.5		86.7
No-Dive Reserve	0.5		0.015		0.285		0.223		0.508		5		92.4
No-Dive Reserve	5		0.015		0.191		0.341		0.532		5.2		82.3
No-Dive Reserve	10		0.012		0.142		0.121		0.263				
Playa Funchi	10	0.021		0.216		0.03		0.246		5.2		85.3	
Playa Funchi	0.5	0.016		0.239		0.101		0.34					
Playa Funchi	10									5.6		88.6	
Playa Funchi	10		0.015		0.089		0.034		0.123		4.7		86.9
Playa Funchi	0.5		0.017		0.208		0.111		0.319		5.4		75.9
Playa Funchi	0.5										7.6		106
Playa Funchi	10										5.6		95.8
Playa Lechi	12	0.015		0.14		0.018		0.158		4.7		80	
Playa Lechi	10	0.014		0.097		0.023		0.12					
Playa Lechi	0.5	0.018		0.138		0.04		0.178					
Playa Lechi	0.5		0.015		0.251		0.073		0.324		4.4		87.8
Playa Lechi	12		0.023		0.366		0.338		0.704		4.7		80
Playa Lechi	10		0.013		0.162		0.036		0.198				
Playa Lechi	12										4.8		86
Red Slave	10	0.011		0.243		0.06		0.303		5		78.5	
Red Slave	16	0.055		0.476		0.124		0.6		5		76.6	
Red Slave	0.5	0.019		0.207		0.049		0.256					
Red Slave	10	0.015		0.165		0.065		0.23					
Red Slave	10		0.025		0.136		0.068		0.204		5		92.4
Red Slave	10		0.021		0.16		0.058		0.218		4.6		87.6
Red Slave	0.5		0.021		0.224		0.124		0.348		6.7		105.1
Red Slave	0.5		0.021		0.27		0.115		0.385		5.1		91.1
Red Slave	0.5		0.02		0.434		0.059		0.493				
Red Slave	8		0.018		0.299		0.213		0.512				
Red Slave	16										5		86.9
Red Slave	16										4.6		91.4
Salt Pier	0.5	0.048		1.536		0.18		1.716					
Salt Pier	10	0.008		0.342		0.066		0.408					
Salt Pier	7	0.005		0.472		0.229		0.701					
Salt Pier	7	0.001		0.844		0.202		1.046					
Salt Pier	0.5	0		0.479		0.148		0.627					
Salt Pier	0.5		0.006		0.249		0.132		0.381		5.2		82.1
Salt Pier	10		0.013		0.254		0.33		0.584		4.8		87.4
Salt Pier	7		0.013		0.337		0.437		0.774		6.3		82.8
Salt Pier	7		0.011		0.374		0.434		0.808		5.7		86.3
South Bay	10	0.008		0.192		0.047		0.239					
South Bay	0.5	0.011		0.447		0.149		0.596					
South Bay	11	0.004		0.266		0.084		0.35					
South Bay	10	0.001		0.692		0.055		0.747					
South Bay	11	0.001		2.337		0.098		2.435					
South Bay	0.5									5.6		77.9	
South Bay	11									4.4		77.6	
South Bay	11									4.1		78.2	
South Bay	10		0.002		0.291		0.146		0.437		4.7		91.4
South Bay	0.5		0.009		0.241		0.181		0.422				
South Bay	7		0.003		0.312		0.253		0.565				
South Bay	10										4.4		89.9
Tori's reef	0.5	0.013		0.351		0.074		0.425		4.9		76.9	
Tori's reef	10	0.024		0.373		0.185		0.558		4.8		80.5	
Tori's reef	0.5	0.014		0.429		0.078		0.507					
Tori's reef	8	0.012		0.367		0.107		0.474					
Tori's reef	10									4.6		76.5	
Tori's reef	10		0.015		0.199		0.125		0.324		6.6		90.2
Tori's reef	10		0.011		0.2		0.124		0.324		5.3		89.6
Tori's reef	0.5		0.014		0.246		0.098		0.344		4.3		77.1
Tori's reef	8		0.015		0.336		0.386		0.722		5.4		94
Tori's reef	8		0.008		0.324		0.345		0.669		5		86.2
Tori's reef	0.5		0.014		0.247		0.088		0.335				

ANNEX 5: Raw data St Eustatius

	Depth	PO4		NH4		NO2+NO3		DIN	
	m	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20
Blue Ocean	0.5	0.107		0.30		0.07		0.37	
Blue Ocean	5	0.031		0.14		0.02		0.16	
Blue Ocean	10	0.041		0.11		0.02		0.13	
Blue Ocean	0.5		0.024		0.13		0.02		0.14
Blue Ocean	5		0.017		0.09		0.01		0.11
Blue Ocean	10		0.017		0.10		0.03		0.13
Charlie Brown	0.5	0.064		0.46		0.29		0.75	
Charlie Brown	5	0.064		0.96		0.31		1.27	
Charlie Brown	10	0.016		0.20		0.23		0.43	
Charlie Brown	0.5		0.017		0.12		0.08		0.20
Charlie Brown	5		0.015		0.09		0.08		0.17
Charlie Brown	10		0.021		0.09		0.11		0.20
Corre Corre	0.5	0.053		0.30		0.29		0.60	
Corre Corre	0.5		0.003		0.77		0.21		0.98
Double wreck	0.5	0.051		0.18		0.06		0.24	
Double wreck	5	0.021		0.19		0.08		0.26	
Double wreck	10	0.034		0.16		0.15		0.30	
Double wreck	0.5		0.050		1.18		0.05		1.23
Double wreck	5		0.019		0.12		0.04		0.17
Double wreck	10		0.023		0.15		0.04		0.19
Drop off	0.5		0.022		0.15		0.21		0.36
Drop off	5		0.024		0.24		0.22		0.45
Drop off	10		0.023		0.26		0.25		0.51
Drop Off	0.5	0.023		0.20		0.12		0.32	
Drop Off	5	0.038		0.16		0.11		0.27	
Drop Off	10	0.015		0.19		0.12		0.31	
Dump	0.5	0.045		0.46		0.66		1.12	
Dump	0.5		0.023		0.23		0.17		0.41
Flat	0.5	0.015		0.11		0.03		0.14	
Flat	5	0.035		0.15		0.03		0.18	
Flat	10	0.050		0.11		0.05		0.16	
Flat	5		0.120		0.20		0.02		0.22
Flat	10		0.015		0.11		0.01		0.13
Harbour	0.5	0.031		0.39		0.49		0.88	
Harbour	5	0.075		0.29		0.31		0.60	
Harbour	0.5		0.016		0.37		1.05		1.42
Harbour	5		0.039		0.29		0.57		0.87
Jenkins bay	0.5	0.100		0.15		0.13		0.28	
Jenkins bay	5	0.098		0.16		0.10		0.26	
Jenkins bay	10	0.035		0.21		0.25		0.46	
Jenkins bay	0.5		0.017		0.18		0.20		0.37
Jenkins bay	5		0.021		0.18		0.15		0.33
Jenkins bay	10		0.019		0.15		0.17		0.32
Kay Bay	0.5	0.040		0.32		0.31		0.63	
Kay Bay	5	0.036		0.31		0.34		0.65	
Kay bay	0.5		0.018		0.93		0.28		1.21
Kay bay	5		0.036		0.96		0.40		1.35

	Depth	PO4		NH4		NO2+NO3		DIN	
	m	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20	Oct'20	Dec'20
Lagoon	0.5	0.067		0.41		0.12		0.53	
Lagoon	5	0.050		0.18		0.10		0.28	
Lagoon	10	0.036		0.13		0.08		0.21	
Lagoon	0.5		0.016		0.16		0.08		0.24
Lagoon	5		0.022		0.13		0.13		0.26
Lagoon	10		0.009		0.11		0.07		0.19
Nustar	0.5	0.185		0.24		0.23		0.47	
Nustar	5	0.381		0.16		0.16		0.32	
Nustar	0.5		0.014		0.14		0.06		0.20
Nustar	5		0.049		0.14		0.07		0.21
Old gin house	0.5	0.062		1.22		9.18		10.40	
Old gin house	0.5		0.023		0.88		7.93		8.81
Scubaqua	0.5	0.043		0.23		0.20		0.43	
Scubaqua	0.5		0.047		0.63		4.34		4.97
Smoke Alley	0.5	0.027		0.32		0.69		1.01	
Smoke Alley	0.5		0.019		7.50		0.24		7.74
Stenapa reef	0.5	0.025		0.12		0.09		0.21	
Stenapa reef	5	0.043		0.14		0.10		0.24	
Stenapa reef	10	0.213		0.29		0.19		0.49	
Stenapa reef	0.5		0.022		0.12		0.04		0.16
Stenapa reef	5		0.020		0.13		0.04		0.18
Stenapa reef	10		0.019		0.14		0.04		0.17
Stuco	0.5	0.169		0.69		45.1		45.82	
Stuco	0.5		0.151		2.91		68.5		71.37
West Jenkin's	0.5	0.066		0.13		0.07		0.20	
West Jenkin's	5	0.022		0.15		0.03		0.18	
West Jenkin's	10	0.243		0.26		0.07		0.33	
West Jenkin's	0.5		0.000		0.78		0.06		0.85
West Jenkin's	5		0.016		0.23		0.02		0.25
West Jenkin's	10		0.023		0.12		0.02		0.13
West Nustar	0.5	0.089		0.12		0.03		0.14	
West Nustar	5	0.121		0.18		0.05		0.22	
West Nustar	10	0.046		0.15		0.08		0.23	
West Nustar	0.5		0.017		0.24		0.01		0.25
West Nustar	5		0.024		0.11		0.02		0.12
West Nustar	10		0.001		0.16		0.01		0.17
White Wall	0.5	0.025		0.12		0.04		0.15	
White Wall	5	0.018		0.14		0.05		0.19	
White Wall	10	0.052		0.83		0.05		0.88	
White Wall	0.5		0.016		0.12		0.05		0.16
White Wall	5		0.006		0.14		0.04		0.18
White Wall	10		0.031		0.13		0.07		0.20

ANNEX 6: Raw data Saba

	depth	PO4	NH4	NO3	DIN
	m	Oct'20	Oct'20	Oct'20	Oct'20
Stone Crusher	0.5	0.044	0.54	0.23	0.77
Stone Crusher	10	0.023	0.48	0.11	0.59
Stone Crusher	5	0.019	0.40	0.13	0.53
Harbour	0.5	0.036	3.08	0.31	3.40
Harbour	5	0.021	0.38	0.18	0.56
Pipe	0.5	0.081	0.31	0.19	0.50
Pipe	10	0.018	0.30	0.10	0.39
Pipe	5	0.022	0.30	0.18	0.47
Beach	0.5	0.050	0.55	0.20	0.75
Beach	7	0.055	0.82	0.20	1.02

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