



Marine Water Quality in Kalaupapa National Historical Park

Summary Report 2008-2014

Natural Resource Data Series NPS/PACN/NRDS—2017/1120



ON THE COVER

Coastline of Kalaupapa National Historical Park.

Photograph by: Anne Farahi

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September 2017

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

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Please cite this publication as:

Raikow, D. F., A. Farahi, A.L. McCutcheon, E. Brown, and S. Kichman. 2017. Marine water quality in Kalaupapa National Historical Park Summary Report 2008-2014. Natural Resource Data Series NPS/PACN/NRDS—2017/1120. National Park Service, Fort Collins, Colorado.

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Abstract

This Natural Resource Data Series Report presents data collected from the marine portion of Kalaupapa National Historical Park, island of Molokai, Hawai‘i, USA. 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 a limited description. The data presented in this report will be analyzed and interpreted for the establishment of expected parameter value ranges and long-term trends in future reports published in the National Park Service Natural Resource Report series. The purpose of collecting data on Vital Signs is to provide park managers information on current conditions and temporal trends in ecosystem health. Surface waters consistently had slightly higher concentrations of total dissolved phosphorus, total dissolved nitrogen, nitrates, chlorophyll, dissolved oxygen, and lower salinity than bottom waters. Sampling methods employed here were not designed to match methods used to evaluate state water quality criteria, and were therefore not directly comparable.

Acknowledgments

We thank Paul Hosten, Sylvester Lee, Senifa Annandale, Randal Watanuki, Albert and James Espaniola and the staff of Kalaupapa National Historical Park for their cooperation and on-site logistical support.

List of Units and Acronyms

°C	Degrees Centigrade
$\mu\text{g} \cdot \text{L}^{-1}$	Micrograms per Liter
μm	Micrometer
HAVO	Hawai'i Volcanoes National Park
I&M	Inventory and Monitoring Program of the National Park Service
KALA	Kalaupapa National Historical Park
m	Meter
ml	Milliliter
$\text{mg} \cdot \text{L}^{-1}$	Milligrams per Liter
$\text{mS} \cdot \text{cm}^{-1}$	Milli-Siemens per Centimeter
n	Number of measurements or samples
NO_2	Nitrite
NO_3	Nitrate
NPS	National Park Service
NRDS	Natural Resource Data Series Report
NRR	Natural Resource Report
NTU	Nephelometric Turbidity Units
ODO	Optical Dissolved Oxygen
ODOsat	Optical Dissolved Oxygen in terms of saturation
PACN	Pacific Island Network, Inventory and Monitoring Division
PN	Particulate Nitrogen
PP	Particulate Phosphorus
ppt	Parts Per Thousand
SD	Standard Deviation
SE	Standard Error
SpC	Specific conductivity
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
UHH	University of Hawai'i 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) Division Pacific Island Network (PACN). This report presents data collected under the PACN water quality protocol (Jones et al. 2011) in the marine portion of Kalaupapa National Historical Park (KALA), island of Molokai, Hawai‘i, USA, between 2008 and 2014.

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 Reports (NRR).

The purpose of collecting data on Vital Signs is to provide park managers with information on current conditions and temporal trends in ecosystem health. Park managers can use this information to respond to resource conditions and evaluate management actions. The mission of the I&M Division 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).

Water quality criteria for Hawai‘i are defined in the Hawai‘i State Department of Health Water Quality Standards (Hawai‘i 2012). The area sampled here is class AA “open coastal, salt, marine waters,” (§11-54-(6) (2) (A) (v), pp.54-41), in areas where salinity is greater than 32 parts per thousand (ppt) (Table 1). Criteria are defined for total nitrogen, total phosphorus, ammonia, nitrate + nitrite ($\text{NO}_3 + \text{NO}_2$), light extinction coefficient, chlorophyll a, and turbidity in terms of geometric means not to be exceeded.

State criteria specify that samples to assess compliance be taken along a transect extending away from shore, within one meter (m) of the surface, and filtered with a 0.7 micrometer (μm) filter. The methods of this protocol do not include such transects, but do include filtered surface samples. However, because transects in this report are not orientated to extend away from shore, summaries presented here are not necessarily directly comparable to state criteria (Table 1). Measurements taken further away from shore are likely to have lower concentrations due to dissipation of terrestrial inputs, and thus, are likely to reduce means across a transect. Moreover, there is no specified time period over which the geometric mean is to be calculated (State of Hawai‘i, personal communication). Nevertheless, we reference state water quality criteria in this report because they are a useful benchmark to consider when examining results.

Table 1. State of Hawai'i water quality criteria for all open coastal waters (Hawai'i 2012).

Parameter	Unit	Season	Geometric mean not to exceed the given value
Total Nitrogen	$\mu\text{gN} \cdot \text{L}^{-1}$	Wet	150.00
		Dry	110.00
Ammonia	$\mu\text{gN} \cdot \text{L}^{-1}$	Wet	3.50
		Dry	2.00
Nitrate + Nitrite	$\mu\text{gN} \cdot \text{L}^{-1}$	Wet	5.00
		Dry	3.50
Total Phosphorus	$\mu\text{gP} \cdot \text{L}^{-1}$	Wet	20.00
		Dry	16.00
Light Extinction Coefficient	k	Wet	0.20
		Dry	0.10
Chlorophyll-a	$\mu\text{g} \cdot \text{L}^{-1}$	Wet	0.30
		Dry	0.15
Turbidity		Wet	0.50
		Dry	0.20

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

Kalaupapa National Historical Park is located on the island of Molokai (Figure 1). This report presents data collected in the off-shore portion only. Site names used by PACN were formatted to designate fixed or temporary sites (“F” or “T” respectively), park (KALA), a number (e.g. 01), and habitat type (“mr” for marine); e.g. “FKALA01_mr”. Names for temporary sites were based on the date of sampling. The marine portion of the park was sampled 14 times from October 2008 to November 2014. Four fixed sites (FKALA03, -06, -11, and -14, Table 2) and a unique set of four temporary sites chosen at random were sampled for water samples and limnological parameters during each trip. Additional limnological parameter readings were taken at fixed and temporary sites during annual benthic marine community surveys (Brown et al., 2011). All sites, including fixed, temporary and additional sites at which limnological parameters were collected with benthic marine surveys, are shown in Figure 1. Sample site locations were chosen based on safety and support of other PACN protocols. Sample sites could not be located closer to shore due to shallowness and surf-breaks. Sites corresponded to the location of sites of benthic marine community surveys conducted by SCUBA, which themselves were limited to a specific depth contour for safety.

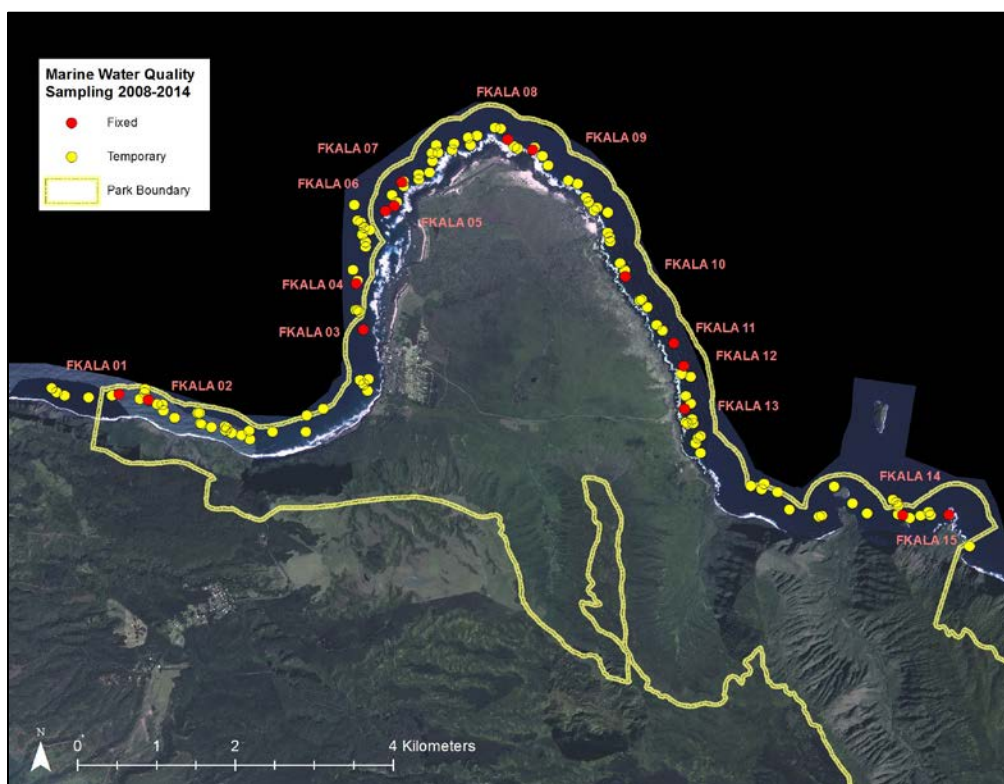


Figure 1. Marine water quality sample sites in Kalaupapa National Historical Park.

Table 2. Fixed marine sample site locations at Kalaupapa National Historical Park that are sampled at during each trip.

PACN site designation	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
FKALA03_mr	21.19380406	-156.98688376
FKALA06_mr	21.20795683	-156.98289430
FKALA11_mr	21.19179755	-156.94898179
FKALA14_mr	21.17179280	-156.92125171

Water Collection

A Niskin bottle was used to sample water from a depth of 1 m (surface sample), and a separate sample was taken 2-3 m above the bottom substrate (bottom sample). Water was dispensed from the Niskin bottle directly into a new or acid-washed 140 milliliter (ml) syringe, or acid washed filter tower. Water was filtered in the field using an in-line filter holder and a 0.7 μm GF/F filter, and 140 ml of sample water was filtered into each sample bottle. Three 140 ml samples were taken at each sample site and placed on ice in the field inside a cooler. Samples were transferred to a freezer on the day of collection until delivery to the EPSCoR Analytical Laboratory at the University of Hawai‘i at Hilo (UHH) Marine Science Department for chemical analysis. Samples were analyzed for TDP, TDN, and $\text{NO}_3 + \text{NO}_2$. Minimum analytical detection limits were 15.0 micrograms per liter ($\mu\text{g} \cdot \text{L}^{-1}$) for TDP, 0.070 milligrams per liter ($\text{mg} \cdot \text{L}^{-1}$) for TDN, and 1.0 $\mu\text{g} \cdot \text{L}^{-1}$ for $\text{NO}_3 + \text{NO}_2$.

Limnological Parameters and General Conditions

A YSI 6600 multiparameter sonde was calibrated within a few days before commencing field sampling. The sonde was used to measure depth (m), temperature ($^{\circ}\text{C}$), specific conductivity (SpC) in milli-Siemens per centimeter ($\text{mS} \cdot \text{cm}^{-1}$), pH, optical dissolved oxygen (ODO) in $\text{mg} \cdot \text{L}^{-1}$, chlorophyll in $\mu\text{g} \cdot \text{L}^{-1}$, and turbidity in nephelometric turbidity units (NTU). The sonde also reported salinity in ppt calculated from SpC, and dissolved oxygen in percent saturation (% ODOsat) calculated from ODO and temperature. The sonde was set to record readings every 30 seconds prior to leaving the dock. The sonde was lowered to a depth of 1 m and allowed to log readings for at least five minutes, then lowered to 2 to 3 m above the bottom and allowed to log readings for at least five minutes, at each site. Between sites the sonde was stored with probes immersed in freshwater. The mean and variance of stable values, isolated by depth, is reported. Average wind speed over three minutes and wind direction were measured using a Kestrel wind speed device. Global positioning system coordinates 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 PACN offices within Hawai‘i Volcanoes National Park (HAVO), scanned, and uploaded to PACN servers. All data including laboratory results were entered into PACN databases. Data were downloaded from the YSI 650 control unit and readings from surface and bottom depths isolated 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 due to instrument or sampling errors were flagged in databases and removed from further consideration. Data were explored visually by plotting time-series. Outlying data and 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.

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 arithmetic mean and the standard error are reported for individual sampling events, because the accuracy of the estimate of the mean is of interest. 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 3-13). 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. Mean values of chlorophyll that were less than zero are reported with a value of zero, i.e. as non-detects. Turbidity probes can return negative values when conditions are at or near zero turbidity. Negative turbidity readings were set to 0.1, the lowest value above zero for the probe. Resetting very low turbidity values to 0.1 NTU is based on the assumption that natural water, while often visually indistinguishable from transparent deionized (distilled) water, can never be particulate-free. With regard to state water quality criteria, the arithmetic mean, or average, of a set of values is defined as the sum of those values divided by the count, while the geometric mean is the n^{th} root of the product of n values.

Spatial Analysis

Data was plotted spatially in ArcMap 10.3.1. The spatial distribution of parameter values at the surface across the marine portion of the park was plotted using the Inverse Distance Weighting (IDW) spatial analyst tool. IDW is based on the principle that values close to one another are more alike than those that are farther apart. We used a variable search radius with 12 points. Such settings, along with the number and dispersion of sample points, affect the appearance of interpolations. Sample locations were not chosen to optimize spatial analysis. Hence the sample sites fell generally on a transect line running north to south. Thus interpolation along the east-west axis was less reliable than along the north-south axis. Based on this, a power option of seven was chosen, which decreases the significance of surrounding points and produced a horizontal (east-west) visual banding effect. We also limited the interpolation to an area within 250 m of all sample points, to avoid displaying results in areas where no samples were taken. The color ramp used in the display of spatial interpolations blends five distinct colors. This method was chosen to aid interpretation. The colors correspond to points along the scale regardless of absolute values: black = 0% of the scale, blue = 25%, green = 50%, yellow = 75%, and white = 100%.

Results

Because data from all sites were collected over a variable number of consecutive days, typically one to three, results are presented as summaries by quarter. Surface samples displayed greater variance than bottom samples, resulting in error bars visible when surface samples were plotted, and fewer or no error bars plotted for bottom samples. Geometric means of parameters by season are presented in comparison to state water quality criteria. Results are presented below as summaries of all replicate samples by parameter, plots of arithmetic means over time, and spatial interpolations. Surface and bottom parameter spatial distributions are presented using the same result range to allow direct comparison. Spatial distributions of bottom nutrients are presented using result ranges observed in bottom samples.

Total Dissolved Phosphorus

Non-detects are presented at $7.5 \mu\text{g} \cdot \text{L}^{-1}$, or half the detection limit, and treated as such for calculation of the mean. Very little TDP was detected across all years, with most measurements being non-detects (Figure 2, Table 3). The highest measurements of TDP were taken on the east side of the peninsula, but these elevated values were only observed in one sampling event during the summer of 2013 (Figures 3-4).

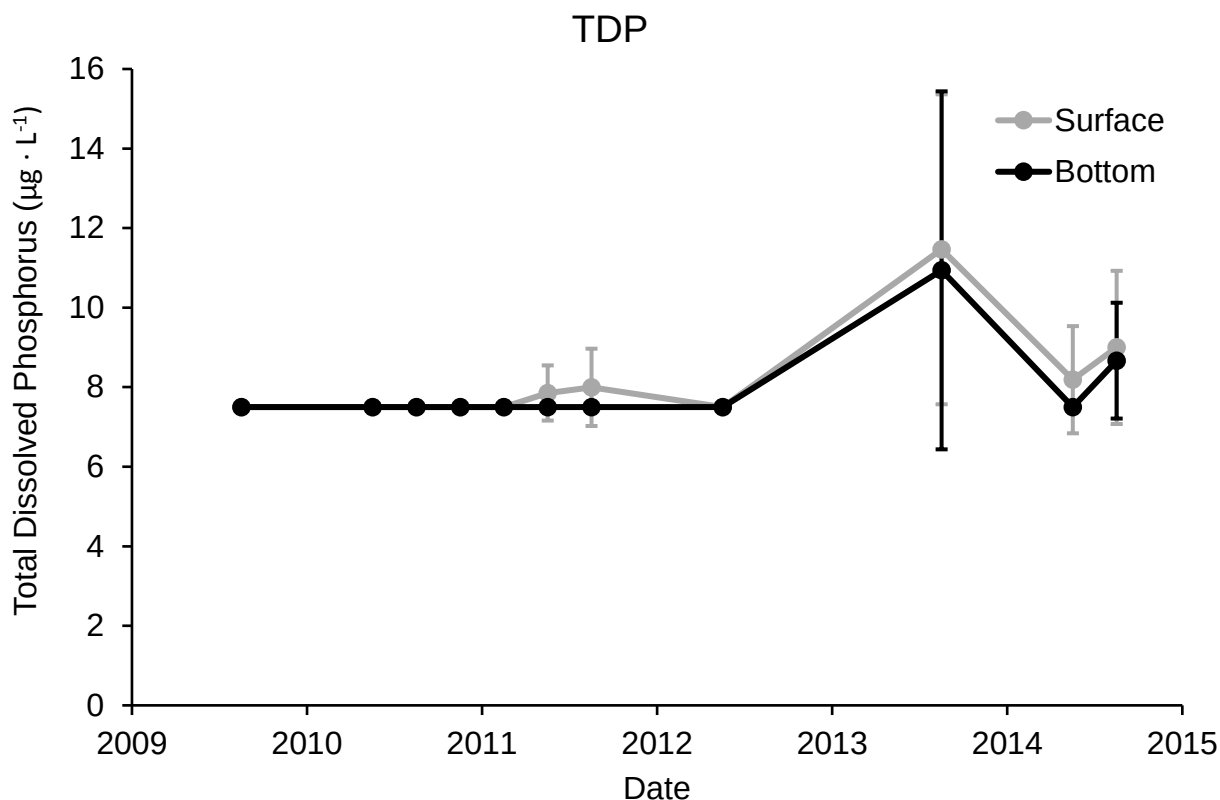


Figure 2. Total dissolved phosphorus in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals. Non-detects are presented as half the detection limit, and treated as such for calculation of the mean.

Table 3. Total dissolved phosphorus ($\mu\text{g} \cdot \text{L}^{-1}$) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	<i>n</i>	Minimum	Median	Maximum	SD
2009	3	Surface	24	7.5	7.5	7.5	0.0
		Bottom	24	7.5	7.5	7.5	0.0
2010	2	Surface	21	7.5	7.5	7.5	0.0
		Bottom	24	7.5	7.5	7.5	0.0
2010	3	Surface	24	7.5	7.5	7.5	0.0
		Bottom	24	7.5	7.5	7.5	0.0
2010	4	Surface	24	7.5	7.5	7.5	0.0
		Bottom	24	7.5	7.5	7.5	0.0
2011	1	Surface	24	7.5	7.5	7.5	0.0
		Bottom	24	7.5	7.5	7.5	0.0
2011	2	Surface	27	7.5	7.5	16.0	1.6
		Bottom	21	7.5	7.5	7.5	0.0
2011	3	Surface	27	7.5	7.5	19.4	2.3
		Bottom	21	7.5	7.5	7.5	0.0
2012	2	Surface	24	7.5	7.5	7.5	0.0
		Bottom	24	7.5	7.5	7.5	0.0
2013	3	Surface	24	7.5	7.5	24.0	6.6
		Bottom	24	7.5	7.5	27.0	6.9
2014	2	Surface	24	7.5	7.5	24.0	3.4
		Bottom	21	7.5	7.5	7.5	0.0
2014	3	Surface	27	7.5	7.5	29.0	5.8
		Bottom	21	7.5	7.5	19.0	3.2

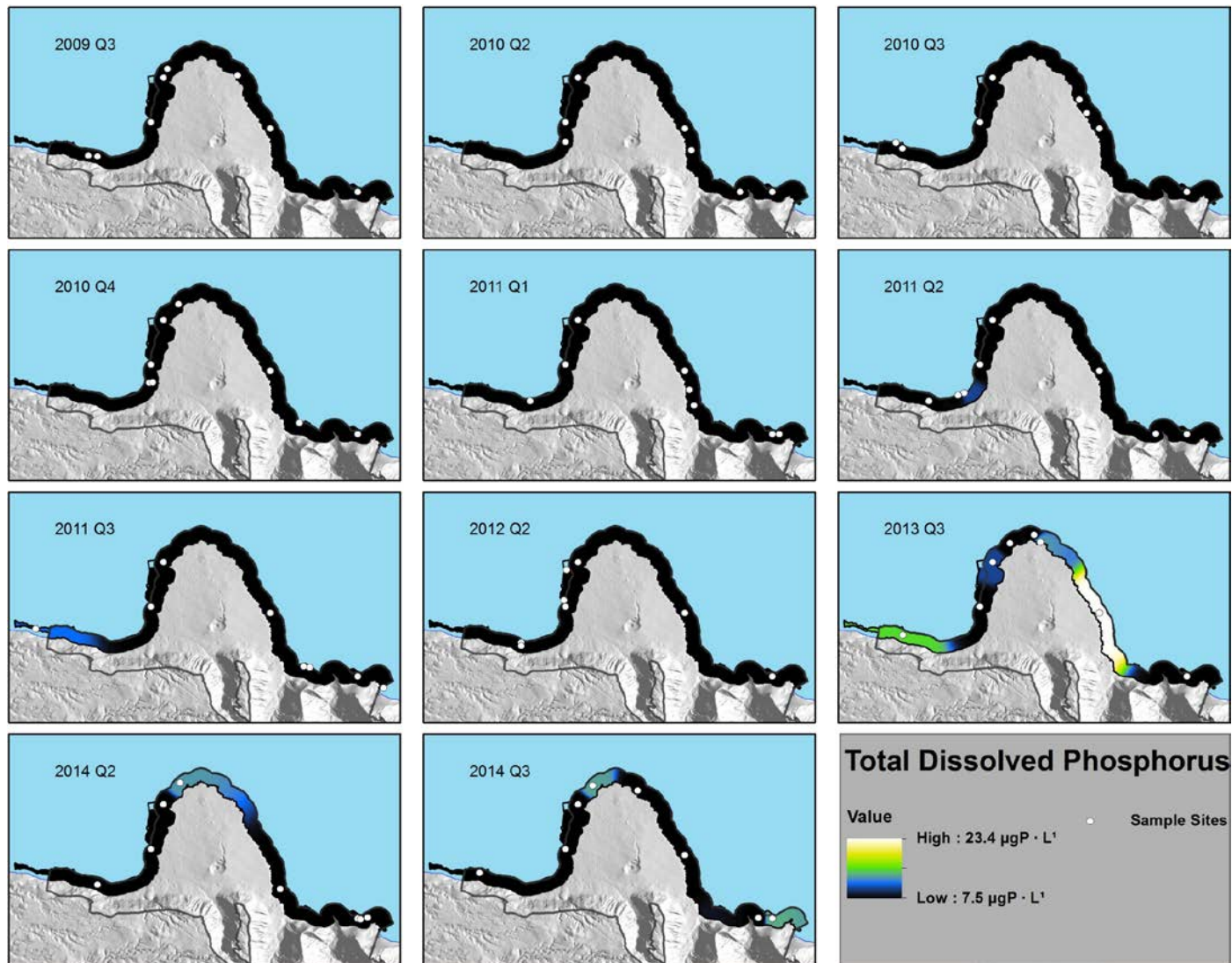


Figure 3. Spatial distribution of surface total dissolved phosphorus in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

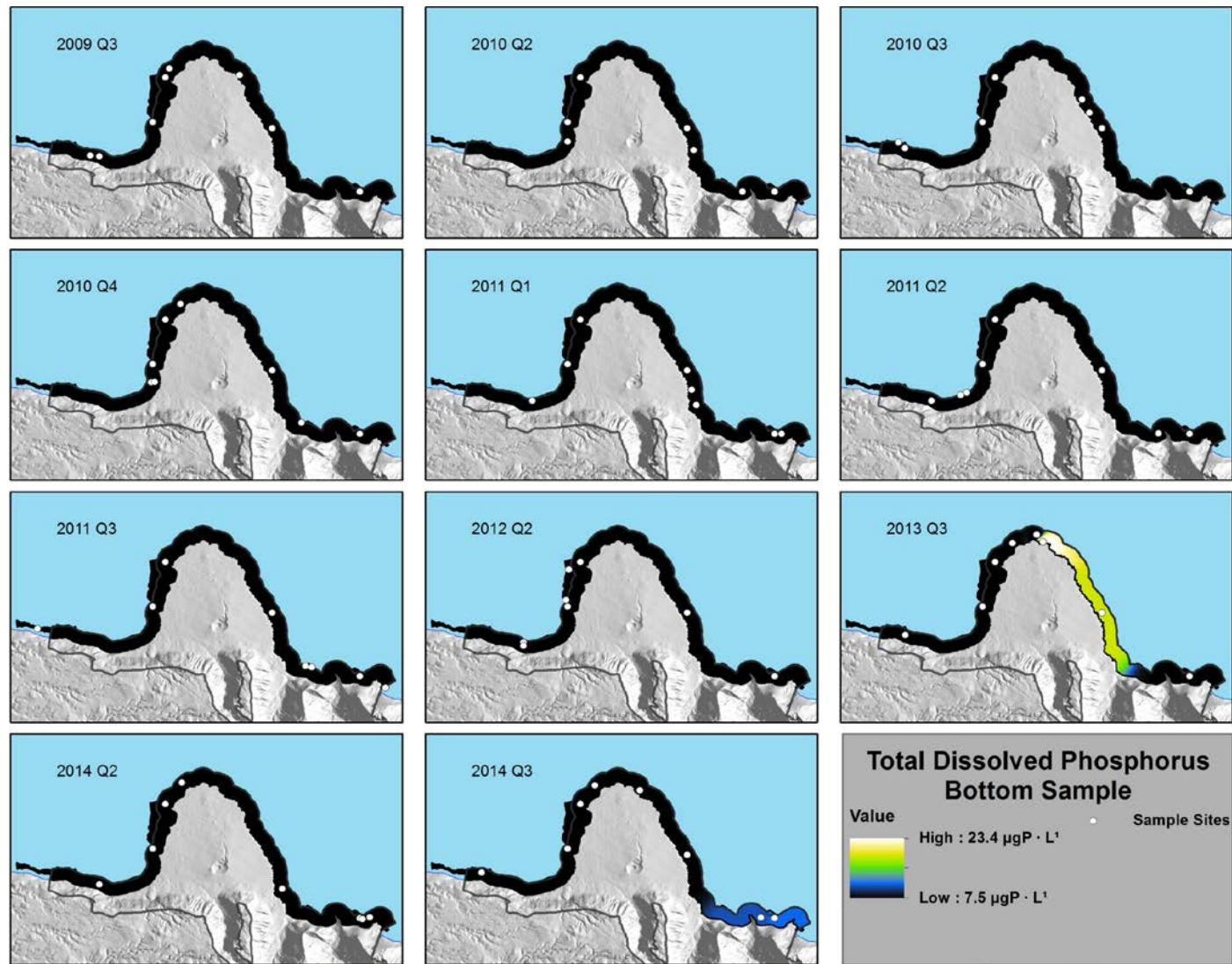


Figure 4. Spatial distribution of bottom total dissolved phosphorus in marine waters of Kalaupapa National Historical Park using the total range of results observed in surface and bottom samples.

Total Dissolved Nitrogen

Concentrations of TDN were relatively constant over the monitoring period. The highest values of TDN were only observed on the west side of the peninsula and only during two sampling events, winter of 2011 and summer of 2013 (Figures 5-7, Table 4).

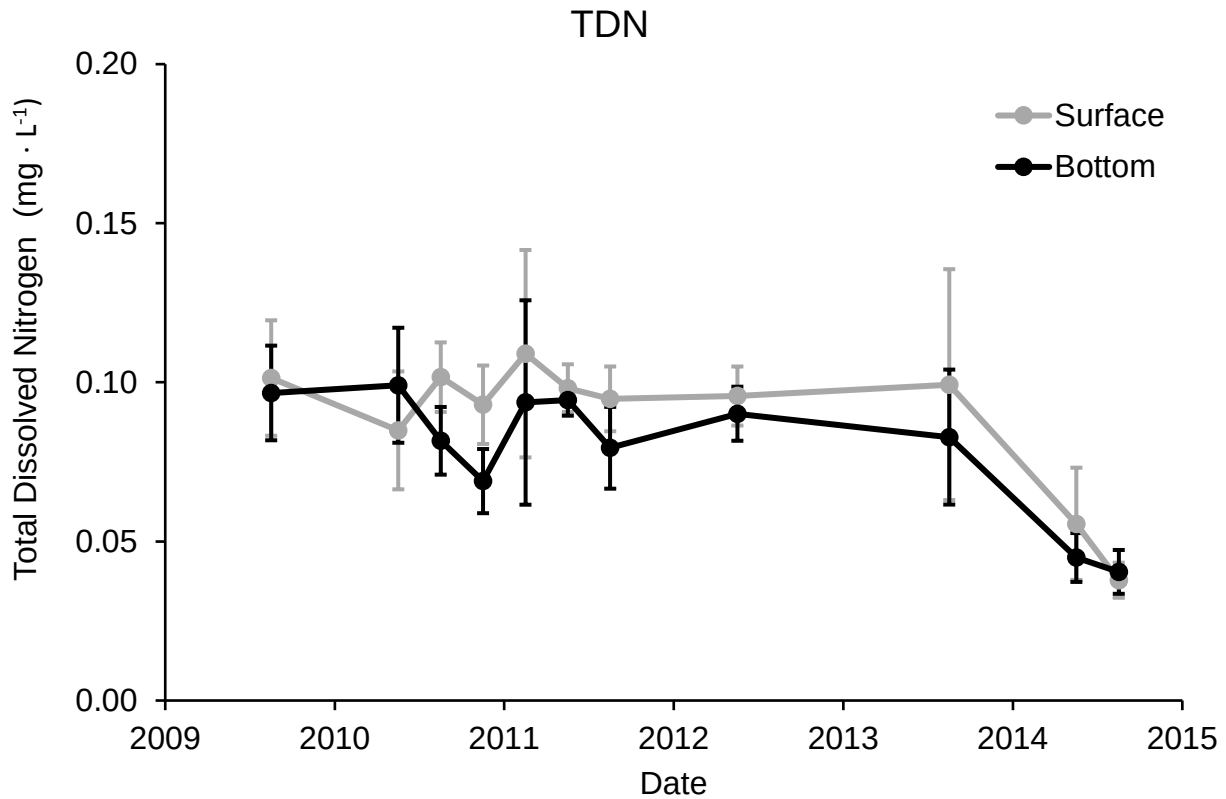


Figure 5. Total dissolved nitrogen in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals of eight sites.

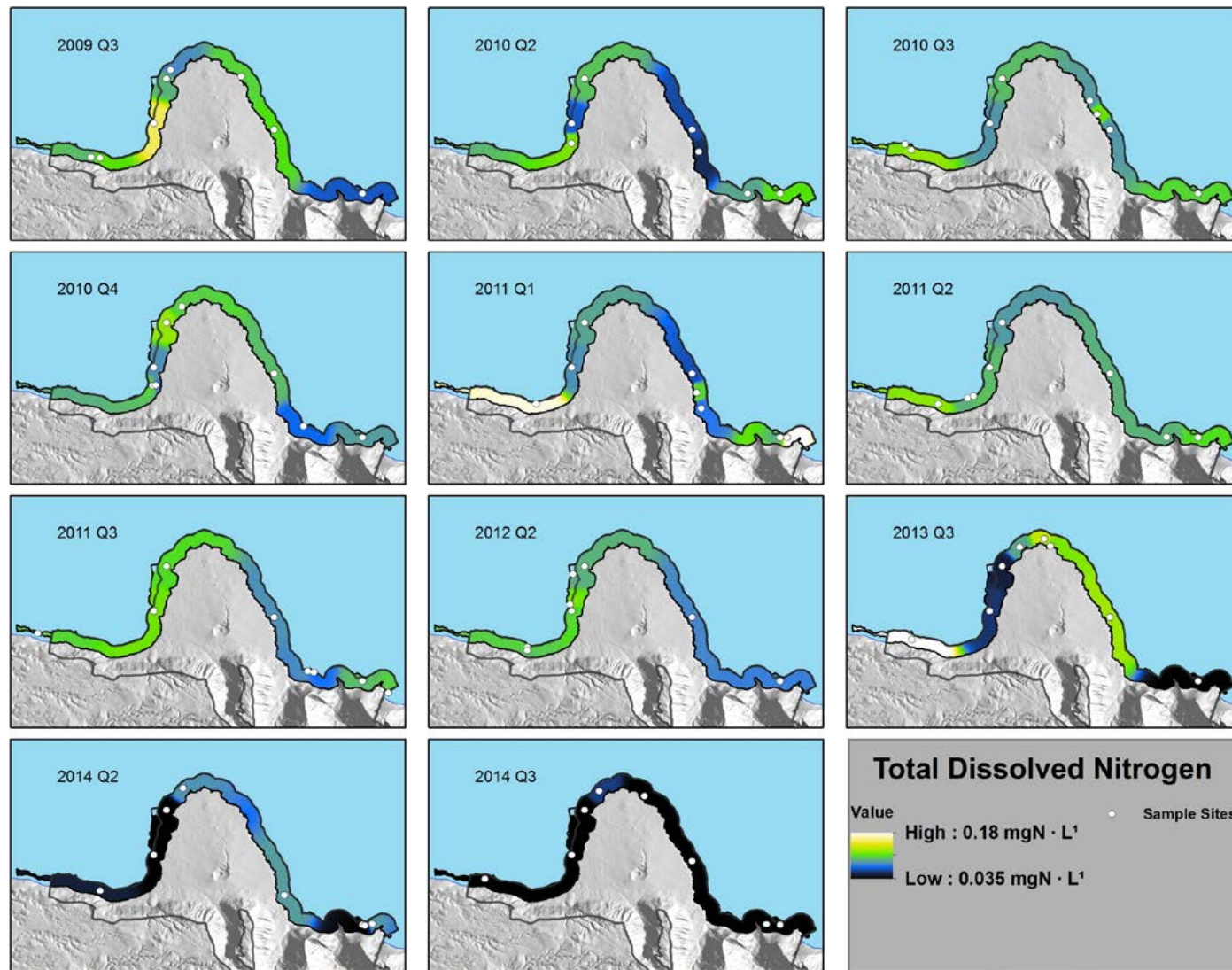


Figure 6. Spatial distribution of surface total dissolved nitrogen in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

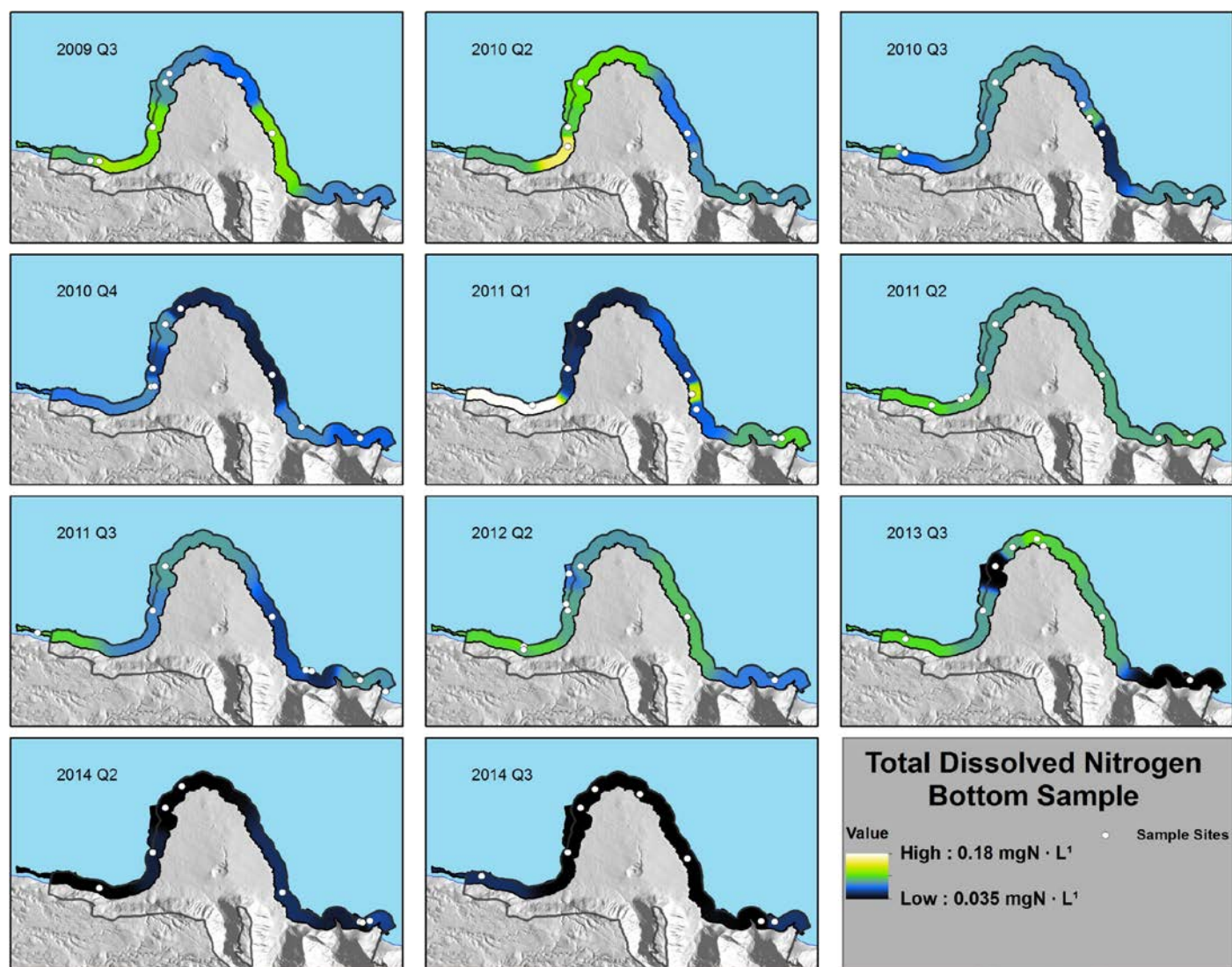


Figure 7. Spatial distribution of bottom total dissolved nitrogen in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 4. Total dissolved nitrogen ($\text{mg} \cdot \text{L}^{-1}$) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2009	3	Surface	24	0.035	0.098	0.174	0.032
		Bottom	24	0.035	0.090	0.157	0.027
2010	2	Surface	21	0.035	0.086	0.137	0.030
		Bottom	24	0.035	0.094	0.214	0.033
2010	3	Surface	24	0.035	0.097	0.171	0.032
		Bottom	24	0.035	0.084	0.130	0.022
2010	4	Surface	24	0.035	0.088	0.177	0.030
		Bottom	24	0.035	0.074	0.134	0.026
2011	1	Surface	24	0.035	0.086	0.297	0.055
		Bottom	24	0.035	0.087	0.204	0.051
2011	2	Surface	27	0.081	0.096	0.138	0.012
		Bottom	21	0.080	0.092	0.126	0.012
2011	3	Surface	27	0.035	0.092	0.148	0.024
		Bottom	21	0.035	0.082	0.113	0.025
2012	2	Surface	24	0.072	0.096	0.162	0.018
		Bottom	24	0.074	0.083	0.157	0.019
2013	3	Surface	24	0.035	0.095	0.229	0.055
		Bottom	24	0.035	0.092	0.131	0.032
2014	2	Surface	24	0.035	0.035	0.098	0.026
		Bottom	21	0.035	0.035	0.088	0.019
2014	3	Surface	27	0.035	0.035	0.121	0.019
		Bottom	21	0.035	0.035	0.096	0.017

Nitrate + Nitrite

Concentrations of $\text{NO}_2 + \text{NO}_3$ were relatively constant over the monitoring period, but were slightly lower in bottom waters than in surface waters (Figure 8, Table 5). The distribution of $\text{NO}_2 + \text{NO}_3$ was inconsistent over time (Figures 9-10).

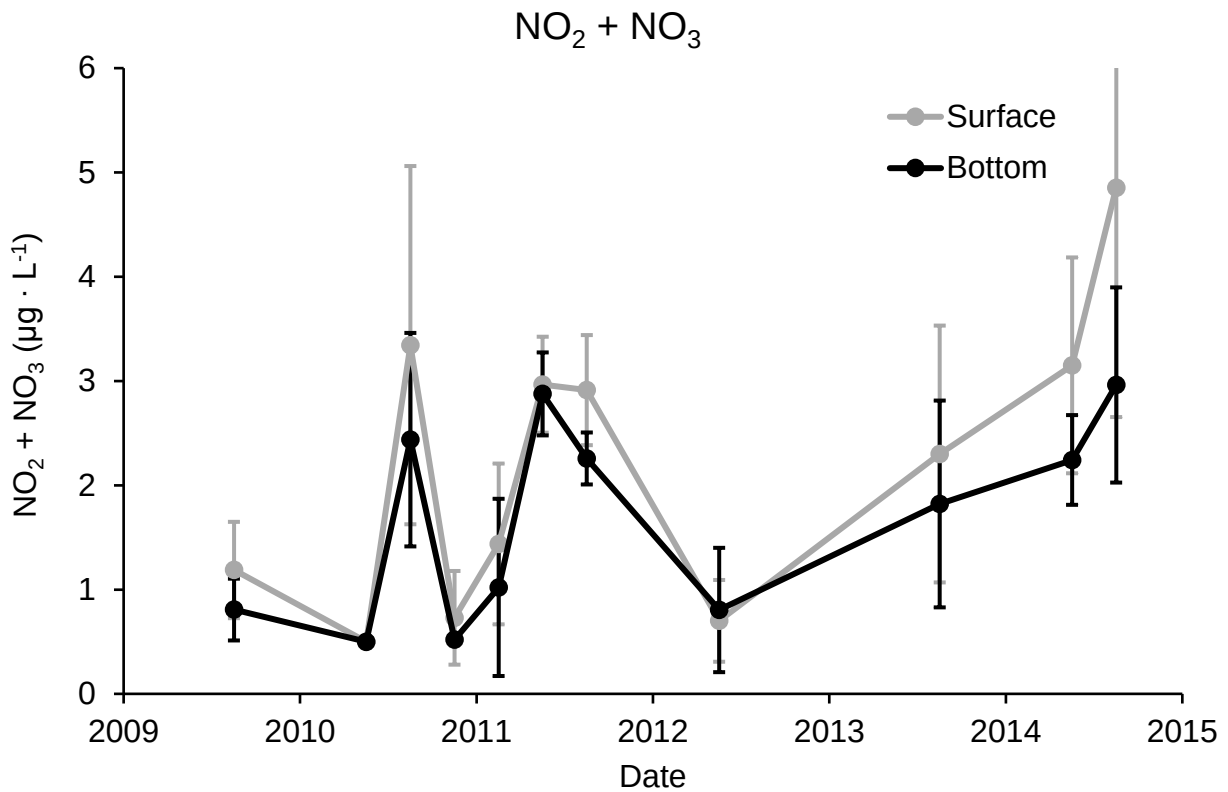


Figure 8. Nitrite + nitrate in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals of eight sites.

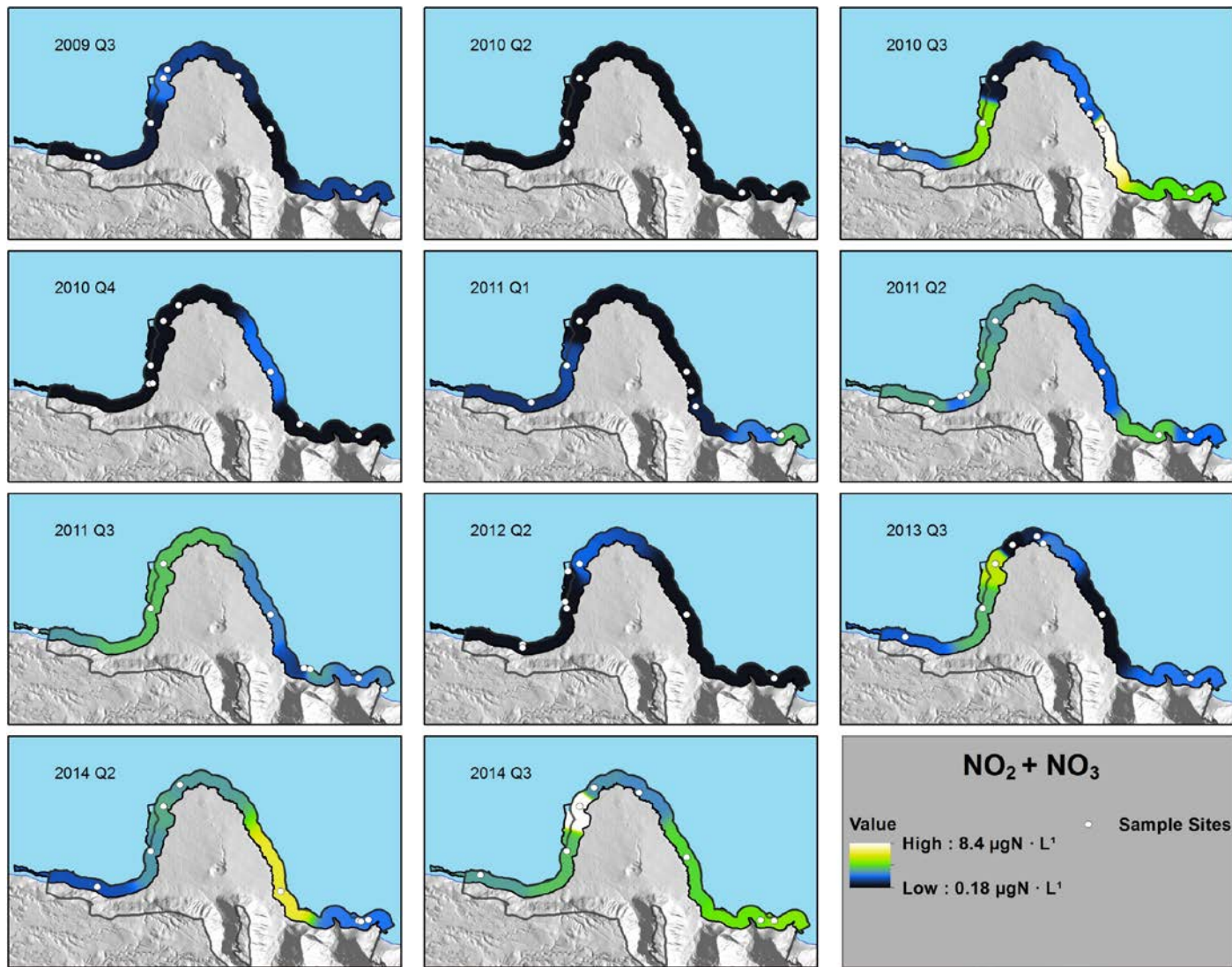


Figure 9. Spatial distribution of surface nitrite + nitrate in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

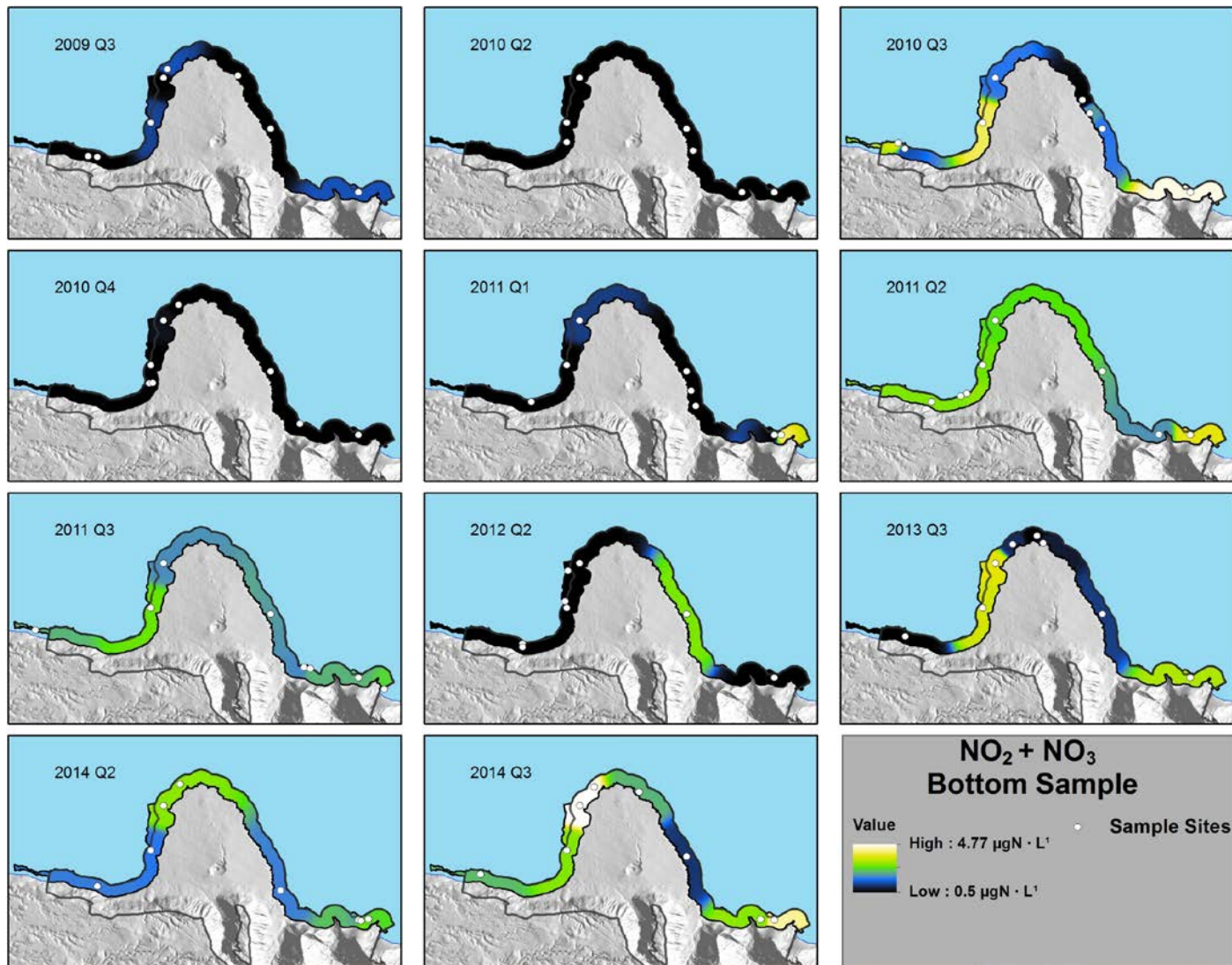


Figure 10. Spatial distribution of bottom Nitrite + Nitrate in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 5. Nitrate + nitrite ($\mu\text{g} \cdot \text{L}^{-1}$) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2009	3	Surface	24	0.5	0.5	4.4	1.0
		Bottom	24	0.5	0.5	2.1	0.6
2010	2	Surface	21	0.5	0.5	0.5	0.0
		Bottom	24	0.5	0.5	0.5	0.0
2010	3	Surface	22	0.5	2.0	14.0	3.3
		Bottom	24	0.5	2.0	7.0	1.9
2010	4	Surface	24	0.5	0.5	6.0	1.1
		Bottom	24	0.5	0.5	1.0	0.1
2011	1	Surface	24	0.5	0.5	10.0	2.0
		Bottom	24	0.5	0.5	7.0	1.4
2011	2	Surface	27	1.4	3.0	5.9	0.8
		Bottom	21	1.5	2.8	5.4	0.8
2011	3	Surface	27	0.5	2.7	5.9	1.1
		Bottom	21	1.4	2.1	3.1	0.5
2012	2	Surface	24	0.5	0.5	5.3	1.0
		Bottom	24	0.5	0.5	7.8	1.5
2013	3	Surface	24	0.5	2.0	7.5	2.1
		Bottom	24	0.5	1.0	4.3	1.4
2014	2	Surface	24	1.5	2.7	6.7	1.5
		Bottom	21	1.1	2.1	4.1	0.7
2014	3	Surface	27	2.1	3.8	13.7	3.1
		Bottom	21	0.5	2.9	6.4	1.4

Chlorophyll

Isolated spikes in chlorophyll concentration were observed during the monitoring period. Surface concentrations were greater than bottom concentrations when chlorophyll was detected (Figure 11, Table 6). Spatial patterns of surface chlorophyll were inconsistent between sampling events (Figures 12-13).

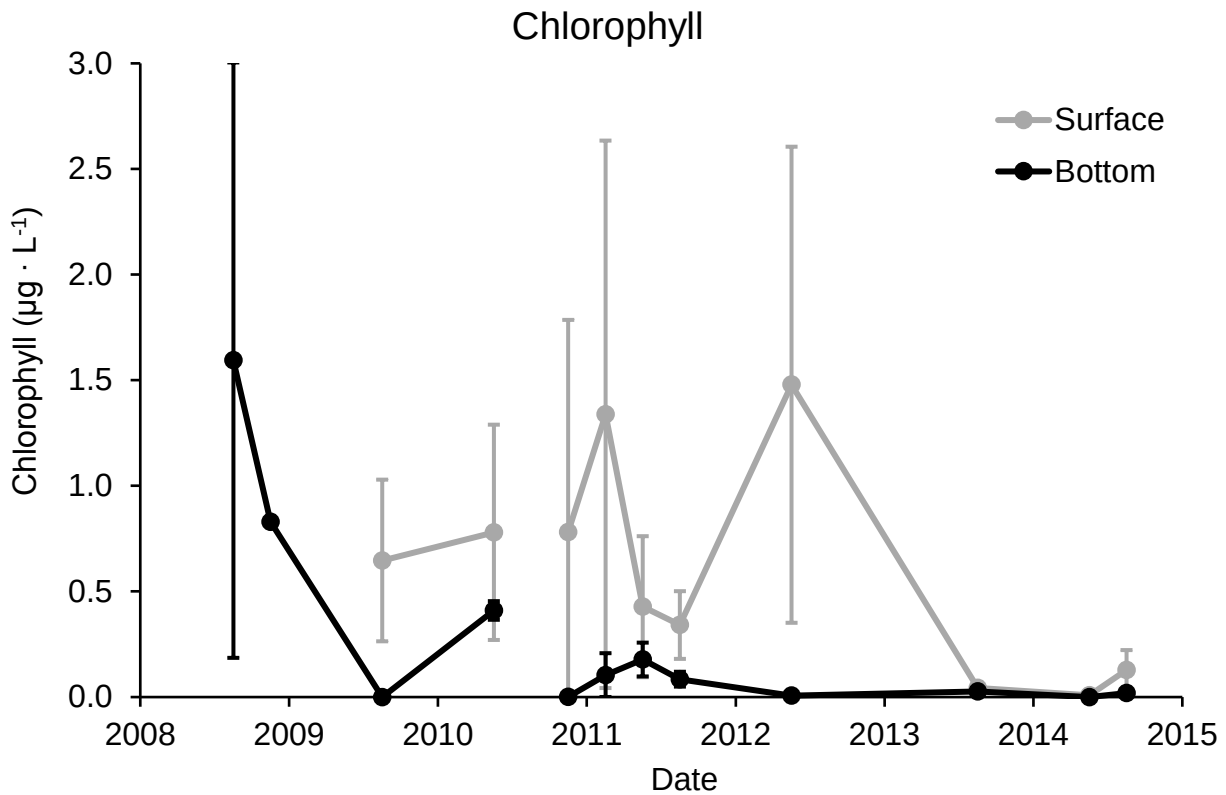


Figure 11. Chlorophyll in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

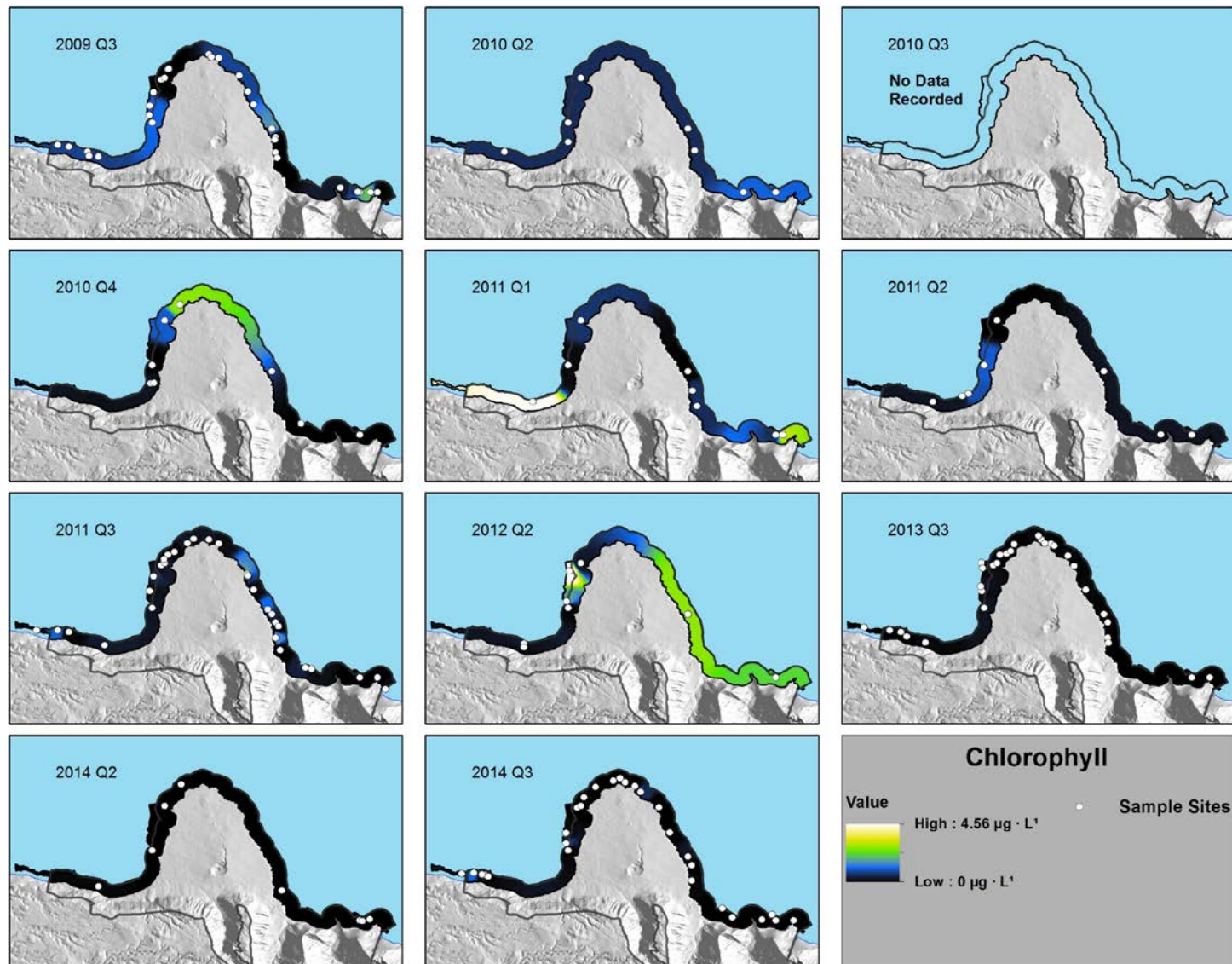


Figure 12. Spatial distribution of surface chlorophyll in surface marine waters of Kalupapa National Historical Park using the total range of results observed in both surface and bottom samples.

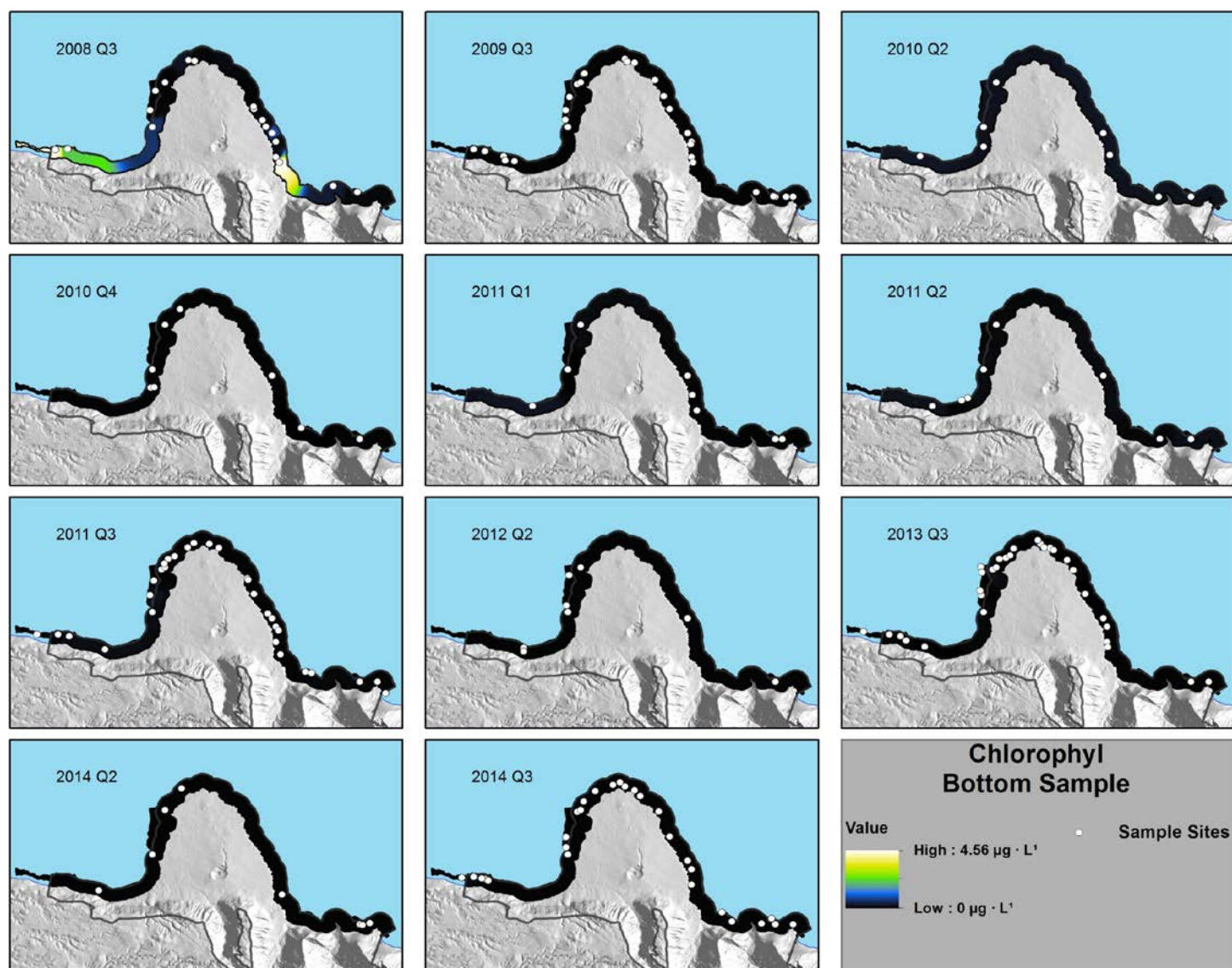


Figure 13. Spatial distribution of bottom chlorophyll in surface marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 6. Chlorophyll ($\mu\text{g} \cdot \text{L}^{-1}$) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2008	3	Bottom	18	0.03	0.20	9.64	3.05
2008	4	Bottom	1	0.83		0.83	
2009	3	Surface	15	0.05	0.36	2.13	0.74
		Bottom	26	0.05	0.00	0.05	0.00
2010	2	Surface	2	0.52	0.78	1.04	0.37
		Bottom	8	0.34	0.40	0.53	0.06
2010	4	Surface	5	0.01	0.20	2.70	1.14
		Bottom	8	0.01	0.00	0.05	0.02
2011	1	Surface	7	0.01	0.56	4.52	1.75
		Bottom	8	0.01	0.04	0.43	0.14
2011	2	Surface	6	0.05	0.23	1.00	0.41
		Bottom	8	0.05	0.17	0.36	0.11
2011	3	Surface	30	0.04	0.18	1.82	0.44
		Bottom	30	0.01	0.06	0.39	0.09
2012	2	Surface	8	0.05	1.02	4.56	1.62
		Bottom	8	0.05	0.00	0.06	0.00
2013	3	Surface	28	0.01	0.03	0.25	0.06
		Bottom	28	0.00	0.00	0.41	0.07
2014	2	Surface	8	0.05	0.00	0.07	0.01
		Bottom	8	0.05	0.00	0.05	0.00
2014	3	Surface	30	0.01	0.00	1.10	0.25
		Bottom	30	0.04	0.00	0.31	0.06

Dissolved Oxygen Concentration

Dissolved oxygen concentrations were generally consistent between years, with slightly greater concentrations measured at the surface (Figures 14-16, Table 7).

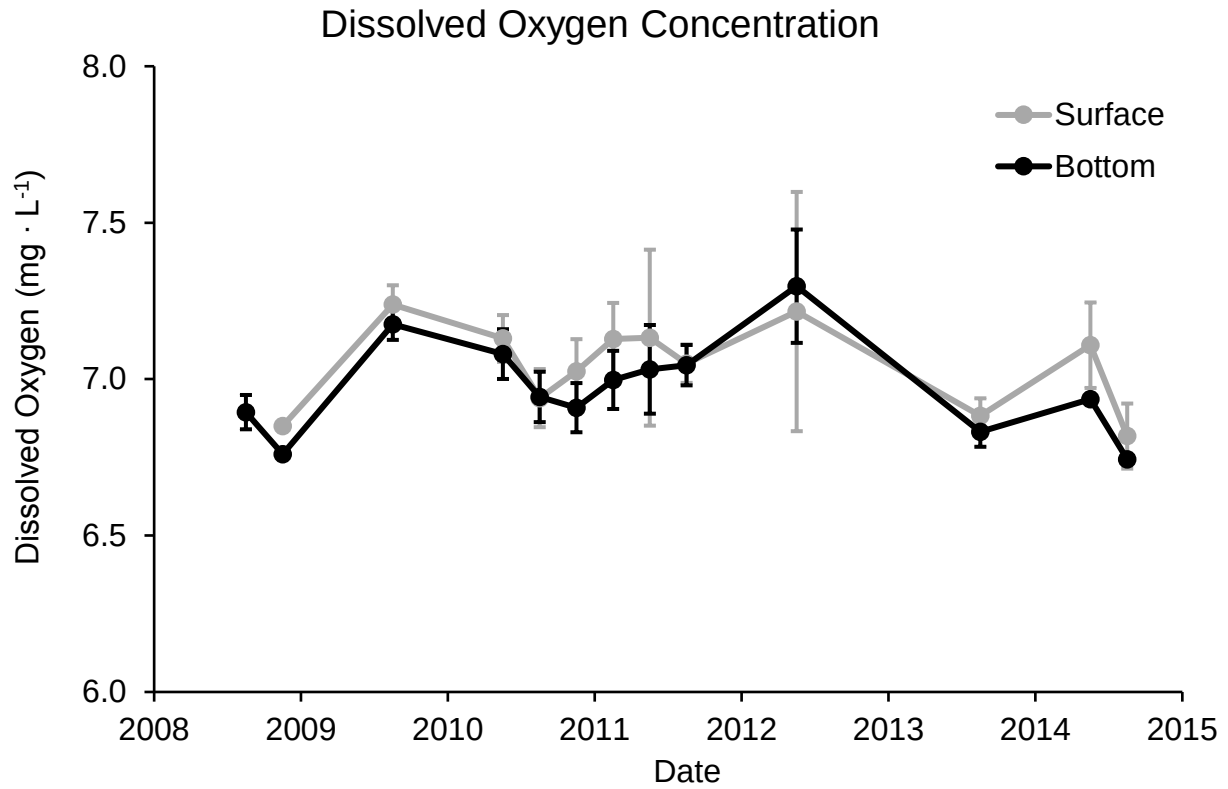


Figure 14. Dissolved oxygen concentration in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

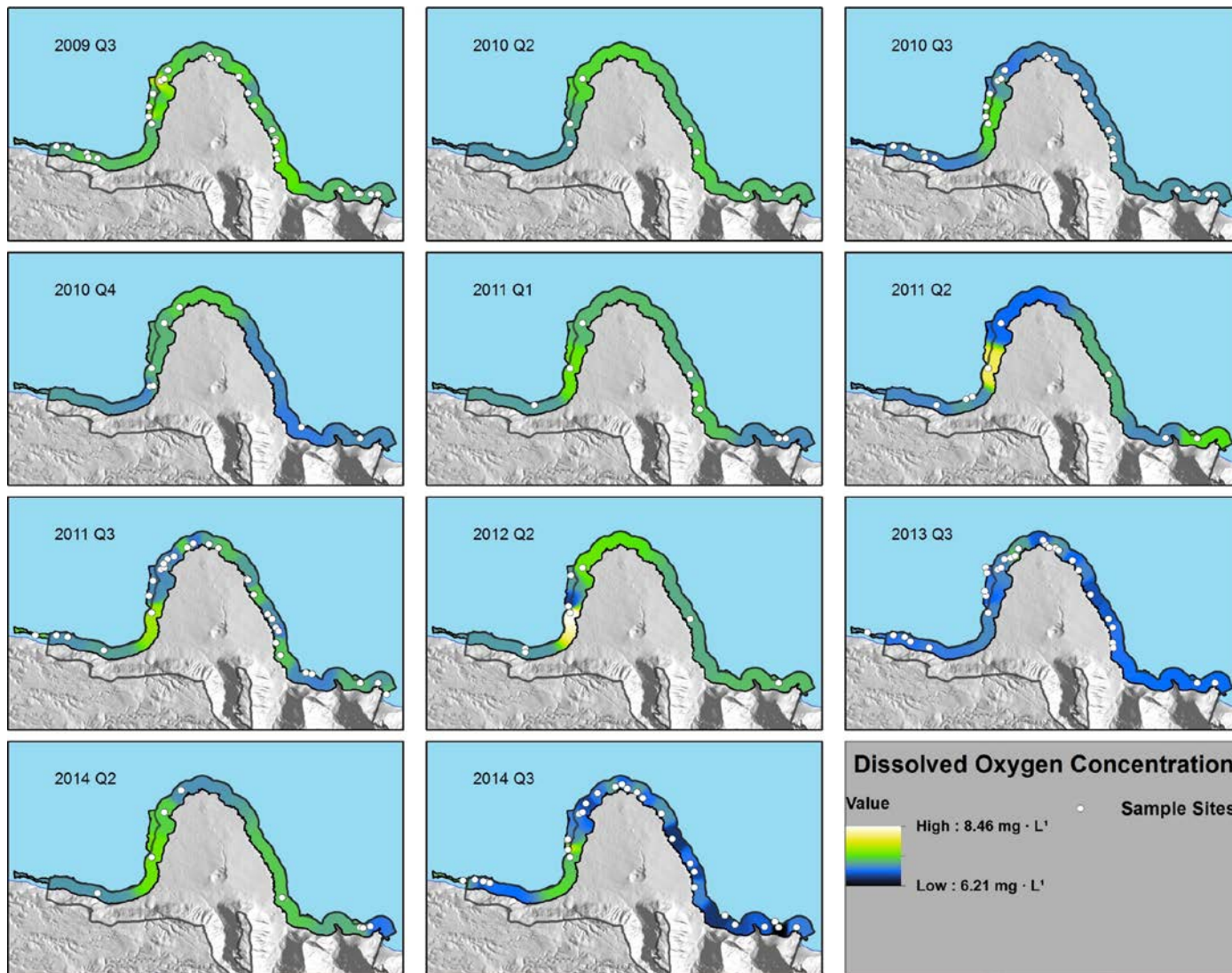


Figure 15. Spatial distribution of surface dissolved oxygen concentration in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

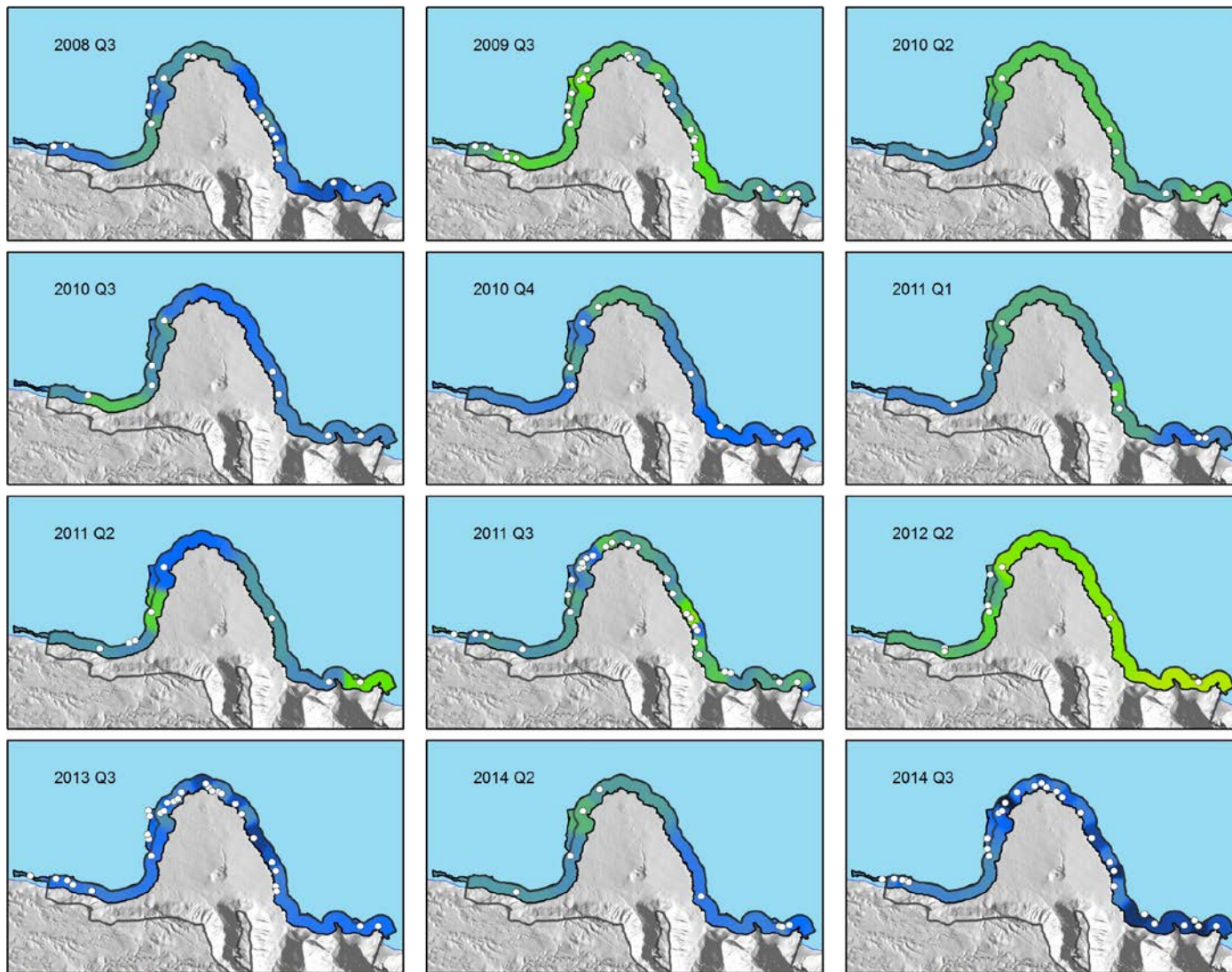


Figure 16. Spatial distribution of bottom dissolved oxygen concentration in marine waters of Kalaupapa National Historical Park. using the total range of results observed in both surface and bottom samples.

Table 7. Dissolved oxygen concentration ($\text{mg} \cdot \text{L}^{-1}$) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2008	3	Bottom	18	6.7	6.9	7.1	0.1
2008	4	Surface	1	6.9	–	6.9	–
		Bottom	1	6.8	–	6.8	–
2009	3	Surface	30	7.0	7.2	7.8	0.2
		Bottom	30	6.9	7.2	7.4	0.1
2010	2	Surface	8	7.0	7.1	7.3	0.1
		Bottom	8	6.9	7.1	7.2	0.1
2010	3	Surface	13	6.6	6.9	7.3	0.2
		Bottom	13	6.6	7.0	7.2	0.1
2010	4	Surface	8	6.9	7.0	7.3	0.1
		Bottom	8	6.8	6.9	7.1	0.1
2011	1	Surface	8	6.9	7.1	7.4	0.2
		Bottom	8	6.8	7.0	7.3	0.1
2011	2	Surface	8	6.8	7.0	8.1	0.4
		Bottom	8	6.8	7.0	7.4	0.2
2011	3	Surface	29	6.9	7.0	7.6	0.2
		Bottom	28	6.8	7.0	7.6	0.2
2012	2	Surface	8	6.6	7.0	8.5	0.6
		Bottom	8	7.0	7.3	7.7	0.3
2013	3	Surface	24	6.7	6.9	7.3	0.1
		Bottom	24	6.6	6.8	7.0	0.1
2014	2	Surface	8	6.8	7.1	7.4	0.2
		Bottom	8	6.8	7.0	7.1	0.1
2014	3	Surface	29	6.2	6.8	7.8	0.3
		Bottom	29	6.4	6.8	7.1	0.2

Dissolved Oxygen Saturation

Dissolved oxygen saturation was also consistent between years with slightly greater concentrations at the surface (Figures 17-19, Table 8).

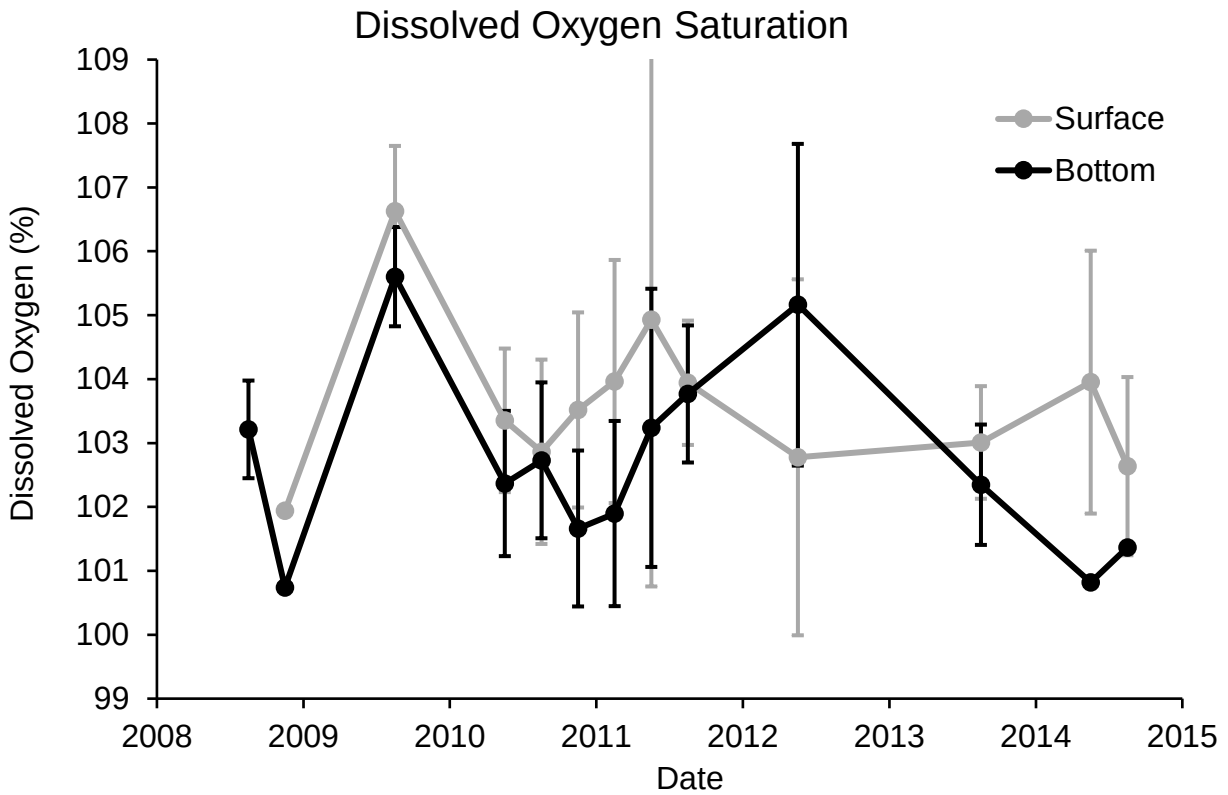


Figure 17. Dissolved oxygen saturation in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

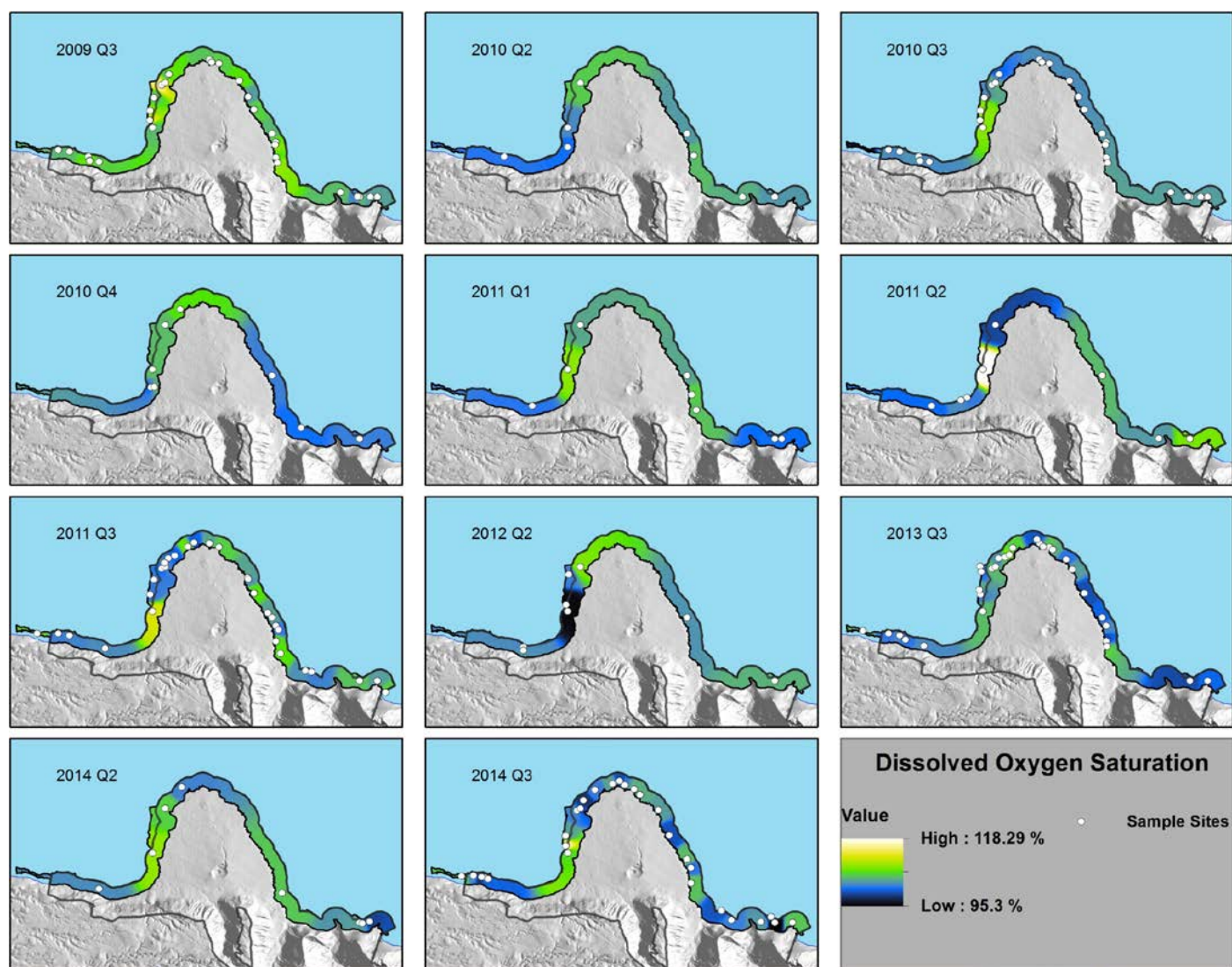


Figure 18. Spatial distribution of surface dissolved oxygen saturation in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

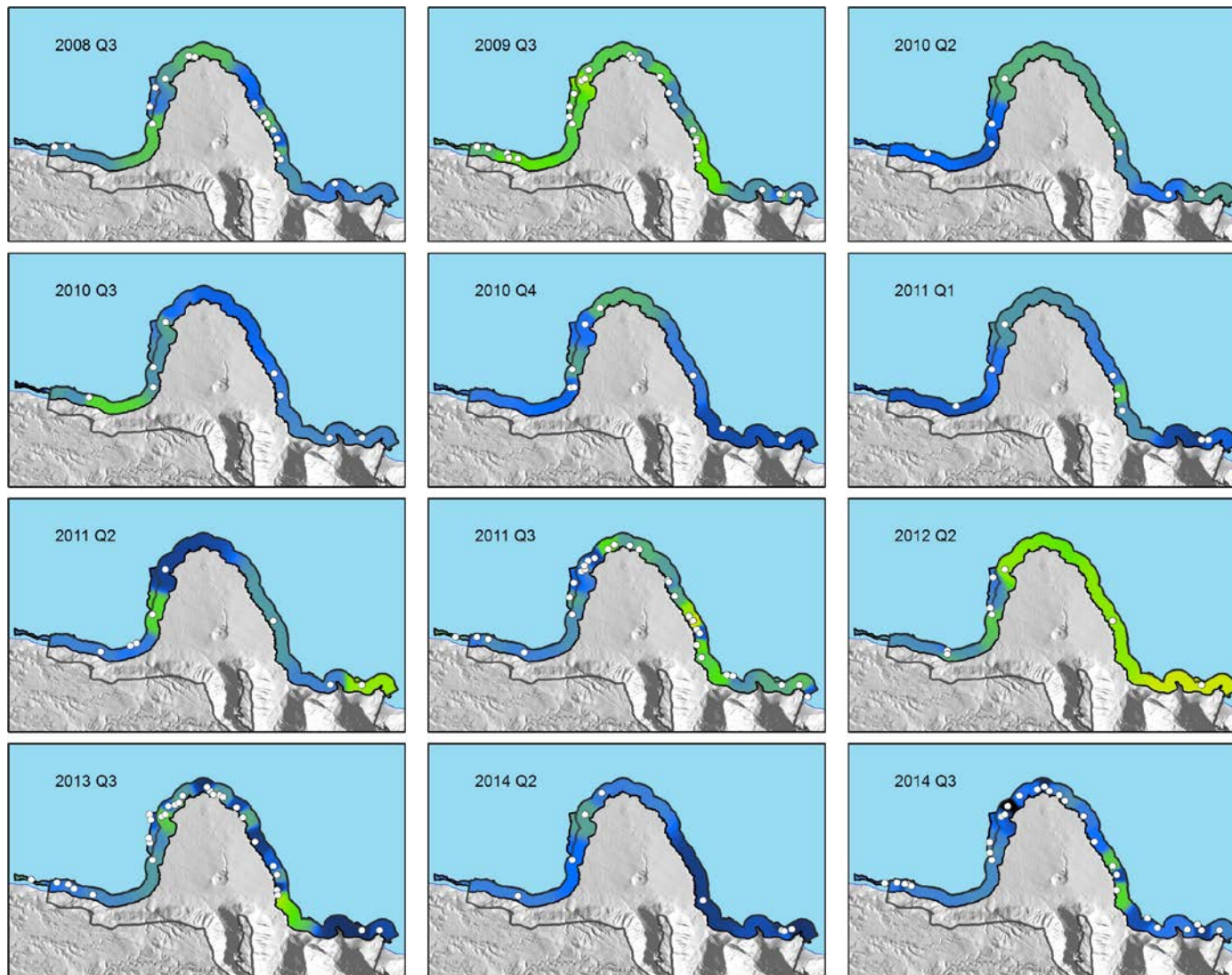


Figure 19. Spatial distribution of bottom dissolved oxygen saturation in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 8. Dissolved Oxygen Saturation (%) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2008	3	Bottom	18	100.2	102.9	105.6	1.7
2008	4	Surface	1	101.9	–	101.9	–
		Bottom	1	100.7	–	100.7	–
2009	3	Surface	30	101.9	105.9	115.5	2.9
		Bottom	30	100.4	105.9	109.3	2.2
2010	2	Surface	8	101.2	103.3	105.7	1.6
		Bottom	8	100.2	102.2	104.4	1.6
2010	3	Surface	13	101.0	102.8	96.8	2.7
		Bottom	13	100.7	103.1	97.3	2.2
2010	4	Surface	8	101.0	103.5	106.9	2.2
		Bottom	8	100.1	101.4	99.7	1.8
2011	1	Surface	8	101.0	104.0	108.9	2.7
		Bottom	8	100.1	101.6	99.2	2.1
2011	2	Surface	8	100.9	103.0	99.4	6.0
		Bottom	8	101.4	102.2	99.2	3.1
2011	3	Surface	29	100.6	103.0	112.1	2.7
		Bottom	28	100.2	103.4	99.4	2.9
2012	2	Surface	7	101.9	103.1	95.8	3.8
		Bottom	8	101.4	105.1	111.4	3.8
2013	3	Surface	29	100.7	102.6	100.0	2.4
		Bottom	30	100.1	102.7	99.6	2.6
2014	2	Surface	8	102.3	103.4	99.2	3.0
		Bottom	8	101.1	101.2	99.2	1.9
2014	3	Surface	29	100.0	102.4	99.9	3.8
		Bottom	29	101.1	101.7	99.7	2.4

pH

Surface and bottom waters displayed essentially identical measurements 2009 through 2011. pH was slightly higher in surface waters 2012 to 2014 relative to bottom samples (Figures 20-22, Table 9).

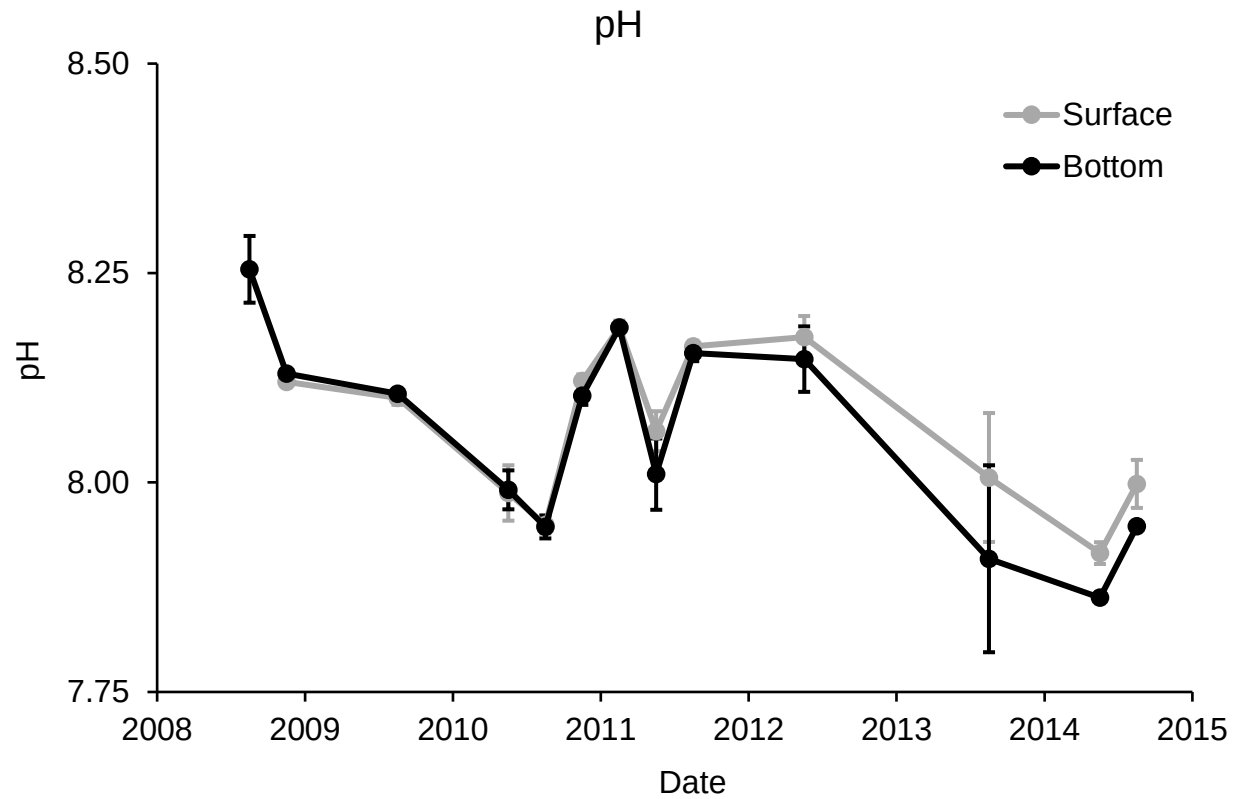


Figure 20. pH in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

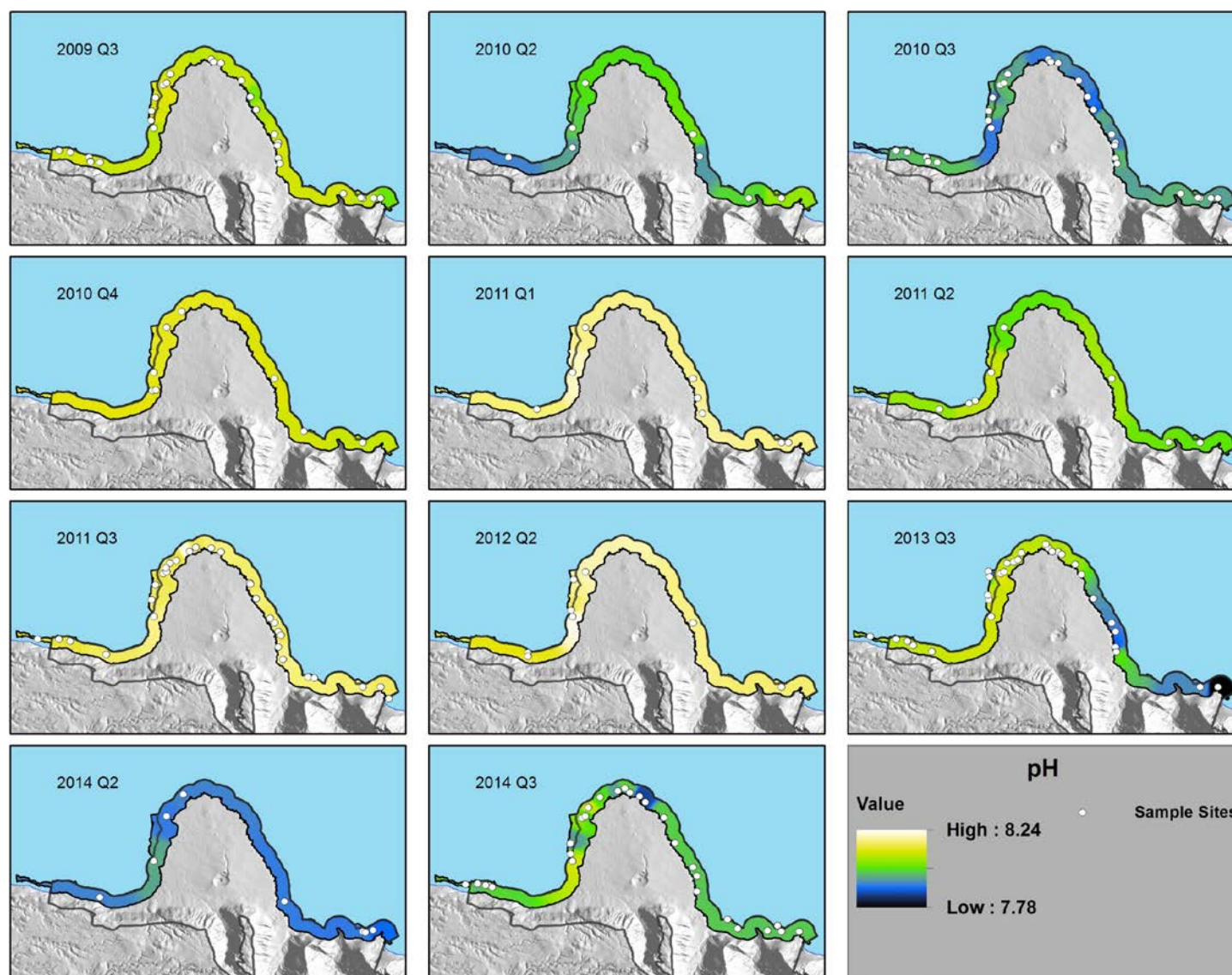


Figure 21. Spatial distribution of surface pH in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

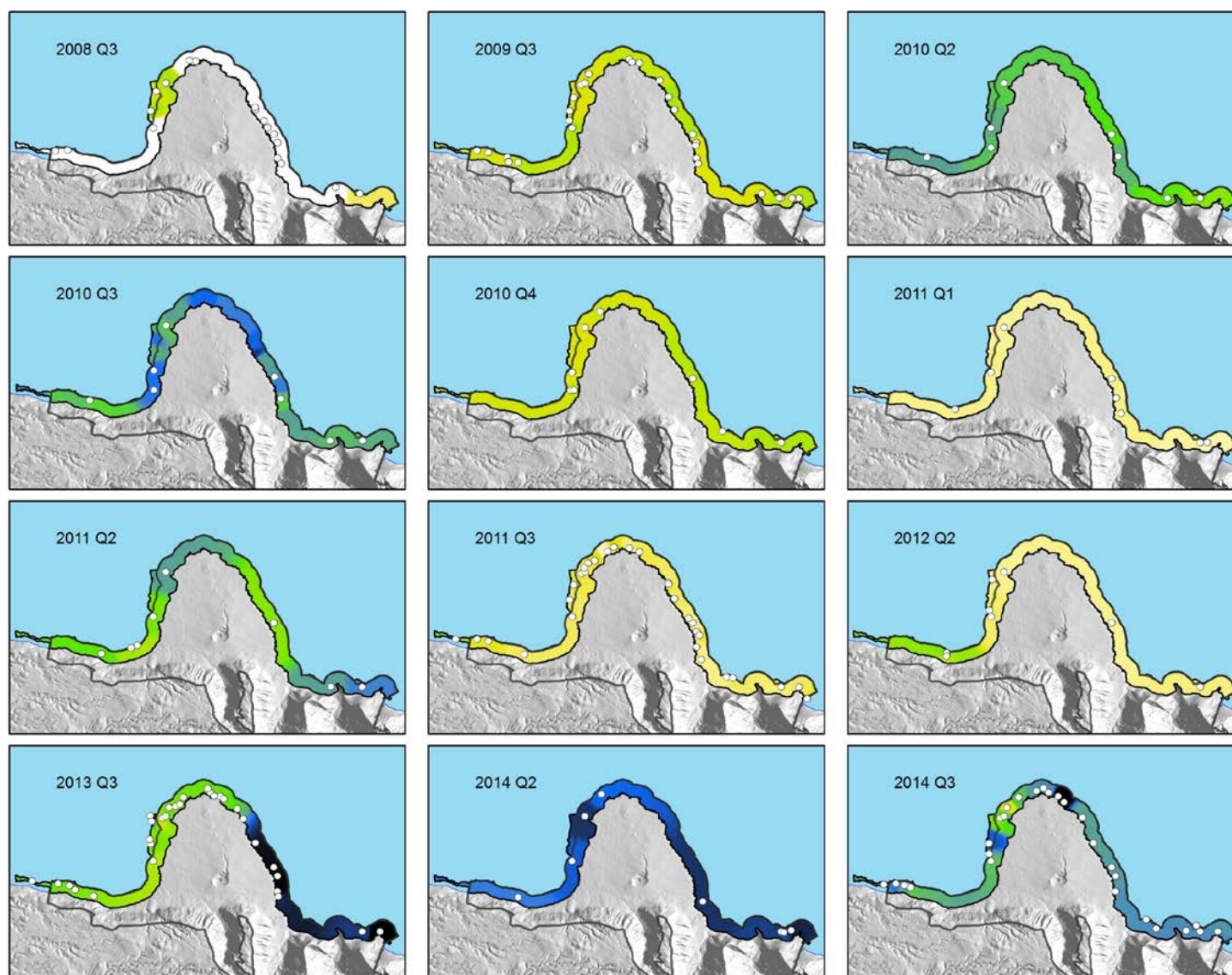


Figure 22. Spatial distribution of bottom pH in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Salinity

Salinity was relatively consistent between years and was essentially identical in surface and bottom samples (Figure 23, Table 10). The east side of the peninsula was generally more saline (Figures 24-25).

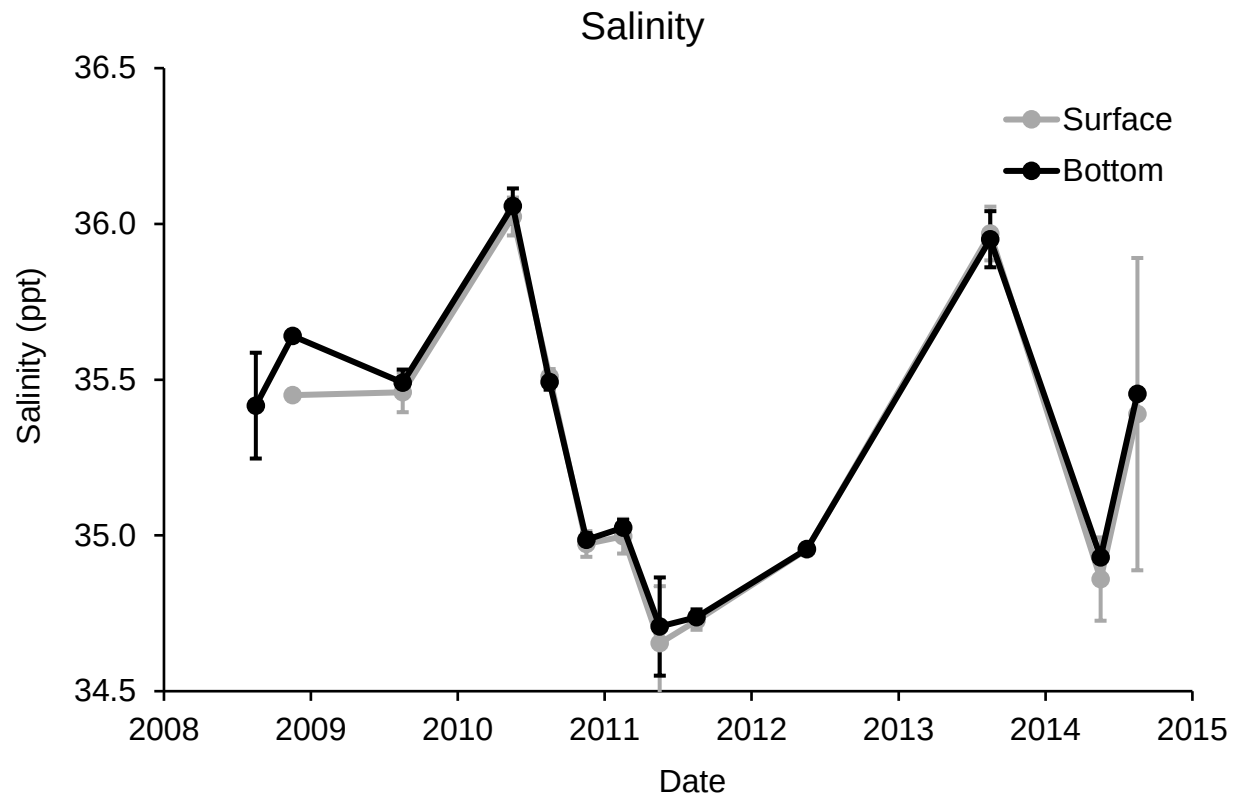


Figure 23. Salinity in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

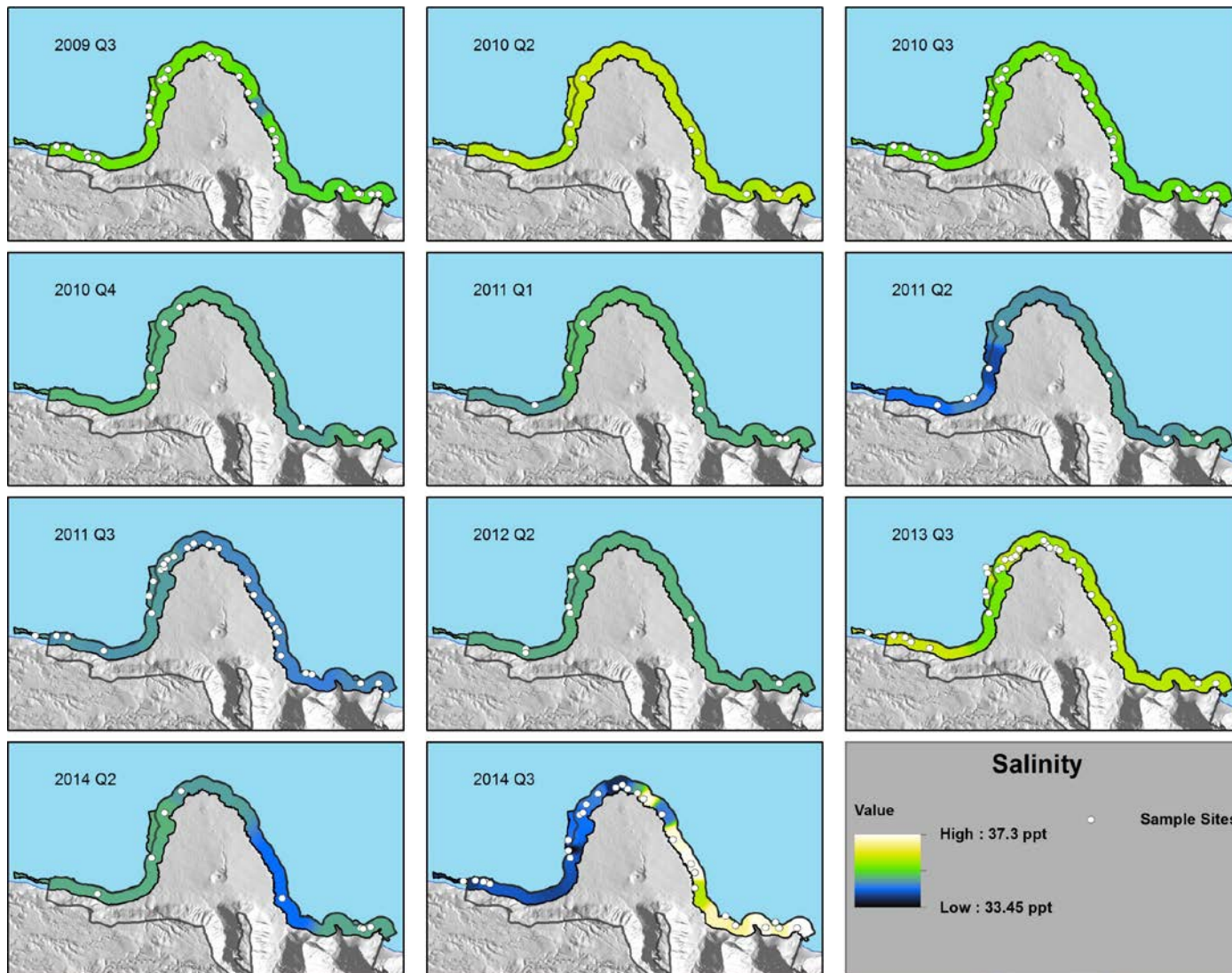


Figure 24. Spatial distribution of surface salinity in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

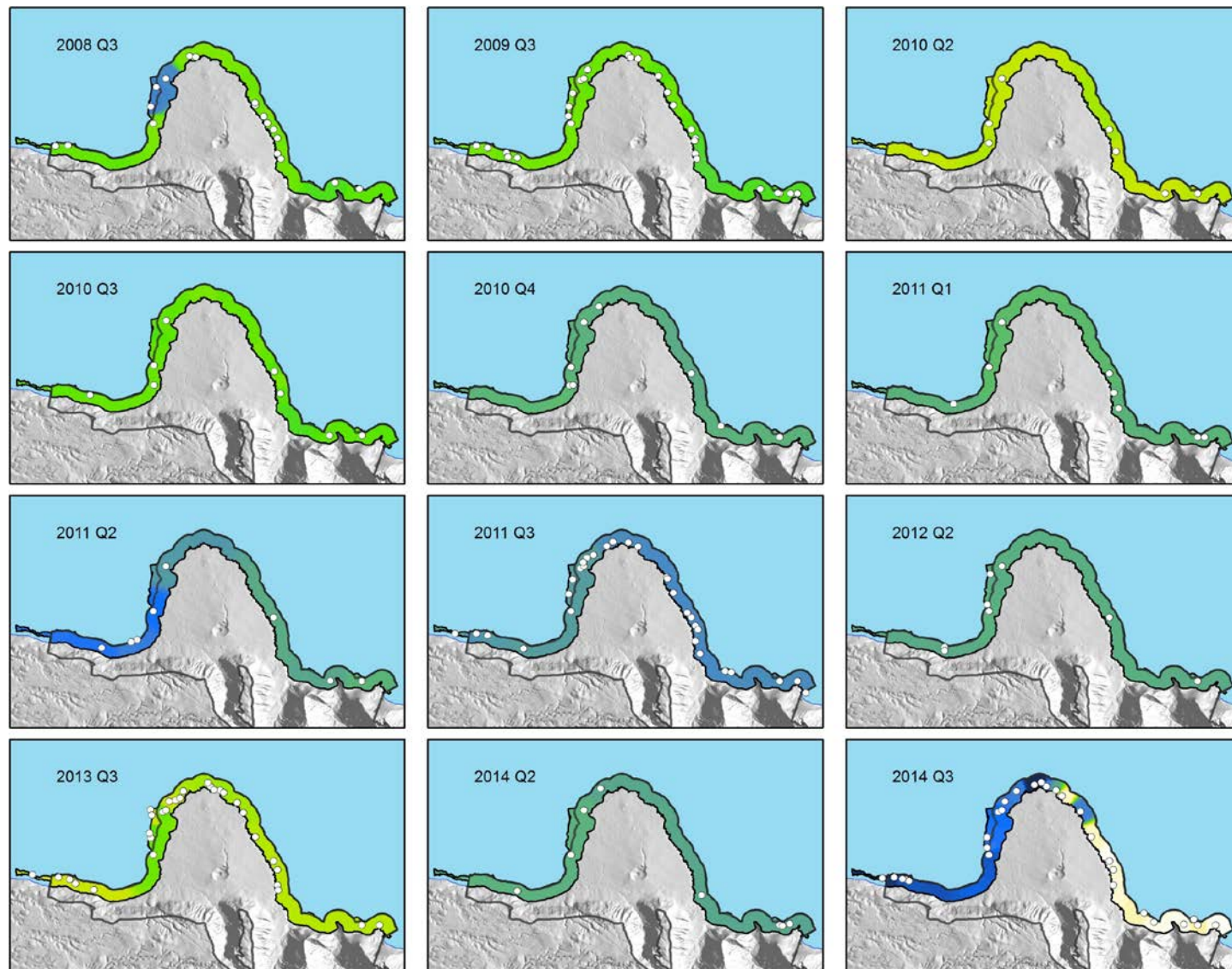


Figure 25. Spatial distribution of bottom salinity in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 10. Salinity (ppt) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2008	3	Bottom	18	34.6	35.6	35.7	0.4
2008	4	Surface	1	35.5	–	35.5	–
		Bottom	1	35.6	–	35.6	–
2009	3	Surface	29	34.8	35.6	35.6	0.2
		Bottom	30	35.3	35.6	35.6	0.1
2010	2	Surface	8	35.9	36.1	36.1	0.1
		Bottom	8	35.9	36.1	36.2	0.1
2010	3	Surface	30	35.3	35.5	35.6	0.1
		Bottom	30	35.3	35.5	35.6	0.1
2010	4	Surface	8	34.9	35.0	35.1	0.1
		Bottom	8	35.0	35.0	35.1	0.0
2011	1	Surface	8	34.8	35.0	35.1	0.1
		Bottom	8	35.0	35.0	35.1	0.0
2011	2	Surface	8	34.2	34.7	35.0	0.3
		Bottom	8	34.4	34.7	35.0	0.2
2011	3	Surface	30	34.6	34.7	34.9	0.1
		Bottom	30	34.7	34.7	34.9	0.1
2012	2	Surface	8	34.9	35.0	35.0	0.0
		Bottom	8	34.9	35.0	35.0	0.0
2013	3	Surface	24	35.6	36.0	36.2	0.2
		Bottom	24	35.5	36.0	36.2	0.2
2014	2	Surface	8	34.4	34.9	35.0	0.2
		Bottom	8	34.9	34.9	35.0	0.0
2014	3	Surface	30	33.5	34.6	37.3	1.4
		Bottom	30	33.9	34.6	37.3	1.4

Specific Conductance

Specific Conductance was relatively consistent between years and was essentially identical in surface and bottom samples (Figure 26, Table 11). Higher conductivity was sporadically observed on the east side of the peninsula (Figures 27-28).

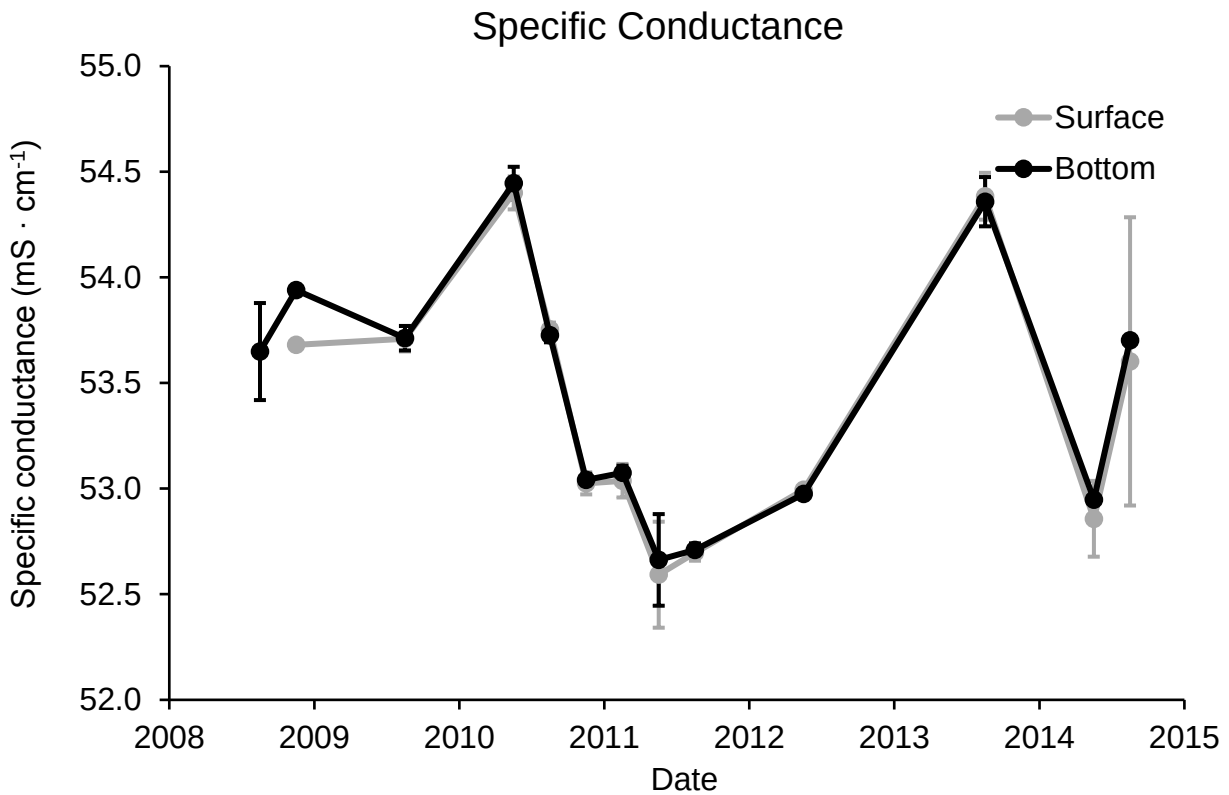


Figure 26. Specific conductance in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

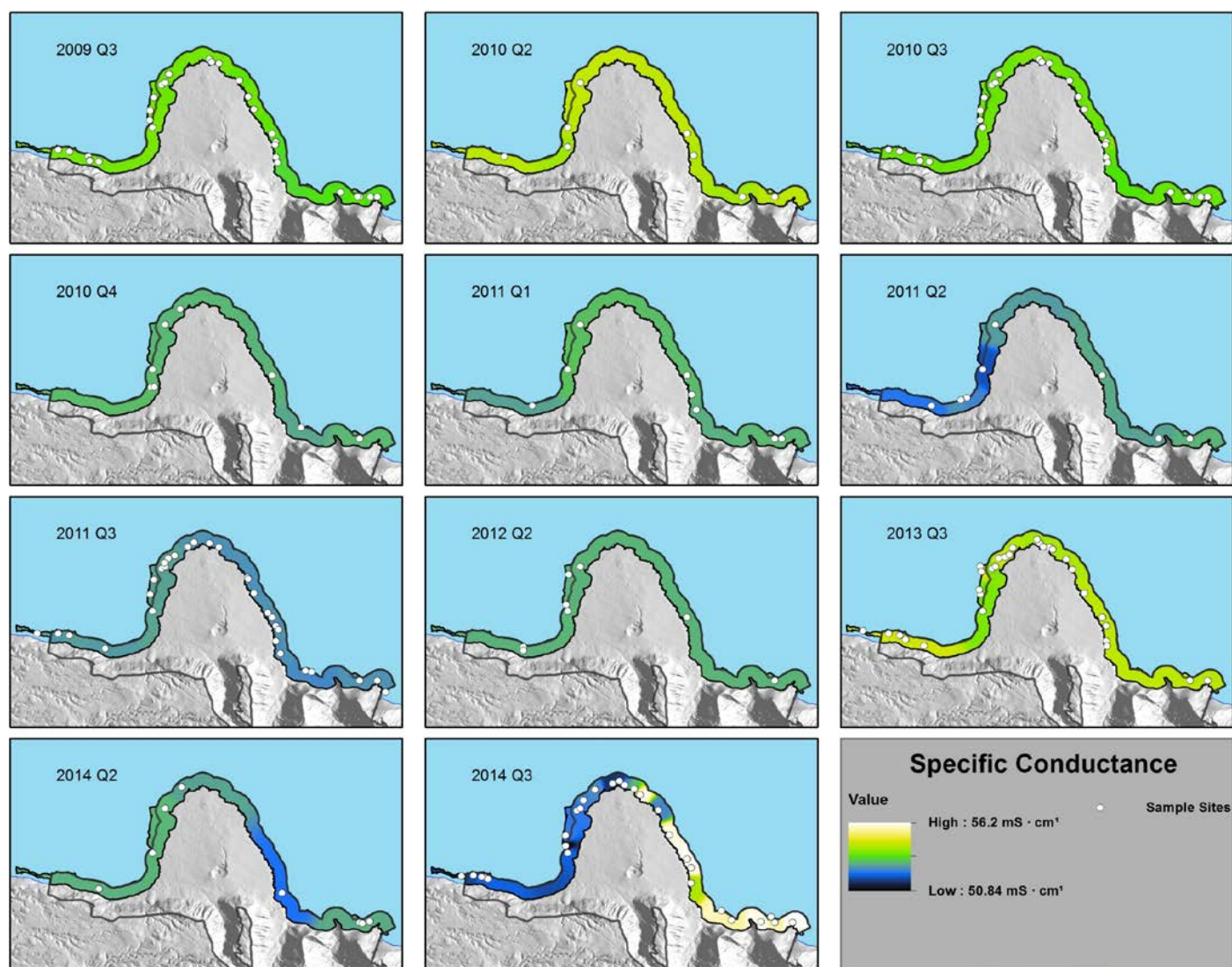


Figure 27. Spatial distribution of surface specific conductance in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

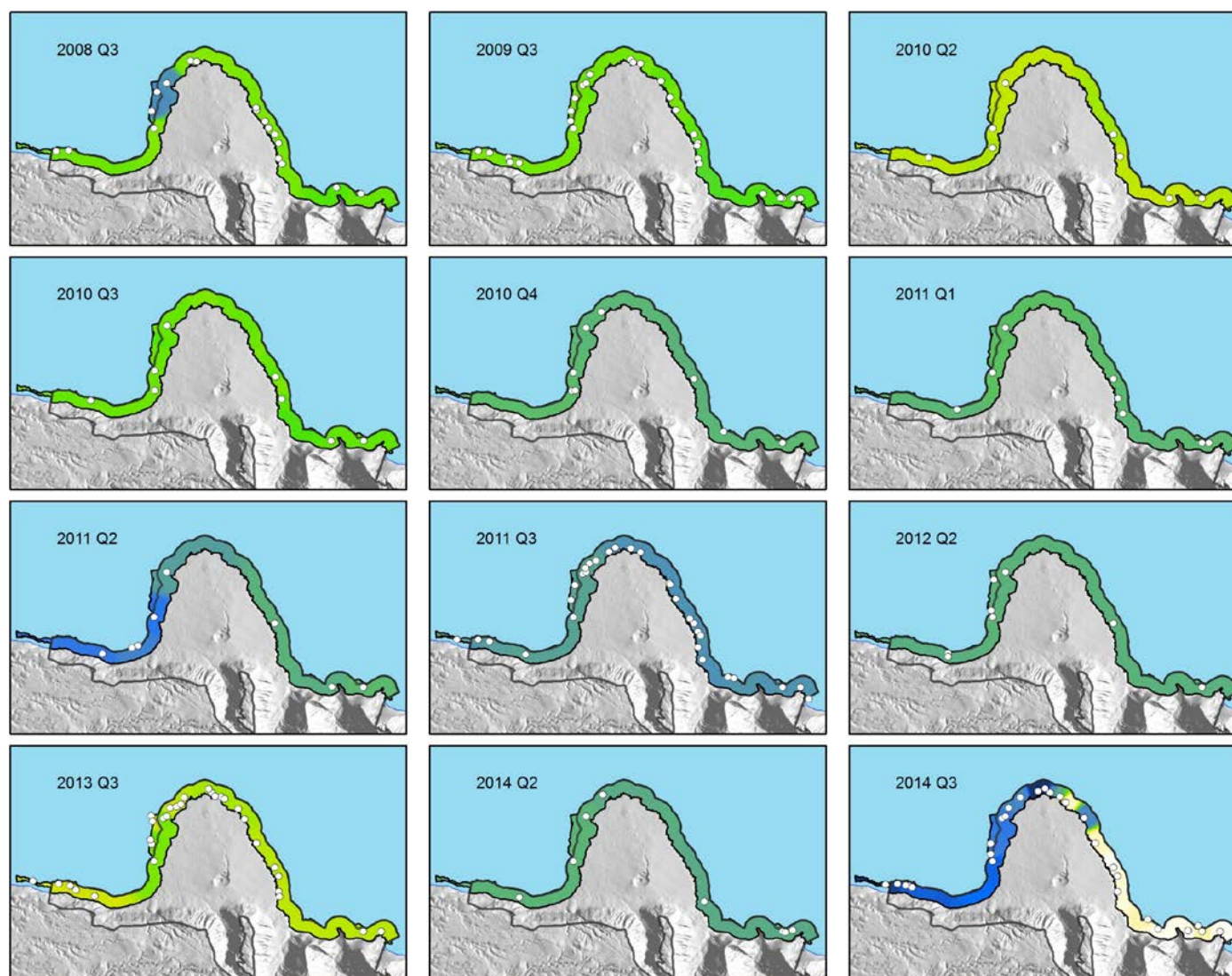


Figure 28. Spatial distribution of bottom specific conductance in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 11. Specific conductance ($\text{mS} \cdot \text{cm}^{-1}$) marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2008	3	Bottom	18	52.6	53.9	54.0	0.5
2008	4	Surface	1	53.7	–	53.7	–
		Bottom	1	53.9	–	53.9	–
2009	3	Surface	28	53.4	53.8	53.9	0.2
		Bottom	30	53.4	53.8	53.9	0.2
2010	2	Surface	8	54.2	54.4	54.5	0.1
		Bottom	8	54.2	54.5	54.6	0.1
2010	3	Surface	30	53.5	53.8	53.9	0.1
		Bottom	30	53.5	53.7	53.9	0.1
2010	4	Surface	8	52.9	53.0	53.1	0.1
		Bottom	8	53.0	53.0	53.1	0.0
2011	1	Surface	8	52.8	53.1	53.2	0.1
		Bottom	8	53.0	53.1	53.2	0.0
2011	2	Surface	8	51.9	52.7	53.0	0.4
		Bottom	8	52.3	52.6	53.1	0.3
2011	3	Surface	30	52.5	52.7	52.9	0.1
		Bottom	30	52.6	52.7	52.9	0.1
2012	2	Surface	8	53.0	53.0	53.0	0.0
		Bottom	8	52.9	53.0	53.0	0.0
2013	3	Surface	24	53.9	54.4	54.7	0.3
		Bottom	24	53.8	54.4	54.7	0.3
2014	2	Surface	8	52.2	52.9	53.0	0.3
		Bottom	8	52.9	53.0	53.0	0.1
2014	3	Surface	30	50.8	52.5	56.2	1.9
		Bottom	30	51.6	52.5	56.2	1.9

Temperature

Temperatures in the surface waters were slightly warmer than bottom samples and varied between years (Figure 29, Table 12). Spatial patterns in temperature were inconsistent between quarters (Figures 30-31).

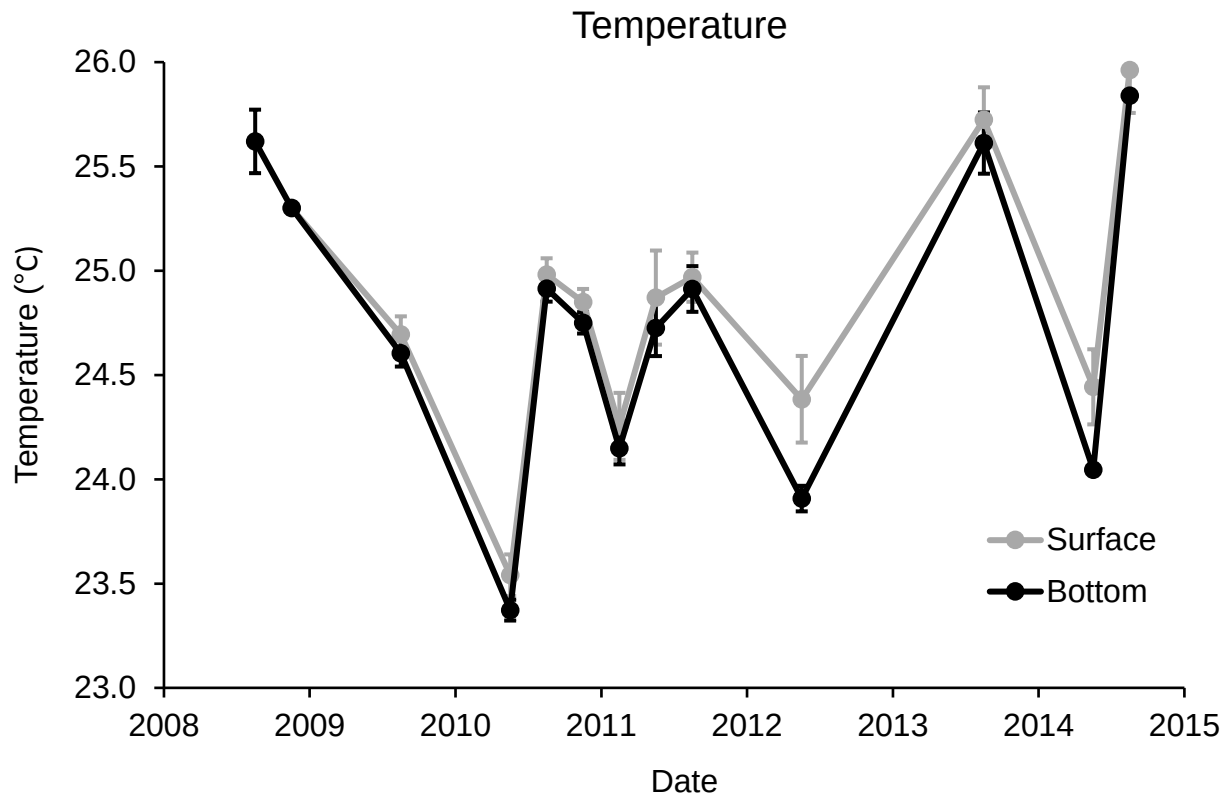


Figure 29. Temperature in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

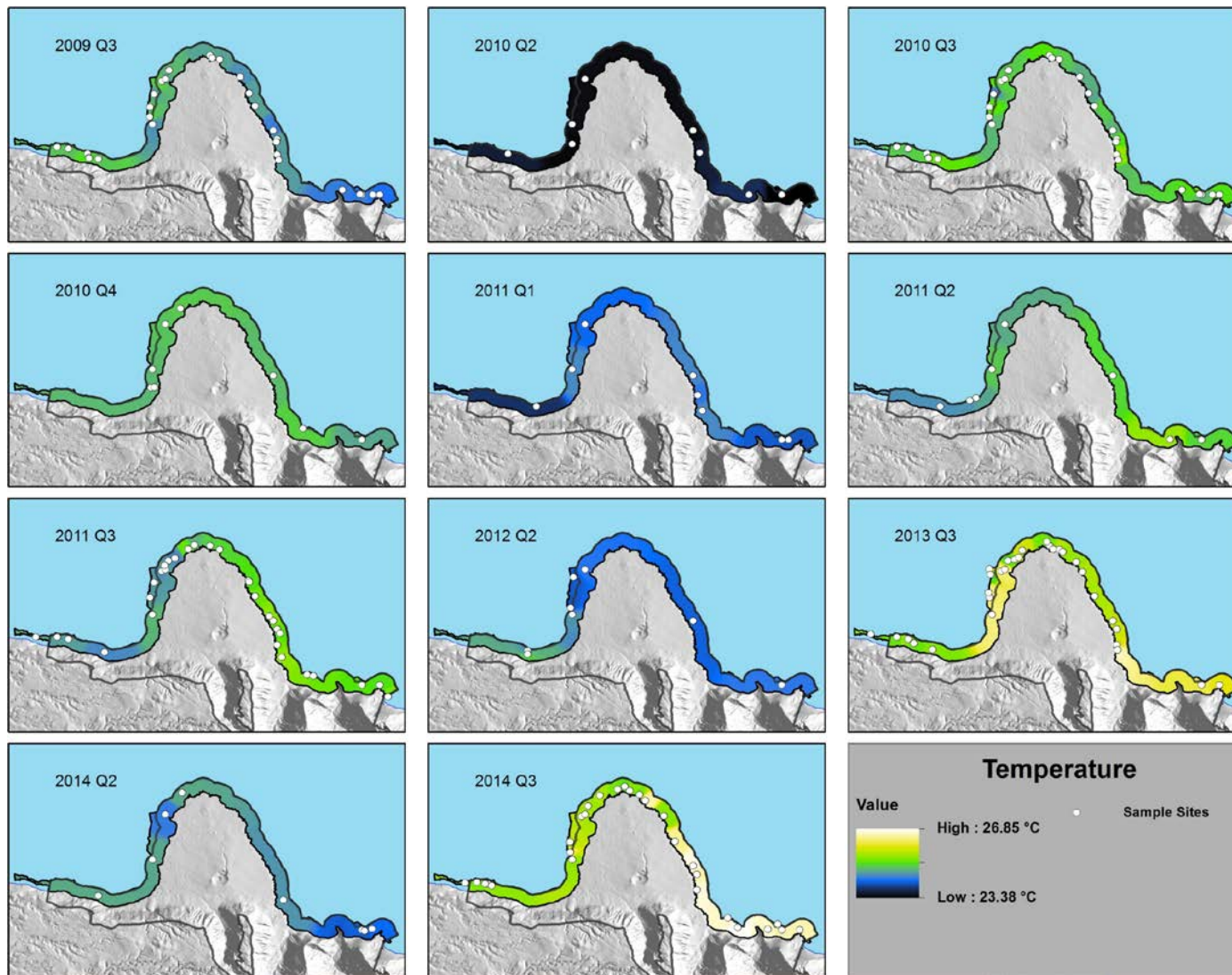


Figure 30. Spatial distribution of surface temperature in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

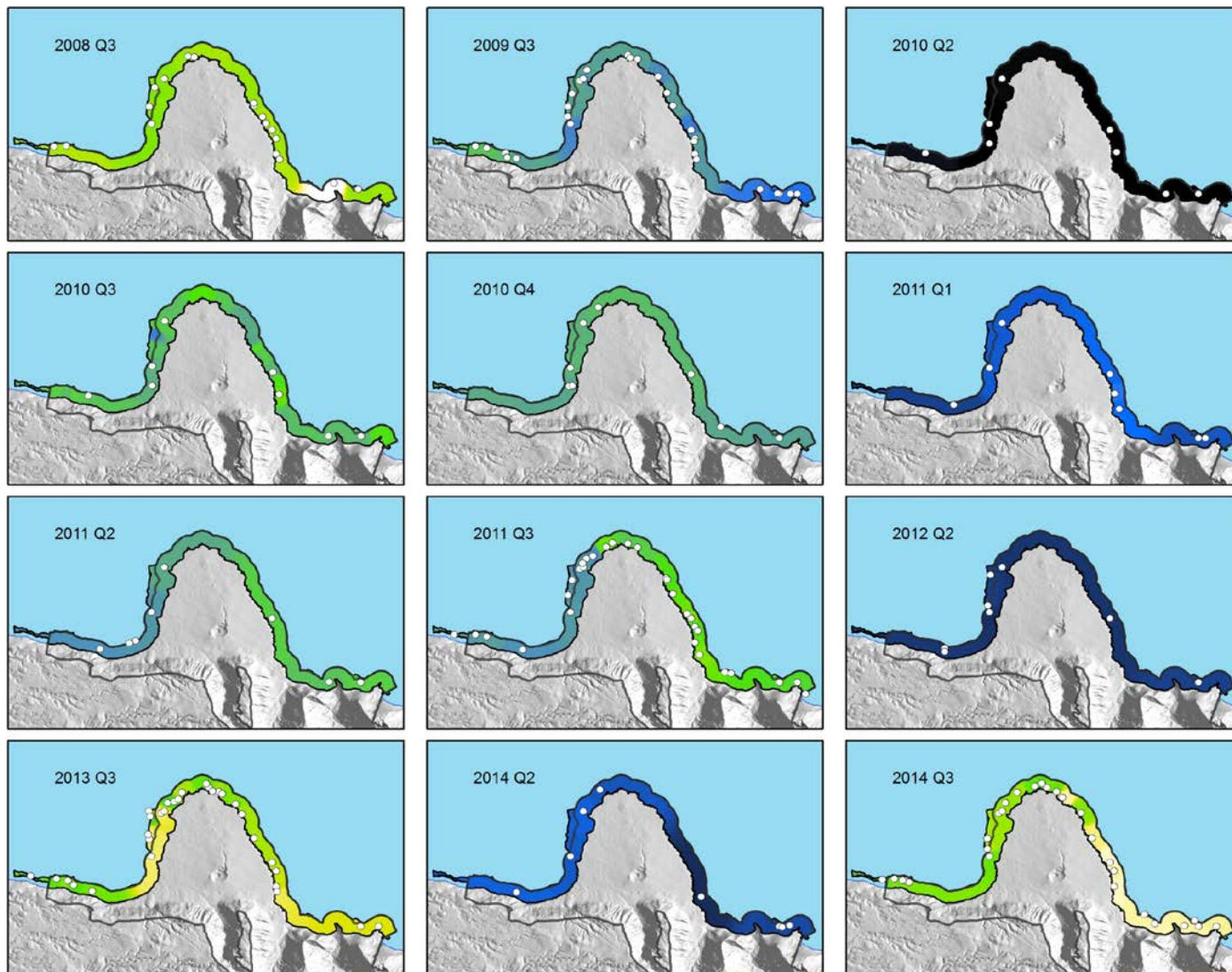


Figure 31. Spatial distribution of bottom temperature in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 12. Temperature (°C) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2008	3	Bottom	18	25.4	25.6	26.9	0.3
2008	4	Surface	1	25.3	–	25.3	–
		Bottom	1	25.3	–	25.3	–
2009	3	Surface	30	24.3	24.7	25.2	0.2
		Bottom	30	24.3	24.7	24.9	0.2
2010	2	Surface	8	23.4	23.5	23.8	0.1
		Bottom	8	23.3	23.4	23.5	0.1
2010	3	Surface	30	24.5	25.0	25.5	0.2
		Bottom	30	24.4	24.9	25.3	0.2
2010	4	Surface	8	24.7	24.8	25.0	0.1
		Bottom	8	24.7	24.7	24.9	0.1
2011	1	Surface	8	23.8	24.3	24.5	0.2
		Bottom	8	24.0	24.1	24.3	0.1
2011	2	Surface	8	24.5	24.8	25.5	0.3
		Bottom	8	24.5	24.7	25.0	0.2
2011	3	Surface	30	24.5	25.1	25.5	0.3
		Bottom	29	24.5	25.0	25.4	0.3
2012	2	Surface	8	24.1	24.3	25.0	0.3
		Bottom	8	23.8	23.9	23.9	0.0
2013	3	Surface	30	25.0	25.7	26.6	0.4
		Bottom	30	24.9	25.6	26.3	0.4
2014	2	Surface	8	24.1	24.5	24.7	0.3
		Bottom	8	23.8	24.1	24.2	0.1
2014	3	Surface	30	25.2	25.6	26.9	0.6
		Bottom	30	25.0	25.6	26.7	0.6

Turbidity

Surface and bottom waters displayed very low turbidity across all years and across the whole peninsula area (Figures 32-34, Table 13).

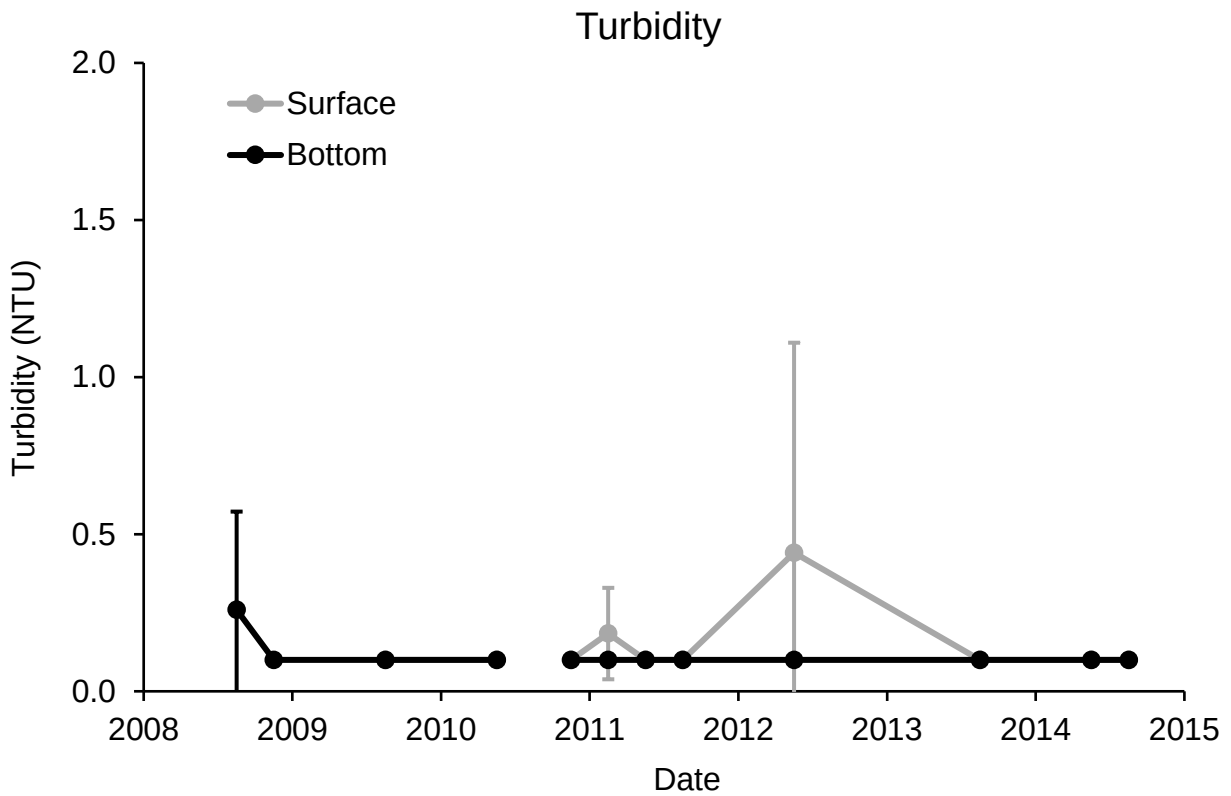


Figure 32. Turbidity in marine waters of Kalaupapa National Historical Park. Data are means and 95% confidence intervals.

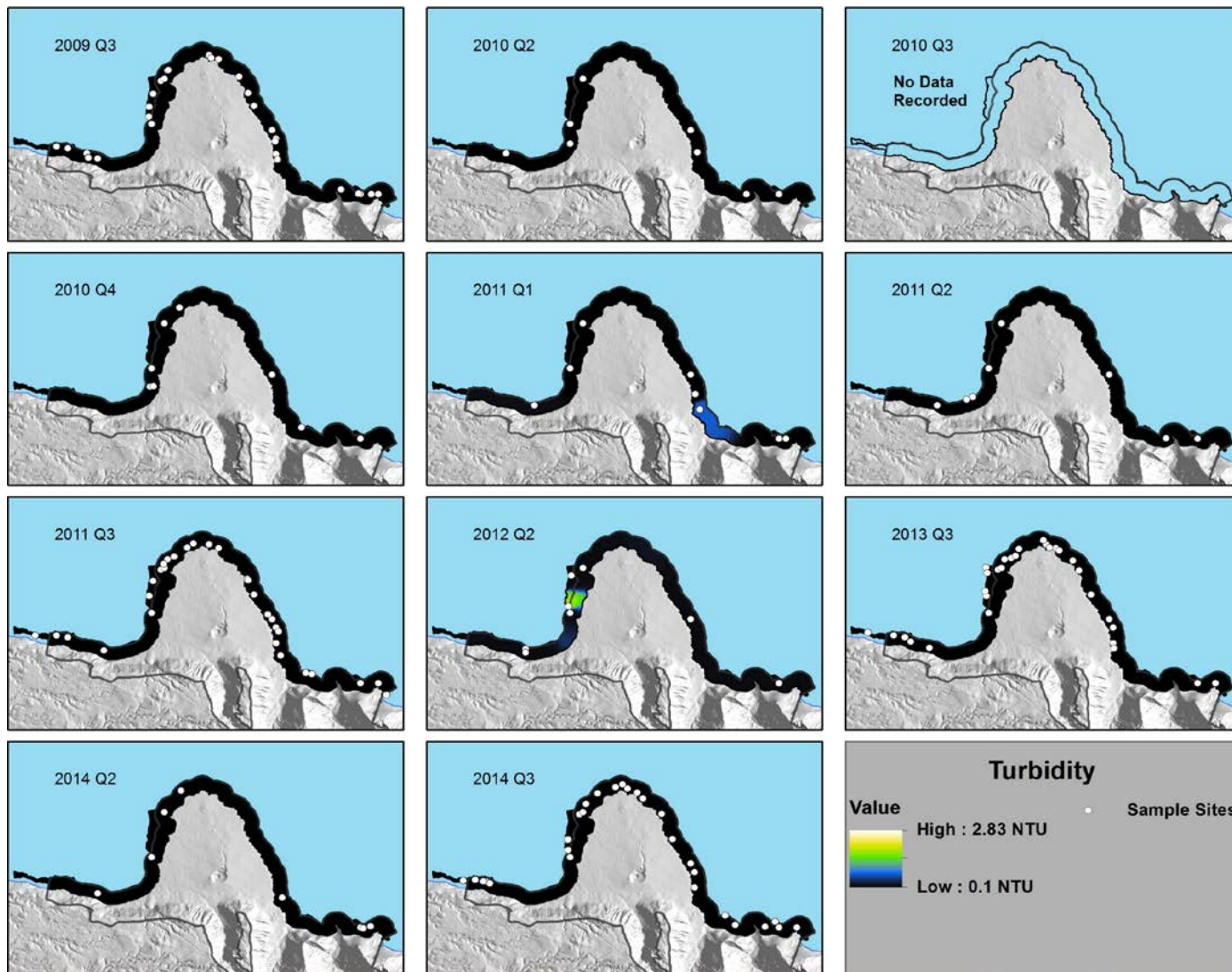


Figure 33. Spatial distribution of surface turbidity in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

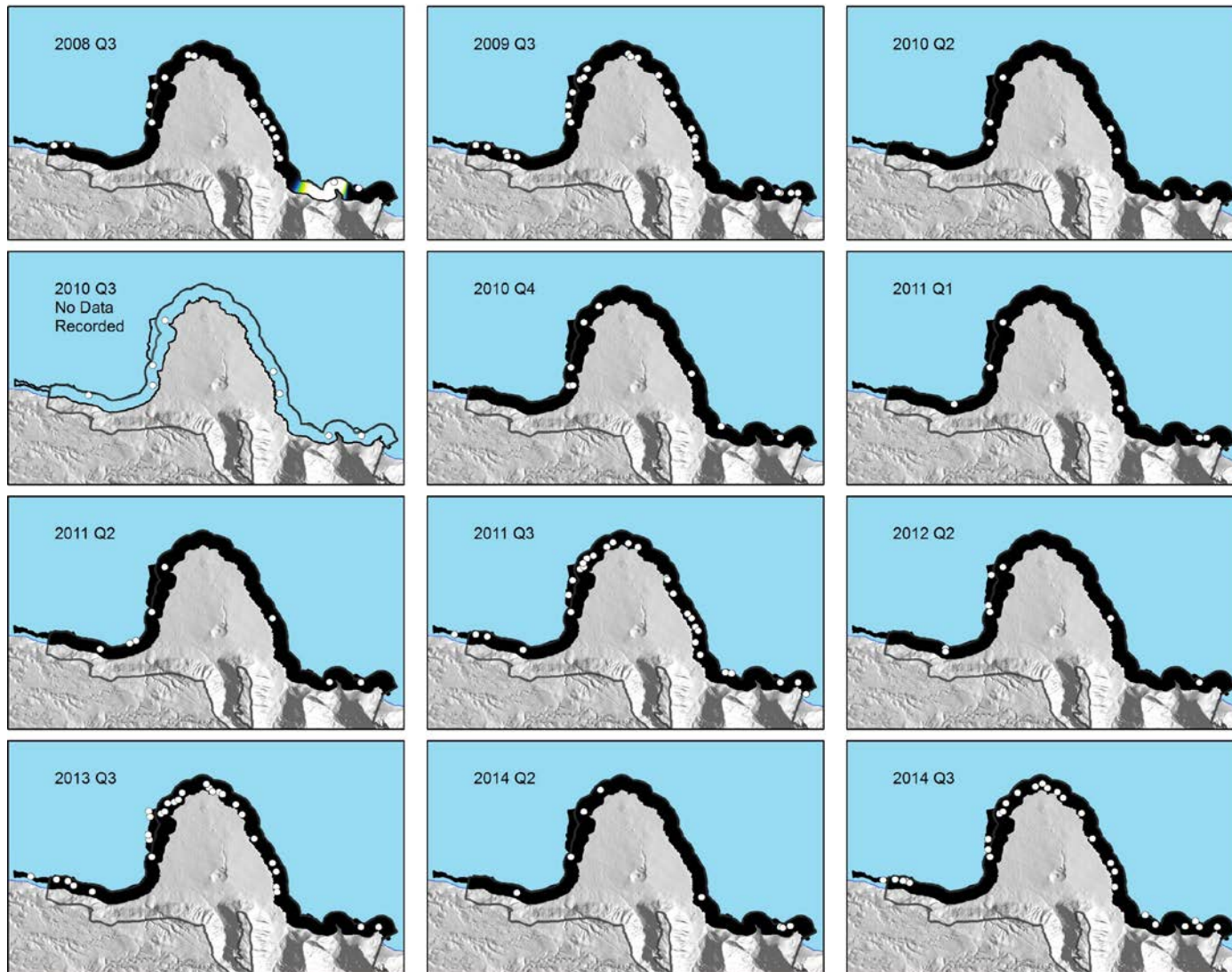


Figure 34. Spatial distribution of bottom turbidity in marine waters of Kalaupapa National Historical Park using the total range of results observed in both surface and bottom samples.

Table 13. Turbidity (NTU) in marine waters of Kalaupapa National Historical Park.

Year	Quarter	Depth	n	Minimum	Median	Maximum	SD
2008	3	Bottom	18	0.1	0.1	3.0	0.7
2008	4	Bottom	1	0.1	–	0.1	–
2009	3	Surface	28	0.1	0.1	0.1	0.0
		Bottom	30	0.1	0.1	0.1	0.0
2010	2	Surface	8	0.1	0.1	0.1	0.0
		Bottom	8	0.1	0.1	0.1	0.0
2010	4	Surface	8	0.1	0.1	0.1	0.0
		Bottom	8	0.1	0.1	0.1	0.0
2011	1	Surface	8	0.1	0.1	0.7	0.2
		Bottom	8	0.1	0.1	0.1	0.0
2011	2	Surface	8	0.1	0.1	0.1	0.0
		Bottom	8	0.1	0.1	0.1	0.0
2011	3	Surface	30	0.1	0.1	0.1	0.0
		Bottom	30	0.1	0.1	0.1	0.0
2012	2	Surface	8	0.1	0.1	2.8	1.0
		Bottom	8	0.1	0.1	0.1	0.0
2013	3	Surface	23	0.1	0.1	0.1	0.0
		Bottom	23	0.1	0.1	0.1	0.0
2014	2	Surface	8	0.1	0.1	0.1	0.0
		Bottom	8	0.1	0.1	0.1	0.0
2014	3	Surface	18	0.1	0.1	0.1	0.0
		Bottom	18	0.1	0.1	0.1	0.0

Comparison to State Water Quality Criteria

Geometric means have been applied to the data by season (Table 14). The only parameter to exceed state criteria was chlorophyll in 2008 and 2012, shown in bold.

Table 14. Geometric means of water quality parameters by season in marine waters of Kalaupapa National Historical Park.

Year	Season	TDP ($\mu\text{gP} \cdot \text{L}^{-1}$)	TDN ($\mu\text{gN} \cdot \text{L}^{-1}$)	$\text{NO}_2 + \text{NO}_3$ ($\mu\text{gN} \cdot \text{L}^{-1}$)	Chlorophyll ($\mu\text{g} \cdot \text{L}^{-1}$)	Turbidity (NTU)
2008	Dry	–	–	–	0.38	0.06
	Wet	6.23	76.50	0.50	0.47	0.05
2009	Dry	7.50	94.60	0.78	0.09	0.05
2010	Dry	7.50	86.40	1.90	–	–
	Wet	7.50	81.90	0.52	0.16	0.05
2011	Dry	7.63	88.90	2.61	0.13	0.05
	Wet	7.50	89.30	0.81	0.16	0.06
2012	Dry	7.50	91.40	0.56	0.17	0.06
2013	Dry	9.82	79.50	1.37	0.00	0.05
2014	Dry	8.03	41.60	2.91	0.06	0.05

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NPS 491/140247, September 2017

National Park Service
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