Effects of populated towns on water quality in neighboring Galapagos bays.

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Project Summary

Dissolved nutrient levels will be measured in three Galapagos Island bays adjacent to population centers and one bay with no adjacent inhabitants to characterize water quality within each bay. Water column and sediment pore-water samples will be collected on the R/V Thomas G. Thompson and zodiac workboat. Micronutrient analyses will be preformed to determine anthropogenic contributions to nitrate, ammonium, and phosphate concentrations. Salinity, oxygen, and temperature measurements will be made using the CTD and/or hand held YSI Model 85. Nutrient concentrations will be normalized to salinity. These analyses will aid in estimating present effects of nutrient contributions from anthropogenic land and harbor sources, which could otherwise lead to eutrophication or species losses.

Introduction

Increasing nitrogen and phosphorous concentrations within a marine environment can have impressive effects in various ways on the marine ecosystems. The most apparent affect it has is changing the biodiversity of the marine ecosystem. Changes can lead to certain favoring of certain species, altering the phytoplankton, zooplankton, and benthic communities (Howarth et al. 2000). These changes have the ability to alter entire food webs within island bays. According to Howarth et al. (2000) nutrient increases can increase primary production which can lead to eutrophication. Eutrophication depletes oxygen levels within the waters; this has the potential to create “dead zones” and fish deaths. Eutrophication also lowers silica concentrations, allowing for toxic dinoflagelates to bloom (Howarth et al. 2002).

Anthropogenic activities profoundly influence the global cycles of nutrient transport to estuaries and other coastal waters (Howarth et al. 2000). The dramatic increases seen in both population growth and tourist rates over the past decade, allows for the Galapagos Islands to be more susceptible to nutrient enrichment in bays adjacent to commercial and tourist centers. Inhabitants, who have moved to the Islands within the past 5-10 years (MacFarland and Cifuentes 1996), often sought only profit with little regards to impacts made to the Galapagos’s marine environment. According to MacFarland and Cifuentes (1996), open garbage dumps near port towns are a major source of pollutants in nearby bays. This could be a cause of increased nitrogen and phosphorous concentrations. Ammonium concentrations could be altered if untreated sewage is allowed to enter the marine systems. Tourism within the islands can also have a large impact on port waters. Qualitatively and quantitatively the amounts of solid waste have rapidly increased over the past decade, especially from waste thrown overboard from vessels (MacFarland and Cifuentes 1996). Oil spills and boat contamination from engine usage, could potentially alter nutrients within the bays. Agriculture, which was large when the islands were first colonized and is now less important, could have a small role in increases of nutrient concentrations. This could contribute to water contamination through direct terrestrial runoff or indirectly though atmospheric wind transport (Howarth et al. 2000).

Experiment locations should be based on greatest potential anthropogenic contributions; this would give a better understanding of what could be the largest nutrient contributions in Galapagos Islands. Figure 1 shows locations of bays that would fulfill this need. Puerto Ayora has the highest population of the 5 inhabited islands approximated at 10,000. 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. Academy Bay, which Puerto Ayora is adjacent to, should show nutrient variation if there are any anthropogenic contributions. The second largest population and tourist center, as well as the capital of the Galapagos Islands, is located on San Cristobal Island. Puerto Baquerizo Moreno has approximately 8,000 inhabitants. San Cristobal's main port, bordering Puerto Baquerizo Moreno, is Bahia Naufragio, or also known as Wreck Bay. This is also the recent grounding site of the oil rig Jessica. Contaminants from this spill could have altered both species diversity and nutrient concentrations within the bay. This would be good location to test nutrient concentrations since there is heavy boat traffic within this bay. Puerto Villamil is on one of the least inhabited islands, Isabela. However, it is a fishermen's village, with many of the inhabitants working in agriculture or fishing industries. Turtle Bay, adjacent to Puerto Villamil, would be likely to show any agricultural contaminants. Figure 2 and Figure 3A show suggested sample locations that would provide a determination of nutrient concentrations spreading outward from the town. Some of the R/V Thomas G. Thompson sample stations from Wreck Bay (Figure 2B) and Turtle Bay (Figure 3A) have not been included due to ship depth restrictions and are therefore not located within the map.

For an area with an unpopulated bay, a region having similar effects to the previous chosen populated bays should be chosen. These regions should have similar temperature, salinity and currents. Bustamante et al. (2002) shows in figure 7.3 (Figure 4) the five biogeographic units that Harris (1969) divided the Galapagos into, which can be used to determine areas with the most similarity in regards to the above parameters. Figure 4 shows that the Turtle Bay, Academy Bay, and Cartago Bay all lie within mixed subtropical regions. The zoning map of the Galapagos National Park, shows areas of the islands that are uninhabited (Constant 1995), and was used to determine that Cartago Bay (Figure 3B) on Isabela, has the characteristics to link it to populated bay areas.

Proposed Research

In order to determine anthropogenic nutrient contributions, water column and sediment pore-water samples will be collected aboard the R/V Thomas G. Thompson and a zodiac workboat. Samples will then be analyzed for nitrate, ammonium, and phosphate concentrations. Nitrate and Phosphate concentrations are important for determining eutrophication effects. These effects are induced by waters rich in nitrate and phosphate which causes an increase in production and reduces oxygen concentrations. Ammonium concentrations would show an increase if sewage contributions are significant in the bay waters. Oxygen levels will be measured for each location, to further test for eutrophication effects created within each bay. Salinity and temperature measurements will be made at each location so as to normalize nutrient concentrations between the bays and to limit any variability due to regional differences in normal seawater concentrations.

Water samples will be collected at 3 depths, spanning the water column at each location. Samples will be collected at the surface, a depth equivalent to the middle of water column, and just above the seafloor. Aboard R/V Thomas G. Thompson, water samples will be collected using the CTD. Salinity, temperature, and oxygen values will also be obtained from the CTD electrodes. CTD oxygen calibrations will be made in collaboration with Tamara Dickson's project. A salinity calibration will be made from a sampling location within Cartago Bay. Sediment pore-water samples will be collected by first using a $0.1m^2$ Van Veen Grab Sampler to collect upper portion of sediment. From this, 5-10 samples will be taken from the bottom layer, the middle layer, and the top layer within the Van Veen and placed into 50ml centrifuge tubes. Samples will then be centrifuged 30min at ~3000rpm, the maximum safe speed of the centrifuge. Pore-waters will be drawn off and combined for each sediment layer collected.

For stations less then 15m deep, a zodiac workboat along with a hand held GPS system will be used to reach sample locations. Water samples will be collected using a hand held bottle sampler, collection depths are determined as above. Sediment pore-waters are collected the same as before, with the exception that a $0.025m^2$ Van Veen Grap Sampler is used. Salinity, temperature, and oxygen at these locations will be measured using YSI Model 85 (handheld oxygen, conductivity, salinity, and temperature system).

Nitrate Analyses. Working stocks of sulfanilamide, N-(1-Napthyl)-ethylenediamine dihydrochloride (N1N), Imidazole Buffer, and $CuSo_4$ + NH_4Cl mix will be prepared as directed by Krogslund and Moeller (2005). All solutions can be kept at room temperature in appropriate bottles throughout cruise. Standard will be made up in only class "A" glass volumetric flasks. The primary standard is a 100mmol L^{-1} solution of 5.0554 g KNO_3 diluted to 500ml with deionized water (diH_2O). Secondary standard is 15.00ml primary standard diluted to 500ml with diH_2O. Both standards can be refrigerated for storage.

A blank and four standard concentrations will be made up in low nutrient SEAWATER daily, in accordance to Table 1. Spectronic 301 Spec will be set to wavelength of 543nm and allowed a 45min warm-up time before proceeding. Sequence of steps of procedure is given by Krogslund and Moeller (2005). Standards are run first, starting with lowest concentration and working up. Each location is started with a "lead-in" sample, a duplicate of the first sample. This allows for elimination of higher concentration carryover between samples.

Samples from each location will be analyzed starting at surface and then with decreasing depth, since concentrations are expected to increase with depth. Peak heights recorded will then be used to determine unknown concentrations using data collected from know nitrate concentrations. Once nitrate concentrations know for each bay, they can be compared to

determine relative impact of anthropogenic activities. Cartago Bay samples, which should have the least anthropogenic impact, should show smallest concentrations if anthropogenic effects are the main contributor to nitrate concentrations. Where as, Academy, Wreck Bay, and Puerto Villamil nitrate concentrations should be larger and show more variation.

Ammonium Analyses. Ammonium will be analyzed using Holmes et al. (1999) methods. These methods involve use of a working reagent (WR) which contains sodium sulfite solution, borate buffer solution, and orthophthaldialdehyde (OPA) solution. Standards, upon suggestion, will be made while in the field. During sampling, ammonium stock solution added at varying concentrations to bottles pre-filled with diH_2O and then WR is added. Samples collected by first rinsing bottles with sample water, and then filling to 80ml mark. 20ml WR is then added and mixed in, bottles are then stored in dark for 2-3 hours. After incubation, standards and samples poured into test tubes and immediately read on the florometer. Concentrations can then be calculated as stated in Holmes et al. (1999).

Phosphate Analyses. Phosphate analysis samples will be kept in polyethylene bottles that have been rinsed twice before filling with sample water. Ammonium molybdate solution, sulfuric acid solution, ascorbic acid solution, and potassium antimonyl-tartrate solution are all made up in accordance to Strickland and Parson Methods (Parson et al. 1984). These solutions are then used to make the mixed reagent solution, which will be added to sample. Once sample and mixed reagent solution have sat for at least 5 min, absorption can be measured at 885nm and corrected for any reagent blank.

Proposed Budget

Equipment/Supplies		Total Cost	Effective Cost
Platform			
R/V Thomas G. Thompson	$18,000/day x 8 days	$144,000.00	$0.00
Sampling Equipment/Supplies			
CTD with 10L Bottles	$135/day x 4 days	$540.00	$0.00
Van Veen (0.1m^2)	$6/day x 4 days	$24.00	$24.00
Zodiac Workboat (+Operator)	$105/day x 4 days	$420.00	$0.00
Hand Held Water Collection and 2L Bottles	$5/day x 4 days	$20.00	$20.00
Van Veen (0.025m^2)	$6/day x 4 days	$24.00	$24.00
GPS, Magellan Hand Held	$6/day x 4 days	$24.00	$24.00
YSI Temp, Salinity, O_2 Meter	$15/day x 4 days	$60.00	$60.00
Laboratory Equipment/Supplies			
Centrifuge	$6/day x 4days	$24.00	$0.00
Lab Fluorometer	$15/day x 4 days	$60.00	$0.00
Auto Analyzer II	$45/day x 4 days	$180.00	$0.00
Spectrophotomer 100	$6/day x 4 days	$24.00	$0.00
Nutrient Bottles (per case)	$3/day x 4 days	$12.00	$0.00
Nutrient Analyses (Nitrate)	$5/sample x 144 samples	$720.00	$0.00
Nutrient Analyses (Ammonium)	$5/sample x 144 samples	$720.00	$0.00
Nutrient Analyses (Phosphate)	$5/sample x 144 samples	$720.00	$0.00
Oxygen Analyses	$6/sample x 6 samples	$36.00	$0.00
50ml Centrifuge Tubes	$/#bottles x ~100	$50.00	50.00
Total		$147,608.00	$202.00

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Figure Captions

Figure 1. Galapagos Island map showing bays in which sampling will occur. Figure is an edited map from Boyce (1998)

Figure 2. Sampling locations from the two highest populated towns in the Galapagos Islands. (A) Academy Bay, Puerto Ayora, Santa Cruz Island, (B) Wreck Bay, Puerto Baquerizo Moreno, San Cristobal Island. Not all R/V Thomas G. Thompson stations shown on this map. Maps are altered from figures in Constant (1995).

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

Figure 4. Galapagos map from Boyce (1998) edited to show biogeographic units proposed by Harris (1969).

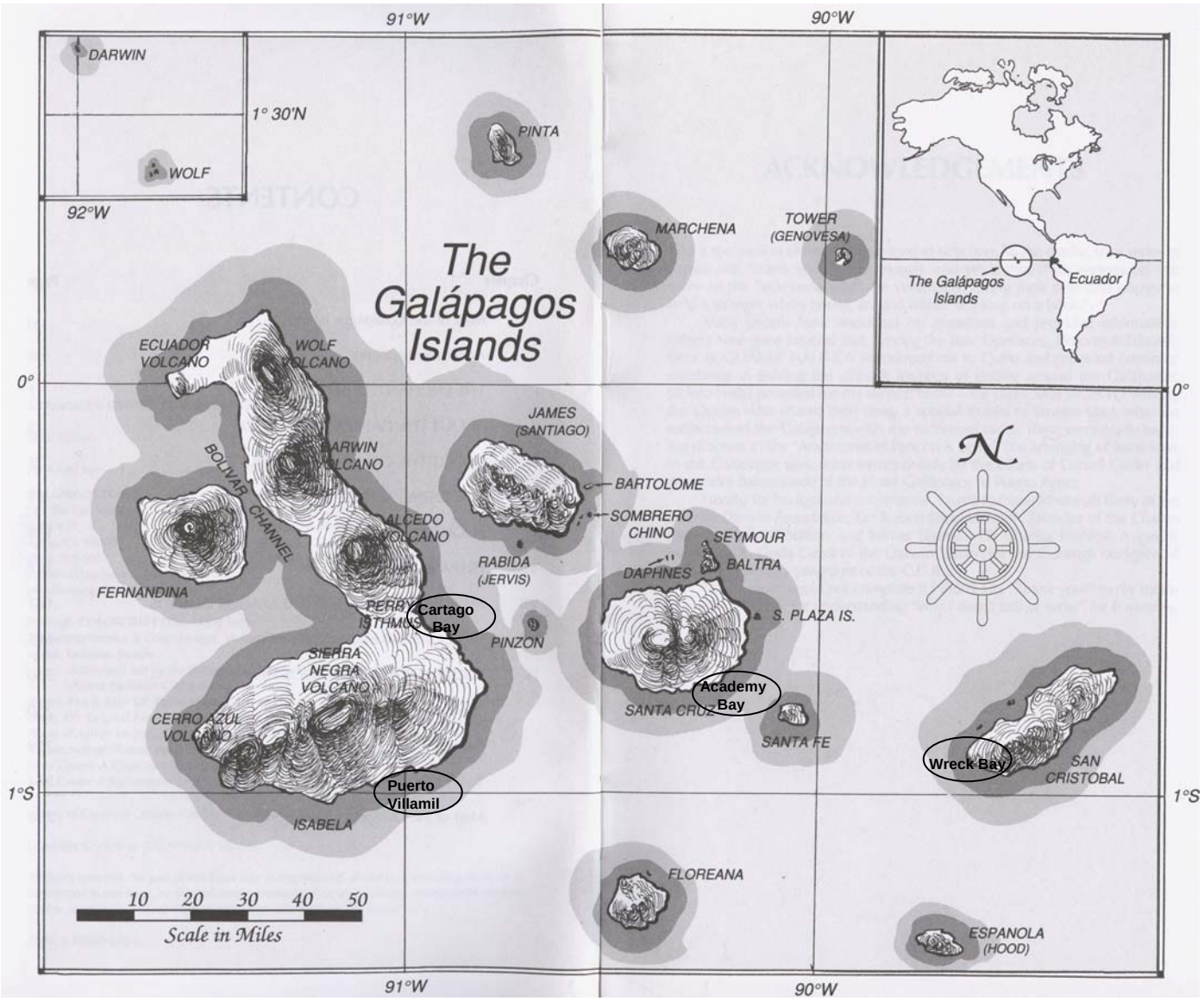
91°W
90°W
DARWIN
1° 30'N
WOLF
92°W
PINTA
MARCHENA
TOWER
(GENOVESA)
The Galápagos Islands
The Galápagos Islands
Ecuador
ECUADOR VOLCANO
WOLF VOLCANO
0°
JAMES
(SANTIAGO)
BARTOLOME
SOMBRERO CHINO
SEYMOUR
BALTRA
DAPHNES
RABIDA
(JERVIS)
ALCEDO VOLCANO
BOLIVAR CHANNEL
FERNANDINA
Cartago Bay
PINZON
S. PLAZA IS.
SIERRA NEGRA VOLCANO
Academy Bay
SANTA CRUZ
SANTA FE
CERRO AZUL VOLCANO
Wreck Bay
SAN CRISTOBAL
Puerto Villamil
1°S
ISABELA
FLOREANA
10 20 30 40 50
Scale in Miles
ESPANOLA
(HOOD)
91°W
90°W

Figure 1.


A
to Bellavista + Baltra
Charles Darwin Station
to Punta Nuñez
Puerto Ayora
old trail
new trail 1990
Trail (1982)
Playa Brava
Divine's Bay
Punta Estrada
Isla Coamaño
Lagoon
Tortuga Bay
Samples to be collected using Zodiac
Samples to be collected on R/V Thomas G. Thompson
Tortuga Bay + Academy Bay
[after the map of uss Bowditch, 1942].
0
1000 m
Piroco 89

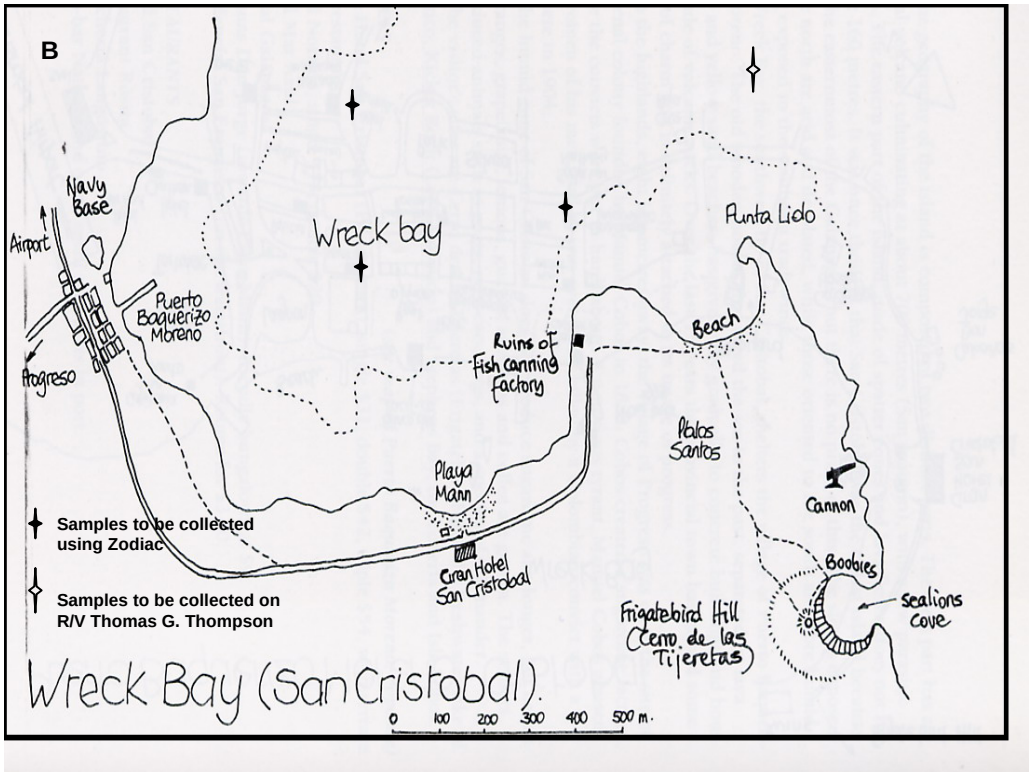
B
Navy Base
Airport
Wreck bay
Punta Lido
Puerto Baquerizo Moreno
Ruins of Fish canning factory
Beach
Progreso
Playa Mann
Palos Santos
Cannon
Samples to be collected using Zodiac
Samples to be collected on R/V Thomas G. Thompson
Gran Hotel San Cristobal
Boobies
Sealions Cove
Frigatebird Hill (Cerro de las Tijeretas)
Wreck Bay (San Cristobal).
0 100 200 300 400 500 m.

Figure 2.

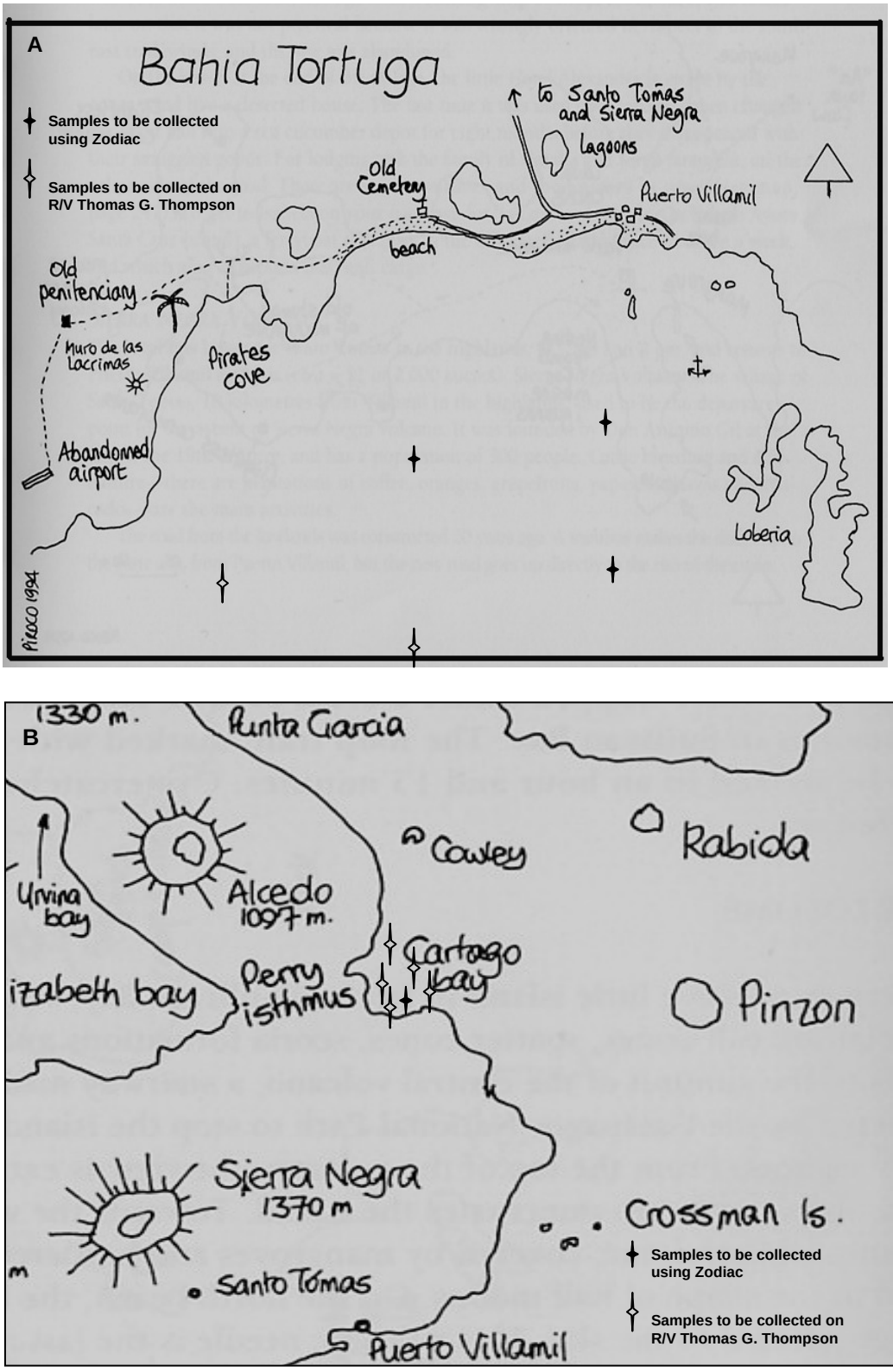
A
Bahia Tortuga
Samples to be collected using Zodiac
Samples to be collected on R/V Thomas G. Thompson
to Santo Tomas and Sierra Negra
Lagoons
Old Cemetery
Puerto Villamil
beach
Old penitenciary
Muro de las Lacrimas
Pirates cove
Abandoned airport
Loberia
Pitoco 1994
B
1330 m.
Punta Garcia
Cowley
Rabida
Urvina bay
Alcedo 1097 m.
Elizabeth bay
Perry isthmus
Cartago bay
Pinzon
Sierra Negra 1370 m
Crossman Is.
Santo Tomas
Puerto Villamil
Samples to be collected using Zodiac
Samples to be collected on R/V Thomas G. Thompson

Figure 3.

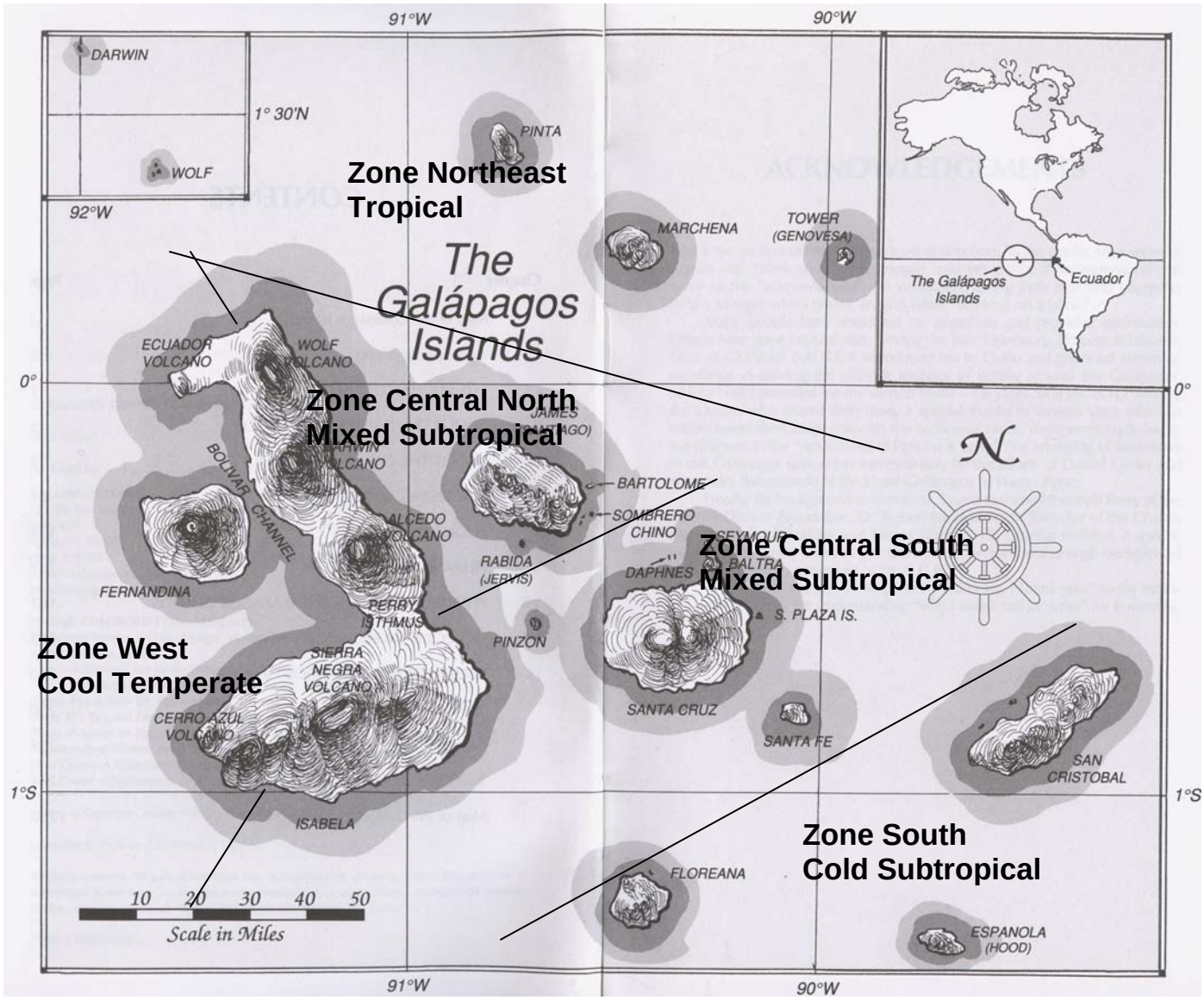
91°W
90°W
DARWIN
1° 30'N
WOLF
92°W
PINTA
Zone Northeast
Tropical
MARCHENA
TOWER
(GENOVESA)
The Galápagos Islands
The Galápagos
Islands
Ecuador
ECUADOR
VOLCANO
WOLF
VOLCANO
0°
Zone Central North
Mixed Subtropical
JAMES
(SANTIAGO)
DARWIN
VOLCANO
BOLIVAR CHANNEL
BARTOLOME
SOMBRERO
CHINO
ALCEDO
VOLCANO
RABIDA
(JERVIS)
SEYMOUR
BALTRA
DAPHNES
Zone Central South
Mixed Subtropical
FERNANDINA
PERRY
ISTHMUS
S. PLAZA IS.
PINZON
Zone West
Cool Temperate
SIERRA
NEGRA
VOLCANO
CERRO AZUL
VOLCANO
SANTA CRUZ
SANTA FE
SAN
CRISTOBAL
1°S
ISABELA
Zone South
Cold Subtropical
FLOREANA
10 20 30 40 50
Scale in Miles
ESPANOLA
(HOOD)
91°W
90°W

Figure 4.

Table 1. Possible range of nitrate running standards concentrations to be used in analyses.

NO3 Concentration ($\mu mol\ L^{-1}$)	2^{o} standard	Low nutrient SEAWATER (ml)
0	0	250
1.5	125µl	249.875
3	250µl	249.75
6	500µl	249.5
12	1ml	249
24	2ml	248
36	3ml	247
48	4ml	246