Effects of populated towns on water quality in neighboring Galàpagos bays

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Non-Technical Summary

Human activities profoundly influence the global cycles of nutrient transport coastal waters. Because of this, dissolved nutrient levels were studied in three Galàpagos Island bays (Academy Bay, Turtle Bay, and Wreck Bay) adjacent to the largest population centers and in one bay with no adjacent inhabitants (Cartago Bay), to characterize water quality within each bay. Water column and sediment samples were collected on the *R/V Thomas G. Thompson* during 20-28 January 2006 and nitrate, ammonium, and phosphate concentrations determined. Salinity, oxygen, and temperature measurements were also made and nutrient concentrations were divided by salinity, normalizing samples to enable direct comparison between sites. If waste products from the population centers have any effects on the water quality, then the salinity-normalized concentrations of nitrate, ammonium, and phosphate would be expected to be greater in these bays than the uninhabited one. All populated bays had an increase in at least one of the three nutrients compared with the control. In particular, Wreck Bay exhibited some of the largest nutrient increases in comparison to Cartago Bay; it also had a greater decrease in oxygen availability compared with other bays. These data support the hypothesis that contributions from the population centers are already present. These observations can serve as a baseline to aid estimates of future nutrient contributions from the growing population and tourist activities within the Galàpagos Islands.

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Abstract

Anthropogenic activities profoundly influence the global cycles of nutrient transport to estuaries and other coastal waters. Because of this, dissolved nutrient levels were studied in three Galàpagos Island bays (Academy Bay, Turtle Bay, and Wreck Bay) adjacent to the largest population centers (Puerto Ayora, Puerto Villamil, and Puerto Baquerizo Moreno, respectively) and in one bay with no adjacent inhabitants (Cartago Bay), to characterize water quality within each bay. Water column and sediment pore-water samples were collected on the *R/V Thomas G. Thompson* during 20-28 January 2006. Macronutrient analyses were performed to determine anthropogenic contributions to nitrate, ammonium, and phosphate concentrations. Salinity, oxygen, and temperature measurements were also made and nutrient concentrations were normalized to salinity, to enable direct comparison between sites. If anthropogenic effects were present, salinity-normalized concentrations of nitrate, ammonium, and phosphate would be expected to be greater in bays associated with human population and/or tourism. All populated bays had an increase in at least one of the three nutrients compared with the control. In particular, Wreck Bay exhibits some of the largest nutrient increases in comparison to Cartago Bay; it also had a greater decrease in oxygen percent saturation than all other bays. These data support the hypothesis that anthropogenic contributions are already present. These observations can serve as a baseline to aid estimates of future nutrient contributions from the growing population and tourist activities within the Galàpagos Islands.

Introduction

Anthropogenic activities profoundly influence the global cycles of nutrient transport to estuaries and other coastal waters. Increased nitrogen and phosphorus concentrations within a marine environment can affect the marine ecosystem in several ways, for example, by favoring certain species, thus altering the phytoplankton, zooplankton, and benthic communities (as well as the overall diversity) in the system (Howarth et al. 2000). Such changes may alter entire food webs within island bays. Increased primary production due to nutrient loading can lead to eutrophication (Howarth et al. 2000). Eutrophication in turn may result in depleted oxygen levels within deeper waters, potentially creating "dead zones" and causing fish deaths. Increased nutrient concentrations within sediment pore-waters could eventually lead to changes in plant diversity as well, it is generally assumed that root uptake from sediments is the favored nutrient source for aquatic plants (McGlathery et al. 2001).

Dramatic increases in both population growth and tourist visits suggest the Galàpagos Islands (Figure 1) may be susceptible to nutrient enrichment in bays adjacent to commercial and tourist centers. Tourist growth in the Galàpagos rose from a little over 4,000 per year in 1970 to about 60,000 per year in 1997 (Boyce 1998). The Galàpagos population increased from about 1,500 people in 1950 to approximately 16,000 people in 1998, with an estimated growth rate of about 12 percent per year (Boyce 1998). As of 2005, the Galàpagos has a resident population of >27,000 and is visited by ~100,000 tourists per year (Boersma et al. 2005). Inhabitants who have moved to the Islands within the past 5-10 years (MacFarland and Cifuentes 1996) often sought profit with little regard to impacts made to the Galàpagos's marine (or terrestrial) environment.

Human populations and tourism within the islands can also have a large impact on port waters. Open garbage dumps near port towns are a major source of pollutants to nearby bays, including potential nutrient enriching components (MacFarland and Cifuentes 1996). The amount of solid waste has rapidly increased over the past decade, especially waste thrown overboard from vessels (MacFarland and Cifuentes 1996). Ammonium concentrations may be enhanced by untreated sewage (from either boats or land). Sewage released into bays could also introduce microbial contamination. NO_x ($NO+NO_2$) emissions from ships may contribute to the increase of nitrogen oxide concentrations within the Marine Boundary Layer (air column up to 5km above sea level; Kasibhatla et al. 2000). Once converted to nitric acid (HNO_3) via the nitrogen cycle, it can be wet deposited into bays potentially increasing nitrate concentrations. Agriculture could have a role in increasing nutrient concentrations due to fertilizer runoff and increased erosion from land alterations. This could contribute to water contaminations through direct terrestrial runoff or, indirectly, through atmospheric wind transport (Howarth et al. 2000).

In order to determine anthropogenic nutrient contributions, the water column and sediment pore-water in bays near towns were examined. Puerto Ayora (Figure 1), with ~10,000 residents, has the highest population of the five inhabited islands. It is also considered the commercial and tourist center of the archipelago (Constant 1995). The majority of all cruises and tourist activities are based out of Puerto Ayora (including ours). This heavy boat traffic could increase nitrate concentrations as mentioned above. Academy Bay, adjacent to Puerto Ayora, should show an increase in nutrient concentration compared to the control, an unpopulated bay, if there are any anthropogenic contributions.

The second largest population and tourist center, as well as the capital of the Galàpagos Islands, is located on San Cristobal Island. Puerto Baquerizo Moreno (Figure 1) has approximately 8,000 inhabitants. San Cristobal's main port, bordering Puerto Baquerizo Moreno, is Bahia Naufragio, also known as Wreck Bay. This is also the grounding site of the fuel tanker *Jessica*. Contaminants from this spill affected some of the vertebrate species living close to the coast (Lougheed et al. 2002). These changes could potentially alter food webs, creating a top-down trophic cascade ultimately affecting nutrient utilization and thus concentrations. Like Puerto Ayora, Puerto Baquerizo Moreno has heavy boat traffic within its neighboring bay.

Puerto Villamil (Figure 1) is on one of the least inhabited islands, Isabela. It is a fishermen's village with a population of around 2,000 residents, most engaged in fishing or agriculture (Boyce 1998). Turtle Bay, adjacent to Puerto Villamil, may therefore be influenced by agricultural contaminants and fishing waste.

An unpopulated bay, otherwise having similar hydrographic characteristics (temperature, salinity, and currents) to the three bays already described was desirable as a control site. For comparative purposes, the Galàpagos can be divided into five biogeographic units (Figure 1), following Harris (1969) and Bustamante et al. (2002). Figure 1 shows that Turtle Bay and Academy Bay lie within the mixed subtropical region, while Wreck Bay lies within the cold subtropical region. However, the surface water temperatures measured in October and November around the Galàpagos Islands show that temperatures between mixed and cold subtropical regions are actually nearly identical, allowing a bay within the mixed subtropical region to serve as an adequate control (Sakamoto et al. 1997). The zoning map of Galàpagos National Park, showing areas on the islands that are uninhabited (Constant 1995), and above maps were used to determine that Cartago Bay (Figure 1, Figure 3B) on Isabela, has suitable characteristics for comparison with populated bay areas. Figure 2 and Figure 3A show sample locations chosen within populated bays, to determine spatial changes in nutrient concentrations with distance from the selected towns. Table 1 is a complete list of *R/V Thomas G. Thompson* and zodiac workboat sampling locations.

If anthropogenic effects were present then nitrate, ammonium, and phosphate would be expected to have increased concentrations in bays associated with human populations and/or tourism. Comparison of the three experimental bays' nitrate, ammonium, and phosphate concentrations (normalized to salinity) was used to determine anthropogenic effects. Significantly larger ratios than determined in the control bay were interpreted as evidences that anthropogenic inputs are regionally significant.

This study was done in collaboration with Ecuadorian scientists, Ana Rodriguez and Maria Carmen Gamboa, who also were examining water quality in coastal bays. Additionally, two Ecuadorian biologists, Maria Elena Tapia and Christian Naranjo, examined phytoplankton and zooplankton assemblages, in particular whether unwanted and/or toxic species were present. These Ecuadorian studies complement mine by strengthening the argument about the sources and effects of nutrient input.

Methods

In order to determine anthropogenic nutrient contributions, water column and sediment pore-water samples were collected and analyzed aboard the *R/V Thomas G. Thompson* and a zodiac workboat during the 20-28 January 2006 cruise in the Galàpagos Islands. Samples were then analyzed for nitrate, ammonium, and phosphate concentrations. I conducted the nitrate and ammonium analyses, with the help of Llyd Wells, while Dickson (2006) performed the phosphate analyses.

Water samples were collected at three depths (surface, middle, and bottom), spanning the water column at each location. Aboard *R/V Thomas G. Thompson*, water samples were collected using the CTD. Salinity, temperature, and oxygen concentrations were obtained from the CTD electrodes, and averaged for the surface layer. CTD oxygen and salinity calibrations were made in collaboration with Gilmore (2006) and Ocampo (2006), respectively. The oxygen percent saturation was determined from salinity and temperature measurements in accordance with Table 6 in Riley and Skirrow (1975). Sediment pore-water samples were collected by first using a 0.1 m^2 Van Veen Grab Sampler to collect the upper portion of sediment. From this, four sediment samples were taken and placed into 50 ml centrifuge tubes. Samples were balanced and centrifuged for 5 minutes at ~3000 rpm, the maximum safe speed of the centrifuge. Pore-waters were drawn off and combined, then transferred to acid-rinsed, amber bottles for analysis. Pore-waters were analyzed only for ammonium concentrations.

For stations shallower than 20 m, a zodiac workboat along with a hand-held GPS system was used to reach sample locations. Water samples were collected using a hand-lowered Niskin bottle sampler, at collection depths determined above. Sediment pore-waters were collected as above, with the exception that a smaller hand-lowered 0.025 m^2 Van Veen Grap Sampler was used.

Nitrate Analyses. Samples were mixed with imidizole and passed through a cadmium column to reduce nitrate (NO_3) to nitrite (NO_2) on a single channel auto-analyzer. NO_3 and NO_2 concentrations were then determined through absorbance values caused by reactant solution turning pink when mixed with N-(1-Napthyl)-ethylenediamine dihydrochloride (N1N). Working stocks of 0.6 mol L^{-1} sulfanilamide in 10% hydrochloric acid (HCl), $4x10^{-3}$ mol L^{-1} N1N, 0.05 mol L^{-1} Imidazole buffer, and $CuSO_4$ + NH_4Cl mix were prepared as directed by Krogslund and

Morello (2006). All solutions were kept at room temperature in appropriate bottles throughout the cruise. A primary standard of 100 mmol L^{-1} KNO_3 was prepared and kept refrigerated; further standards were made from dilutions of it.

A blank and four standard concentrations were made fresh in low nutrient seawater (LNSW), according to Krogslund and Morello (2006). A Spectronic 301 Spectrophotometer was used to measure absorbance at 543 nm wavelength, following a >45 minute warm-up period. The sequence of steps is given by Krogslund and Morello (2006). First, standards were run in triplicate, starting with the lowest concentration. Each location was started with a "lead-in" sample (a duplicate of the first sample) and preceded from surface to bottom. A LNSW and 12 μmol L^{-1} standard were run between inshore and offshore locations, as well as different bays, to account for drifts cause by the machine. Final concentrations of samples were determined from a standard curve relating absorbance to known NO_3 concentrations.

Ammonium Analyses. Ammonium was analyzed according to Holmes et al. (1999) methods. Their method involves use of a working reagent (WR) which contained sodium sulfite solution, borate buffer solution, and orthophthaldialdehyde (OPA) solution. Samples were collected by first rinsing amber bottles with sample water, and then filling them with the sample water. 10 ml were then transferred to a separate amber bottle (cleaned as above), 2.5 ml WR were added, the bottle was mixed, and then stored in a cool, dark place for 2-3 hours. After this interval to allow color development, standards and samples were poured into test tubes and immediately read on a Turner 10-AU fluorometer with a 350 nm interference excitation filter and a 410-600 nm combination emission filter. Concentrations were calculated as stated in Holmes et al. (1999). Sediment samples were run as above; with the exception that they were diluted 1:10 and 1:50 to allow higher values to fall within the standard curve.

Phosphate Analyses (Preformed by T. Dickson). Samples to be analyzed for dissolved phosphate were kept in polyethylene bottles that had been rinsed three times before being filled with sample water. Ammonium molybdate solution, sulfuric acid solution, ascorbic acid solution, and potassium antimonyl-tartrate solution were made up according to Strickland and Parsons methods (Parsons et al. 1984). These solutions were then used to make the mixed reagent solution, which were added to the sample. Once the sample and mixed reagent solution had sat for at least 5 minutes, for color development, absorption was measured at 885 nm and corrected for the reagent blank.

Samples were analyzed from a total of 26 stations within four bays (Table 1). All of these stations had samples collected at three depths with the exception of AB-Inshore1 and AB-Offshore3, where bottom samples could not be analyzed due to instrument or human error.

Results

Each bay had its own set of characteristics, as well as some trends that were similar amongst the multiple bays. Cartago Bay, and to a lesser extent Turtle Bay, proved to be more open and less constricted than the other bays. Because of this, there was more wave action leading to choppier waters. Mangroves lined the shore of Cartago Bay, and contributed drifting leaves and terrestrial plant debris to the bay. Organic debris was noted floating on the surface of other bays as well. Wreck Bay's shallow reefs, located on the outskirts of the bay, amplified existing swell. Because of these reefs, offshore stations were in deeper water than at the other bays. Academy Bay had the most boat traffic within the bays, with Wreck Bay following closely in numbers.

The initial calculated nutrient concentrations were normalized to salinity either obtained directly from CTD casts, or by averaging offshore surface values obtained from the CTD casts to use for inshore stations (Table 2, 3). An average of the top 20 m was used for salinity and temperature estimates within Cartago and Academy Bays, while the average of the top 10 m was used for Turtle and Wreck Bays. These depths were picked based on the average inshore bottom depth of each bay. Inshore samples were averaged for each bay; likewise offshore samples were grouped together. The error in concentrations was determined by calculating the standard error of these averages. The CTD's salinity error was calculated to be ~-0.011 from Ocampo (2006) chemical measurements.

Salinity-normalized nitrate (NO_3^-) values (Figure 4) showed that averaged Academy Bay surface concentrations were similar inshore (~0.20 μmol L^{-1} PSU^{-1}) and offshore (~0.21 μmol L^{-1} PSU^{-1}) and were approximately double those of Cartago Bay's surface waters (~0.10 μmol L^{-1} PSU^{-1}). Wreck Bay's offshore stations also averaged higher than Cartago Bay, ranging between ~0.17-0.25 μmol L^{-1} PSU^{-1}. Turtle Bay and Wreck Bay inshore stations' surface water had no significant difference in comparison with Cartago Bay. At their middle depths, all populated bays had NO_3^- concentrations higher than Cartago Bay (which varied little from its surface values). Academy Bay's middle depth concentrations were also very similar to its surface concentrations, with inshore values of ~0.20 μmol L^{-1} PSU^{-1} and slightly greater offshore (~0.26 μmol L^{-1} PSU^{-1}). Turtle Bay's inshore concentrations measured at ~0.16 μmol L^{-1} PSU^{-1}, while offshore was more comparable to Academy Bay at ~0.23 μmol L^{-1} PSU^{-1}, both of which were increased from surface values. Wreck Bay's inshore stations were only slightly higher than Cartago Bay at ~0.15 μmol L^{-1} PSU^{-1}. However, offshore stations were approximately triple these concentrations ranging from ~0.30-0.45 μmol L^{-1} PSU^{-1}.

With the exception of Turtle Bay's offshore stations, all bays showed an increase in NO_3^- concentrations between middle and bottom depths. All stations, except Academy Bay and

Wreck Bay' offshore stations, had NO_3^- concentrations that fell within either inshore or offshore ranges of Cartago Bay (~0.12-0.18 μmol L^{-1} PSU^{-1} and 0.16-0.25 μmol L^{-1} PSU^{-1} respectively). However, populated inshore stations all had higher concentrations than Cartago Bay's inshore values. Academy Bay offshore had a range ~0.25-0.35 μmol L^{-1} PSU^{-1}, while Wreck Bay offshore was ~0.50-0.54 μmol L^{-1} PSU^{-1}.

Salinity-normalized ammonium (NH_4^+) values (Figure 5) show that, with the exception of Academy Bay offshore (~.008 μmol L^{-1} PSU^{-1}), all populated bays had greater concentrations than the control bay at the surface. Inshore NH_4^+ concentrations were greater than offshore values for all of the populated bays, with the biggest difference being seen in Academy Bay (~0.017 μmol L^{-1} PSU^{-1} inshore). Turtle Bay inshore had the largest concentration of all bays with a range of ~0.017-0.027 μmol L^{-1} PSU^{-1}. As with the NO_3^- concentrations, Cartago Bay's NH_4^+ did not change significantly between surface and middle depths. All populated bays at their middle depths, also, had no significant changes from their surface concentrations. For bottom samples, all inshore stations fell within Cartago Bay's inshore range of ~0.026-0.047 μmol L^{-1} PSU^{-1}. Similarly, all offshore stations were within Cartago Bay's offshore concentrations (~0.013-0.021 μmol L^{-1} PSU^{-1}). Concentrations from all stations were larger than in overlying water, with inshore values still being greater than offshore. Wreck Bay's deeper stations (middle and bottom) still fell within the range of NH_4^+ concentrations seen in the other bays.

Academy Bay and Turtle Bay's surface phosphate (PO_4^-) concentrations were below Cartago Bay's inshore stations (~0.028-0.035 μmol L^{-1} PSU^{-1}). However, they were within the lower half of Cartago Bay's offshore range (~0.020-0.034 μmol L^{-1} PSU^{-1}). This suggests concentrations could actually be decreasing compared to the control bay. Wreck Bay, however, showed much higher concentrations than Cartago Bay. Its inshore and offshore values ranged between ~0.050-0.062 μmol L^{-1} PSU^{-1} and ~0.050-0.078 μmol L^{-1} PSU^{-1}, respectively. At middle depths, Cartago Bay and Academy Bay had similar concentrations, with inshore values (~0.019-0.025 μmol L^{-1} PSU^{-1} and ~0.022-0.027 μmol L^{-1} PSU^{-1}) being smaller than offshore values (~0.042-0.050 μmol L^{-1} PSU^{-1} and ~0.034-0.050 μmol L^{-1} PSU^{-1}). Turtle Bay and Wreck Bay's inshore and offshore concentrations were identical (specific to each bay), although inshore stations show larger errors (greater intra-bay variability). Turtle Bay's concentrations (~0.028 μmol L^{-1} PSU^{-1}) were within Cartago Bay's offshore values, while Wreck Bay's concentrations (~0.070-0.080 μmol L^{-1} PSU^{-1} inshore and ~0.072-0.077 μmol L^{-1} PSU^{-1} offshore) were greater than these values. In bottom samples, both Academy Bay and Turtle Bay's PO_4^- concentrations were below all Cartago Bay values, with the smallest difference being ~0.010 μmol L^{-1} PSU^{-1}. Wreck Bay's inshore stations were larger than inshore concentrations in Cartago Bay having a range of ~0.085-0.10 μmol L^{-1} PSU^{-1}. Wreck Bay offshore stations ranged from ~0.15-0.17 μmol L^{-1} PSU^{-1}, which was much larger than all other bays. Two of Wreck Bay's deeper bottom samples were associated with high PO_4^- concentrations, while the rest of the samples were within a common range of concentrations.

Oxygen concentrations were obtained from offshore CTD casts and converted to percent saturation (Table 3). Error of the CTD's oxygen concentrations was calculated to be ~-0.083 from Gilmore (2006) chemical measurements of O_2. Figure 7 depicts the difference of averaged offshore O_2 percentage saturation for each bay with depth. At the surface, no significant difference was found between bays. Wreck Bay's middle depth had an O_2 percentage saturation ~20% lower than Cartago Bay at its equivalent depth. Wreck Bay showed a continued decrease of 5-10% from middle to bottom samples. Figure 7 shows Wreck Bay had the largest decrease with depth, while Turtle Bay had smallest decrease compared with other bays.

To further analyze the data, specific nutrients were compared against each other within each bay. First, the nitrogen to phosphate ratio was determined, to check if there was any comparison to the Redfield Ratio (C:N:P 106:16:1; Arrigo 2005). To determine a usable nitrogen number for comparison, nitrate and ammonium numbers of un-normalized concentrations were added together. This was plotted against un-normalized phosphate concentrations (Figure 8). All bays showed low N:P ratios (~1.8-8.4). The r^2 values for linear fits were also all below 0.5, suggesting linear relationships may not hold. Cartago Bay, with the exception of two outliners, looks to have a slope actually smaller than the suggested 1.8 slope. Academy Bay has an outlier as well; not considering this point would actually increase the linear slope. Turtle Bay stations had no real linear relationship making it hard to determine a definite slope for its N:P ratio. At Wreck Bay, it was also hard to define a slope that represented all of the data points. All of the bay's N:P ratios were actually very similar to ratios seen by Dickson (2006) at offshore bio-stations, in which three of her stations had slopes that varied between ~4 and 11 and high r^2 values.

The relationship between nitrate and ammonium concentrations was also compared given the possible importance of each for primary production. Figure 9 shows that all bays had linear relations associated with very small r^2 values, meaning linear relationships were not reliable. Cartago Bay has three major outliers and a region of clustering with no apparent linear relation. Academy Bay, Turtle Bay, and Wreck Bay do show more linearity within their points than Cartago Bay; however, it is hard to determine a single best-fit line for each.

Table 4 details collection sites and description of sediments collected. Sediments were not obtained from all stations; also not all sediments collected had sufficient pore-water for analysis. Almost all samples consisted of coral and calcareous shell fragments of varying size. Cartago Bay's samples were examined under a microscope to verify this observation. NH_4^+ concentrations were adjusted in diluted samples to account for fluorescence of the diluting deionized distilled water. Cartago Bay's samples, even after this correction, were still beyond the standard curve range (~0-2.8 μmol L^{-1}), but concentrations were estimated nonetheless. Cartago Bay's inshore samples had NH_4^+ concentrations (both being ~214μmol L^{-1}) lower than offshore samples (~885 and 367 μmol L^{-1}). Academy Bay and Turtle Bay had similar concentrations, which were both lower than Cartago Bay's inshore samples (>165 and ~108 μmol L^{-1}, respectively). Wreck Bay's inshore sample (~3.65 μmol L^{-1}) had NH_4^+ a concentration that was approximately half the off shore samples' concentrations (7.96 and 10.4 μmol L^{-1}). Benthic organisms were obtained at a few stations, showing sediment-water interface was obtained.

Discussion

Cartago Bay proved to be a suitable control bay, which lacked noticeable human perturbations, although it was not completely identical in physical characteristics of other bays. Both its nitrate and ammonium profiles seemed reasonable with small values increasing slightly with depth. The oxygen saturation profile showed no drastic changes occurring with depth. Estimated sediment pore-water ammonium concentrations were extremely high in comparison with overlying waters. This could be due to large accumulation rates of sinking organic particles, possibly related to large mangrove population along the shore. This mangrove population could also account for lower inshore concentrations, since more ammonium would be utilized for growth in these sediments.

Academy Bay nutrients varied in their values compared with Cartago Bay. Nitrates were higher in concentration, while ammonium was equal and phosphates were lower. This could reflect inputs of phosphate to Cartago Bay, but it seems more likely that NO_3^-/NH_4^+ inputs to Academy Bay have led to reduced PO_4^- levels there. As primary production increases due to excess nitrate and ammonium within the bay, little or no phosphate is added to balance the needs of intake. This limitation might be the reason why eutrophication is not obvious within the oxygen saturation profiles.

Ammonium values within Turtle Bay were the most significant nutrient difference it had with Cartago Bay. This was expected because Puerto Villamil is less populated and associated with more agriculture. Phosphate concentrations were lower than in Cartago Bay; again, suggesting it might be a limiting nutrient. Turtle Bay had similarities to nutrient concentrations measured in Academy Bay. This was not expected, since Puerto Villamil has such a smaller population and less tourist activities than Puerto Ayora does.

In comparison to offshore samples taken Dickson's (2006) eastern Isabela Island stations, ammonium concentrations were found to be similar to Cartago Bay and less than populated bays. However, nitrate concentrations offshore were on average higher than all studied bays and almost double the largest concentrations measured. Dickson's (2006) phosphate concentrations were also larger than all bays with the exception of Wreck Bay, which had similar concentrations. This suggests both anthropogenic nutrient contributions and increased uptake and utilization of these nutrients are occurring within the bays.

Oxygen percent saturation (Figure 7) showed that Wreck Bay had the most substantial decrease in oxygen percentage saturation. There are several possible explanations. First, increased primary production is occurring in the surface layer due to high nutrient content influenced by anthropogenic sources. Nutrient profiles did show that most stations had higher concentrations of nitrate, ammonium, and phosphate than at Cartago Bay. These higher nutrient concentrations could be linked to the early signs of eutrophication, which can be seen by the decreased oxygen with depth. Another explanation is that upwelling from the Undercurrent is the source of nutrient loading and the distribution of dissolved oxygen (Houvenaghel 1978). This argument is supported with a map (Fig. 14, Houvenaghel 1978) showing that Wreck Bay is the only sampled bay that falls within a region of prominent upwelling. The last thing to consider is the long-term effects caused by the *Jessica* grounding. Hydrocarbon contamination from this event could have an effect on the oxygen concentrations. It is most plausible that there is a combination between anthropogenic and upwelling contributions causing the higher nutrient concentrations. Ammonium concentrations within the sediment pore-waters here were much smaller than at the other bays, although still higher than overlying waters. This could be due biological utilization limiting accumulation of ammonium within the sediments. Wreck Bay's greater nutrient concentrations could be attributed to its stations' greater depths. Most of its middle water samples were taken from depths similar to other bays bottom samples. Meanwhile, its bottom samples were taken from much greater depths than any other bays' stations.

Although surprising, the low nitrogen to phosphate ratios seen in figure 8 might simply be explained by the changing needs of phytoplankton. It has recently been suggested that phytoplankton change their cellular components based on surrounding conditions and can alter their N:P ratios (Arrigo 2005). This means that phytoplankton in the Galàpagos could need a different ratio of nitrogen and phosphate to facilitate their growth more efficiently. This can be supported by similar ratios found for stations outside of the bays (Dickson, 2006).

Conclusions

Many observations in the Galàpagos accorded with predictions. Populated bays had increased nutrients, suggesting that anthropogenic contributions cannot be ruled out as a cause. Data collected from Academy Bay and Turtle Bay suggested that their increased nutrient contributions have an unexpected similarity. Meanwhile, Wreck Bay was unique in both its nutrient and oxygen saturation values, and had little in common with the other bays. In examination of the nitrogen phosphate ratios, an untraditional (non-Redfield) ratio was determined for the region, and with other data suggested that phosphate could be limiting.

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Table 1. Latitudes and longitudes of all *R/V Thomas G. Thompson* and workboat nutrient sample collection sites along with bottom depth within Cartago Bay (CB), Academy Bay (AB), Turtle Bay (PV), and Wreck Bay (WB).

Station Name	**Depth (m)**	**Latitude**	**Longitude**
CB-Inshore1	18	S0°35.27’	W90°55.97’
CB-Inshore2	21	S0°36.48’	W90°56.26’
CB-Inshore3	15	S0°36.86’	W90°55.43’
CB-Inshore4	17	S0°35.5’	W90°57.9’
CB-Offshore1	47.9	S0°35.32’	W90°54.49’
CB-Offshore2	30.1	S0°34.74’	W90°55.49’
CB-Offshore3	24.8	S0°34.66’	W90°56.49’
AB-Inshore1	6	S0°44.90’	W90°18.28’
AB-Inshore2	6	S0°45.1’	W90°18.0’
AB-Inshore3	1	S0°45.6’	W90°18.0’
AB-Offshore1	15	S0°45.08’	W90°17.87’
AB-Offshore2	19	S0°45.49’	W90°17.54’
AB-Offshore3	31.6	S0°45.68’	W90°17.69’
PV-Inshore1	29.8	S0°58.4’	W90°58.3’
PV-Inshore2	9.5	S0°57.72’	W90°58.14’
PV-Inshore3	11	S0°58.0’	W90°58.7’
PV-Offshore1	17.7	S0°59.06’	W90°53.50’
PV-Offshore2	14.7	S0°58.60’	W90°58.81’
PV-Offshore3	20.3	S0°58.35’	W90°59.31’
WB-Inshore1	12	S0°53.6’	W89°37.19’
WB-Inshore2	12	S0°53.77’	W89°36.64’
WB-Inshore3	7.5	S0°53.3’	W89°37.9’
WB-Inshore4	17	S0°53.45’	W89°37.05’
WB-Offshore1	35.4	S0°53.48’	W89°37.52’
WB-Offshore2	82.9	S0°53.18’	W89°37.32’
WB-Offshore3	86.5	S0°52.17’	W89°37.19’

Table 2. Station properties obtained from CTD data and analysis on water samples for Cartago Bay (A), Academy Bay (B), Turtle Bay (C), and Wreck Bay (D). Temperature, Salinity, and Oxygen values for inshore values were averaged from surface values of offshore CTD casts.

A.

Station Name	Depth (m)	Temp. (^{o}C)	Salinity (PSU)	[Nitrate] (µmol L^{-1})	[Ammonium] (µmol L^{-1})	[Phosphate] (µmol L^{-1})	Oxygen (ml L^{-1})	Fluoro. (µg L^{-1})
CB-Inshore 1-surf	0	24.5	33.9	4.06	0.323	0.274	4.5	-----------
CB-Inshore 1-mid	8	24.5	33.9	4.17	0.324	0.674	4.5	-----------
CB-Inshore 1-btm	17	24.5	33.9	4.83	0.551	1.12	4.5	-----------
CB-Inshore 2-surf	0	24.5	33.9	2.89	0.346	1.33	4.5	-----------
CB-Inshore 2-mid	10	24.5	33.9	3.45	0.341	0.925	4.5	-----------
CB-Inshore 2-btm	20	24.5	33.9	10.7	>3.3	2.58	4.5	-----------
CB-Inshore 3-surf	0	24.5	33.9	2.95	0.359	1.23	4.5	-----------
CB-Inshore 3-mid	7	24.5	33.9	3.25	0.311	0.123	4.5	-----------
CB-Inshore 3-btm	14	24.5	33.9	3.00	0.584	0.524	4.5	-----------
CB-Inshore 4-surf	0	24.5	33.9	2.92	0.305	1.48	4.5	-----------
CB-Inshore 4-mid	8	24.5	33.9	2.90	0.408	1.38	4.5	-----------
CB-Inshore 4-btm	16	24.5	33.9	3.08	0.504	3.08	4.5	-----------
CB-Offshore 1-surf	1.2	24.59	33.95	3.24	0.458	0.224	4.63	1.13
CB-Offshore 1-mid	22	24.18	34.00	3.77	0.531	1.78	4.53	1.86
CB-Offshore 1-btm	43	18.29	34.68	13.2	1.07	4.83	2.77	1.69
CB-Offshore 2-surf	1.1	24.96	33.74	4.03	0.379	0.925	4.47	0.29
CB-Offshore 2-mid	13.1	24.55	33.84	4.08	0.310	1.776	4.53	1.44
CB-Offshore 2-btm	24.1	24.22	33.91	4.24	0.375	2.13	4.44	1.58
CB-Offshore 3-surf	1.2	24.82	33.82	4.03	0.033	1.73	4.51	0.58
CB-Offshore 3-mid	10.4	24.49	33.86	3.88	0.287	1.23	4.54	1.6
CB-Offshore 3-btm	18.4	24.26	33.93	3.99	0.364	2.93	4.40	1.76

B.

Station Name	Depth (m)	Temp. (^{o}C)	Salinity (PSU)	[Nitrate] (µmol L^{-1})	[Ammonium] (µmol L^{-1})	[Phosphate] (µmol L^{-1})	Oxygen (ml L^{-1})	Fluoro. (µg L^{-1})
AB-Inshore 1-surf	0	23.5	34.1	6.90	0.666	1.06	4.1	-----------
AB-Inshore 1-mid	2	23.5	34.1	6.00	0.787	1.02	4.1	-----------
AB-Inshore 2-surf	0	23.5	34.1	7.16	0.505	0.885	4.1	-----------
AB-Inshore 2-mid	5	23.5	34.1	7.42	0.314	0.709	4.1	-----------
AB-Inshore 2-btm	9	23.5	34.1	7.47	1.00	0.499	4.1	-----------
AB-Inshore 3-surf	0	23.5	34.1	6.40	0.585	0.709	4.1	-----------
AB-Inshore 3-mid	7	23.5	34.1	7.02	0.325	0.885	4.1	-----------
AB-Inshore 3-btm	14	23.5	34.1	7.22	0.321	0.779	4.1	-----------
AB-Offshore 1-surf	2.2	23.42	34.08	6.85	0.335	0.569	4.45	2.61
AB-Offshore 1-mid	13.2	22.46	34.16	8.23	0.447	0.885	4.12	2.11
AB-Offshore 1-btm	18.1	22.48	34.16	8.38	0.485	1.02	4.06	2.21
AB-Offshore 2-surf	2.7	23.67	34.06	7.07	0.216	0.779	4.34	2.55
AB-Offshore 2-mid	14.2	22.11	34.17	10.3	0.341	1.17	3.89	1.69
AB-Offshore 2-btm	27.6	19.02	34.55	12.7	0.434	1.20	3.15	2.05
AB-Offshore 3-surf	2.4	23.49	34.07	7.47	0.252	0.604	4.30	2.03
AB-Offshore 3-mid	13.2	23.00	34.10	8.42	0.206	2.32	4.22	1.93

Table 2. Continued.

C.

Station Name	Depth (m)	Temp. (°C)	Salinity (PSU)	[Nitrate] (μmol L^{-1})	[Ammonium] (μmol L^{-1})	[Phosphate] (μmol L^{-1})	Oxygen (ml L^{-1})	Fluoro. (μg L^{-1})
PV-Inshore 1-surf	0	21.9	34.3	0.84	0.477	0.674	4.4	-----------
PV-Inshore 1-mid	5	21.9	34.3	6.99	0.765	0.920	4.4	-----------
PV-Inshore 1-btm	10	21.9	34.3	10.2	0.919	0.885	4.4	-----------
PV-Inshore 2-surf	0	21.9	34.3	4.69	1.34	0.850	4.4	-----------
PV-Inshore 2-mid	5	21.9	34.3	5.95	1.39	1.10	4.4	-----------
PV-Inshore 2-btm	8.5	21.9	34.3	8.87	1.17	1.10	4.4	-----------
PV-Inshore 3-surf	0	21.9	34.3	0.33	0.546	0.534	4.4	-----------
PV-Inshore 3-mid	5	21.9	34.3	4.11	1.21	0.885	4.4	-----------
PV-Inshore 3-btm	10	21.9	34.3	7.75	0.892	1.06	4.4	-----------
PV-Offshore 1-surf	0.9	22.67	34.23	3.27	0.455	0.534	4.58	0.92
PV-Offshore 1-mid	7.2	22.14	34.28	7.44	0.599	0.850	4.10	1.47
PV-Offshore 1-btm	12.0	21.26	34.43	6.93	0.565	0.744	4.16	1.46
PV-Offshore 2-surf	1.0	23.27	34.09	3.89	0.400	0.885	4.94	2.16
PV-Offshore 2-mid	5.8	22.04	34.29	7.96	0.666	1.02	4.24	1.96
PV-Offshore 2-btm	10.6	21.29	34.41	7.02	0.611	0.885	3.82	1.04
PV-Offshore 3-surf	1.0	21.38	34.39	4.39	0.601	0.850	4.72	2.04
PV-Offshore 3-mid	8.0	21.55	34.37	7.74	0.800	0.990	4.26	1.73
PV-Offshore 3-btm	15.0	21.38	34.39	7.46	0.747	0.464	4.05	1.81

D.

Station Name	Depth (m)	Temp. (°C)	Salinity (PSU)	[Nitrate] (μmol L^{-1})	[Ammonium] (μmol L^{-1})	[Phosphate] (μmol L^{-1})	Oxygen (ml L^{-1})	Fluoro. (μg L^{-1})
WB-Inshore 1-surf	0	21.3	34.1	3.58	0.543	2.53	4.3	-----------
WB-Inshore 1-mid	5.5	21.3	34.1	5.89	0.950	1.73	4.3	-----------
WB-Inshore 1-btm	11	21.3	34.1	9.48	0.676	1.83	4.3	-----------
WB-Inshore 2-surf	0	21.3	34.1	5.15	0.712	0.724	4.3	-----------
WB-Inshore 2-mid	5.5	21.3	34.1	5.70	0.850	3.43	4.3	-----------
WB-Inshore 2-btm	11	21.3	34.1	7.98	0.824	3.38	4.3	-----------
WB-Inshore 3-surf	0	21.3	34.1	3.88	0.880	2.23	4.3	-----------
WB-Inshore 3-mid	3	21.3	34.1	4.93	0.873	2.93	4.3	-----------
WB-Inshore 3-btm	6.5	21.3	34.1	6.33	1.74	3.38	4.3	-----------
WB-Inshore 4-surf	0	21.3	34.1	2.86	0.350	2.38	4.3	-----------
WB-Inshore 4-mid	3	21.3	34.1	3.92	0.374	2.18	4.3	-----------
WB-Inshore 4-btm	7	21.3	34.1	8.22	0.508	4.03	4.3	-----------
WB-Offshore 1-surf	1.1	25.25	33.67	14.2	0.654	3.58	4.44	0.94
WB-Offshore 1-mid	16	18.62	34.62	4.70	0.335	2.83	2.98	1.42
WB-Offshore 1-btm	30.9	17.32	34.77	16.1	0.664	6.78	2.69	1.24
WB-Offshore 2-surf	1.3	25.65	33.60	4.07	0.302	1.78	4.44	0.6
WB-Offshore 2-mid	37.9	16.86	34.82	17.8	0.578	2.53	2.58	1.31
WB-Offshore 2-btm	77.2	15.64	34.94	18.80	0.693	6.28	2.30	0.8
WB-Offshore 3-surf	1.2	23.27	33.47	4.43	0.406	1.48	4.30	0.56
WB-Offshore 3-mid	42	16.87	34.82	17.1	0.521	2.48	2.59	1.67
WB-Offshore 3-btm	81.8	15.46	34.95	19.6	0.653	4.23	2.17	0.54

Table 3. Salinity normalized nutrient and oxygen percentage saturation values for Cartago Bay (A), Academy Bay (B), Turtle Bay (C), and Wreck Bay (D).

A.

Station Name	Sal Norm NO_3^- (μmol L^{-1} PSU^{-1})	Sal Norm NH_4^+ (μmol L^{-1} PSU^{-1})	Sal Norm PO_4^- (μmol L^{-1} PSU^{-1})	O_2 % Saturation
CB-Inshore 1-surf	0.120	0.010	0.008	-------------
CB-Inshore 1-mid	0.123	0.010	0.020	-------------
CB-Inshore 1-btm	0.143	0.016	0.033	-------------
CB-Inshore 2-surf	0.085	0.010	0.039	-------------
CB-Inshore 2-mid	0.102	0.010	0.027	-------------
CB-Inshore 2-btm	0.314	0.097	0.076	-------------
CB-Inshore 3-surf	0.087	0.011	0.036	-------------
CB-Inshore 3-mid	0.096	0.009	0.004	-------------
CB-Inshore 3-btm	0.089	0.017	0.015	-------------
CB-Inshore 4-surf	0.086	0.009	0.044	-------------
CB-Inshore 4-mid	0.086	0.012	0.041	-------------
CB-Inshore 4-btm	0.091	0.015	0.091	-------------
CB-Offshore 1-surf	0.095	0.014	0.007	95.7
CB-Offshore 1-mid	0.111	0.016	0.052	93.6
CB-Offshore 1-btm	0.381	0.031	0.139	51.3
CB-Offshore 2-surf	0.119	0.011	0.027	93.6
CB-Offshore 2-mid	0.121	0.009	0.052	93.2
CB-Offshore 2-btm	0.125	0.011	0.063	91.7
CB-Offshore 3-surf	0.119	0.001	0.051	92.8
CB-Offshore 3-mid	0.115	0.008	0.036	93.3
CB-Offshore 3-btm	0.118	0.011	0.086	91.0

B.

Station Name	Sal Norm NO_3^- (μmol L^{-1} PSU^{-1})	Sal Norm NH_4^+ (μmol L^{-1} PSU^{-1})	Sal Norm PO_4^- (μmol L^{-1} PSU^{-1})	O_2 % Saturation
AB-Inshore 1-surf	0.202	0.020	0.031	-------------
AB-Inshore 1-mid	0.176	0.023	0.030	-------------
AB-Inshore 2-surf	0.210	0.015	0.026	-------------
AB-Inshore 2-mid	0.218	0.009	0.021	-------------
AB-Inshore 2-btm	0.219	0.029	0.015	-------------
AB-Inshore 3-surf	0.188	0.017	0.021	-------------
AB-Inshore 3-mid	0.206	0.010	0.026	-------------
AB-Inshore 3-btm	0.212	0.009	0.023	-------------
AB-Offshore 1-surf	0.201	0.010	0.017	90.5
AB-Offshore 1-mid	0.241	0.013	0.026	82.2
AB-Offshore 1-btm	0.245	0.014	0.030	81.0
AB-Offshore 2-surf	0.208	0.006	0.023	88.2
AB-Offshore 2-mid	0.302	0.010	0.034	77.7
AB-Offshore 2-btm	0.368	0.013	0.035	59.5
AB-Offshore 3-surf	0.219	0.007	0.018	87.3
AB-Offshore 3-mid	0.247	0.006	0.068	85.8

Table 3. Continued.

C.

Station Name	Sal Norm NO_3^- (μmol L^{-1} PSU^{-1})	Sal Norm NH_4^+ (μmol L^{-1} PSU^{-1})	Sal Norm PO_4^- (μmol L^{-1} PSU^{-1})	O_2 % Saturation
PV-Inshore 1-surf	0.0243	0.0139	0.0197	-------------
PV-Inshore 1-mid	0.2037	0.0223	0.0268	-------------
PV-Inshore 1-btm	0.2984	0.0268	0.0258	-------------
PV-Inshore 2-surf	0.1367	0.0392	0.0248	-------------
PV-Inshore 2-mid	0.1734	0.0406	0.0319	-------------
PV-Inshore 2-btm	0.2585	0.0341	0.0319	-------------
PV-Inshore 3-surf	0.0096	0.0159	0.0156	-------------
PV-Inshore 3-mid	0.1198	0.0353	0.0258	-------------
PV-Inshore 3-btm	0.2259	0.0260	0.0309	-------------
PV-Offshore 1-surf	0.0955	0.0133	0.0156	91.5
PV-Offshore 1-mid	0.2170	0.0175	0.0248	81.9
PV-Offshore 1-btm	0.2013	0.0164	0.0216	81.6
PV-Offshore 2-surf	0.1141	0.0117	0.0259	100.1
PV-Offshore 2-mid	0.2321	0.0194	0.0299	84.7
PV-Offshore 2-btm	0.2040	0.0177	0.0257	74.9
PV-Offshore 3-surf	0.1277	0.0175	0.0247	92.5
PV-Offshore 3-mid	0.2252	0.0233	0.0288	83.5
PV-Offshore 3-btm	0.2170	0.0217	0.0135	79.4

D.

Station Name	Sal Norm NO_3^- (μmol L^{-1} PSU^{-1})	Sal Norm NH_4^+ (μmol L^{-1} PSU^{-1})	Sal Norm PO_4^- (μmol L^{-1} PSU^{-1})	O_2 % Saturation
WB-Inshore 1-surf	0.105	0.016	0.074	-------------
WB-Inshore 1-mid	0.173	0.028	0.051	-------------
WB-Inshore 1-btm	0.278	0.020	0.054	-------------
WB-Inshore 2-surf	0.151	0.021	0.021	-------------
WB-Inshore 2-mid	0.167	0.025	0.101	-------------
WB-Inshore 2-btm	0.234	0.024	0.099	-------------
WB-Inshore 3-surf	0.114	0.026	0.065	-------------
WB-Inshore 3-mid	0.145	0.026	0.086	-------------
WB-Inshore 3-btm	0.186	0.051	0.099	-------------
WB-Inshore 4-surf	0.084	0.010	0.070	-------------
WB-Inshore 4-mid	0.115	0.011	0.064	-------------
WB-Inshore 4-btm	0.241	0.015	0.118	-------------
WB-Offshore 1-surf	0.420	0.019	0.106	92.8
WB-Offshore 1-mid	0.136	0.010	0.082	55.1
WB-Offshore 1-btm	0.462	0.019	0.195	48.8
WB-Offshore 2-surf	0.121	0.009	0.053	92.8
WB-Offshore 2-mid	0.511	0.017	0.073	46.0
WB-Offshore 2-btm	0.538	0.020	0.180	40.2
WB-Offshore 3-surf	0.132	0.012	0.044	87.4
WB-Offshore 3-mid	0.492	0.015	0.071	46.2
WB-Offshore 3-btm	0.561	0.019	0.121	38.1

Table 4. Descriptions of sediments collected at Cartago Bay (CB), Academy Bay (AB), Turtle Bay (PV), and Wreck Bay (WB), the organisms found, and pore-water ammonium concentrations found within the four bays.

Station Name	Sediment Obtained	Describtion (color, apparent size)	Benthic/Other Organisms	Pore Water	NH_4^+ (μmol L^{-1})
CB-Inshore1	Yes	Tan, sand, mostly bottom water	No	No	------------
CB-Inshore2	Yes	Grey/tan, sand w/ white and black shell fragements	No	Yes	214 (apparent)
CB-Inshore3	No		No	No	------------
CB-Inshore4	Yes	Light brown/gray, mud to sand w/shell fragments	Small clear fish	Yes	214 (apparent)
CB-Offshore1	Yes	Brown/grey, white/black specs, mud to sands	Brittle star, spiky worm	Yes, Yellow/Brownish	885 (apparent)
CB-Offshore2	Yes	Tan, gritty shell fragments	No	Yes	
CB-Offshore3	Yes	Brown/grey, white/black specs, mud to sands	Feathery worm	Yes	367 (apparent)
AB-Inshore1	Yes	Tan, sand with shell debris	No	No	------------
AB-Inshore2	No		No	No	------------
AB-Inshore3	No		No	No	------------
AB-Offshore1	Yes	Light brown/white, white, sand	No	No	------------
AB-Offshore2	Yes	Light brown/tan, muddy, fine grained	No	Yes	>165
AB-Offshore3	Yes	Red coral, large rock	Tube worm, anenome, larvae attached	No	------------
PV-Inshore1	No		No	No	------------
PV-Inshore2	Yes	White/grey, mostly bottom water	No	Yes	~108
PV-Inshore3	No		No	No	------------
PV-Offshore1	No		No	No	------------
PV-Offshore2	Yes	Red/brown, chunks of coral, shells and other debris	No	No	------------
PV-Offshore3	No		No	No	------------
WB-Inshore1	No		No	No	------------
WB-Inshore2	Yes	White, sand with fine shell particles	No	Yes	3.65
WB-Inshore3	No		No	No	------------
WB-Inshore4	No		No	No	------------
WB-Offshore1	Yes	Tan/brown, shell fragments, red medium size coral	No	No	------------
WB-Offshore2	Yes	Brown, shell fragments, small coral pieces	Red algea	Yes	7.96
WB-Offshore3	Yes	Brown/tan, fine silt to mud, shell particles	No	Yes	10.4

Figure Captions

Figure 1. Galàpagos Island map showing bays in which sampling occurred. Map divides the Galàpagos into Harris's (1969) biogeographic units. The figure is adapted from Boyce (1998).

Figure 2. Sampling locations from bays adjacent to the two highest populated towns in the Galàpagos Islands. (A) Academy Bay, Puerto Ayora, Santa Cruz Island, (B) Wreck Bay, Puerto Baquerizo Moreno, San Cristobal Island. Maps were altered from figures in Constant (1995).

Figure 3. Sampling locations in (A) Turtle Bay, Puerto Villamil, Isabela Island. (B) Cartago Bay located on an uninhabited part of Isabela Island. Maps were altered from figures in Constant (1995).

Figure 4. Salinity normalized nitrate (NO_3^-) concentrations seen at each station at the surface (A), middle of the water column (B), and at the bottom (C).

Figure 5. Salinity normalized ammonium (NH_4^+) concentrations seen at each station at the surface (A), middle of the water column (B), and at the bottom (C).

Figure 6. Salinity normalized phosphate concentrations seen at each station at the surface (A), middle of the water column (B), and at the bottom (C). Please note that axes for bottom samples are different from surface and middle samples.

Figure 7. Averaged offshore oxygen percent saturation profile with depth for all bays.

Figure 8. Nitrogen (NO_3^-+NH_4^+) versus phosphate concentrations for Cartago Bay (A), Academy Bay (B), Turtle Bay (C), and Wreck Bay (D). Please note differences between figures axes.

Figure 9. Relationship between NO_3^- and NH_4^+ for Cartago Bay (A), Academy Bay (B), Turtle Bay (C), and Wreck Bay (D). Please note differences between figures axes.

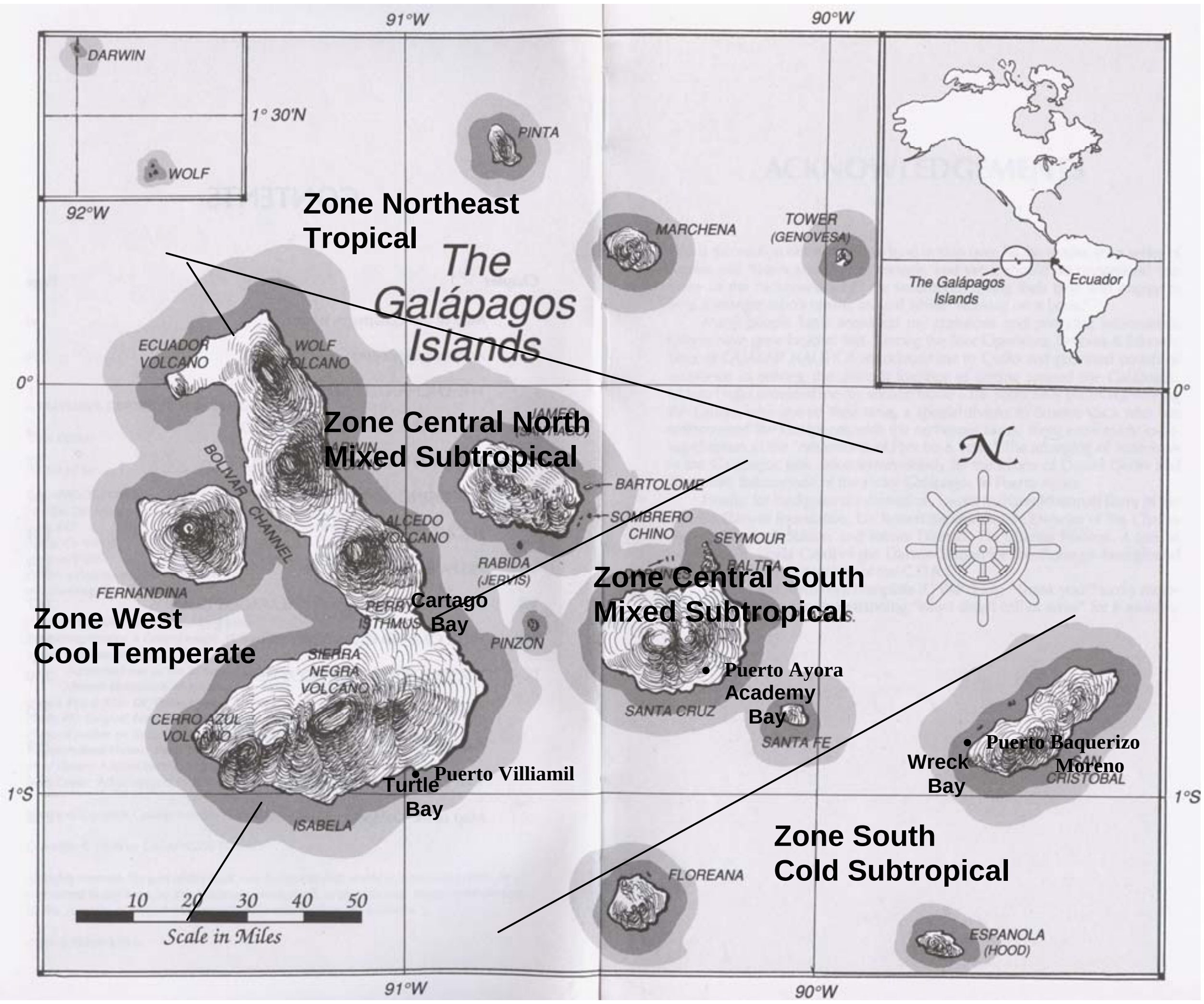


Figure 1.
Joni Werdeman

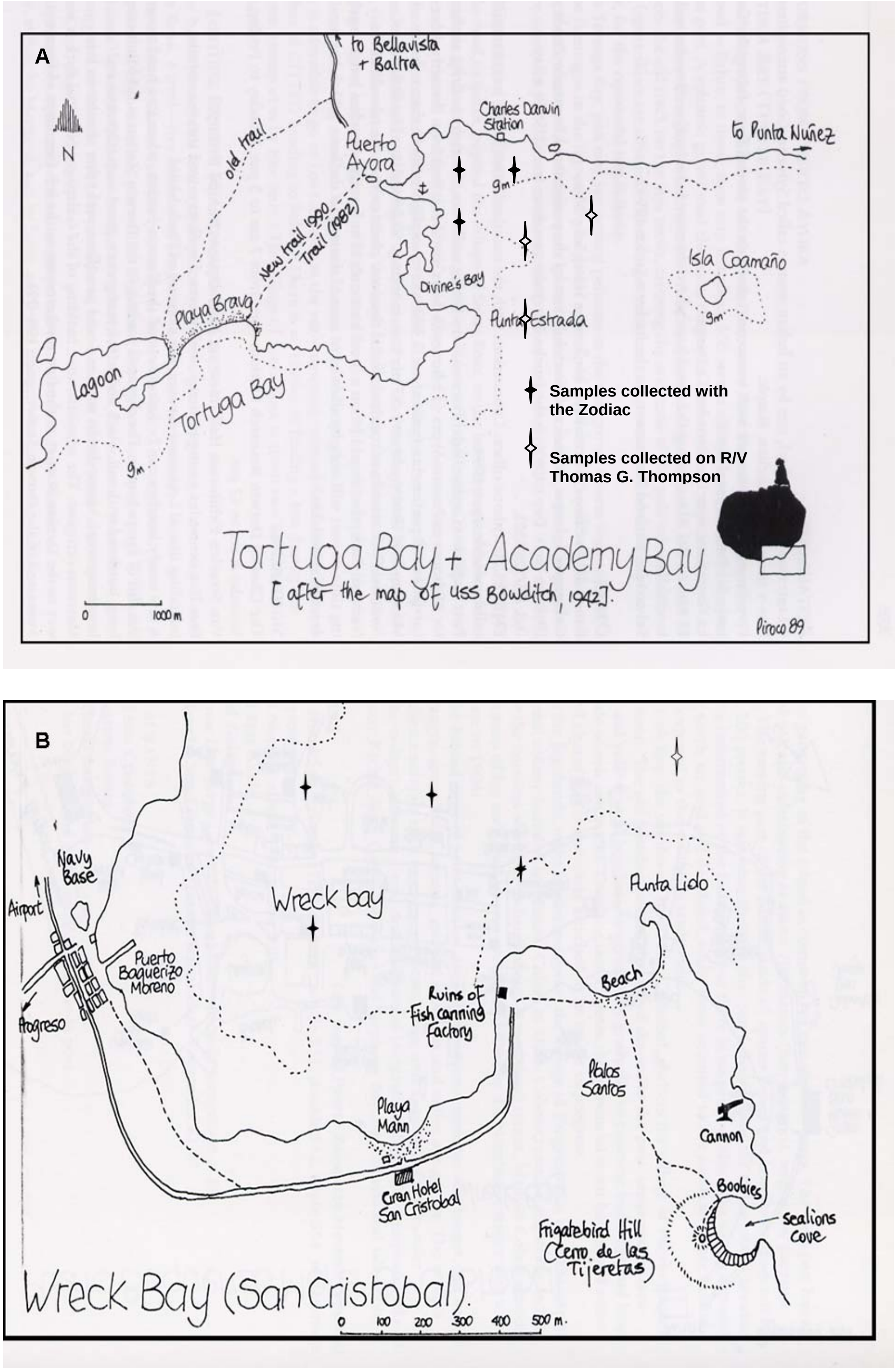


Figure 2.
Joni Werdeman

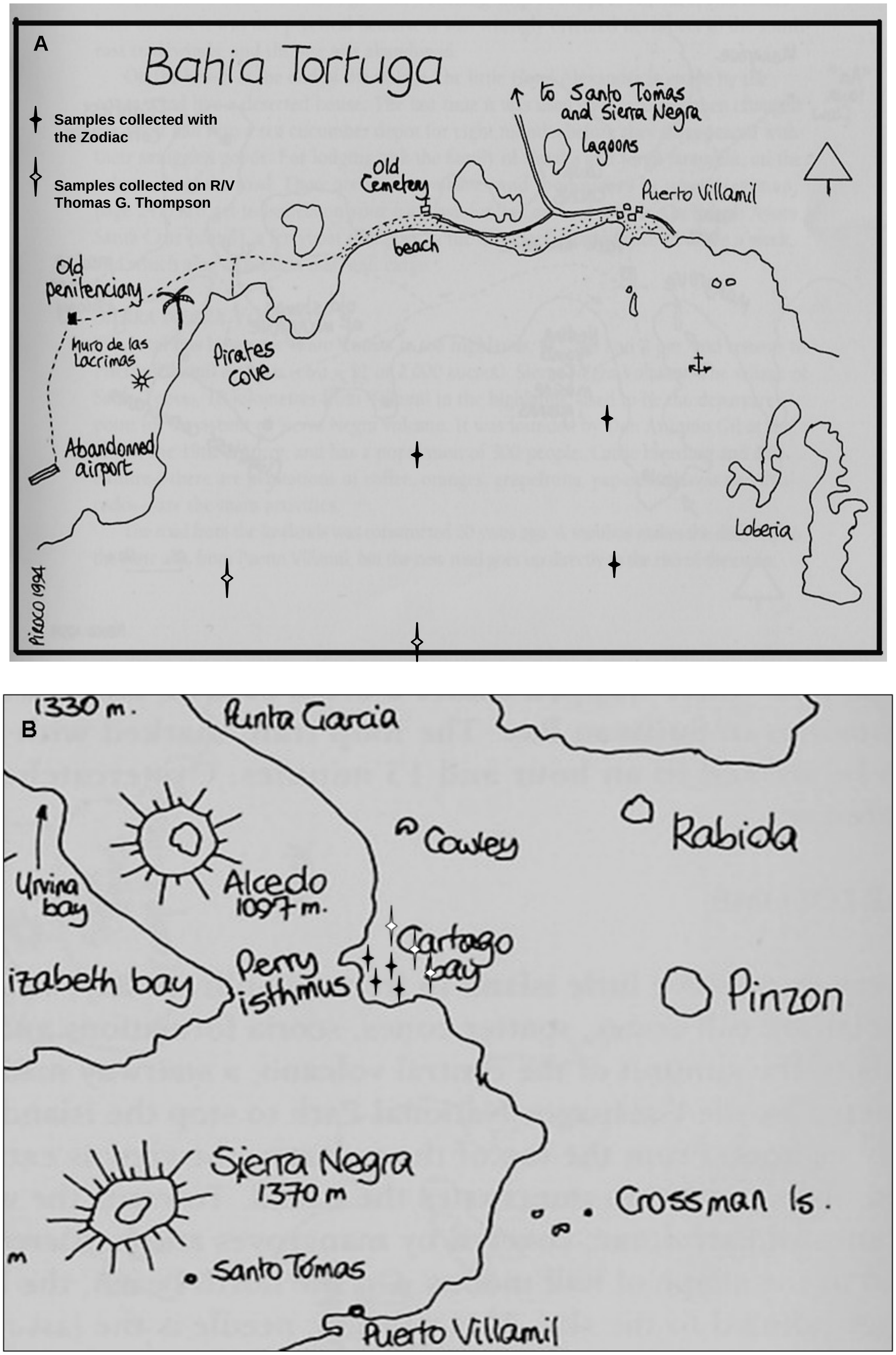


Figure 3.
Joni Werdeman

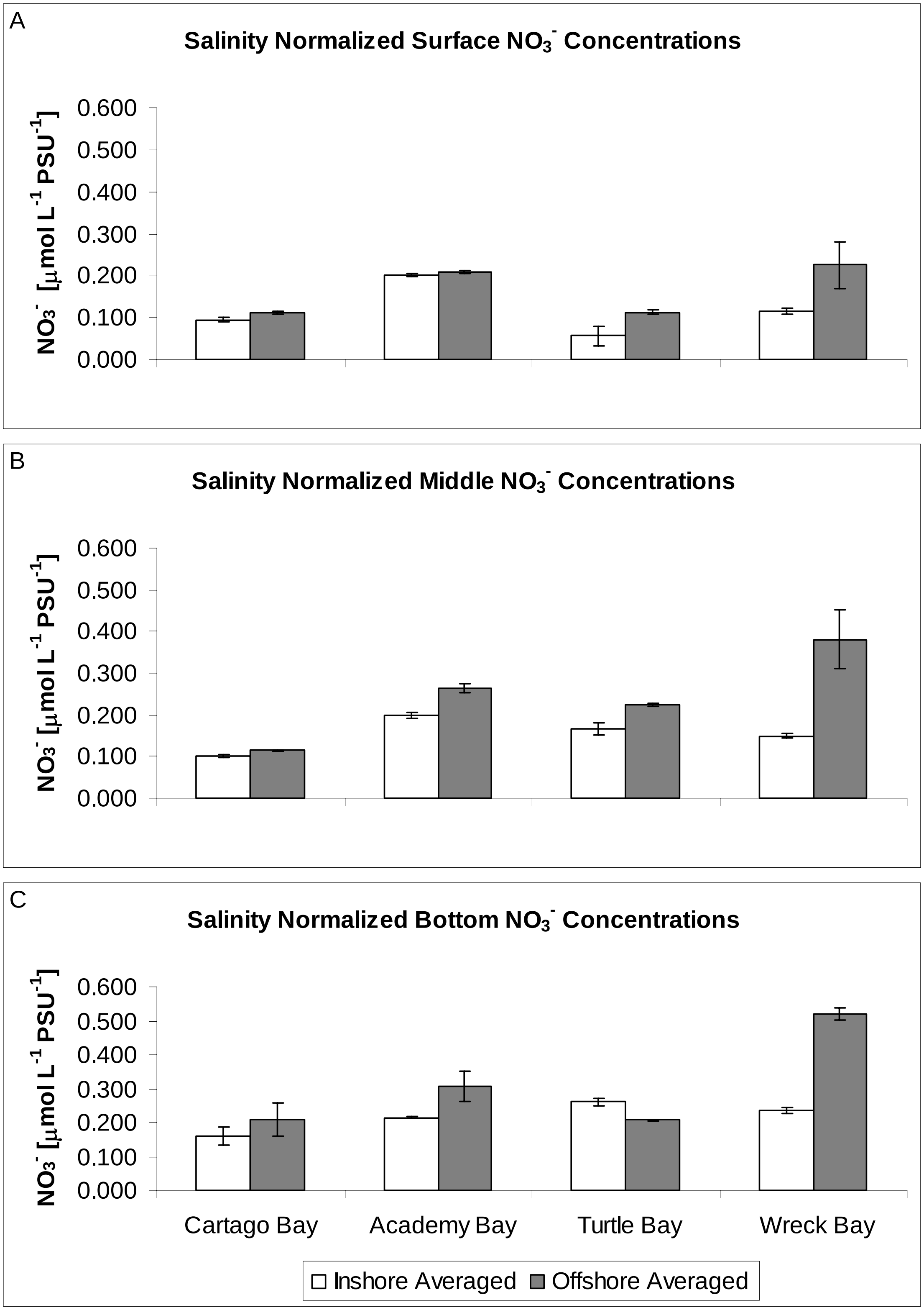
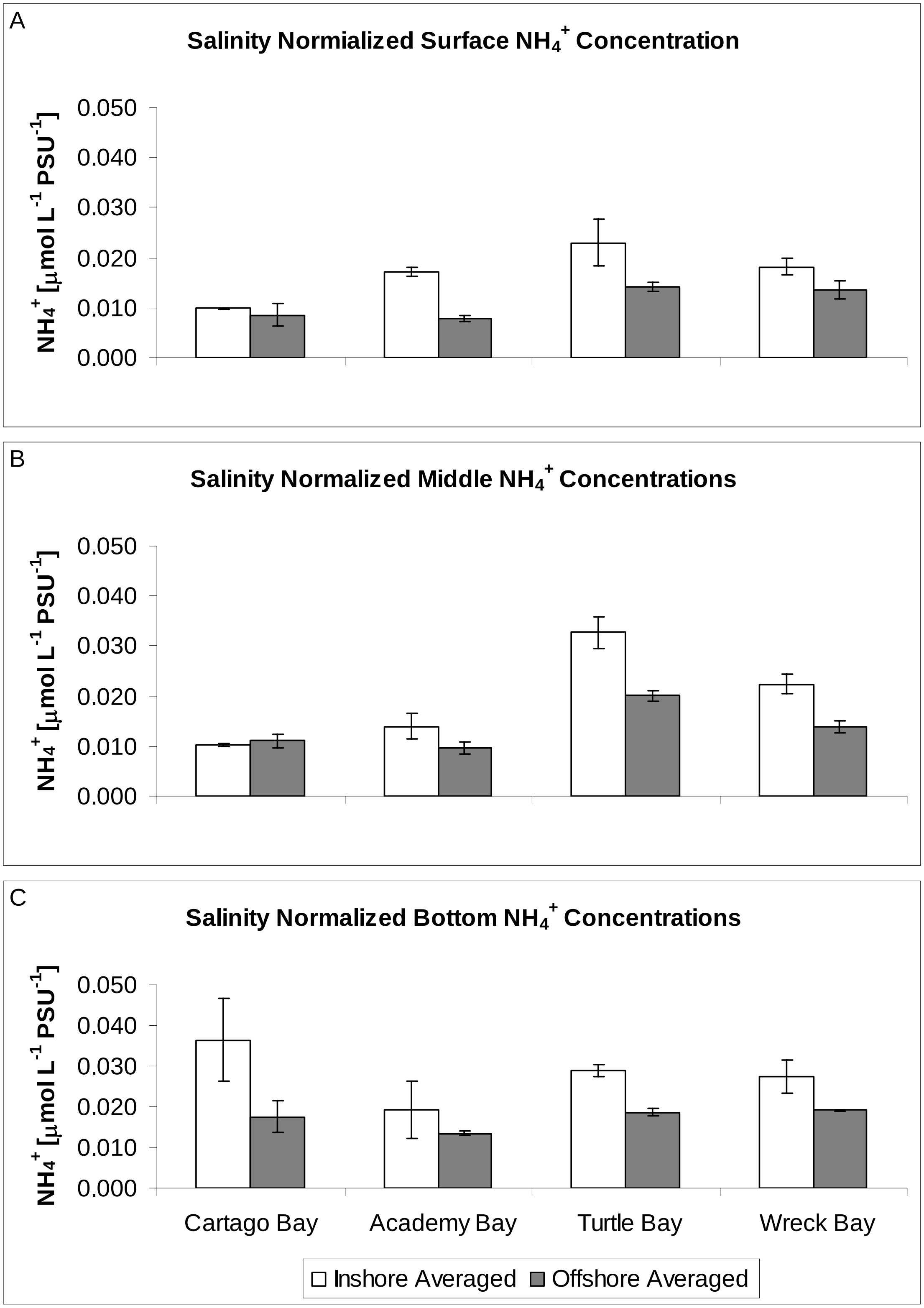


Figure 4.
Joni Werdeman


A

Salinity Normialized Surface NH_4^+ Concentration

B

Salinity Normalized Middle NH_4^+ Concentrations

C

Salinity Normalized Bottom NH_4^+ Concentrations

Figure 5.
Joni Werdeman

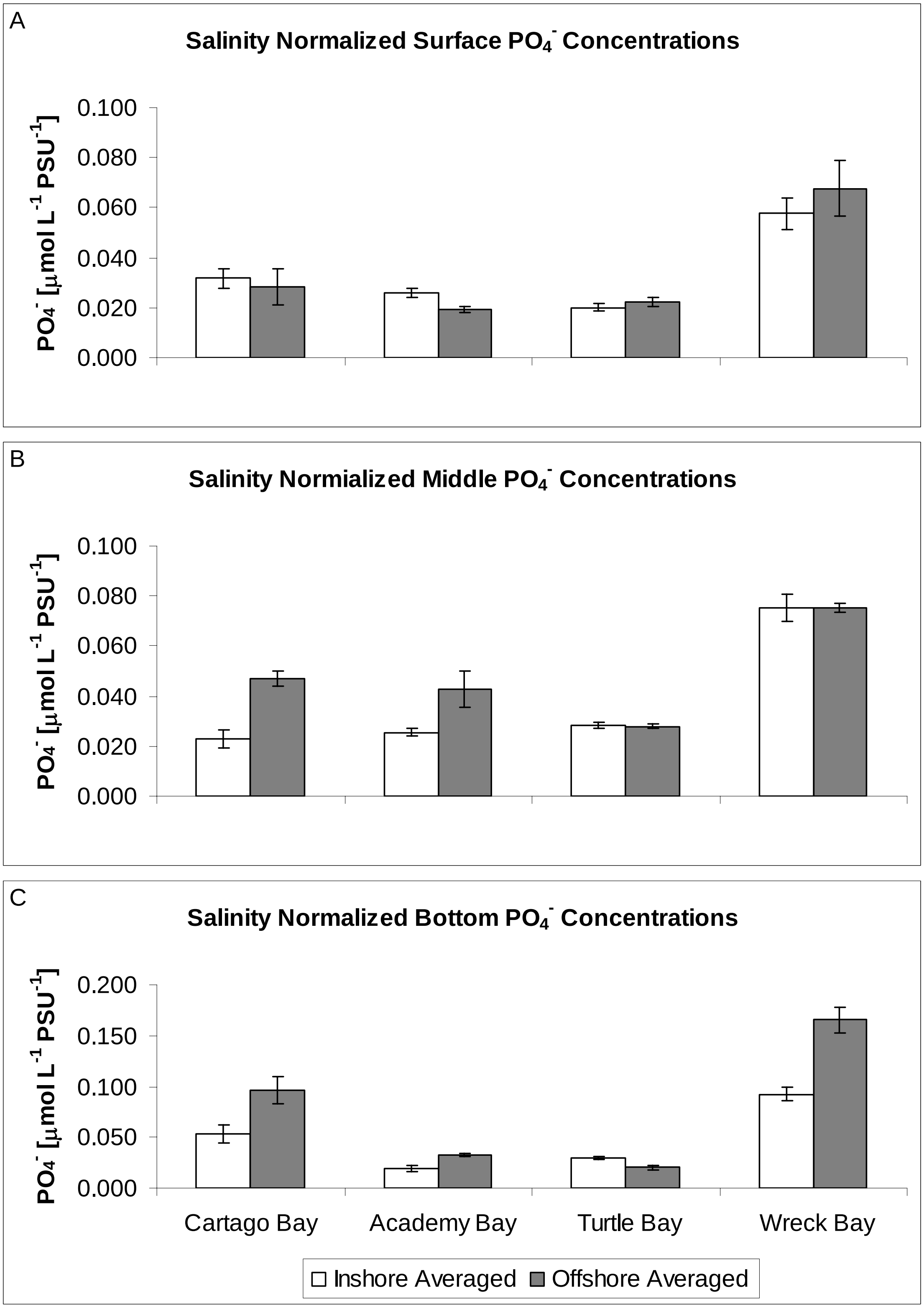


Figure 6.
Joni Werdeman

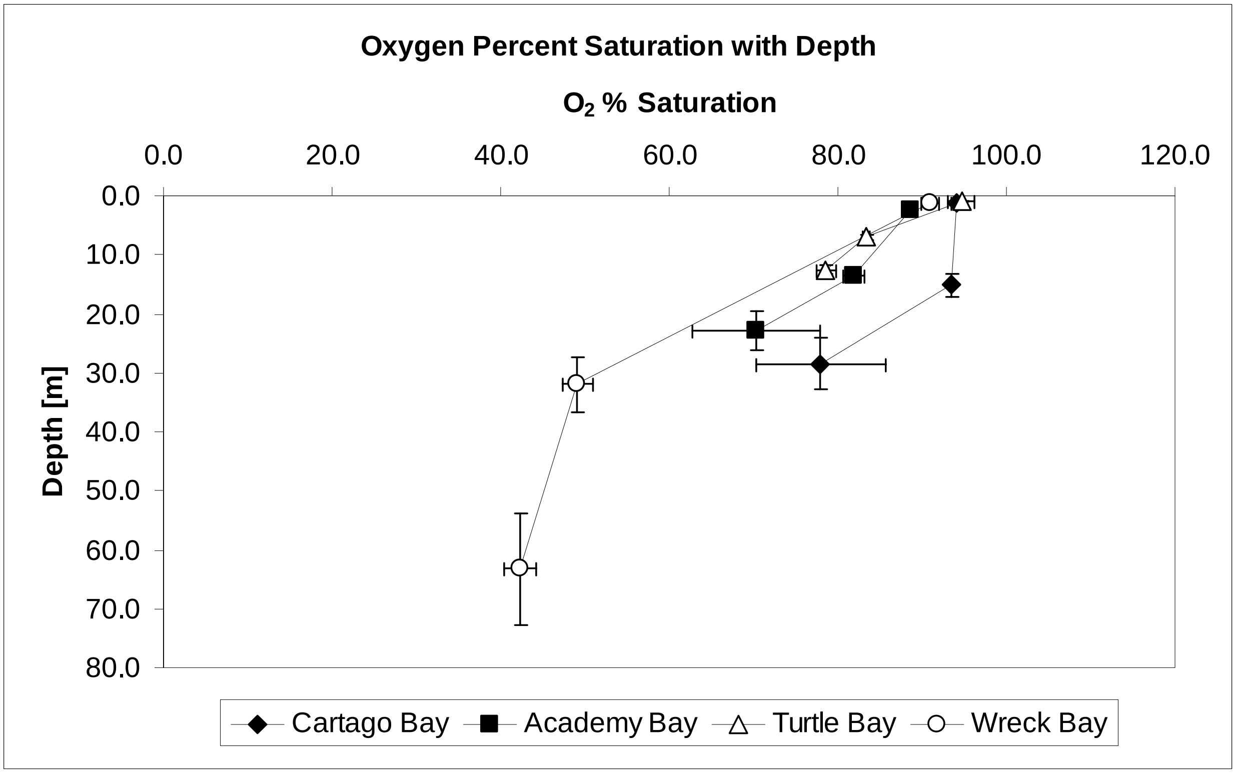


Figure 7.
Joni Werdeman

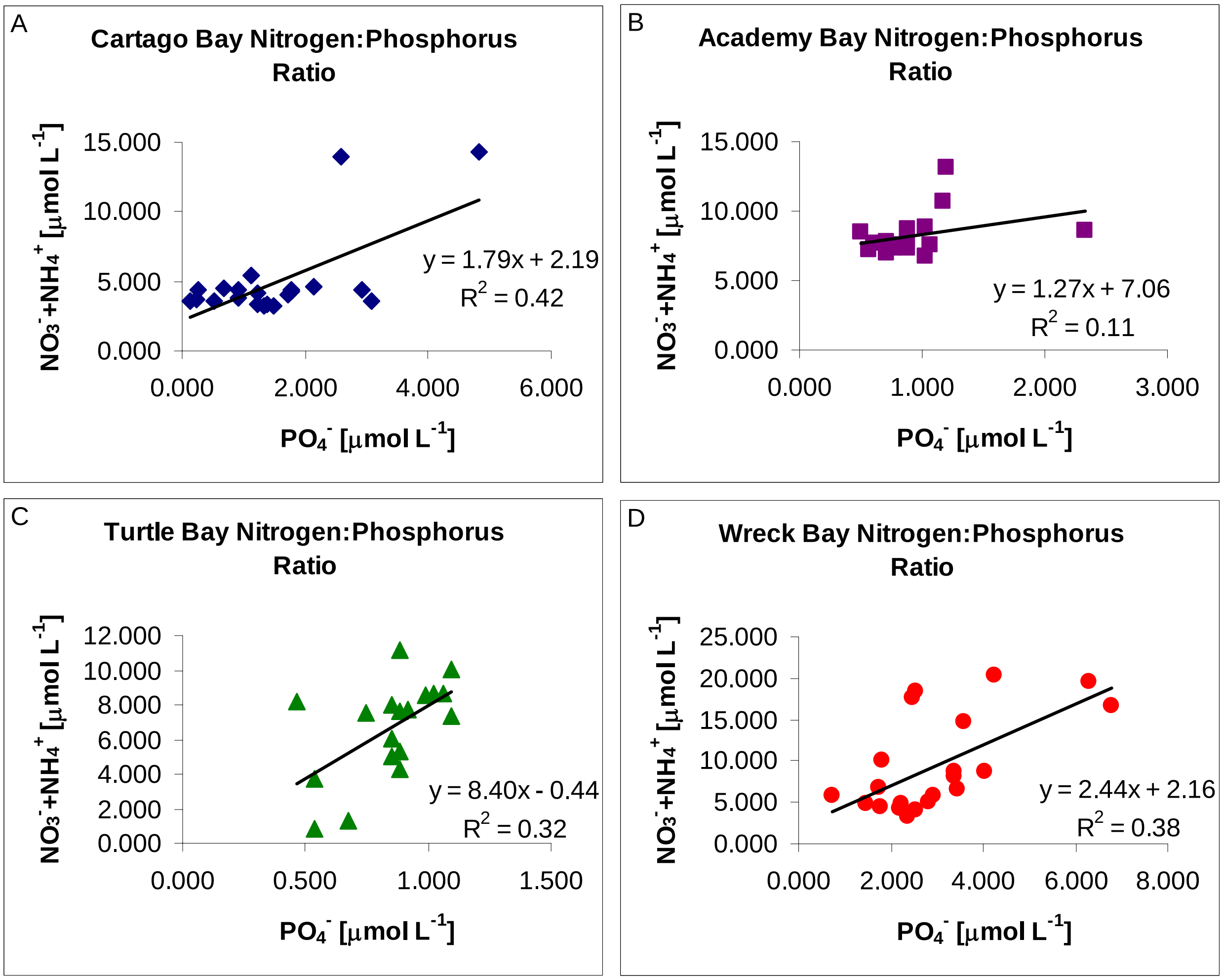


Figure 8.
Joni Werdeman

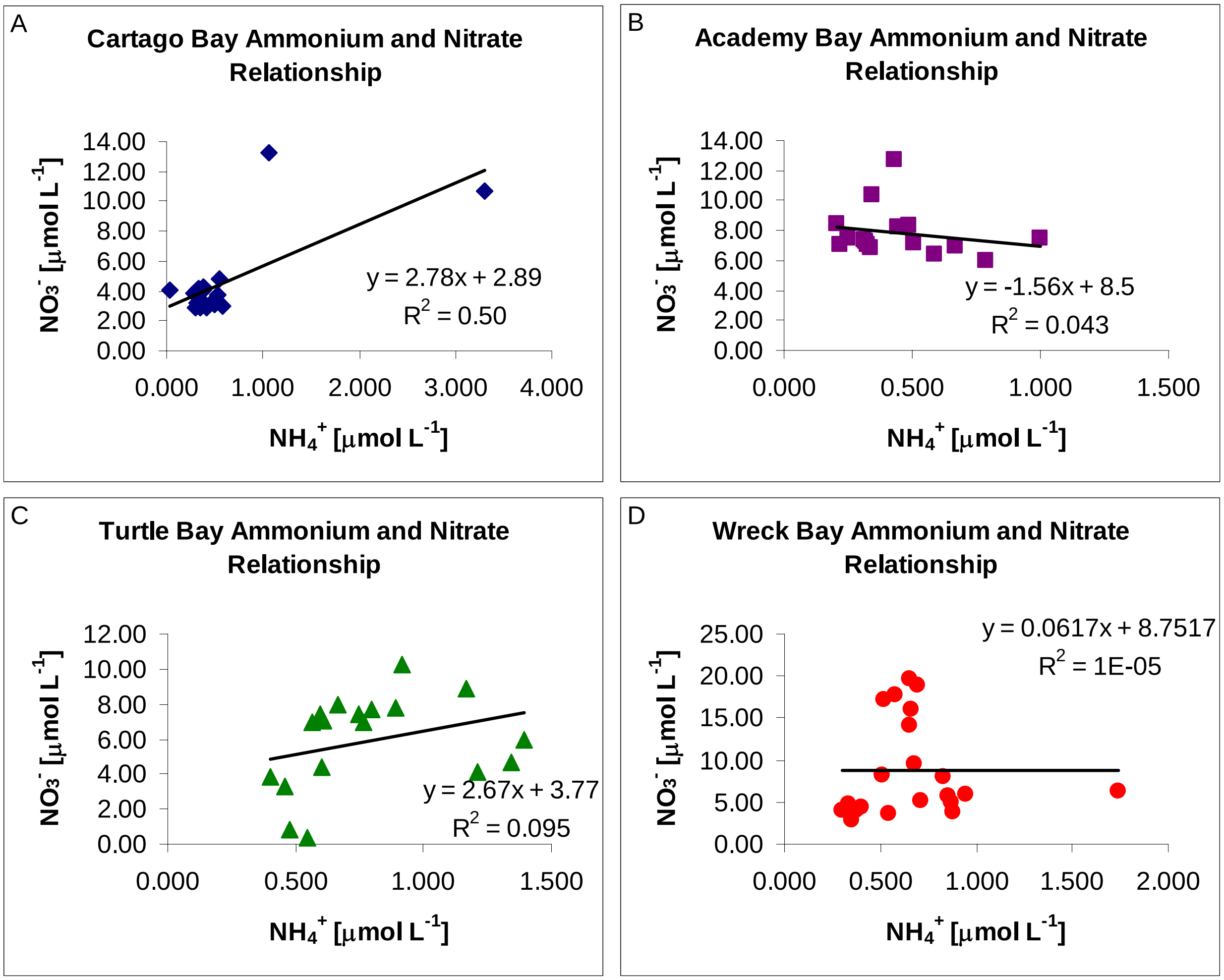


Figure 9.
Joni Werdeman