



Water Quality in Anchialine Pools of Ala Kahakai National Historic Trail

Summary Report 2008-2011

Natural Resource Data Series NPS/PACN/NRDS—2014/663



ON THE COVER

The anchialine pool at Kahalu`u Beach Park in April 2011 during restoration and wall construction.

Water Quality in Anchialine Pools of Ala Kahakai National Historic Trail

Summary Report 2008-2011

Natural Resource Data Series NPS/PACN/NRDS—2014/663

David F. Raikow and Anne Farahi

National Park Service
Pacific Island Network
Inventory & Monitoring Program
1 Crater Rim Dr., Building 22
Hawaii National Park, HI 96718

May 2014

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Pacific Island Network Inventory & Monitoring program website (<http://science.nature.nps.gov/im/units/pacn/index.cfm>) and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Raikow, D. F., and A. Farahi. 2014. Water quality in anchialine pools of Ala Kahakai National Historic Trail: Summary report 2008-2011. Natural Resource Data Series NPS/PACN/NRDS—2014/663. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	v
Tables.....	vi
Abstract.....	viii
Acknowledgments.....	ix
List of Units and Acronyms.....	ix
Introduction.....	1
Methods.....	2
Sample Sites.....	2
Water Collection.....	4
Limnological Parameters and General Conditions	5
Data Analysis, Management, and Quality Control.....	5
Results.....	1
F-ALKA-01	1
F-ALKA-02	1
F-ALKA-03	1
F-ALKA-04	1
Summaries by parameter	6
Total Dissolved Phosphorus	6
Total Dissolved Nitrogen.....	8
Nitrate + Nitrite.....	10
Chlorophyll	12
Oxygen Concentration	14
Oxygen Saturation	16

Contents (continued)

	Page
pH.....	18
Salinity	20
Specific Conductance.....	22
Temperature	24
Turbidity	26
Discussion	28
Literature Cited	28

Figures

	Page
Figure 1. Sample sites associated with Ala Kahakai National Historic Trail on the island of Hawai`i.....	3
Figure 2. Box plot explanation.....	6
Figure 3. Box plots of Total Dissolved Phosphorus in anchialine pools associated with Ala Kahakai NHT.	6
Figure 4. Box plots of Total Dissolved Nitrogen in anchialine pools associated with Ala Kahakai NHT.	8
Figure 5. Box plots of nitrate + nitrite in anchialine pools associated with Ala Kahakai NHT.	10
Figure 6. Box plots of chlorophyll in anchialine pools associated with Ala Kahakai NHT.	12
Figure 7. Box plots of oxygen concentration in anchialine pools associated with Ala Kahakai NHT.	14
Figure 8. Box plots of oxygen saturation in anchialine pools associated with Ala Kahakai NHT.	16
Figure 9. Box plots of pH in anchialine pools associated with Ala Kahakai NHT.	18
Figure 10. Box plots of salinity in anchialine pools associated with Ala Kahakai NHT.	20
Figure 11. Box plots of specific conductance (SpC, $\text{mS} \cdot \text{cm}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.....	22
Figure 12. Box plots of temperature in anchialine pools associated with Ala Kahakai NHT.	24
Figure 13. Box plots of turbidity in anchialine pools associated with Ala Kahakai NHT.	26

Tables

	Page
Table 1. Ala Kahakai NHT Sample site designations.....	4
Table 2. Ala Kahakai NHT sampling events.....	4
Table 3. 2008 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.	2
Table 4. 2009 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.	3
Table 5. 2010 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.	4
Table 6. 2011 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.	5
Table 7. Mean Total Dissolved Phosphorus (TDP, $\mu\text{gP} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.....	7
Table 8. Mean Total Dissolved Nitrogen (TDN, $\text{mgN} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.....	9
Table 9. Mean nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$, $\mu\text{gN} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.	11
Table 10. Mean chlorophyll-a ($\mu\text{g} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.....	13
Table 11. Mean oxygen concentration (ODO, $\text{mg} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.	15
Table 12. Mean oxygen saturation (%) in anchialine pools associated with Ala Kahakai NHT.	17
Table 13. Mean pH in anchialine pools associated with Ala Kahakai NHT.....	19
Table 14. Mean salinity (ppt) in anchialine pools associated with Ala Kahakai NHT.....	21
Table 15. Mean specific conductance (SpC, $\text{mS} \cdot \text{cm}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.	23
Table 16. Mean temperature ($^{\circ}\text{C}$) in anchialine pools associated with Ala Kahakai NHT.	25

Tables (continued)

Page

Table 17. Mean turbidity (NTU) in anchialine pools associated with Ala Kahakai

NHT. 27

Abstract

This Natural Resource Data Series Report (NRDS) presents data collected from anchialine pools associated with the Ala Kahakai National Historic Trail on the west coast of the island of Hawai`i, Hawaii. This is a summary or “data report” as described in the Water Quality Vital Signs Monitoring Protocol for the Pacific Island Network Version 1.0, Natural Resource Report NPS/PACN/NRR-2011/418. This report is restricted to data presentation and limited description. The data presented in this report will be analyzed for the establishment of expected parameter value ranges and long-term trends in future reports published in the NPS Natural Resource Technical Report (NRTR) series. The purpose of collecting data on Vital Signs is to provide park managers information on current conditions and temporal trends in ecosystem health. Four anchialine pools were sampled up to 17 times from the first quarter of 2008 through 2011. Two major events occurred during the sample period: a tsunami on 11 March 2011, and extensive restoration of one pool (F-ALKA-01) by the State of Hawaii. The tsunami buried one pool (F-ALKA-02) such that water no longer reached the surface, and hence sampling was suspended. Inundation by seawater into F-ALKA-01 was observable as elevated salinity 21 days later but not 48 days later. No notable events were observed in the two subterranean pools F-ALKA-03 and F-ALKA-04.

Acknowledgments

We thank Aric Arakaki, Superintendent, and the staff of Ala Kahakai NHT for their cooperation and on-site logistical support.

List of Units and Acronyms

ALKA	Ala Kahakai National Historic Trail
°C	Degrees Centigrade
$\mu\text{g} \cdot \text{L}^{-1}$	Micrograms per Liter
$\mu\text{gP} \cdot \text{L}^{-1}$	Micrograms of Phosphorus per Liter
$\text{mS} \cdot \text{cm}^{-1}$	Milli-Siemens per Centimeter
Chl	Chlorophyll
HAVO	Hawaii Volcanoes National Park
I&M	Inventory and Monitoring Program of the National Park Service
$\text{mg} \cdot \text{L}^{-1}$	Milligrams per Liter
$\text{mgN} \cdot \text{L}^{-1}$	Milligrams of Nitrogen per Liter
n	Number of measurements or samples
NHT	National Historic Trail
NO_2	Nitrite
NO_3	Nitrate
NPS	National Park Service
NRDS	Natural Resource Data Series Report
NRTR	Natural Resource Technical Report
NTU	Nephelometric Turbidity Units
ODO	Optical Dissolved Oxygen
ODOsat	Optical Dissolved Oxygen in terms of saturation
PACN	Pacific Island Inventory and Monitoring Network
ppt	Parts Per Thousand
SD	Standard Deviation
SE	Standard Error
SpC	Specific conductivity
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
Temp	Temperature
Turb	Turbidity
UHH	University of Hawaii at Hilo

Introduction

Water quality is widely used as an indicator of aquatic ecosystem condition. The National Park Service (NPS) has designated water quality as a “Vital Sign”, or an indicator of physical, chemical, biological elements or ecosystem processes selected to represent the overall health or condition of natural resources within parks. Water quality is one Vital Sign monitored by the NPS Inventory and Monitoring (I&M) Pacific Island Network (PACN). This report presents data collected under the PACN water quality protocol (Jones et al. 2011) on anchialine pools associated with the Ala Kahakai National Historic Trail on the island of Hawai`i, Hawaii, between 2008-2011.

Anchialine pools are spatially distinct waterbodies subject to tides fed both by freshwater and seawater groundwater inputs (Holthuis 1973). While anchialine pools have no regular overland input of water, and no direct connection to the sea, exceptional events like tsunamis can introduce water to anchialine pools. Within this broad definition, the geomorphology of anchialine pools is quite variable, including pools in caves, pools in open pits, and pools at the surface. Size, substrate including lava, sand, or organic sediment, extent of macrophyte vegetation, periphyton, or other algae, presence of fish and/or native shrimp, exposure to sunlight, and alteration by humans, both historical and contemporary, vary greatly between pools. Some pools are of great cultural importance. Most of the world’s known anchialine pools occur along the Kona coast of the big island of Hawai`i, Hawaii, USA.

This report is a Natural Resource Data Series Report (NRDS), defined by the NPS as an annual or periodic data summary report for long-term monitoring projects. NRDSs are intended only for the release of basic data sets and summaries, with minimal interpretation. This report is one part of the I&M reporting process. Data presented in this report will be incorporated into future I&M trend-analysis reports to be published as NPS Natural Resource Technical Reports (NRTR).

The mission of the I&M Program is to provide data to inform management decisions and support the NPS mission of preserving the natural resources of parks unimpaired for the enjoyment of future generations (16 U.S.C. §1). The purpose of collecting data on Vital Signs is to provide park managers information on current conditions and temporal trends in ecosystem health. The primary purposes of the water monitoring protocol are to characterize the ecosystem and identify existing problems, and identify temporal trends especially with regard to emerging problems. Park managers can use this information to respond to resource conditions and evaluate management actions.

Methods

Water was collected for nutrient analyses, a sonde was used to measure limnological parameters, and weather conditions were recorded. Data were collected using methods described in version 1.0 of the PACN water quality protocol (Jones et al. 2011).

Sample Sites

Portions of the 175-mile historic Ala Kahakai trail can be accessed in sections on private land, state land, and four National Parks on the Island of Hawaii including Hawai'i Volcanoes National Park, Pu'u'honua O Hōnaunau National Historical Park, Kaloko-Honokōhau National Historical Park and Pu'ukoholā Heiau National Historic Site. Four pools associated with the trail but not within national parks were initially chosen for sampling (Fig. 1). Sites were designated F-ALKA-01, F-ALKA-02, and F-ALKA-03, and F-ALKA-04 (Table 1), where F means “fixed location”, as opposed to temporary locations designated with a “T” at sample sites in other parks. Because anchialine pools are sensitive ecological and archeological sites, their precise locations are not published here.

F-ALKA-01 is a pool at the Kahalu'u Beach Park that currently has artificial rock walls to discourage entry by the public and to prevent infiltration by surrounding sand. It is located at the surface, fully exposed to sunlight, has fish, algae, and macrophytes, and is managed by the State of Hawaii. F-ALKA-02 was a shallow depression in an a'a lava flow of loose rocks very close to the shore. A tsunami in March of 2011 caused the surrounding substrate to fill-in F-ALKA-02, preventing water from reaching the surface. F-ALKA-02 could not be sampled after the tsunami. F-ALKA-03 is a covered well where sampling was eventually dropped for safety reasons. F-ALKA-04 is inside a cave of cultural significance on private land. There are no inland water quality criteria for anchialine pools under §11-54-5.1b of the State of Hawaii Department of Health Water Quality Standards (Hawaii 2012). Data were collected from March 2008 - November 2011 (Table 2).

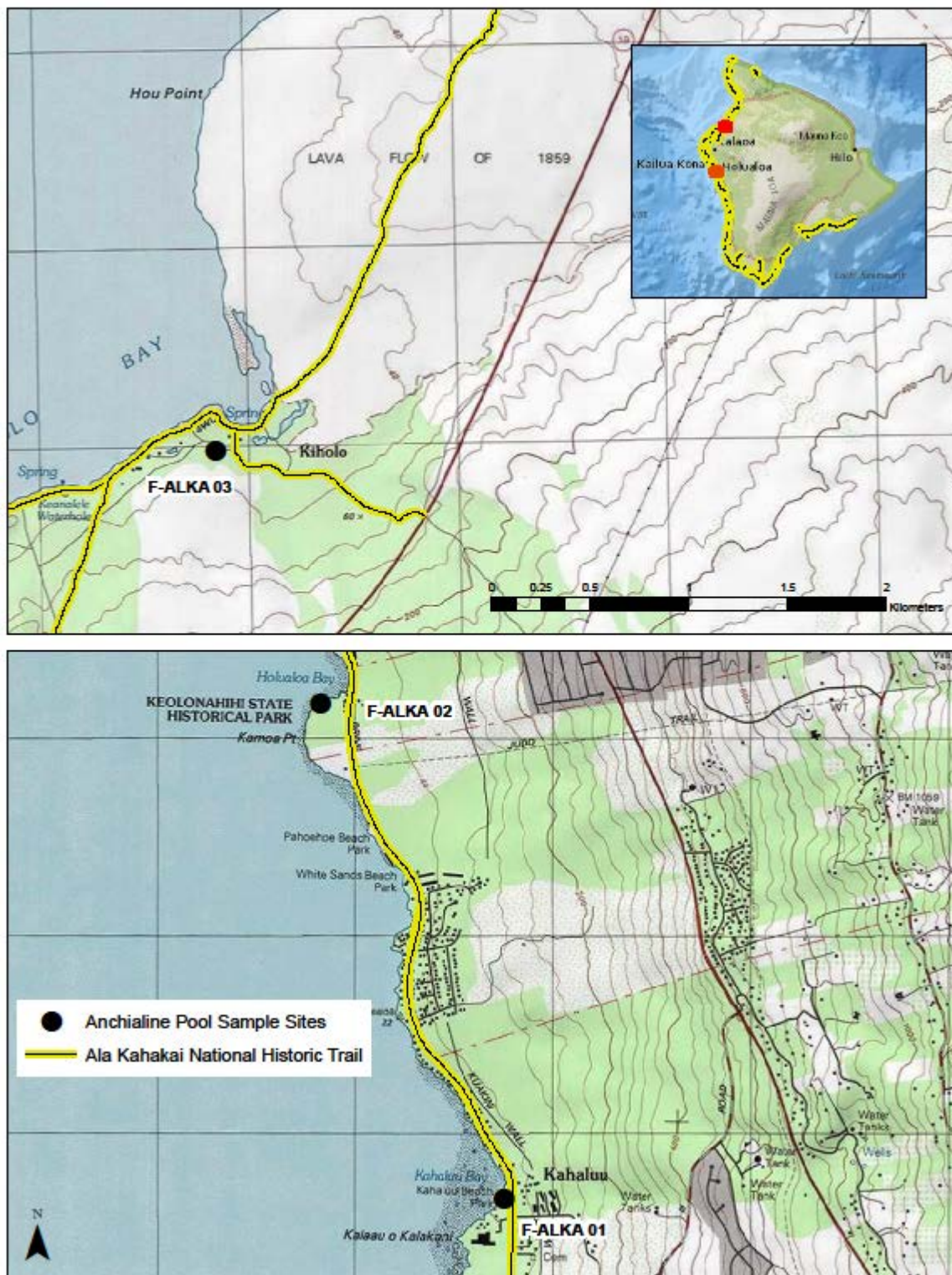


Figure 1. Sample sites associated with Ala Kahakai National Historic Trail on the island of Hawai'i.

Table 1. Ala Kahakai NHT Sample site designations.

I&M Site Designation	Park Site Designation
F-ALKA-01	Kahaluu001
F-ALKA-02	Holual001
F-ALKA-03	Puuwaa001
F-ALKA-04	Puuwaa002

Table 2. Ala Kahakai NHT sampling events.

Park	Year	Date	Personnel
ALKA	2008	20-Mar-08	Anne Farahi, Lindsey Kramer, Tahzay Jones
ALKA	2008	20-May-08	Anne Farahi, Lindsey Kramer
ALKA	2008	25-Nov-08	Anne Farahi, Lindsey Kramer
ALKA	2009	30-Mar-09	Anne Farahi, Lindsey Kramer
ALKA	2009	26-Jun-09	Anne Farahi, Lindsey Kramer, Rachael Addlesberger
ALKA	2009	09-Sep-09	Ida Hanohano, Lindsey Kramer
ALKA	2009	18-Nov-09	Lindsey Kramer, Lisa Nelson
ALKA	2010	26-Feb-10	Gregory Kudray, Lily Souza, Lindsey Kramer
ALKA	2010	10-May-10	Lily Souza, Lindsey Kramer
ALKA	2010	13-Aug-10	Colleen McHugh, Lindsey Kramer
ALKA	2010	01-Dec-10	Lindsey Kramer, Michelle Tomas
ALKA	2011	09-Feb-11	Lindsey Kramer, M. Jerolaman
ALKA	2011	01-Apr-11	Anne Farahi, Ben McMillan, M. Jerolaman
ALKA	2011	02-May-11	Asia Addlesberger, M. Jerolaman
ALKA	2011	11-Aug-11	Anne Farahi, Danielle Gross, Malia Laber, Tonnie Casey
ALKA	2011	31-Oct-11	Anne Farahi, Danielle Gross
ALKA	2011	02-Nov-11	Danielle Gross, Rick Gmirkin

Water Collection

Water was collected using a new or acid-washed 140 cc syringe just below the stream surface to avoid disturbance of sediment on the bottom or collection of floating material. This water was then discarded away from the collection location to rinse the syringe. Water was again collected using the rinsed syringe. An in-line filter holder and 0.7 μm filter were then placed on the syringe. Filtered water was used to rinse each sample bottle three times, for a total of 50ml per bottle, discarding water between each rinse. The filter assembly was removed, water again was drawn into the syringe, and a filter assembly was placed onto the syringe to input 140ml of filtered water into each sample bottle. Three 140ml samples were taken at each sample site. Sample bottles were placed on ice in the field inside an insulated backpack. Samples were transported to Hawai'i Volcanoes National Park (HAVO) on the day of collection and then frozen, or deposited into a freezer on the day of collection and later transported while frozen to HAVO. Samples were then delivered to the EPSCoR Analytical Laboratory at the University of Hawai'i at Hilo (UHH) Marine Science Department, 200 W. Kawili St., Hilo, Hawaii 96720 for chemical analysis. Samples were analyzed for total dissolved phosphorous (TDP), total dissolved nitrogen (TDN) and nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$).

Limnological Parameters and General Conditions

A YSI 6600 Multiparameter Sonde was calibrated a few days before commencing field sampling. The sonde was used to measure temperature ($^{\circ}\text{C}$), specific conductivity (SpC) in milli-Siemens per centimeter (mS cm^{-1}), pH, optical dissolved oxygen in milligrams per liter ($\text{mg} \cdot \text{L}^{-1}$, ODO), chlorophyll in micrograms per liter ($\mu\text{g} \cdot \text{L}^{-1}$), and turbidity in nephelometric turbidity units (NTU). The sonde also reported salinity in parts per thousand (ppt) calculated from SpC, dissolved oxygen in percent saturation (% ODOsat) calculated from ODO, and temperature. The sonde was placed under the surface of the water at a sample site for ten minutes with readings taken every 30 seconds. The mean and variance of stable values, excluding initial readings prior to reaching stability, over this time period is reported. Minimum analytical detection limits were $15.0 \mu\text{gP} \cdot \text{L}^{-1}$ for total dissolved phosphorus (TDP), $0.070 \text{ mgN} \cdot \text{L}^{-1}$ for total dissolved nitrogen (TDN), and $1.0 \mu\text{gN} \cdot \text{L}^{-1}$ for nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$).

Environmental conditions, canopy cover, and water depth were estimated. Average wind speed over three minutes and wind direction were measured using a Kestrel wind speed device. Global positioning system coordinates and site elevation were recorded. Photographs of sample sites were also taken.

Data Analysis, Management, and Quality Control

Environmental parameters, habitat descriptions, and general observations were recorded on datasheets in the field. Datasheets were stored at park offices, scanned, and uploaded to PACN servers. All data including results of laboratory analyses were entered into PACN databases. Data were downloaded from the YSI 650 control unit and uploaded to databases. Accuracy of data entry into databases was verified by comparing database entries to the original datasheets by a person who did not enter the data into databases. Data were then certified by the PACN freshwater program lead at the time, either Tazhay Jones or David Raikow. Data determined to be unreliable were flagged in databases, removed from further consideration. Data were explored visually by plotting time-series and boxplots. Data that deviated from regular temporal patterns were identified. Corroboration between related parameters and field notes was used to identify possible causes of deviation from regular temporal patterns. Statistical analysis of water quality data followed recommendations by the USGS (Helsel and Hirsch 2002) as described in the Water Quality Protocol (Jones et al. 2011).

Measurements from a series of water samples or sonde readings taken at an individual site within minutes of each other were expected to be normally distributed around the true value of the parameter, because the parameter should not change appreciably over the short time required to take multiple samples or readings. Variation in sample values should be most influenced by external factors. Therefore the mean and the standard error are reported for individual sampling events, because the accuracy of the estimate of the mean is of interest (Tables 7-17). Non-normal distributions, however, are generally expected when summarizing limnological conditions over a time period such as a year due to censoring (values cannot drop below zero or have a minimum analytical detection limit) and positive skewness (having infrequent high values) (Helsel and Hirsch 2002). Therefore the median and standard deviation are reported for annual summaries, because the variance of the parameter over the study period is of interest (Tables 3-6). The median equals the

mean in normally-distributed parameters. For the purposes of descriptive statistics, values below detection limits were assigned values equal to one-half of the detection limit. Standard deviation was not calculated for sets of data with $n \leq 2$.

Within boxplots, the upper edge of the box indicates the third quartile (Q_3 , upper quartile, or 75th percentile), and the lower edge indicates the first quartile (Q_1 , lower quartile, or 25th percentile, Fig. 2). Within the box, the line indicates the median (Q_2 , or 50th percentile). The whiskers extend up or down until the maximum or minimum value within 1.5 IQRs (inter-quartile range, or $Q_3 - Q_1$). Data outside 1.5 IQRs are displayed as dots, and considered outliers. If there are no outliers the box or whiskers display the entire range of data.

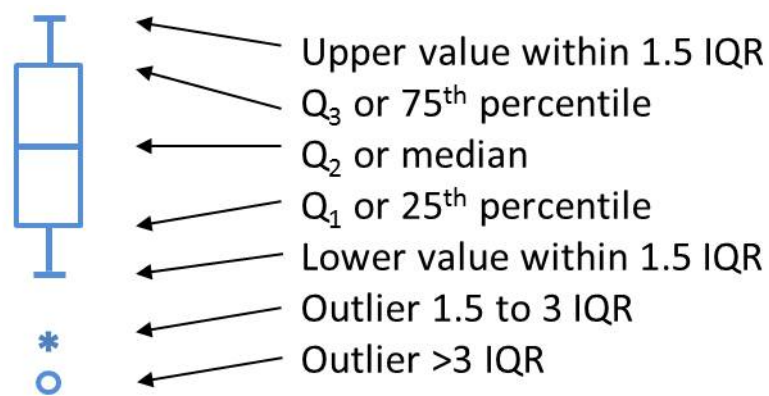


Figure 2. Box plot explanation.

Results

Sites associated with Ala Kahakai NHT were sampled up to 17 times from 2008 to 2011. Results are presented in summaries by year (Tables 3-6, Figs. 3-13) and parameter (Tables 7-17). Annual summaries present the minimum, maximum, median, and variance as standard deviation of all individual measurements at each site across an entire year. Parameter summaries present stable sonde readings and nutrient concentrations from each site and sampling event as mean and standard error of the mean. Data missing from tables were due to probe failure or the pool not being sampled on that date. Box plots display data lumped from all three sample sites by year.

F-ALKA-01

2008: No notable events were observed.

2009: An algal bloom may have occurred in late-2009 as indicated by elevated chlorophyll.

2010: An algal bloom may have occurred in mid-2010 as indicated by elevated chlorophyll.

2011: Two important events occurred. A tsunami hit Hawaii on 11 March 2011. The sampling event on 1 April 2011 recorded elevated salinity and SpC, but no other notable measurements. F-ALKA-01 also underwent extensive restoration and wall construction by the state. Macrophytes and a tree providing shade were removed. TDP dropped considerably in F-ALKA-01, while TDN and NO_3+NO_2 remained similar compared to previous years. Oxygen, pH, temperature, and turbidity increased in F-ALKA-01 in 2011 following restoration efforts. An algal bloom may have occurred following restoration efforts as indicated by elevated chlorophyll.

F-ALKA-02

2008: No notable events were observed, but variable salinity may indicate intermittent overland inundation of seawater.

2009: No notable events were observed, but variable salinity may indicate intermittent overland inundation of seawater. Nutrient levels fluctuated widely.

2010: No notable events were observed, but variable salinity may indicate intermittent overland inundation of seawater. Nutrient levels fluctuated widely.

2011: This pool was filled-in with surrounding substrate (rocks) following the tsunami on 11 March 2011. Water no longer reached the surface, and sampling was suspended.

F-ALKA-03

2008: No notable events were observed.

2009: No notable events were observed.

2010: No notable events were observed.

2011: No notable events were observed. Sampling at this site was suspended due to safety concerns.

F-ALKA-04

2008: No notable events were observed.

2009: No notable events were observed.

2010: No notable events were observed.

2011: No notable events were observed.

Table 3. 2008 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.

Parameter	Unit	Site	n	Minimum	Maximum	Median	SD
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-ALKA-01	9	31.0	129.0	109.0	39.5
		F-ALKA-02	9	64.0	96.0	73.0	11.1
		F-ALKA-03	9	49.0	67.0	62.0	6.6
		F-ALKA-04	9	43.0	59.0	52.0	5.7
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-ALKA-01	9	0.3	0.6	0.4	0.1
		F-ALKA-02	9	0.4	1.1	0.7	0.2
		F-ALKA-03	9	0.4	0.9	0.6	0.2
		F-ALKA-04	9	0.4	0.7	0.6	0.1
Nitrite + Nitrate	$\mu\text{gN} \cdot \text{L}^{-1}$	F-ALKA-01	9	<1.0 ¹	258.0	172.0	112.7
		F-ALKA-02	9	213.0	830.0	530.0	176.9
		F-ALKA-03	9	484.0	877.0	654.0	142.3
		F-ALKA-04	9	340.0	781.0	512.0	173.0
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-ALKA-01	3	9.0	14.2	9.2	3.0
		F-ALKA-02	3	2.6	3.1	2.7	0.3
		F-ALKA-03	3	0.0	0.0	0.0	0.0
		F-ALKA-04	3	0.0	0.0	0.0	0.0
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-ALKA-01	3	1.1	1.9	1.3	0.4
		F-ALKA-02	3	3.4	6.0	3.4	1.5
		F-ALKA-03	3	8.0	8.3	8.2	0.1
		F-ALKA-04	3	8.1	8.3	8.3	0.1
Dissolved Oxygen Saturation	%	F-ALKA-01	3	7.0	22.3	12.5	7.7
		F-ALKA-02	3	41.4	79.0	45.4	20.6
		F-ALKA-03	3	92.1	95.5	94.6	1.8
		F-ALKA-04	3	92.4	95.6	95.4	1.8
pH	none	F-ALKA-01	2	7.1	7.2	7.1	0.0
		F-ALKA-02	3	7.2	7.5	7.3	0.1
		F-ALKA-03	3	7.6	7.7	7.6	0.1
		F-ALKA-04	3	7.6	7.8	7.7	0.1
Salinity	ppt	F-ALKA-01	3	4.1	5.0	4.7	0.5
		F-ALKA-02	3	10.2	24.1	20.2	7.2
		F-ALKA-03	3	2.0	2.1	2.0	0.0
		F-ALKA-04	3	1.8	1.8	1.8	0.0
Specific conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-ALKA-01	3	7.4	9.0	8.5	0.8
		F-ALKA-02	3	17.3	38.0	32.3	10.7
		F-ALKA-03	3	3.9	3.9	3.9	0.0
		F-ALKA-04	3	3.4	3.4	3.4	0.0
Temperature	$^{\circ}\text{C}$	F-ALKA-01	3	22.9	23.3	23.1	0.2
		F-ALKA-02	3	22.8	23.4	23.4	0.4
		F-ALKA-03	3	21.5	21.6	21.5	0.1
		F-ALKA-04	3	21.4	21.5	21.5	0.1
Turbidity	NTU	F-ALKA-01	3	1.4	11.0	8.4	5.0
		F-ALKA-02	3	0.9	5.2	1.8	2.3
		F-ALKA-03	3	0.0	0.0	0.0	0.0
		F-ALKA-04	3	0.0	0.0	0.0	0.0

¹Non-detection, i.e. less than the analytical detection limit of $1.0 \mu\text{gN} \cdot \text{L}^{-1}$.

Table 4. 2009 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.

Parameter	Unit	Site	n	Minimum	Maximum	Median	SD
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-ALKA-01	12	40.2	126.4	92.1	30.5
		F-ALKA-02	12	52.8	185.0	87.4	43.8
		F-ALKA-03	12	47.4	81.0	62.6	10.0
		F-ALKA-04	12	39.3	70.1	55.8	10.3
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-ALKA-01	12	0.3	0.7	0.4	0.1
		F-ALKA-02	12	0.6	1.5	0.9	0.3
		F-ALKA-03	12	0.5	1.1	0.8	0.2
		F-ALKA-04	12	0.5	0.9	0.7	0.1
Nitrite + Nitrate	$\mu\text{gN} \cdot \text{L}^{-1}$	F-ALKA-01	12	57.0	267.7	145.5	62.0
		F-ALKA-02	12	428.6	1432.2	874.5	335.8
		F-ALKA-03	12	520.8	911.0	773.9	149.8
		F-ALKA-04	12	523.8	780.0	586.3	91.0
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-ALKA-01	3	4.0	62.3	11.2	31.8
		F-ALKA-02	3	0.6	3.2	0.7	1.4
		F-ALKA-03	3	0.0	0.0	0.0	0.0
		F-ALKA-04	3	0.0	0.0	0.0	0.0
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-ALKA-01	4	2.8	5.0	3.1	1.0
		F-ALKA-02	4	4.3	7.4	6.4	1.3
		F-ALKA-03	4	8.2	8.4	8.3	0.1
		F-ALKA-04	4	8.3	8.4	8.3	0.1
Dissolved Oxygen Saturation	%	F-ALKA-01	4	34.7	61.5	38.2	12.6
		F-ALKA-02	4	53.5	92.3	85.1	18.0
		F-ALKA-03	4	93.9	96.2	95.2	1.0
		F-ALKA-04	4	95.2	96.5	95.5	0.6
pH	none	F-ALKA-01	4	7.1	7.5	7.2	0.1
		F-ALKA-02	4	7.1	7.7	7.3	0.3
		F-ALKA-03	4	7.5	7.6	7.5	0.0
		F-ALKA-04	4	7.6	7.7	7.6	0.1
Salinity	ppt	F-ALKA-01	4	4.2	7.7	4.6	1.6
		F-ALKA-02	4	7.8	25.8	8.9	8.7
		F-ALKA-03	4	2.0	2.2	2.1	0.1
		F-ALKA-04	4	1.8	1.9	1.9	0.0
Specific conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-ALKA-01	4	7.6	13.4	8.3	2.7
		F-ALKA-02	4	13.6	40.4	15.3	12.9
		F-ALKA-03	4	3.9	4.2	4.0	0.1
		F-ALKA-04	4	3.5	3.6	3.5	0.1
Temperature	$^{\circ}\text{C}$	F-ALKA-01	4	22.9	25.8	24.7	1.3
		F-ALKA-02	4	23.5	25.4	24.1	0.8
		F-ALKA-03	4	21.4	21.7	21.5	0.1
		F-ALKA-04	4	21.4	21.6	21.5	0.1
Turbidity	NTU	F-ALKA-01	4	3.6	7.6	5.5	1.8
		F-ALKA-02	2	0.0	0.1	0.0	0.0
		F-ALKA-03	4	0.0	0.0	0.0	0.0
		F-ALKA-04	4	0.0	1.8	0.0	1.3

Table 5. 2010 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.

Parameter	Unit	Site	n	Minimum	Maximum	Median	SD
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-ALKA-01	12	60.0	158.0	86.5	32.9
		F-ALKA-02	12	36.0	117.0	88.5	27.3
		F-ALKA-03	12	47.0	82.0	66.0	11.1
		F-ALKA-04	12	46.0	80.0	58.5	11.7
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-ALKA-01	12	0.5	0.7	0.5	0.1
		F-ALKA-02	12	0.4	1.2	1.0	0.3
		F-ALKA-03	12	0.7	1.0	0.9	0.1
		F-ALKA-04	12	0.5	1.4	0.7	0.2
Nitrite + Nitrate	$\mu\text{gN} \cdot \text{L}^{-1}$	F-ALKA-01	12	7.0	343.0	207.0	114.4
		F-ALKA-02	12	212.0	1085.0	775.5	302.8
		F-ALKA-03	12	619.0	863.0	826.0	74.1
		F-ALKA-04	12	496.0	752.0	707.0	72.0
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-ALKA-01	4	3.5	85.7	6.0	40.3
		F-ALKA-02	3	0.3	10.2	1.2	5.5
		F-ALKA-03	4	0.0	0.0	0.0	0.0
		F-ALKA-04	4	0.0	0.0	0.0	0.0
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-ALKA-01	4	1.2	2.3	1.8	0.5
		F-ALKA-02	4	3.1	6.5	4.7	1.9
		F-ALKA-03	4	8.1	8.4	8.3	0.1
		F-ALKA-04	4	8.0	8.4	8.3	0.2
Dissolved Oxygen Saturation	%	F-ALKA-01	4	14.8	29.0	21.3	6.4
		F-ALKA-02	4	38.2	81.4	59.5	22.3
		F-ALKA-03	4	93.3	96.5	95.3	1.4
		F-ALKA-04	4	92.0	95.9	95.5	1.9
pH	none	F-ALKA-01	4	7.0	7.3	7.1	0.1
		F-ALKA-02	4	7.2	7.7	7.3	0.2
		F-ALKA-03	4	7.5	8.0	7.6	0.2
		F-ALKA-04	4	7.5	8.3	7.7	0.3
Salinity	ppt	F-ALKA-01	4	4.2	6.3	4.8	0.9
		F-ALKA-02	4	7.9	25.4	10.6	8.0
		F-ALKA-03	4	2.0	2.1	2.0	0.1
		F-ALKA-04	4	1.8	1.9	1.8	0.0
Specific conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-ALKA-01	4	7.6	11.0	8.5	1.5
		F-ALKA-02	4	13.6	39.9	17.9	11.9
		F-ALKA-03	4	3.7	4.0	3.8	0.1
		F-ALKA-04	4	3.4	3.5	3.4	0.1
Temperature	$^{\circ}\text{C}$	F-ALKA-01	4	22.8	25.1	23.0	1.1
		F-ALKA-02	4	21.7	24.5	22.8	1.3
		F-ALKA-03	4	21.5	21.7	21.5	0.1
		F-ALKA-04	4	21.5	21.6	21.6	0.0
Turbidity	NTU	F-ALKA-01	4	1.5	4.5	1.7	1.5
		F-ALKA-02	3	0.0	4.2	2.2	2.4
		F-ALKA-03	4	0.0	1.0	0.0	0.8
		F-ALKA-04	4	0.0	0.6	0.0	0.4

Table 6. 2011 summary of water quality parameters in anchialine pools associated with Ala Kahakai NHT.

Parameter	Unit	Site	n	Minimum	Maximum	Median	SD
Total Dissolved Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	F-ALKA-01	15	15.0	139.1	34.5	46.7
		F-ALKA-02	3	93.6	96.0	93.7	1.3
		F-ALKA-03	3	64.0	74.4	69.2	5.2
		F-ALKA-04	12	47.7	63.3	56.7	4.6
Total Dissolved Nitrogen	$\text{mgN} \cdot \text{L}^{-1}$	F-ALKA-01	15	0.1	0.5	0.4	0.1
		F-ALKA-02	3	1.1	1.2	1.2	0.1
		F-ALKA-03	3	0.8	0.9	0.9	0.1
		F-ALKA-04	12	0.5	0.8	0.8	0.1
Nitrite + Nitrate	$\mu\text{gN} \cdot \text{L}^{-1}$	F-ALKA-01	15	1.0	338.7	46.1	117.3
		F-ALKA-02	3	1068.4	1197.3	1194.5	73.6
		F-ALKA-03	3	919.4	938.1	930.3	9.4
		F-ALKA-04	12	526.3	766.9	716.4	64.8
Chlorophyll	$\mu\text{g} \cdot \text{L}^{-1}$	F-ALKA-01	5	7.1	107.3	42.6	38.4
		F-ALKA-02	1	1.4	1.4	1.4	0.0
		F-ALKA-03	1	0.0	0.0	0.0	0.0
		F-ALKA-04	4	0.0	0.0	0.0	0.0
Dissolved Oxygen Concentration	$\text{mg} \cdot \text{L}^{-1}$	F-ALKA-01	5	2.3	19.8	5.8	6.8
		F-ALKA-02	1	6.6	6.6	6.6	0.0
		F-ALKA-03	1	8.4	8.4	8.4	0.0
		F-ALKA-04	4	8.3	8.4	8.3	0.1
Dissolved Oxygen Saturation	%	F-ALKA-01	5	27.7	270.1	80.6	93.4
		F-ALKA-02	1	78.7	78.7	78.7	0.0
		F-ALKA-03	1	95.7	95.7	95.7	0.0
		F-ALKA-04	4	94.3	96.4	94.8	0.9
pH	none	F-ALKA-01	5	7.0	9.2	8.7	0.9
		F-ALKA-02	1	7.2	7.2	7.2	0.0
		F-ALKA-03	1	7.4	7.4	7.4	0.0
		F-ALKA-04	4	7.5	7.8	7.7	0.1
Salinity	ppt	F-ALKA-01	5	4.5	18.3	5.7	5.7
		F-ALKA-02	1	4.9	4.9	4.9	0.0
		F-ALKA-03	1	2.0	2.0	2.0	0.0
		F-ALKA-04	4	1.8	1.9	1.9	0.1
Specific conductance	$\text{mS} \cdot \text{cm}^{-1}$	F-ALKA-01	5	8.2	29.6	10.1	8.9
		F-ALKA-02	1	8.8	8.8	8.8	0.0
		F-ALKA-03	1	3.8	3.8	3.8	0.0
		F-ALKA-04	4	3.4	3.6	3.6	0.1
Temperature	$^{\circ}\text{C}$	F-ALKA-01	5	23.0	29.9	26.7	2.5
		F-ALKA-02	1	22.9	22.9	22.9	0.0
		F-ALKA-03	1	21.4	21.4	21.4	0.0
		F-ALKA-04	4	21.3	21.6	21.4	0.1
Turbidity	NTU	F-ALKA-01	5	3.6	33.1	8.7	13.4
		F-ALKA-02	1	0.0	0.0	0.0	0.0
		F-ALKA-03	1	0.0	0.0	0.0	0.0
		F-ALKA-04	4	0.0	0.0	0.0	0.0

¹Non-detection, i.e. less than the analytical detection limit of $1.0 \mu\text{gN} \cdot \text{L}^{-1}$.

Summaries by parameter
Total Dissolved Phosphorus

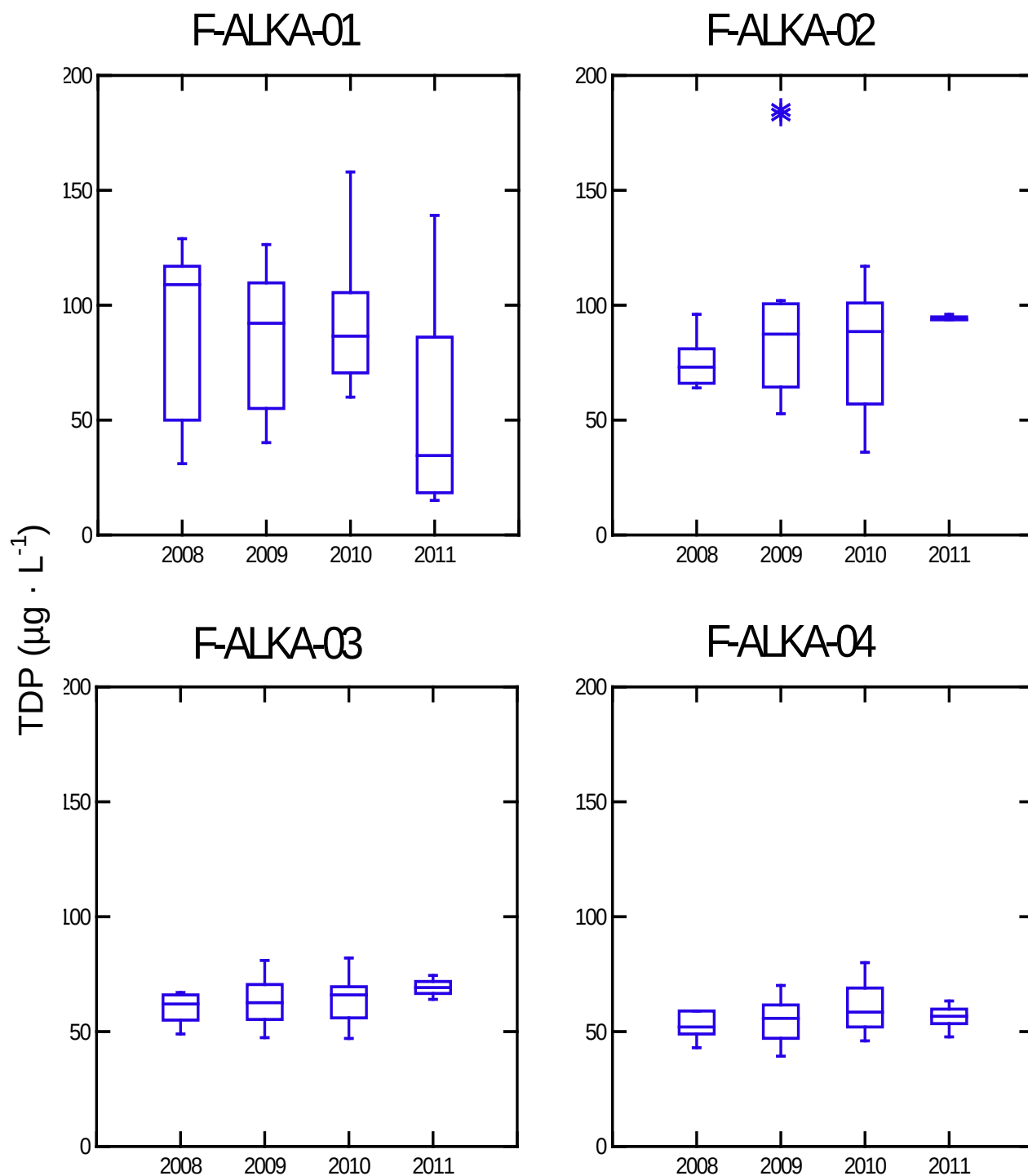


Figure 3. Box plots of Total Dissolved Phosphorus in anachialine pools associated with Ala Kahakai NHT.

Table 7. Mean Total Dissolved Phosphorus (TDP, $\mu\text{gP} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	TDP	SE ¹	n	TDP	SE ¹	n	TDP	SE ¹	n	TDP	SE ¹	n
3/20/2008	118.7	5.5	3	78.7	6.7	3	59.0	3.5	3	46.7	1.9	3
5/20/2008	37.3	6.3	3	69.7	3.5	3	54.0	2.6	3	51.7	0.9	3
11/25/2008	110.0	4.4	3	78.3	9.1	3	66.3	0.3	3	59.0	0.0	3
3/30/2009	111.0	5.6	3	152.0	32.0	3	74.0	3.5	3	57.7	1.2	3
6/26/2009	44.5	2.2	3	57.8	2.8	3	50.5	1.7	3	40.2	0.4	3
9/9/2009	110.9	7.8	3	96.9	3.8	3	60.7	1.9	3	54.5	0.6	3
11/18/2009	73.0	6.3	3	79.7	6.7	3	67.4	3.8	3	67.3	2.1	3
2/26/2010	60.0	0.0	3	42.7	3.4	3	48.3	0.9	3	46.3	0.3	3
5/10/2010	85.3	2.3	3	112.7	3.0	3	75.7	4.5	3	75.3	4.2	3
8/13/2010	87.0	2.3	3	83.0	5.5	3	69.0	1.0	3	58.3	0.9	3
12/1/2010	143.0	11.7	3	84.0	8.6	3	63.7	0.9	3	62.3	4.4	3
2/9/2011	133.3	3.1	3	94.4	0.8	3	69.2	3.0	3	54.2	1.8	3
4/1/2011	73.1	19.2	3									
4/29/2011	17.2	1.0	3									
5/2/2011										54.9	0.9	3
8/11/2011	36.9	13.4	3							56.4	4.6	3
10/31/2011	26.1	4.3	3									
11/2/2011										60.6	1.2	3

¹SE = Standard Error

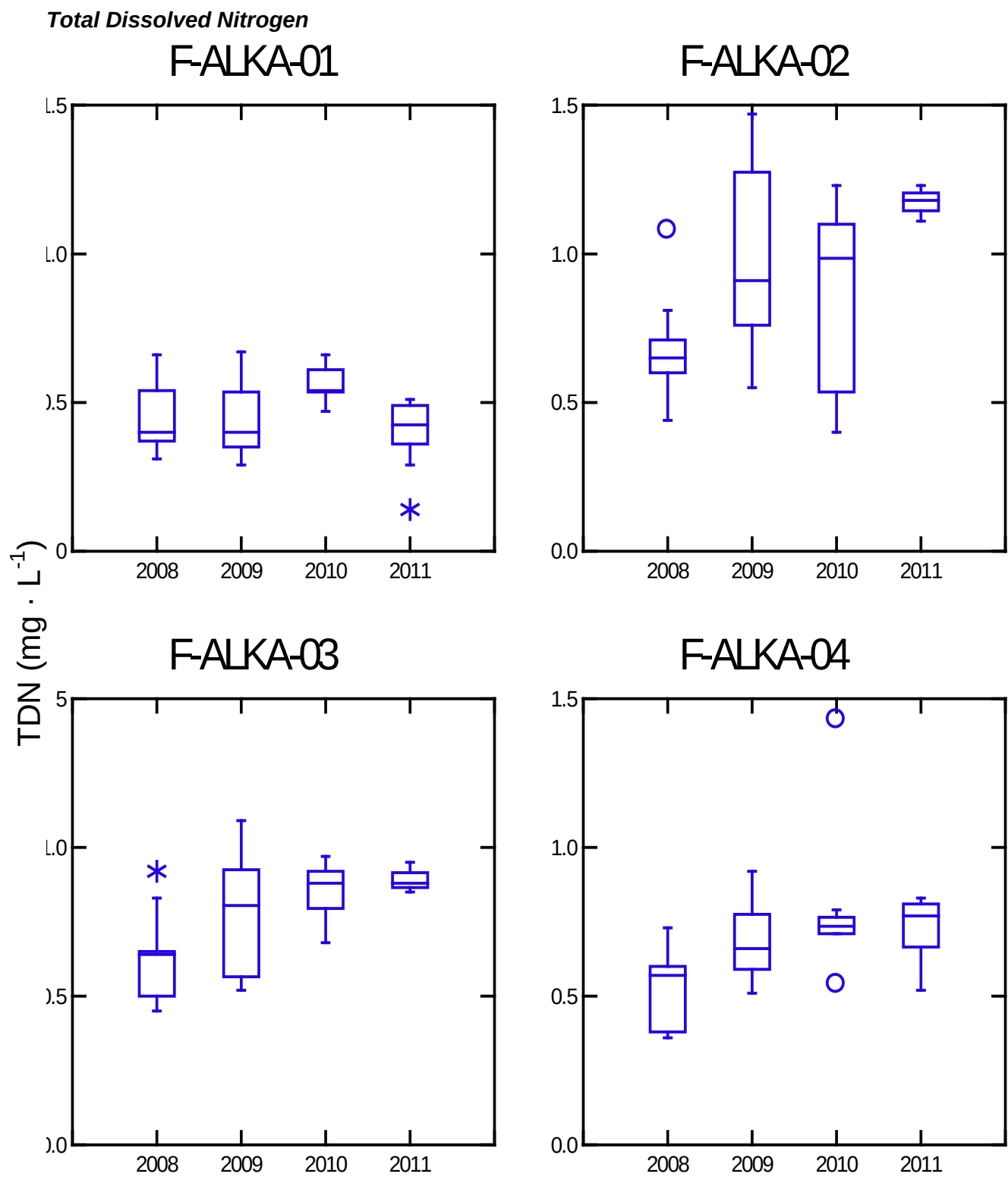


Figure 4. Box plots of Total Dissolved Nitrogen in anchialine pools associated with Ala Kahakai NHT.

Table 8. Mean Total Dissolved Nitrogen (TDN, $\text{mgN} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	TDN	SE ¹	n	TDN	SE ¹	n	TDN	SE ¹	n	TDN	SE ¹	n
3/20/2008	0.39	0.03	3	0.56	0.12	3	0.60	0.05	3	0.37	0.00	3
5/20/2008	0.36	0.03	3	0.67	0.01	3	0.58	0.05	3	0.54	0.05	3
11/25/2008	0.59	0.02	3	0.80	0.15	3	0.73	0.14	3	0.69	0.04	3
3/30/2009	0.64	0.02	3	0.88	0.03	3	1.05	0.03	3	0.87	0.05	3
6/26/2009	0.33	0.02	3	1.19	0.08	3	0.83	0.03	3	0.62	0.08	3
9/9/2009	0.51	0.04	3	1.25	0.18	3	0.71	0.09	3	0.59	0.05	3
11/18/2009	0.37	0.02	3	0.62	0.04	3	0.55	0.02	3	0.67	0.04	3
2/26/2010	0.50	0.02	3	0.41	0.00	3	0.80	0.06	3	0.68	0.07	3
5/10/2010	0.55	0.01	3	1.06	0.02	3	0.84	0.05	3	0.74	0.03	3
8/13/2010	0.62	0.02	3	0.90	0.13	3	0.88	0.06	3	0.72	0.01	3
12/1/2010	0.58	0.04	3	1.02	0.15	3	0.90	0.02	3	0.97	0.23	3
2/9/2011	0.35	0.02	3	1.17	0.03	3	0.89	0.03	3	0.65	0.02	3
4/1/2011	0.39	0.02	3									
4/29/2011	0.46	0.02	3									
5/2/2011										0.79	0.02	3
8/11/2011	0.30	0.09	3							0.68	0.09	3
10/31/2011	0.50	0.00	3									
11/2/2011										0.80	0.02	3

¹SE = Standard Error

Nitrate + Nitrite

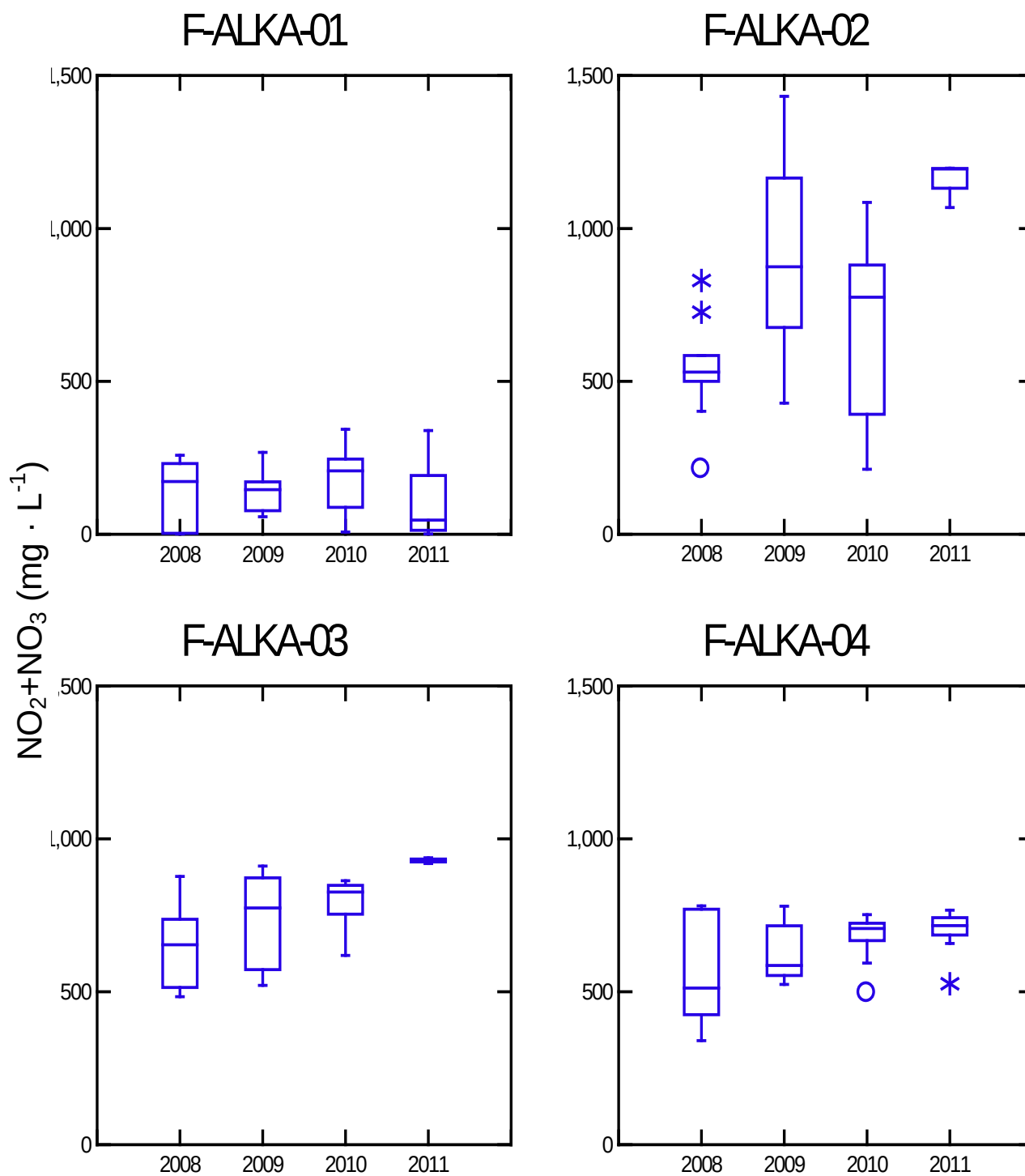


Figure 5. Box plots of nitrate + nitrite in anchialine pools associated with Ala Kahakai NHT.

Table 9. Mean nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$, $\mu\text{N} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	$\text{NO}_3 + \text{NO}_2$	SE^1	n	$\text{NO}_3 + \text{NO}_2$	SE^1	n	$\text{NO}_3 + \text{NO}_2$	SE^1	n	$\text{NO}_3 + \text{NO}_2$	SE^1	n
3/20/2008	173.7	29.2	3	447.0	149.8	3	605.3	45.7	3	387.7	25.1	3
5/20/2008	1.7	0.7	3	513.0	8.9	3	670.0	96.8	3	608.7	87.5	3
11/25/2008	248.3	8.7	3	663.0	83.5	3	699.3	115.0	3	686.3	87.2	3
3/30/2009	70.3	6.7	3	857.3	17.4	3	885.3	12.9	3	728.3	14.4	3
6/26/2009	158.9	5.8	3	1056.4	108.7	3	786.5	22.6	3	641.9	69.3	3
9/9/2009	207.4	30.2	3	1247.0	159.5	3	728.1	109.1	3	562.0	33.5	3
11/18/2009	100.5	21.5	3	464.3	32.0	3	558.1	17.3	3	572.1	13.5	3
2/26/2010	243.7	1.9	3	220.0	4.9	3	731.0	59.9	3	661.3	82.8	3
5/10/2010	7.7	0.3	3	802.3	24.0	3	787.0	43.0	3	688.0	6.1	3
8/13/2010	177.7	5.8	3	768.3	118.4	3	806.0	26.9	3	655.0	35.2	3
12/1/2010	288.7	34.0	3	887.7	122.2	3	853.7	5.2	3	720.7	4.4	3
2/9/2011	46.8	2.6	3	1153.4	42.5	3	929.3	5.4	3	716.0	31.8	3
4/1/2011	176.4	22.9	3									
4/29/2011	1.0	0.0	3									
5/2/2011										693.1	7.7	3
8/11/2011	15.4	3.1	3							657.4	65.8	3
10/31/2011	288.6	32.6	3									
11/2/2011										746.1	13.5	3

¹SE = Standard Error

²Non-detection, i.e. less than the analytical detection limit of $1.0 \mu\text{N} \cdot \text{L}^{-1}$.

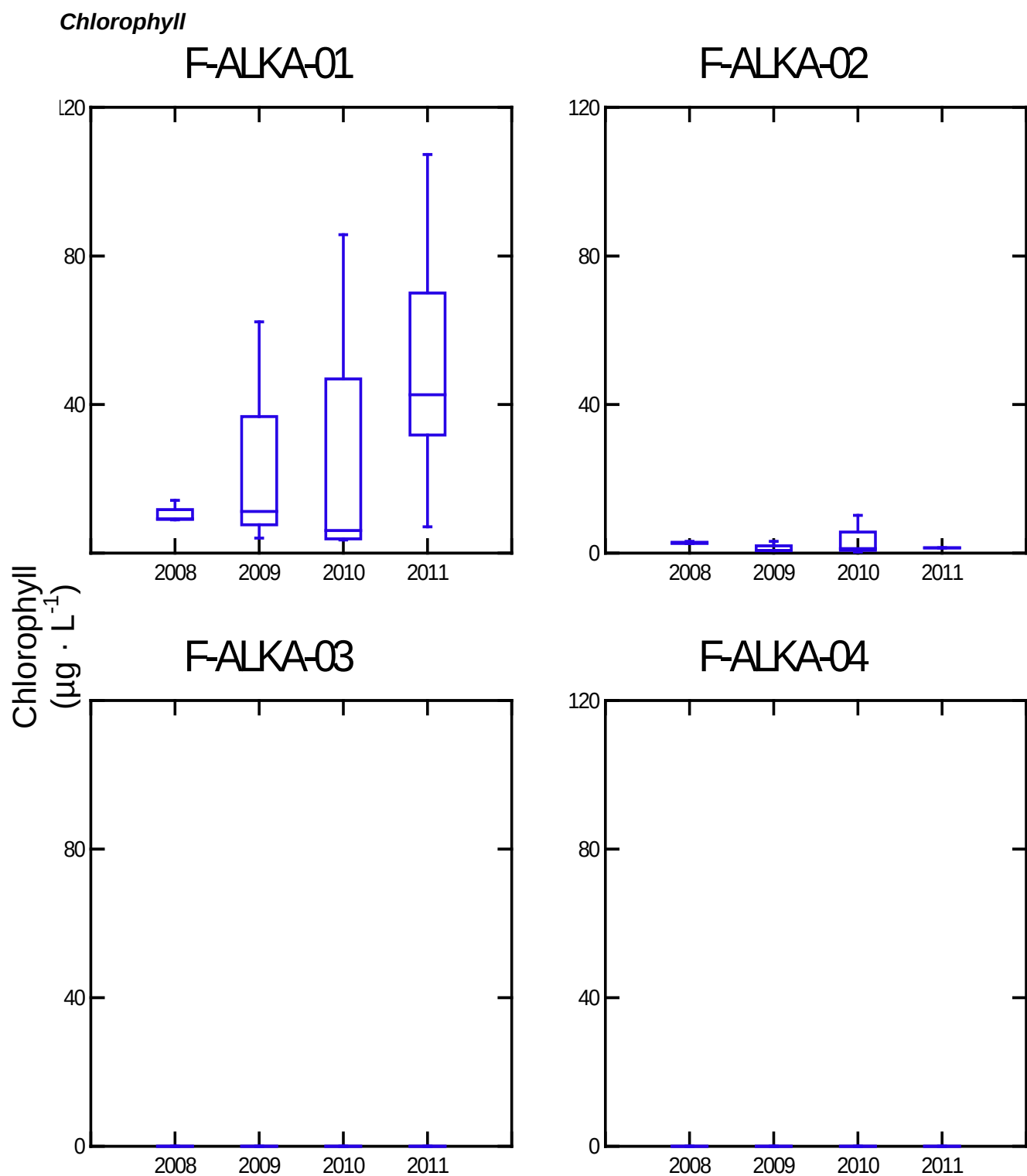


Figure 6. Box plots of chlorophyll in anichaline pools associated with Ala Kahakai NHT.

Table 10. Mean chlorophyll-a ($\mu\text{g} \cdot \text{L}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	Chl	SE ¹	n	Chl	SE ¹	n	Chl	SE ¹	n	Chl	SE ¹	n
3/20/2008	9.2	0.40	17	2.7	0.23	8	0.0	0.1	19	0.0	0.1	12
5/20/2008	9.0	0.08	6	3.1	0.19	12	0.0	0.1	12	0.0	0.1	9
11/25/2008	14.2	0.88	14	2.6	0.25	19	0.0	0.1	19	0.0	0.1	13
3/30/2009												
6/26/2009	11.2	0.42	11	3.2	0.48	12	0.0	0.2	15	0.0	0.3	14
9/9/2009	4.0	0.29	11	0.7	0.22	15	0.0	0.1	11	0.0	0.5	13
11/18/2009	62.3	0.21	30	0.6	0.14	15	0.0	0.1	13	0.0	0.1	22
2/26/2010	8.0	0.19	20				0.0	0.1	10	0.0	0.2	11
5/10/2010	85.7	0.61	12	10.2	0.57	21	0.0	0.1	17	0.0	0.1	16
8/13/2010	3.5	0.14	17	1.2	0.14	14	0.0	0.1	15	0.0	0.1	17
12/1/2010	4.1	0.14	13	0.3	0.11	21	0.0	0.1	12	0.0	0.2	10
2/9/2011	31.8	0.75	16	1.4	0.08	20	0.0	0.1	17	0.0	0.0	22
4/1/2011	107.3	0.49	19									
4/29/2011	70.0	1.84	14									
5/2/2011										0.0	0.0	20
8/11/2011	42.6	0.11	19							0.0	0.1	15
10/31/2011	7.1	0.17	14									
11/2/2011										0.0	0.1	18

¹SE = Standard Error

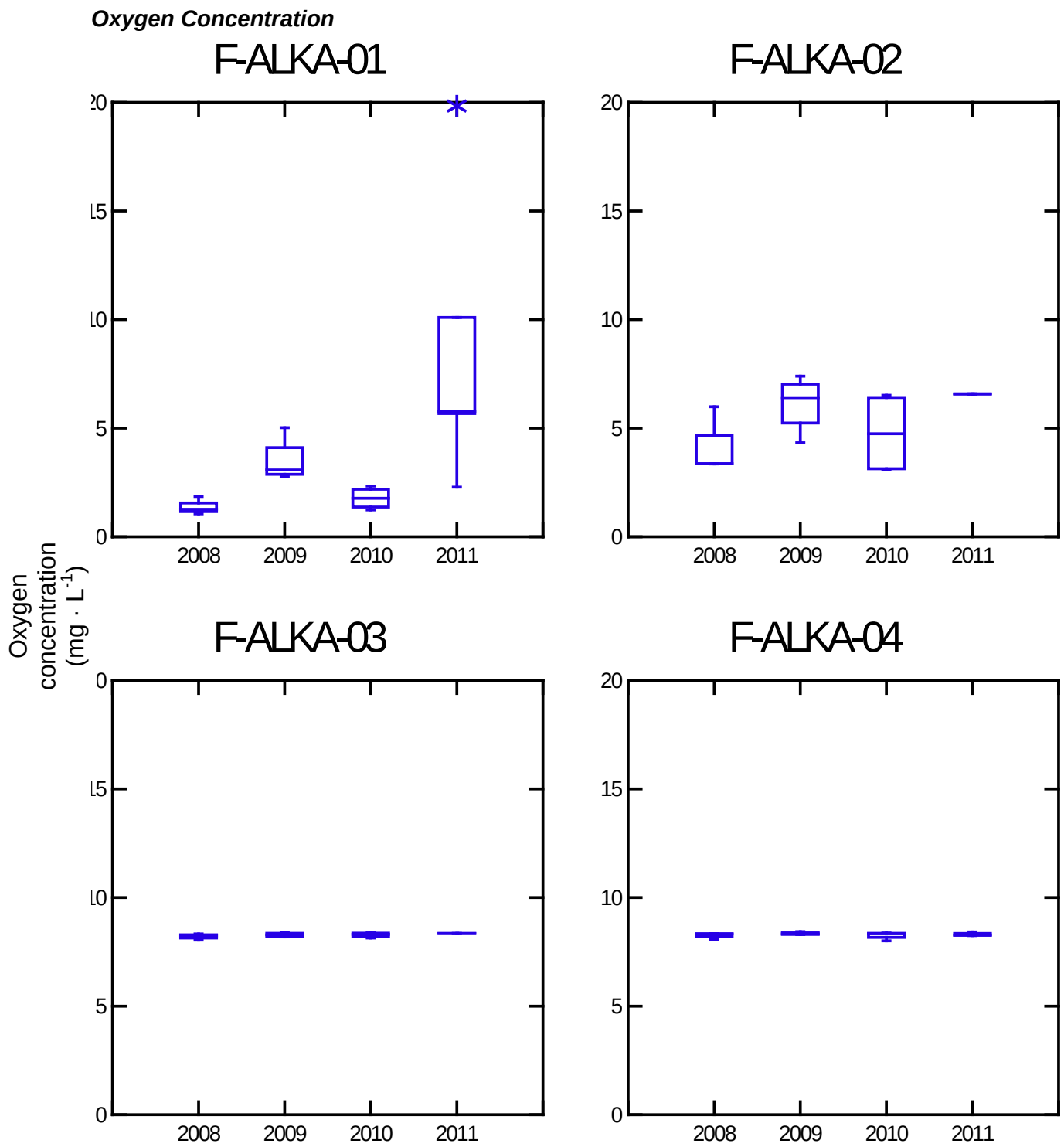


Figure 7. Box plots of oxygen concentration in anchialine pools associated with Ala Kahakai NHT.

Table 11. Mean oxygen concentration (ODO, mg · L⁻¹) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	ODO	SE1	n	ODO	SE1	n	ODO	SE1	n	ODO	SE1	n
3/20/2008	1.1	0.04	17	3.4	0.01	8	8.0	0.01	19	8.1	0.01	12
5/20/2008	1.9	0.17	6	3.4	0.03	12	8.3	0.03	12	8.3	0.01	9
11/25/2008	1.3	0.12	14	6.0	0.01	19	8.2	0.00	19	8.3	0.02	13
3/30/2009	3.0	0.07	13	4.3	0.02	11	8.2	0.01	14	8.3	0.00	19
6/26/2009	3.2	0.01	11	6.1	0.05	12	8.4	0.01	15	8.4	0.01	14
9/9/2009	2.8	0.08	11	7.4	0.04	15	8.3	0.01	11	8.3	0.01	13
11/18/2009	5.0	0.04	30	6.7	0.08	15	8.3	0.04	13	8.3	0.01	22
2/26/2010	1.5	0.03	20	3.1	0.07	15	8.1	0.00	10	8.0	0.02	11
5/10/2010	2.0	0.02	12	3.2	0.02	21	8.3	0.02	17	8.3	0.01	16
8/13/2010	2.3	0.02	17	6.5	0.01	14	8.4	0.02	15	8.4	0.01	17
12/1/2010	1.2	0.01	13	6.3	0.00	21	8.3	0.00	12	8.3	0.01	10
2/9/2011	2.3	0.02	16	6.6	0.02	20	8.4	0.01	17	8.3	0.01	22
4/1/2011	5.8	0.03	19									
4/29/2011	5.7	0.01	14									
5/2/2011										8.3	0.01	20
8/11/2011	10.1	0.02	19							8.3	0.01	15
10/31/2011	19.8	0.30	14									
11/2/2011										8.4	0.00	18

¹SE = Standard Error

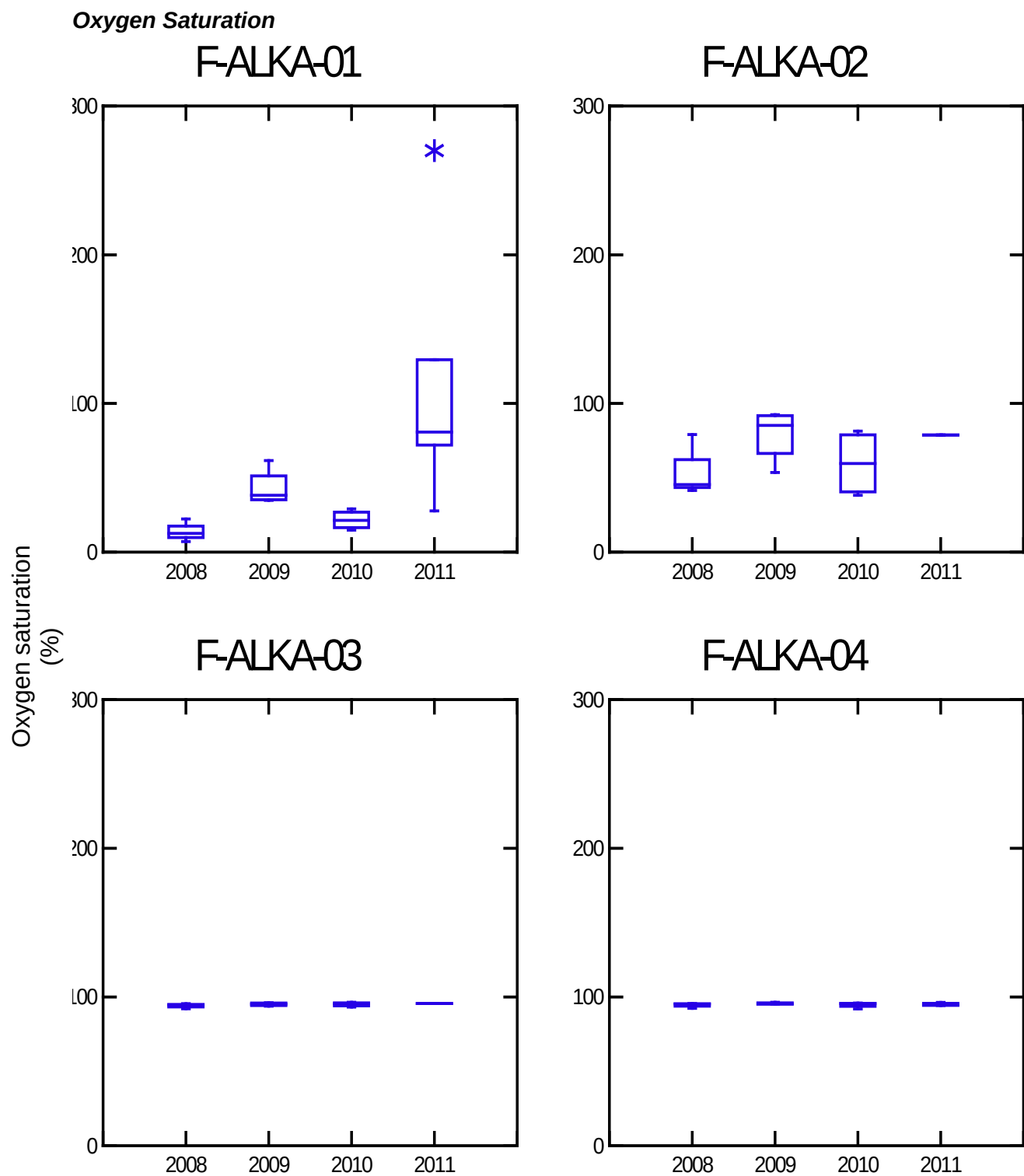


Figure 8. Box plots of oxygen saturation in anchialine pools associated with Ala Kahakai NHT.

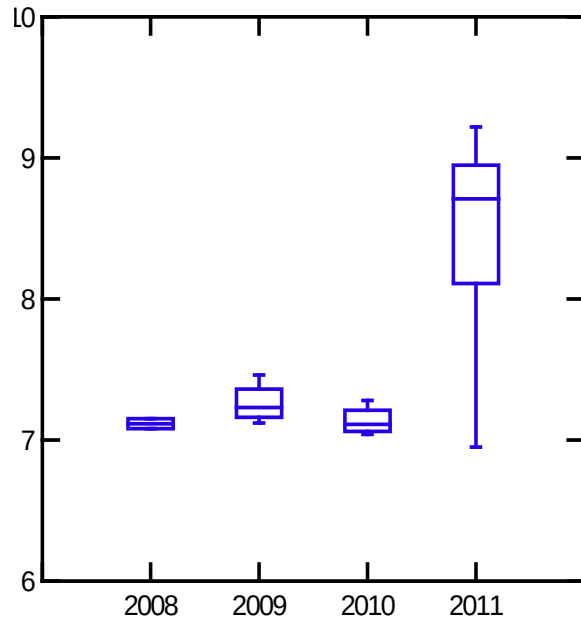
Table 12. Mean oxygen saturation (%) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	ODOsat	SE ¹	n	ODOsat	SE ¹	n	ODOsat	SE ¹	n	ODOsat	SE ¹	n
3/20/2008	13	0.5	17	45	0.2	8	92	0.2	19	92	0.1	12
5/20/2008	22	2.0	6	41	0.3	12	96	0.3	12	95	0.1	9
11/25/2008	7	0.0	14	79	0.1	19	95	0.0	19	96	0.2	13
3/30/2009	36	0.8	13	54	0.2	11	94	0.1	14	95	0.0	19
6/26/2009	41	0.2	11	79	0.6	12	96	0.1	15	96	0.0	14
9/9/2009	35	1.0	11	91	0.3	15	96	0.2	11	96	0.1	13
11/18/2009	62	0.5	30	92	1.0	15	95	0.4	13	95	0.1	22
2/26/2010	18	0.4	20	43	1.0	15	93	0.0	10	92	0.2	11
5/10/2010	25	0.2	12	38	0.3	21	95	0.2	17	95	0.1	16
8/13/2010	29	0.2	17	81	0.2	14	97	0.3	15	96	0.1	17
12/1/2010	15	0.2	13	76	0.0	21	96	0.0	12	96	0.1	10
2/9/2011	28	0.3	16	79	0.2	20	96	0.1	17	95	0.1	22
4/1/2011	81	0.4	19									
4/29/2011										94	0.1	20
5/2/2011	72	0.1	14									
8/11/2011	129	0.2	19							95	0.1	15
10/31/2011	270	4.1	14									
11/2/2011										96	0.0	18

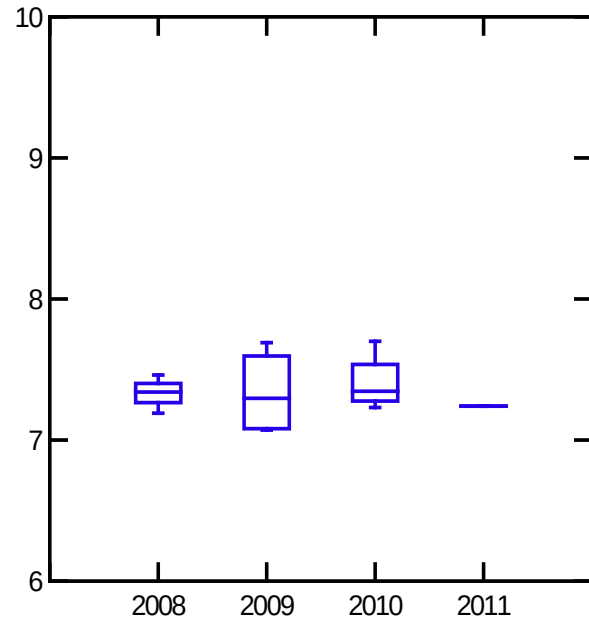
¹SE = Standard Error

pH

F-ALKA-01

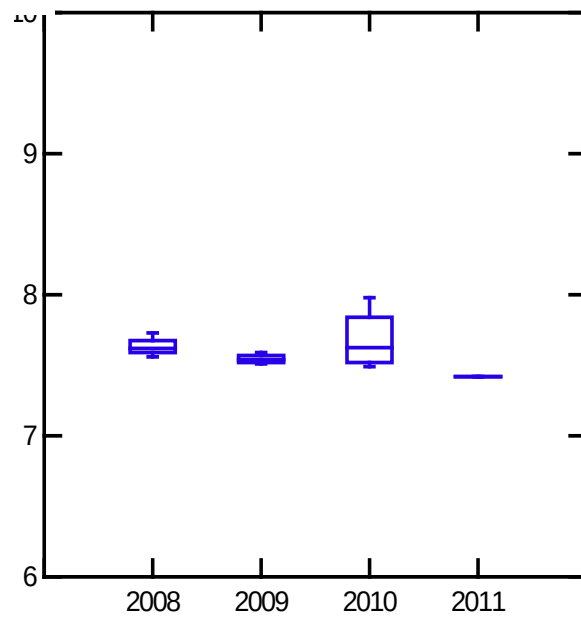


F-ALKA-02



pH

F-ALKA-03



F-ALKA-04

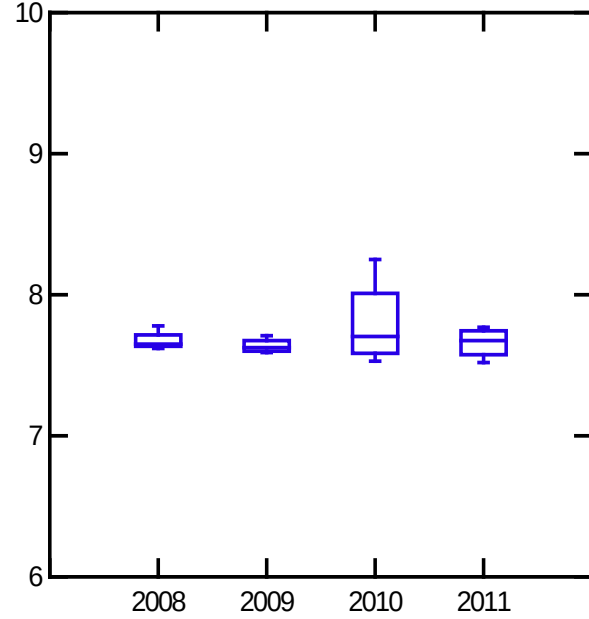


Figure 9. Box plots of pH in anchialine pools associated with Ala Kahakai NHT.

Table 13. Mean pH in anchialine pools associated with Ala Kahakai NHT.

	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
Date	pH	SE1	n	pH	SE1	n	pH	SE1	n	pH	SE1	n
3/20/2008	7.2	0.01	17	7.5	0.00	8	7.7	0.00	19	7.8	0.01	12
5/20/2008	7.1	0.00	6	7.2	0.00	12	7.6	0.02	12	7.7	0.00	9
11/25/2008				7.3	0.00	19	7.6	0.00	19	7.6	0.00	13
3/30/2009	7.1	0.01	13	7.1	0.00	11	7.5	0.01	14	7.6	0.00	19
6/26/2009	7.3	0.00	11	7.5	0.00	12	7.6	0.00	15	7.6	0.00	14
9/9/2009	7.2	0.00	11	7.1	0.01	15	7.5	0.01	11	7.6	0.01	13
11/18/2009	7.5	0.02	30	7.7	0.02	15	7.6	0.01	13	7.7	0.00	22
2/26/2010	7.1	0.00	20	7.4	0.01	15	7.6	0.00	10	7.6	0.00	11
5/10/2010	7.3	0.00	12	7.2	0.00	21	7.7	0.00	17	7.8	0.00	16
8/13/2010	7.1	0.00	17	7.3	0.01	14	7.5	0.01	15	7.5	0.00	17
12/1/2010	7.0	0.01	13	7.7	0.04	21	8.0	0.04	12	8.3	0.02	10
2/9/2011	7.0	0.00	16	7.2	0.00	20	7.4	0.01	17	7.5	0.00	22
4/1/2011	8.1	0.00	19									
4/29/2011	8.7	0.00	14									
5/2/2011										7.8	0.00	20
8/11/2011	9.0	0.00	19							7.6	0.00	15
10/31/2011	9.2	0.02	14									
11/2/2011										7.7	0.00	18

¹SE = Standard Error

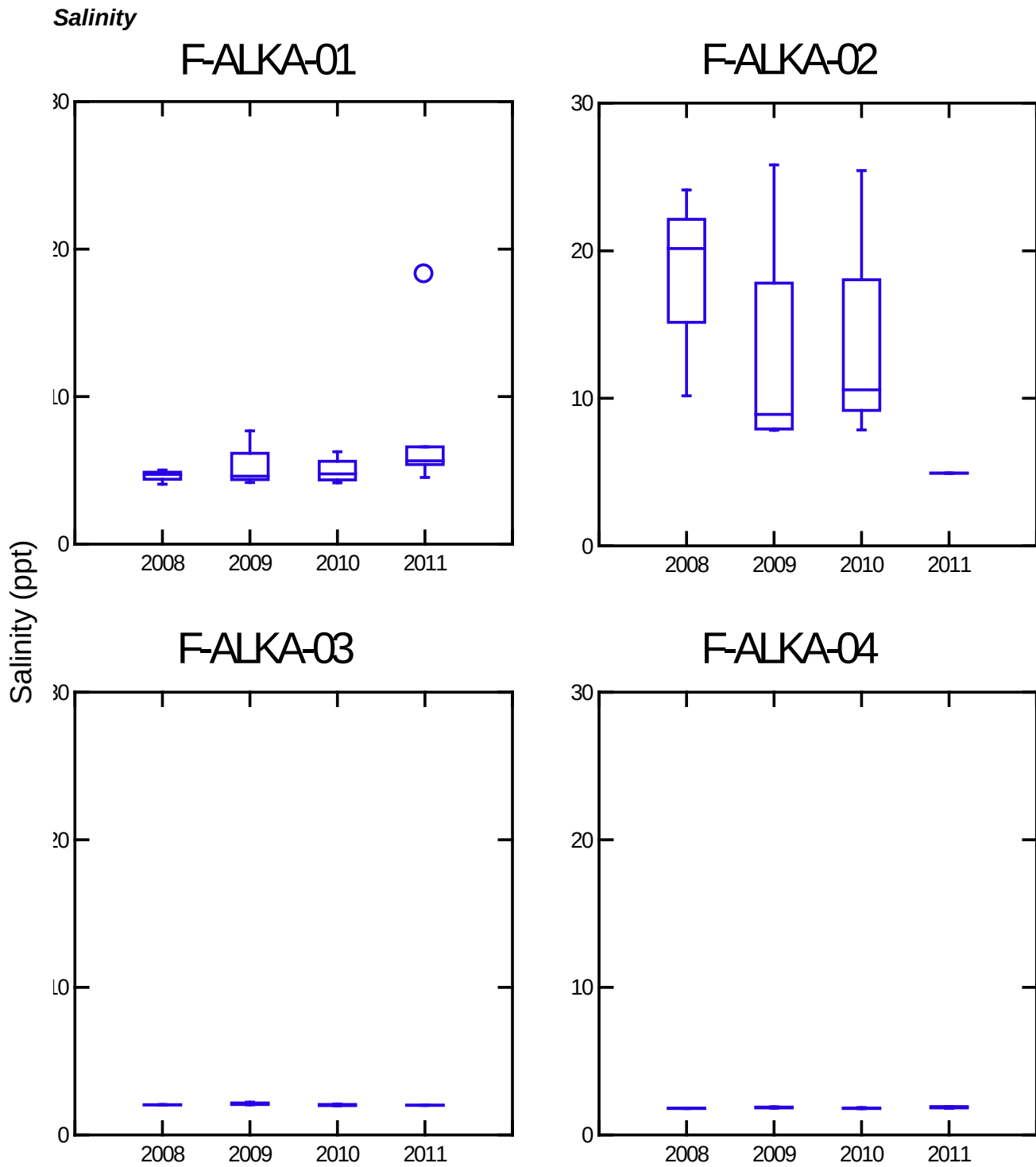


Figure 10. Box plots of salinity in anchialine pools associated with Ala Kahakai NHT.

Table 14. Mean salinity (ppt) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	Salinity	SE ¹	n	Salinity	SE ¹	n	Salinity	SE ¹	n	Salinity	SE ¹	n
3/20/2008	4.1	0.00	17	24.1	0.03	8	2.1	0.00	19	1.8	0.00	12
5/20/2008	4.7	0.00	6	10.2	0.00	12	2.0	0.00	12	1.8	0.00	9
11/25/2008	5.0	0.01	14	20.2	0.06	19	2.0	0.00	19	1.8	0.00	13
3/30/2009	4.6	0.00	13	7.8	0.00	11	2.1	0.00	14	1.9	0.00	19
6/26/2009	7.7	0.00	11	9.8	0.00	12	2.2	0.00	15	1.9	0.00	14
9/9/2009	4.2	0.00	11	8.0	0.01	15	2.0	0.00	11	1.8	0.00	13
11/18/2009	4.6	0.00	30	25.8	0.03	15	2.1	0.00	13	1.9	0.00	22
2/26/2010	6.3	0.00	20	25.4	0.01	15	2.0	0.00	10	1.8	0.00	11
5/10/2010	4.6	0.00	12	7.9	0.00	21	2.0	0.00	17	1.8	0.00	16
8/13/2010	4.2	0.01	17	10.5	0.01	14	2.1	0.00	15	1.9	0.00	17
12/1/2010	5.0	0.00	13	10.6	0.01	21	2.0	0.00	12	1.8	0.00	10
2/9/2011	6.6	0.00	16	4.9	0.01	20	2.0	0.00	17	1.8	0.00	22
4/1/2011	18.3	0.08	19									
4/29/2011	5.7	0.00	14									
5/2/2011										1.9	0.00	20
8/11/2011	4.5	0.00	19							1.9	0.00	15
10/31/2011	5.4	0.00	14									
11/2/2011										1.9	0.00	18

¹SE = Standard Error

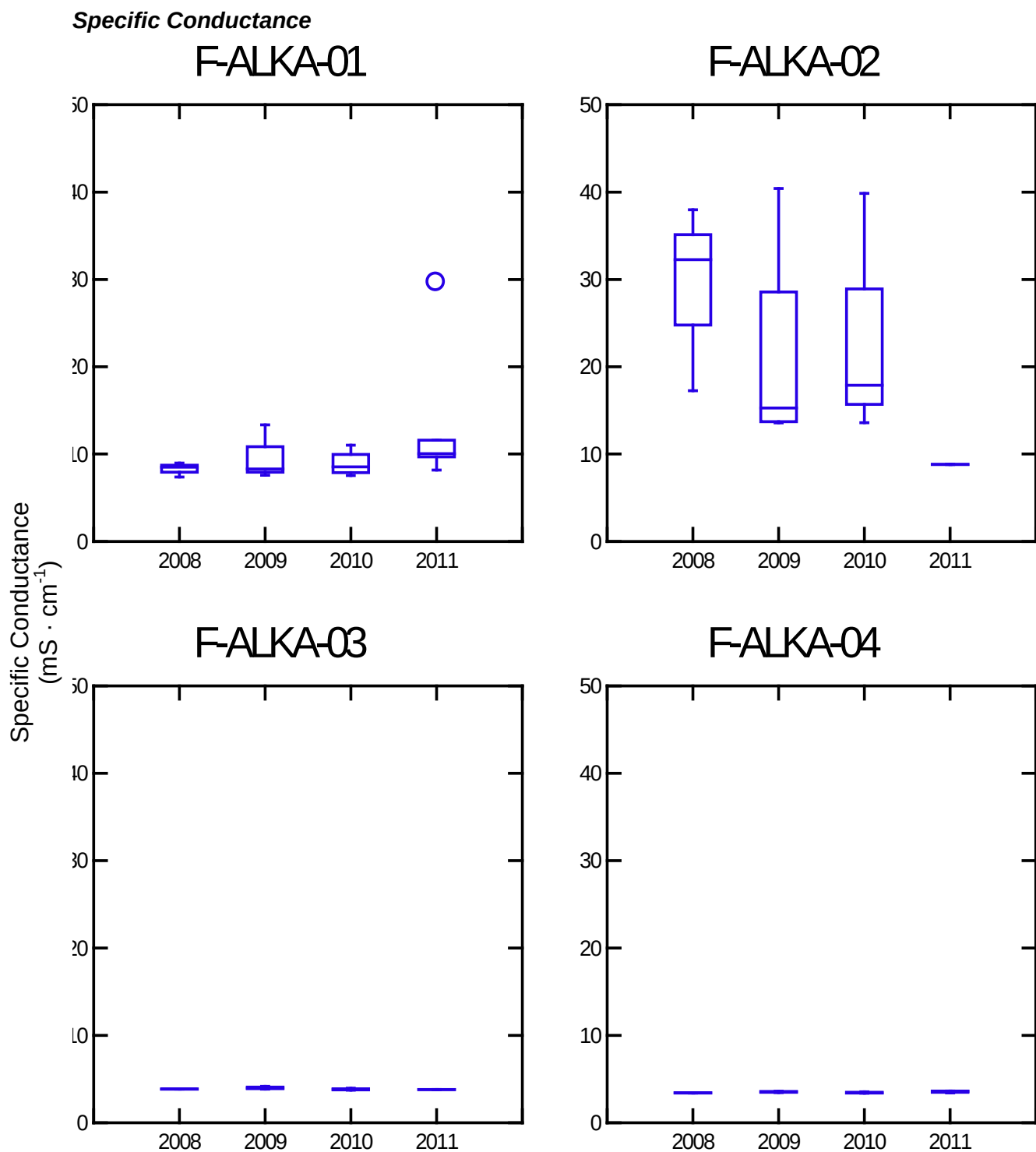


Figure 11. Box plots of specific conductance (SpC, $\text{mS} \cdot \text{cm}^{-1}$) in anchialine pools associated with Ala Kahakai NHT.

Table 15. Mean specific conductance (SpC, mS · cm⁻¹) in anchialine pools associated with Ala Kahakai NHT.

	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
Date	SpC	SE ¹	n	SpC	SE ¹	n	SpC	SE ¹	n	SpC	SE ¹	n
3/20/2008	7.4	0.00	17	38.0	0.05	8	3.9	0.00	19	3.4	0.00	12
5/20/2008	8.5	0.00	6	17.3	0.00	12	3.9	0.00	12	3.4	0.00	9
11/25/2008	9.0	0.01	14	32.3	0.09	19	3.9	0.00	19	3.4	0.00	13
3/30/2009	8.3	0.00	13	13.6	0.01	11	4.0	0.00	14	3.5	0.00	19
6/26/2009	13.4	0.00	11	16.7	0.00	12	4.2	0.00	15	3.6	0.00	14
9/9/2009	7.6	0.00	11	13.8	0.02	15	3.9	0.00	11	3.5	0.00	13
11/18/2009	8.3	0.00	30	40.4	0.05	15	4.0	0.00	13	3.6	0.00	22
2/26/2010	11.0	0.00	20	39.9	0.01	15	3.8	0.00	10	3.4	0.00	11
5/10/2010	8.2	0.00	12	13.6	0.00	21	3.8	0.00	17	3.4	0.00	16
8/13/2010	7.6	0.01	17	17.8	0.02	14	4.0	0.00	15	3.5	0.00	17
12/1/2010	8.9	0.00	13	18.0	0.02	21	3.7	0.01	12	3.4	0.00	10
2/9/2011	11.6	0.00	16	8.8	0.01	20	3.8	0.00	17	3.4	0.00	22
4/1/2011	29.6	0.12	19									
4/29/2011	10.1	0.00	14									
5/2/2011										3.6	0.00	20
8/11/2011	8.2	0.00	19							3.6	0.00	15
10/31/2011	9.7	0.01	14									
11/2/2011										3.6	0.00	18

¹SE = Standard Error

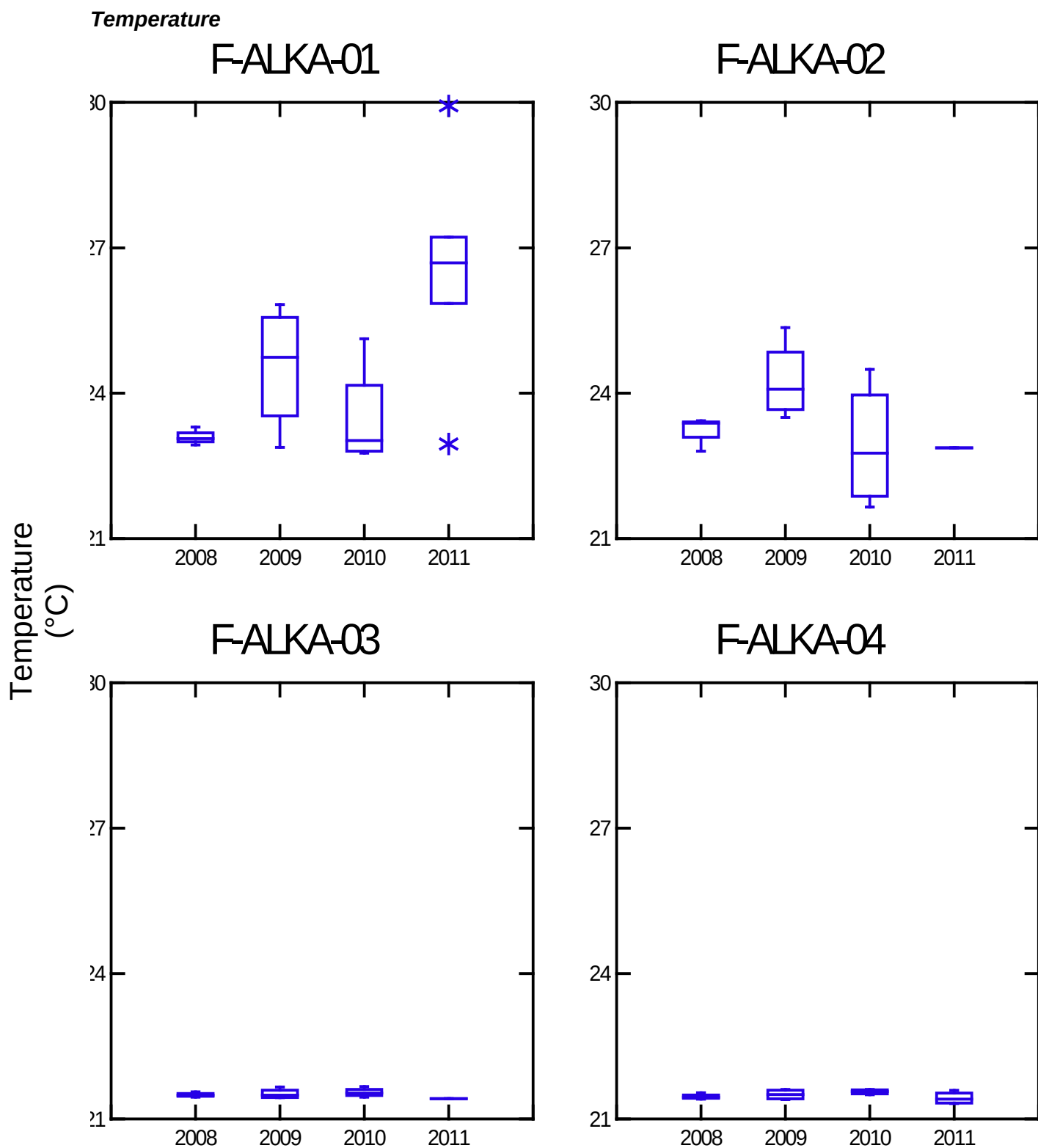


Figure 12. Box plots of temperature in anchialine pools associated with Ala Kahakai NHT.

Table 16. Mean temperature (°C) in anchialine pools associated with Ala Kahakai NHT.

	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
Date	Temp	SE ¹	n	Temp	SE ¹	n	Temp	SE ¹	n	Temp	SE ¹	n
3/20/2008	22.9	0.01	17	23.4	0.01	8	21.5	0.00	19	21.4	0.00	12
5/20/2008	23.3	0.00	6	22.8	0.01	12	21.5	0.01	12	21.5	0.01	9
11/25/2008	23.1	0.01	14	23.4	0.00	19	21.6	0.01	19	21.5	0.02	13
3/30/2009	22.9	0.01	13	23.8	0.00	11	21.4	0.01	14	21.4	0.01	19
6/26/2009	25.8	0.01	11	25.4	0.02	12	21.5	0.01	15	21.4	0.01	14
9/9/2009	25.3	0.00	11	23.5	0.09	15	21.7	0.01	11	21.6	0.01	13
11/18/2009	24.2	0.00	30	24.3	0.00	15	21.5	0.01	13	21.6	0.01	22
2/26/2010	22.8	0.00	20	24.5	0.00	15	21.5	0.00	10	21.6	0.01	11
5/10/2010	23.2	0.01	12	22.1	0.01	21	21.5	0.01	17	21.5	0.01	16
8/13/2010	25.1	0.02	17	23.4	0.06	14	21.7	0.02	15	21.5	0.00	17
12/1/2010	22.8	0.00	13	21.7	0.00	21	21.6	0.01	12	21.6	0.00	10
2/9/2011	23.0	0.02	16	22.9	0.01	20	21.4	0.01	17	21.3	0.00	22
4/1/2011	27.2	0.02	19									
4/29/2011	25.9	0.03	14									
5/2/2011										21.3	0.01	20
8/11/2011	26.7	0.01	19							21.6	0.01	15
10/31/2011	29.9	0.01	14									
11/2/2011										21.5	0.00	18

¹SE = Standard Error

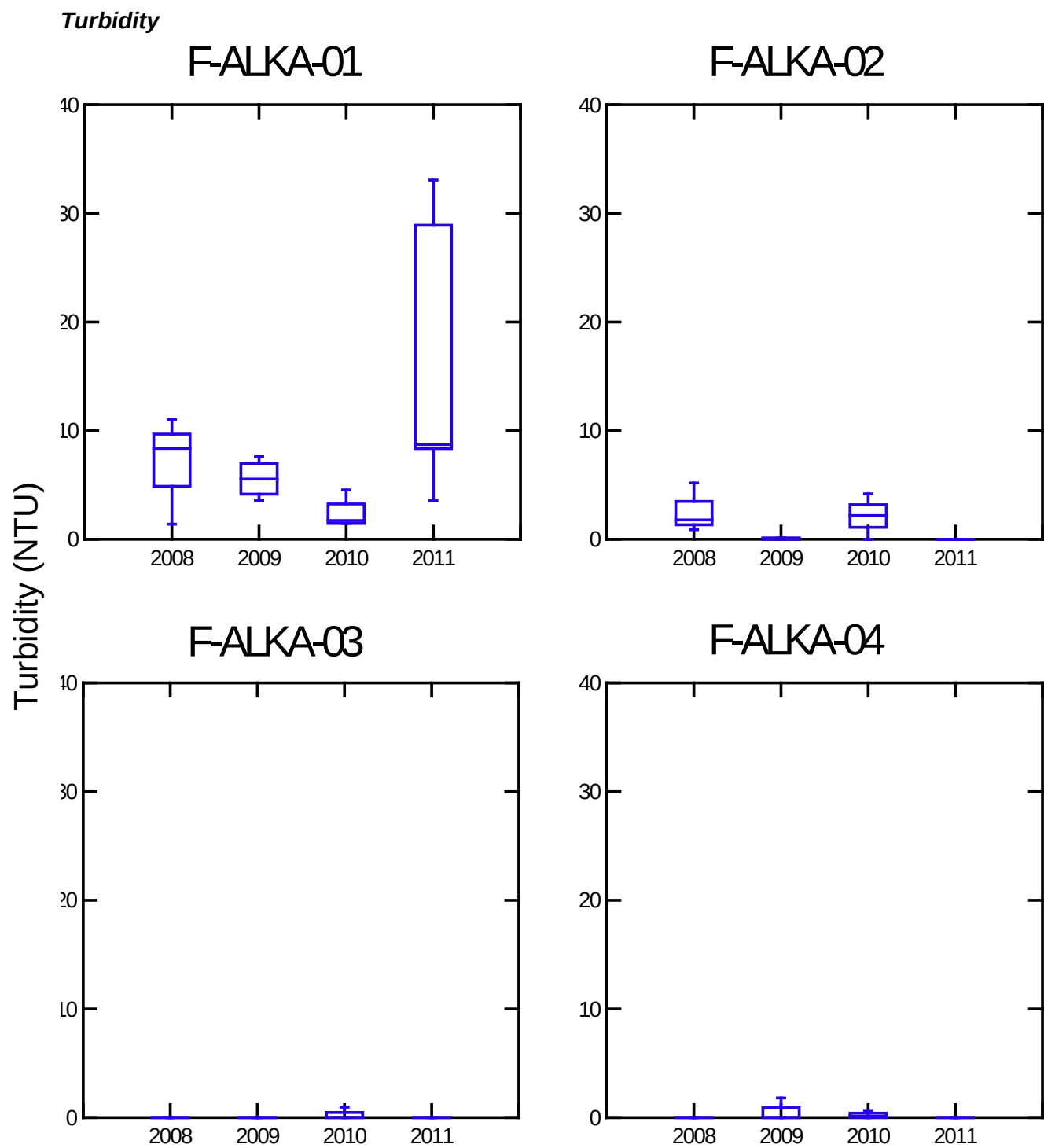


Figure 13. Box plots of turbidity in anchialine pools associated with Ala Kahakai NHT.

Table 17. Mean turbidity (NTU) in anchialine pools associated with Ala Kahakai NHT.

Date	F-ALKA-01			F-ALKA-02			F-ALKA-03			F-ALKA-04		
	NTU	SE ¹	n	NTU	SE ¹	n	NTU	SE ¹	n	NTU	SE ¹	n
3/20/2008	1.4	0.2	17	5.2	0.7	8	0.0	0.0	19	0.0	0.0	12
5/20/2008	8.4	0.5	6	1.8	0.3	12	0.0	0.0	12	0.0	0.0	9
11/25/2008	11.0	3.5	14	0.9	0.2	19	0.0	0.0	19	0.0	0.0	13
3/30/2009	7.6	1.2	13				0.0	0.0	14	0.0	0.0	19
6/26/2009	6.3	0.6	11				0.0	0.0	15	0.0	0.0	14
9/9/2009	3.6	0.6	11	0.0	0.0	15	0.0	0.0	11	0.0	0.0	13
11/18/2009	4.7	0.4	30	0.1	0.2	15	0.0	0.0	13	1.8	0.1	22
2/26/2010	2.0	0.1	20	4.2	0.3	15	0.0	0.0	10	0.2	0.1	11
5/10/2010	4.5	0.3	12				0.0	0.0	17	0.0	0.0	16
8/13/2010	1.5	0.2	17	2.2	0.2	14	1.0	0.2	15	0.6	0.1	17
12/1/2010	1.5	0.2	13	0.0	0.0	21	0.0	0.0	12	0.0	0.0	10
2/9/2011	3.6	0.1	16	0.0	0.0	20	0.0	0.0	17	0.0	0.0	22
4/1/2011	33.1	0.7	19									
4/29/2011	28.9	1.4	14									
5/2/2011										0.0	0.0	20
8/11/2011	8.3	0.0	19							0.0	0.0	15
10/31/2011	8.7	0.4	14									
11/2/2011										0.0	0.0	18

¹SE = Standard Error

Discussion

Four anchialine pools associated with Ala Kahakai NHT were sampled quarterly from the first quarter of 2008 through 2011. During this time two notable events were observed: a tsunami and extensive restoration of a pool, both in 2011. The burying of F-ALKA-02 following the tsunami was likely the result of the close proximity to the shore, overall shallowness, and substrate, which consisted generally of loose rocks. Inundation by seawater into F-ALKA-01 by the tsunami was observable as elevated salinity 21 days later but not 48 days later, providing evidence for a rapid turnover time for water in this pool. Long-term effects of the tsunami on F-ALKA-01 cannot be inferred, because of the confounding effects of extensive alteration by restoration efforts.

The restoration of F-ALKA-01 had profound effects on pool biogeochemistry. Increased exposure to sunlight caused temperatures to rise. Chlorophyll rose dramatically with a corresponding increase in oxygen. Consumption of CO₂ by phytoplankton likely caused pH to become more alkaline through reduction of carbonic acid abundance (Wetzel 2001). TDP dropped dramatically, a likely result of uptake by phytoplankton.

Both F-ALKA-03 and F-ALKA-04 behaved similarly in each year as a result of both sources being underground and not exposed to direct sunlight. Data from these sites should be compared to groundwater samples taken from monitoring wells to investigate the effect of groundwater exposure to air but not sunlight.

Literature Cited

Helsel, D. R. and R. M. Hirsch. 2002. Statistical Methods in Water Resources. US Geological Survey Techniques of Water Resources Investigations, Book 4, Chapter A3.

Holthuis, L.B., 1973, Caridean shrimps found in land-locked saltwater pools at four indo-west Pacific localities (Sinai peninsula, Funafuti atoll, Maui and Hawaii islands), with the description of one genus and four new species, Zoologische Verhandelingen 128:3-55.

Jones, T., K. DeVerse, G. Dicus, D. McKay, A. Farahi, K. Kozar, and E. Brown. 2011. Water quality vital signs monitoring protocol for the Pacific Island Network: Volume 1; Version 1.0. Natural Resource Report NPS/PACN/NRR—2011/418. National Park Service, Fort Collins, CO.

https://irma.nps.gov/Reference.mvc/DownloadDigitalFile?code=430113&file=2011_PACN_water_quality_protocol_narrative.pdf

National Park Service, Department Of The Interior, Part 1 - General Provisions, 16 U.S.C. 1,3,9a,460 1-6a(e), 462(k); C.F.R. Title 36 Chapter I, (Parts 1-199).Hawaii, 2012, Title 11, Chapter 54, Water Quality Standards, Hawaii Administrative Rules, Department of Health.

Wetzel, R. G., 2001, Limnology, 3rd Ed., Academic Press, San Diego, CA, USA.