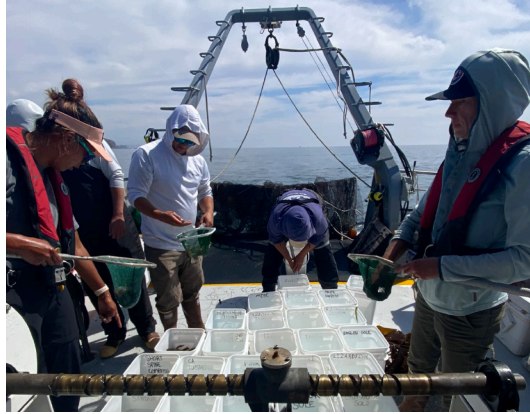




# Benthic Infauna

BIG BIGHT '23



Southern California Bight  
2023 Regional Monitoring Program  
Volume III

SCCWRP Technical Report 1486

# **Southern California Bight 2023 Regional Monitoring Program: Volume III. Benthic Infauna**

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## FOREWORD

The Southern California Bight (SCB) is a 100,000-square-mile body of water and submerged continental shelf and slope that extends from Point Conception, California, in the north to Cabo Colonet, Baja California, Mexico in the south. This area is a unique and important ecological and economic resource in southern California that includes diverse habitats for a broad range of marine life including more than 3,000 species of invertebrates, 500 species of fish, and many marine mammals and birds.

The coastal region along the SCB is one of the most densely populated coastlines in the U.S. and the world. The activities of this dense human population stress the coastal marine environment by introducing pollutants from point and non-point sources, modifying natural habitats and increasing extraction of natural resources.

Millions of dollars are spent annually to monitor coastal environmental quality in the SCB. These localized monitoring programs provide important site-specific information about the impacts of individual waste discharges, but do not assess the condition of the SCB as a whole. The assessment of environmental quality on a more regional scale provides a context for localized monitoring that helps environmental regulators and resource managers understand the relative influence of local and regional factors on the coastal ecosystem.

The 2023 SCB Regional Monitoring Program (Bight '23) is the continuation of an ongoing effort that provides an integrated assessment of the SCB through cooperative region-scale monitoring. The 2023 survey represents the joint effort of more than 100 organizations. The Bight 23 survey is organized into six technical elements: 1. Sediment Quality Assessment; 2. Bioaccumulation of Contaminants in Shellfish; 3. Ocean Acidification; 4. Estuary Wetland Assessment; 5. Trash & Microplastics Assessment; and 6. Submerged Aquatic Vegetation Assessment. This report presents the results of the benthic macrofauna component of Bight 23, which is a part of the Sediment Quality Assessment element. Other Sediment Quality Assessment components include sediment toxicity, sediment chemistry, as well as demersal fish and megabenthic invertebrates. Copies of this and other Bight '23 guidance manuals, data, and reports are available for download at <https://www.sccwrp.org/about/research-areas/regional-monitoring/southern-california-bight-regional-monitoring-program/bight-program-documents/>.

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This report is the product of the dedication and hard work of many individuals who share a common goal of improving our understanding of the environmental quality of the Southern California Bight. The authors thank all of those who contributed to this report. While space limitations do not allow us to acknowledge all contributors by name, we are grateful to the following people and agencies whose efforts were crucial to our success. The members of the 2023 Southern California Bight Regional Monitoring Program Steering Committee provided the impetus, vision, and resources that guided and fueled our efforts. The Bight 23 Sediment Quality Planning Committee coordinated our efforts with other disciplines; their critical and timely reviews improved this document.

The field teams collected our samples with efficiency and care. The captains, crew and scientists on the Early Bird III, R/V Dangler, Hey Jude, La Mer, Marine Surveyor, Oceanus, Monitor III, R/V Ocean Sentinel, Davis, Shearwater, Green Machine, M/V Nerissa, and R/V Benthic Cat were responsible for field collection and sample processing. They contributed to our success in no small measure. The Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) provides a mechanism for standardizing the names of organisms in southern California and promotes communication among taxonomists and was an integral part of this effort.

We appreciate the efforts and expertise of the taxonomists who produced the primary data on which this report was built. Danielle Ayala, Chip Barrett, Kelvin Barwick, Katherine Beauchamp, Craig Campbell, Andy Davenport, Wayne Dossett, David Drumm, Wendy Enright, Nicholas Galliani, Brent Haggin, Shay Hengen, Matt Hill, Maiko Kasuya, Coulson Lantz, Cody Larsen, Norbert Lee, JoAnne Linnenbrink, Greg Lyon, Ricardo Martinez-Lara, Chase McDonald, Erin Oderlin, Dean Pasko, Tony Phillips, Mac Power, Michael Reuscher, Veronica Rodriguez-Villanueva, Zoe Scott, Stephanie Smith, Jennifer Smolenski, Lauren Valentino, Amber Von Tungeln, and Adam Webb identified and counted every one of the individuals used in this study. Special thanks are due to Wendy Enright, Terra Petry, and Brent Haggin for coordinating the quality assurance/quality control efforts. Additionally, Regina Wetzler from the Natural History Museum of Los Angeles County needs to be mentioned for coordinating the acquisition and archiving of the voucher collections and QA/QC samples, ensuring their preservation and availability to future generations of scientists.

We are grateful to Abel Santana for supporting the sampling design and making the maps, Paul Smith and Robert Butler for assisting with the internet data submission system, and Emily Lau for layout and editing. The efforts of these individuals made many complicated tasks seem easy.

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## EXECUTIVE SUMMARY

One of the central tenets of benthic ecology is that changes in macrobenthic (i.e., those animals that live in and on the bottom of the ocean) community structure can be used to infer the overall health and condition of the location where the organisms are collected. Macrobenthic community structure is a good indicator of ecosystem condition and health because these animals are directly associated with the sediment where most toxics accumulate, they have limited mobility to escape stressors, and they display a wide range of physiological responses and tolerances to different types of stressors. In addition to their use as ecosystem condition indicators, macrobenthic community composition also provides direct measures of Estuarine Habitat, Marine Habitat, and Shellfish Harvesting beneficial uses, as well as indirect or partial measures of a variety of other beneficial uses.

This report presents the results and interpretation of the macrobenthic infaunal component of the 2023 Southern California Bight Regional Monitoring Program's Sediment Quality Assessment element. The primary objectives of this study were to measure the extent and magnitude of macrobenthic community composition across the Southern California Bight and to characterize the trends in that condition over the last 25 years (1998-2023).

Samples of benthic macrofauna were successfully collected at 340 sites across the Southern California Bight, ranging from Point Conception in the north to the US-Mexico border in the south using a random tessellation stratified design. Samples were allocated across 10 different strata: 4 in enclosed embayments, 4 on the continental shelf, and 2 on the continental slope. Approximately a third of those sites (115) were revisits of sites that had previously been sampled in 2018, 2013, 2008, and either 2003 or 1998. An additional 8 samples were targeted (i.e., non-random) from the parts of estuaries that historically had lower (<27 PSU) salinities as a Freshwater Estuary stratum. Samples were collected with a 0.1-m<sup>2</sup> Van Veen grab, sieved on a 1-mm screen, and then preserved for identification. Specimens from each sample were sorted from the detritus and identified to the lowest possible taxonomic level, typically species.

The entire dataset passed Quality Assurance/Quality Control Data Quality Objectives set for sorting accuracy (95%), taxonomic identification accuracy (90%), and taxonomic discrimination (90%), and counting accuracy (90%). Sorting accuracy was 98.5% across all samples, with a minimum number of corrective actions needed. The taxonomy labs averaged 97.2 % accuracy of identification, 95.6% precision in taxonomic discrimination, and 94.6% accuracy in counting.

The condition of the soft sediments of the continental shelf portions of the Southern California Bight (6-200 m deep) and embayments were assessed based upon the benthic macrofauna collected there. These areas represent approximately 36% of the total area of the Southern California Bight. The Benthic Response Index (BRI) was used to assess samples from the

continental shelf, the California Sediment Quality Objectives Benthic Line of Evidence (SQO BLOE) framework was used for samples from embayments with salinity greater than 27 PSU (practical salinity units), and the US version of the Multivariate AZTI Marine Biotic Index (M-AMBI) was used for low salinity waters (salinity less than 27 PSU). Each of these indices had four condition categories, but for simpler interpretation this gradient in condition can also be viewed as two categories: good condition (reference + low disturbance conditions) and poor condition (moderate disturbance + high disturbance conditions).

Benthic macrofaunal composition indicated that the majority of the Southern California Bight was doing well in 2023. More than 99% of the assessable portions of the region were in good condition (88.1% reference condition + 11.1% low disturbance condition) and less than 1% were in poor condition. However, macrobenthic community conditions were not uniform across the different parts of the region. The embayment strata were in relatively poorer condition compared to the rest of the region with over 35.5% of the embayment area in moderate (31.1%) or high disturbance (4.4%) condition categories. In contrast, the continental shelf strata were in relatively better condition with no portions of the strata in the moderate or high disturbance condition categories.

As previously noted, from the perspective of macrobenthic community composition the vast majority of the region was in good condition in 2023, and the trend in habitat condition from 1998-2023 was relatively stable at the regional scale. The trend in the distribution of percent area across the four condition categories in each of the offshore strata was stable and healthy (>90% of a given stratum in reference condition in all surveys). Conversely, the pattern in percent area was less stable among the embayment strata, with a trend towards increasing amounts of poorer conditions in modern years in most of the strata.

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## I. INTRODUCTION

Benthic macrofauna are useful indicators of the condition of marine and estuarine habitat because the community composition changes in a relatively predictable fashion when disturbed (e.g., Pearson and Rosenberg 1978; Rhodes et al. 1978; Gray et al. 2002). This predictability is because most benthic macrofaunal communities include a taxonomically diverse mixture of organisms spanning multiple phyla, with which comes a wide range of physiological responses to stress. Benthic macrofauna also serve as good integrators of their local environmental conditions, as they live directly in the sediment where many toxins accumulate, they have limited mobility, and many species live for multiple years.

Because of these traits, benthic macrofauna are one of the most commonly used elements of bioassessment programs in the coastal ocean and estuaries across the US (e.g., Dauer et al. 2012; USEPA 2012; Llansó et al. 2015; Schiff et al. 2016) and the world (e.g., Van Hoey et al. 2010). Despite their utility as indicators, changes in macrobenthic community structure in response to stress can be complex and difficult to communicate to non-specialists. One of the most common approaches to synthesize this complex information is the creation of biotic indices that distill complex community information into a relatively simple scale of condition that can easily be understood by resource managers and environmental policy makers (e.g., Karr 1991; Diaz et al. 2004; O'Brien et al. 2016).

The use of benthic macrofauna in the regional monitoring programs of Southern California's coastal oceans has become more robust since the early regional surveys prior to 1990 (Setty et al. 2010). The 2023 Southern California Bight Regional Monitoring Program (Bight 23) marks the seventh monitoring survey of the Southern California Bight, beginning with a pilot study in 1994 (Bergen et al. 1998, 2000) and expanding in spatial and technical scope in each subsequent survey from 1998 (Ranasinghe et al. 2003), to 2003 (Ranasinghe et al. 2007), to 2008 (Ranasinghe et al. 2012, Schiff et al. 2016), to 2013 (Gillett et al. 2017), and to 2018 (Gillett et al. 2022). The modern Southern California Bight regional surveys have been designed not only to characterize biological assemblages and to quantify regional reference condition, but also to assess the spatial extent and magnitude of impact to benthic habitats. This design provides an opportunity to evaluate cumulative effects from multiple point source and non-point source discharges, as well as basin-scale forcing factors like ocean acidification and El Niño/Southern Oscillation (ENSO) cycling. In addition, regional monitoring surveys have improved benthic macrofaunal condition assessments by creating taxonomic standardization across the region (Southern California Association of Marine Invertebrate Taxonomists 2023), developing assessment tools (Smith et al. 2001; Ranasinghe et al. 2009), and evaluating new habitats (Ranasinghe et al. 2007; Ranasinghe et al. 2012; Gillett et al. 2021).

The objectives of the Southern California Bight 2023 Regional Macrobenthic Community Monitoring are to:

1. Present a characterization of the macrobenthic communities found in the different soft-sediment habitats of the Southern California Bight.
2. Provide spatial estimates of habitat condition for the continental shelf and embayments of the Southern California Bight in 2023 based upon macrobenthic community composition.
3. Present the temporal trend in condition across the continental shelf and embayments of the Southern California Bight from 1998 to 2023.

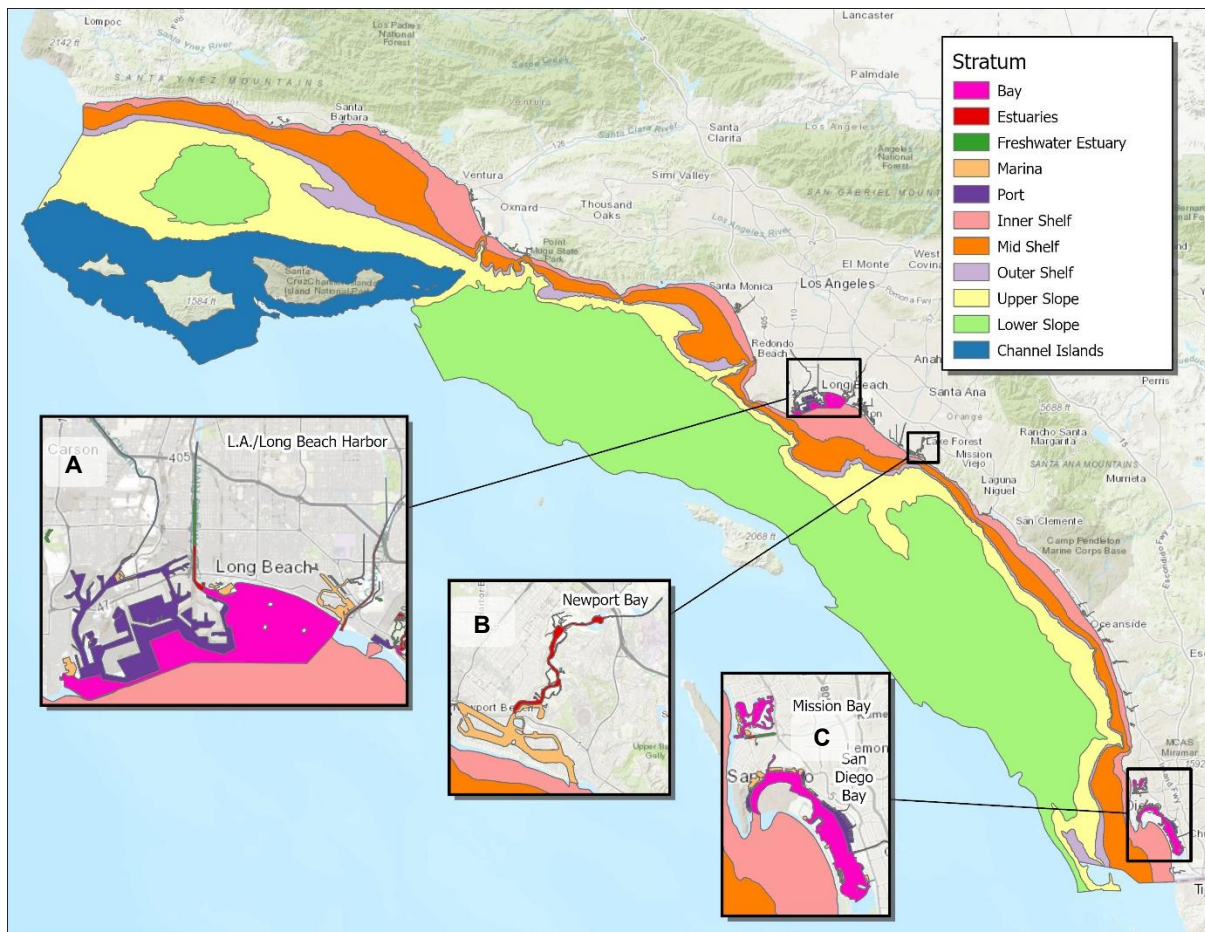
The report is organized into 8 chapters and 6 appendices. Chapter 2 describes the study design and the field, laboratory, and data analysis methods. Chapter 3 presents the quality assurance procedures that ensured comparability of data produced by participating organizations and the results of quality control audits measuring their success. Chapter 4 presents the results of the macrobenthic community characterization and habitat condition assessment analyses. The results are discussed in Chapter 5. Chapters 6 and 7 present the conclusions and recommendations, respectively. Chapter 8 lists the literature cited.

Appendix A contains the taxonomic nomenclature updates for taxa used in the Benthic Response Index. Appendix B contains the taxonomic nomenclature updates for taxa used in the Sediment Quality Objectives Benthic Line of Evidence indices Appendix C contains the summaries of the taxa collected in each stratum (total abundance, relative abundance, frequency of occurrence). Appendix D contains the detailed similarity percentage (SIMPER) outputs for each stratum and assemblage. Appendix E presents the details of % area calculations for the condition of each stratum in 2023, the condition of each stratum from each Bight Survey, and the areal extent of improving/stable/declining trends in condition at revisit sites. Appendix F contains graphs of the temporal trend in condition at each of the revisit sites and details on the characterization of the trend in BRI scores at all of the revisit sites.

## II. METHODS

### Study Design

The survey area for the Bight 23 spanned from Point Conception, CA in the north to the US-Mexico border in the south and from the mainland coastal embayments west to the Channel Islands (Figure 1). The soft sediment portions of this region less than 1,000 m deep were divided into ten strata based upon known biogeographic breaks in community composition (e.g., estuaries or deep continental shelf) or area of different regulatory/management interest (e.g., ports or continental slope) (Table 1). For the 2023 survey, an additional stratum – Freshwater Estuaries – was established for estuarine waters historically less than 27 PSU salinity and consisted only of targeted, non-probabilistic sites.



**Figure 1. A map of the Southern California Bight delineating the 11 sample strata used in the survey. Insets show the details of: A) The harbors of Long Beach/Los Angeles and San Pedro Bay, B) Newport Bay, and C) San Diego and Mission bays.**

**Table 1. Sample strata for the 2023 survey including the number of probabilistic benthic stations assigned within each stratum, the number of revisit stations, and the range of depth at which those stations were located. § indicates strata for which no condition assessment tool was available for some or all of these stations.**

Habitat	Stratum	Number of Samples	Number of Revisits	Depth Range(m)
Embayments	Freshwater Estuaries	8	3	0.3-1.5
	Estuaries	33	13	0.8-8.8
	Marinas	46	16	2.6-10
	Ports	55	17	4-27
	Bays	47	21	0.35-26
Offshore	Inner Shelf	30	15	8-29
	Mid Shelf	27	15	29.6-119
	Channel Islands	14	14	25-123.3
	Outer Shelf	30	16	120-209
Deepwater	Upper Slope§	29	15	210-516
	Lower Slope§	29	15	465-874

Across these eleven strata, 340 sites were allocated via a stratified, random tessellated design (e.g., Stevens and Olsen 2003, 2004; Olsen and Peck 2008). The random allocation process allows for an even distribution of sites among strata and the assignment of area weights for each site. The area weights can then be used for calculating unbiased areal assessments of condition in the survey area (Bergen 1996; Stevens 1997).

Among the 340 probabilistic sites assigned in the survey, 157 of those were revisit sites that had previously been sampled as part of the Southern California Bight Regional Monitoring Program in either 1998 or 2003, 2008, and 2013 (Table 1). Revisit sites provide an opportunity to assess the temporal trend in habitat condition independent of the spatial variation inherent in using data from multiple random surveys for temporal trends analysis (Urquhart and Kincaid 1999; Larsen et al. 2001).

### Sample Processing

Sediment samples for benthic macrofauna analysis were collected between July 1 and September 28, 2023. Benthic samples from each site were collected and processed following the Southern California Bight 2023 Regional Marine Monitoring Survey Field Operations Manual (Bight 23 Field Sampling and Logistics Committee 2023) and Macrobenthic (Infaunal) Sample Analysis Laboratory Manual (Bight 23 Benthic Committee 2023). In short, sediments from all strata were collected with a 0.1-m<sup>2</sup> Van Veen grab and sieved on a 1-mm screen. Material retained on the screen was placed in a chemical relaxant solution and then fixed with 10%

buffered formalin. Samples were rinsed and transferred from formalin to 70% ethanol 2-5 days after collection. Samples were subsequently distributed among twelve laboratories for sorting, identification, and enumeration of the fauna. Quality Assurance/Quality Control (QA/QC) protocols and data quality objectives (DQO) for sample sorting, identification, and enumeration are detailed in the Macro-benthic Sample Analysis Laboratory Manual (Bight 23 Benthic Committee 2023) and in the QA/QC chapter below.

## Data Analysis

Macro-benthic community composition among the different strata was evaluated using non-metric Multi-Dimensional Scaling (nMDS) ordination of Bray-Curtis similarity values calculated from presence-absence transformed abundance of all samples. After the ordination, natural environmental factors (% sand, silt, and clay, total organic carbon and total nitrogen content, water depth, latitude, and longitude) and species abundance were correlated to the ordination plot pattern to provide insight into any distribution patterns of samples observed in the ordination (e.g., Gibson et al. 2013). Characteristic species contributing to within-group similarity and distinguishing taxa accounting for the mean Bray-Curtis dissimilarity between sample groupings illustrated in the nMDS were characterized using similarity percentage (SIMPER) analysis (Clarke et al. 2008; Warton et al. 2012). Community analyses were done with the metaMDS (similarity and ordination) and envFit (species and environmental factor correlations) programs within the R Vegan package (v2.7.2 Oksanen et al. 2025 [R version 4.5.2]) or PRIMER v7 (SIMPER analysis) (Clarke et al. 2014).

Habitat condition based upon macro-benthic community composition was assessed using the Southern California Benthic Response Index (BRI) (Smith et al. 2001), the California Sediment Quality Objectives Benthic Line of Evidence tool (SQO BLOE) (Ranasinghe et al. 2009; Bay et al. 2021), or the US version of the Multivariate AZTI Marine Biotic Index (M-AMBI) (Pelletier et al. 2018; Gillett et al. 2019) depending upon the applicable habitat. The BRI is an abundance-weighted tolerance value index that, within the Southern California Bight Monitoring Program, is applied to samples collected from the continental shelf of the Southern California Bight in 6 – 200 m of water (e.g., Ranasinghe et al. 2003, 2007, 2012). The index scores a sample from 0-100 (good to bad condition), which can then be separated into four condition categories (Table 2). Following Smith et al. (2001), the four condition categories can be defined as: **Reference** – the condition at which natural benthic assemblages occur; **Low Disturbance** – marginal deviation, wherein there are changes in the relative abundance of taxa, but not yet species replacement; **Moderate Disturbance** – loss of biodiversity wherein 25% of the taxa in the reference condition would not be expected to occur; **High Disturbance** – loss in community function and defaunation wherein expected major taxonomic groups are absent.

**Table 2. Definition of condition categories used in the assessment framework for offshore and embayment habitats used from the 2023 survey. § - Modified M-AMBI Categories from Gillett et al. (2019)**

Summary Benthic Condition Level	Benthic Condition Level for Bight Program	BRI Condition Category	SQO BLOE Condition Category	M-AMBI Condition Category <sup>§</sup>
Good	Reference	Reference	Reference	Reference
	Low Disturbance	Marginal Disturbance	Low Disturbance	Low Disturbance
Poor	Moderate Disturbance	Biodiversity Loss	Moderate Disturbance	Moderate Disturbance
	High Disturbance	Community Function Loss or Defaunation	High Disturbance	High Disturbance

The SQO BLOE is a combination of four indices: two multi-metric indices (Index of Biotic Integrity [IBI] and Relative Benthic Index [RBI]), a BRI (abundance-weighted tolerance index), and an Observed:Expected (O:E) index. The SQO BLOE is applicable to the soft, unvegetated sediments of Southern California Embayments with overlying waters of 27 PSU or greater (Ranasinghe et al. 2009; Bay et al. 2014). The four SQO BLOE are scored and integrated into four condition categories functionally equivalent to those of the Smith et al. (2001) BRI (Ranasinghe et al. 2012) (Table 2). Following Ranasinghe et al. (2009), the four condition categories can be defined as: **Reference** – a community that would occur at a reference site; **Low Disturbance** – a community that exhibits some indication of stress but might be within the measurement variability of reference condition; **Moderate Disturbance** – a community that exhibits clear evidence of physical, chemical, natural, or anthropogenic stress; **High Disturbance** – a community exhibiting a high magnitude of stress.

The M-AMBI of Pelletier et al. (2018) is an index that uses a combination of species diversity, species richness, abundance-weighted pollution tolerance score (AMBI of Gillett et al. 2015) and the relative abundance of oligochaetes. The M-AMBI is applicable in all soft sediment estuarine habitats of California from tidal freshwater to euhaline salinities. Following Gillett et al.'s (2019) modifications of M-AMBI thresholds for better integration into California's Sediment Quality Objectives framework, the four condition categories correspond to those of the SQO BLOE indices noted above.

The goal of this report, and the Bight Monitoring Program in general, was to assess condition at a regional scale. To that end, the condition results have been framed as proportions of the region's area instead of proportions of individual sites. The areal extent of habitat condition expressed as the proportional amount of each condition category within a stratum was

calculated using the area weights assigned to each site. As the area weights were calculated within a stratified probabilistic sampling design, percent area estimates can be calculated without bias from the different sizes of the sample strata. Furthermore, samples can be aggregated within or across different strata. Estimates were calculated using a localized mean estimate in lieu of a stratified mean because an unknown fraction of each stratum cannot be sampled (e.g., hard bottom). Confidence intervals (95%) for the estimates were calculated using a local neighborhood estimator that takes into account the spatial proximity of samples to each other when calculating the population variance (e.g., Diaz-Ramos et al. 1996). All calculations were made with the `cat.estimate` function of the R `spSurvey` package (v5.6.1 Dumelle et al 2023 [R version 4.5.2]).

**Table 3. Number of probabilistic stations sampled within each stratum during each Southern California Bight Survey from 1994-2023. § indicates strata for which no condition assessment tool was available for some or all of these stations.**

Habitat	Stratum	1994	1998	2003	2008	2013	2018	2023
Estuaries	Estuaries	0	0	51	64	44	45	33
	Marinas	0	40	32	44	44	44	46
Embayments	Ports	0	43	9	46	45	56	55
	Bays	1	40	18	38	37	43	47
Continental Shelf	Inner Shelf	69	71	45	31	31	36	30
	Mid Shelf	135	96	83	32	30	36	27
	Outer Shelf	40	0	24	28	29	31	30
	Channel Islands	0	36	32	30	15	15	14
Continental Slope	Upper Slope§	6	0	33	34	41	31	29
	Lower Slope§	0	0	32	35	21	27	29

Temporal trends in habitat condition of the assessable portions of the Southern California Bight were calculated with two complementary techniques: a multi-survey approach and a revisit-site approach. The multi-survey approach is a higher-level approach to temporal analysis that focused on the proportional change in each of the condition categories across the whole of the survey area through time. This analysis entailed a visual inspection of the areal extent estimates of each condition category (+/- the local neighborhood-based confidence intervals) within each stratum from 1998 – 2023. Trends were characterized by survey-to-survey increases or decreases in the area of a given condition class. However, because a large number of these sites were randomly selected within the stratum for each survey the observed differences represented a mix of both spatial and temporal variability.

The revisit sites approach complemented the multi-survey approach by providing a more granular measure of condition change focusing solely on temporal variance. This approach

measured the trend in BRI scores<sup>1</sup> at 114 of the 145 revisit sites, which were sampled either four or five times: in 2023, 2018, 2013, 2008, and either 2003 or 1998. At each revisit site the trend across the (typically) five BRI scores (Appendix F) was evaluated using a Mann-Kendall trend test using the MannKendall function in the Kendall package (v2.2.2 McLeod (2025)) in R (version 4.5.2). Sites with a Kendall's Tau significantly ( $\alpha=0.1$ ) greater than 0 were characterized as having a **declining** trend; those with a Tau <0 were characterized as having an **improving** trend; all other sites were characterized as **stable**.

As each site had an area weight, the percent area with improving, declining, or stable trends was estimated using the cat.estimate function in the R spSurvey package as noted above (v5.6.1 Dumelle et al. 2023 [R version 4.5.2]). This approach had a relatively lower data density per stratum (Table 1), but because the station locations were held constant, most of the change in BRI score can be attributed to temporal variance versus the co-mingled spatial-temporal variance inherent in the multi-survey approach (Urquhart and Kincaid 1999; Olsen et al. 1999).

## **Taxonomic Updates**

All of the benthic indices (BRI, SQO benthic indices, and M-AMBI) used for assessment of condition rely upon the taxonomic identity and number of organisms collected. As such, each index has an associated list of taxa that it recognizes and uses in its formulations. The most recent, consensus-based versions of the BRI and SQO benthic indices contained species lists based upon the 5<sup>th</sup> edition of the Southern California Association of Marine Invertebrate (SCAMIT) list of macro- and megabenthic invertebrates (SCAMIT 2008) – a 15 year-old taxonomic standard. As noted above, the data generated in this survey were based upon the 14<sup>th</sup> edition SCAMIT list from 2023. The names of many different species have changed between editions of the SCAMIT species lists, so there was a potential disconnect between the names used by the index calculators and the names assigned during identification.

To resolve this disconnect, a Benthic Index Taxonomy Subcommittee was created to update the names used in calculating both the BRI and SQO benthic indices, so that they would work more smoothly with modern (i.e., SCAMIT ed 14) benthic infauna data. This subcommittee was comprised of taxonomic experts who regularly work with the benthic infauna of the region. Importantly, this exercise did not seek to change the taxa used in the benthic indices (e.g., re-evaluating an organism's assigned tolerance values or sensitivity designation), but rather only focused on updating the nomenclature. Detailed cross walk tables linking the original nomenclature for the taxa used in the BRI and the SQO benthic indices to modern nomenclature are presented in Appendix A and Appendix B, respectively.

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<sup>1</sup> Smith et al. (2001) BRI for continental shelf sites or Ranasinghe et al. (2009) SQO BLOE BRI for embayment sites

Based upon the success of this work, it is recommended that this type of taxonomic update effort is included into each subsequent Bight Survey to help ensure the precision of condition assessments made from benthic infauna community composition.

### **III. QUALITY ASSURANCE AND QUALITY CONTROL**

The field and laboratory analysis of benthic samples for Bight 23 involved three processes: sample washing and preservation, sample sorting, and organism identification and enumeration. Quality assurance in the form of procedures and standardized reporting requirements are provided in this document for the latter two processes. Empirical quality control measurements were implemented at stages for which DQOs had been established during the design of the survey (i.e., sample sorting, taxonomic identification and enumeration). The quality control practices were designed to ensure high quality data to inform subsequent analyses (e.g., condition assessment, community characterization) and ensure comparability of data produced by different benthic laboratories and even different surveys. The following sections provided summaries of the DQO for each task, a description of the QA/QC exercise, and the results of the different labs participating in this survey. Full details of the QA/QC exercises, example forms, etc. can be found in the Bight 23 Macrobenthic (Infaunal) Sample Analysis Laboratory Manual (Bight 23 Benthic Committee 2023).

#### **Sample Sorting**

The objective of the sorting procedure was to remove the organisms from the associated sediment and detritus of a sample. For the 2023 survey, a DQO of 95% sorting efficiency (i.e., a minimum of 95% of the total number of organisms in a sample had to be removed) was established. A minimum of 10% of all material in Bight '18 samples was re-sorted to monitor sorter performance and to determine efficiency. Sorting efficiency was assessed following the aliquot method, wherein a representative aliquot of at least 10% of the sample volume of every sample processed was re-sorted by an experienced sorter different than the original sorter.

Sorting efficiency was calculated as follows:

$$\%Efficiency = 100 * \{ \#original / [\#original + (\#resort / aliquot\ fraction)] \}$$

Sorting efficiencies below 95% required continuous monitoring (i.e., 100% re-sorting) of that sorter until efficiency was improved. Organisms found in the re-sort were included in sample identification and enumeration. Average efficiency across all samples was 98.5%, meeting the DQO (Table 4).

**Table 4. Summary of sorting QA/QC results. Average sorting accuracy is presented for each participating lab and across the dataset as a whole. Method 1= 100% resort, Method 2=aliquot resort**

Sorting Lab	# of Samples	Method	Mean % Efficiency
A	43	1,2	98.2
B	98	2	99.2
C	132	1,2	97.9
D	13	1	99.7
E	59	2	99.0
F	3	1	97.1
Totals	348		98.5

### Identification and Enumeration

The objective of the identification and enumeration procedures was to accurately identify and count each organism in the sample. For the 2023 survey, three QA/QC measures related to identification and enumeration – each with a DQO of 90% – were used to evaluate performance as accuracy in identification, precision in taxonomic discrimination, and accuracy in counting. A minimum of 10% of each identification laboratory’s samples were re-identified by a QC laboratory to assess the quality of the identification and enumeration process. Samples for re-identification were randomly selected *a priori* from each lab's assigned set of samples by the Bight 23 Benthic Committee Chairperson and provided to the QC laboratories after the initial identification. The taxonomists conducting the re-identification did not have access to the original results.

Upon completion of the re-analysis, the results were submitted to SCCWRP and a match/not match comparison of primary and secondary results was produced for the reconciliation process. The original taxonomists and the re-identification taxonomists for a given sample then met to reconcile any differences between the original data and those from the QC reanalysis. Once differences in identification and enumeration were reconciled, the number and types of discrepancies/errors (Table 5) were recorded. These results were then used to calculate the % error of the original laboratory's analysis.

$$\text{Identification Accuracy} = [1 - (\# \text{ Individuals Mis-ID'd} / \# \text{ Individuals Resolved})] * 100$$

$$\text{Taxa Discriminated} = \{1 - [ |(\# \text{ Taxa Resolved} - \# \text{ Taxa Original})| / \# \text{ Taxa Resolved} ]\} * 100$$

$$\text{Count Accuracy} = \{1 - [ |(\# \text{ Individuals Original} - \# \text{ Individuals Resolved})| / \# \text{ Individuals Resolved}] \} * 100$$

**Table 5. Potential taxonomic identification & enumeration errors the QA/QC process is designed to detect and the prescribed remedial actions. The True Errors are those directly measured by the three taxonomic QA/QC equations. A TRC (Taxonomic Request for Change) is an update of taxonomic information in the species look up list to match the most currently accepted naming standard.**

Resolution codes:	Error type	
	(* requires data change)	Action
1 = Primary taxonomist misidentification	True*	TRC, Training
3 = Primary taxonomist miscount	True*	TRC, Review best practices
7 = Primary naming convention discrepancy	True*	TRC, Review best practices
2 = QC taxonomist misidentification	True	Training
4 = QC taxonomist miscount	True	Review best practices
8 = QC naming convention discrepancy	True	Review best practices
5 = Primary taxonomist data entry error	Random*	Review best practices
11 = organism added from another vial	Random*	Review best practices
6 = QC taxonomist data entry error	Random	Review best practices
12 = organism lost	Random	Review best practices
13 = specimen vouchered	Non-Error	Data Tracking
14 = specimen damaged during primary ID, not identifiable by QC taxonomist	Non-Error	No Action
9 = Primary variation in level of expertise	Non-Error	Training
10 = QC variation in level of expertise	Non-Error	Training

Across all of the samples, the average accuracy in identification was 97.2%, average precision in taxonomic discrimination was 95.6%, and average accuracy of counting was 94.6% (Table 6); all of which passed the 90% DQO.

**Table 6. Taxonomic QA/QC results for the random 10% of samples selected from each lab participating in 2023 survey. Each lab’s mean values, as well as the mean for the entire dataset are presented for each QC measure**

<b>Lab</b>	<b>Taxonomic Discrimination</b>	<b>Count Accuracy</b>	<b>Identification Accuracy</b>
A	91.9	92.3	99.1
B	92.6	86.4	98.9
C	94.9	98.1	91.7
D	98.7	99.4	99.1
E	100.0	96.8	97.2
<b>Dataset Mean</b>	95.6	94.6	97.2

*Taxonomic comparability* – After the sample-by-sample QA/QC reconciliation among the primary and re-identification taxonomists and any true errors were fixed, all of the taxonomists convened virtually for a synoptic data review. The goal of this exercise was to ensure comparability of taxa among the different laboratories that did the identifications. When taxon names were compared across all of the different laboratories, some taxa were either synonymized under one agreed upon name or the level of identification was backed off to a higher, more inclusive level (e.g., species to genus, or genus to family).

To ensure comparability of this survey to other surveys, voucher collections from each lab were created. The voucher collections contain specimen lots of one or more individuals of each reported taxon identified to species. The voucher specimens are understood to be representative of the taxon as defined within the Bight 23 survey. After the completion of analyses and publication of reports, vouchers will be transported to the Natural History Museum of Los Angeles County (NHM). The vouchers will be placed into the NHM invertebrate collection and specimens can be borrowed for further analysis following the standard protocols of the museum. Vouchers of tentatively identified taxa that are not resolved at the time of publication of this report will also be transferred to the NHM. Further research on these taxa can be conducted through the NHM by visiting scientists.

### **QA/QC Discussion**

The challenge of producing and verifying an accurate and internally consistent description of the species composition of benthic macrofaunal communities over a wide range of habitats and depths was considerable. The necessity of relying on a large number of taxonomists added to the complexity of the task. However, measures to coordinate and standardize taxonomic practices effectively met these challenges.

Across 348 samples, we provided species-level identifications for 77.5% of the specimens that were collected, a 2.8 % decrease from the 2018 survey. A total of 1,524 taxa were reported, which was 14 less than in 2018. The primary reason for this high level of consistency among surveys was that Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) has continued to use taxonomic problems discovered in the Bight surveys to focus its activities in the period between surveys. Keys and other identification aids were produced for many problem taxa from previous regional surveys, facilitating consistent treatment in the present survey. Within the Bight Program and regular year-to-year taxonomic activities, taxonomists create voucher sheets for provisional taxa they erect or to provide clarification for multi-taxa groups that can be challenging. We would encourage this continued practice and re-encourage the distribution of these sheets via the taxonomy email list-serves that are created for each new Bight Program and within SCAMIT. Distribution of these materials ensures greater consistency of identification and uniformity across the datasets produced by the survey.

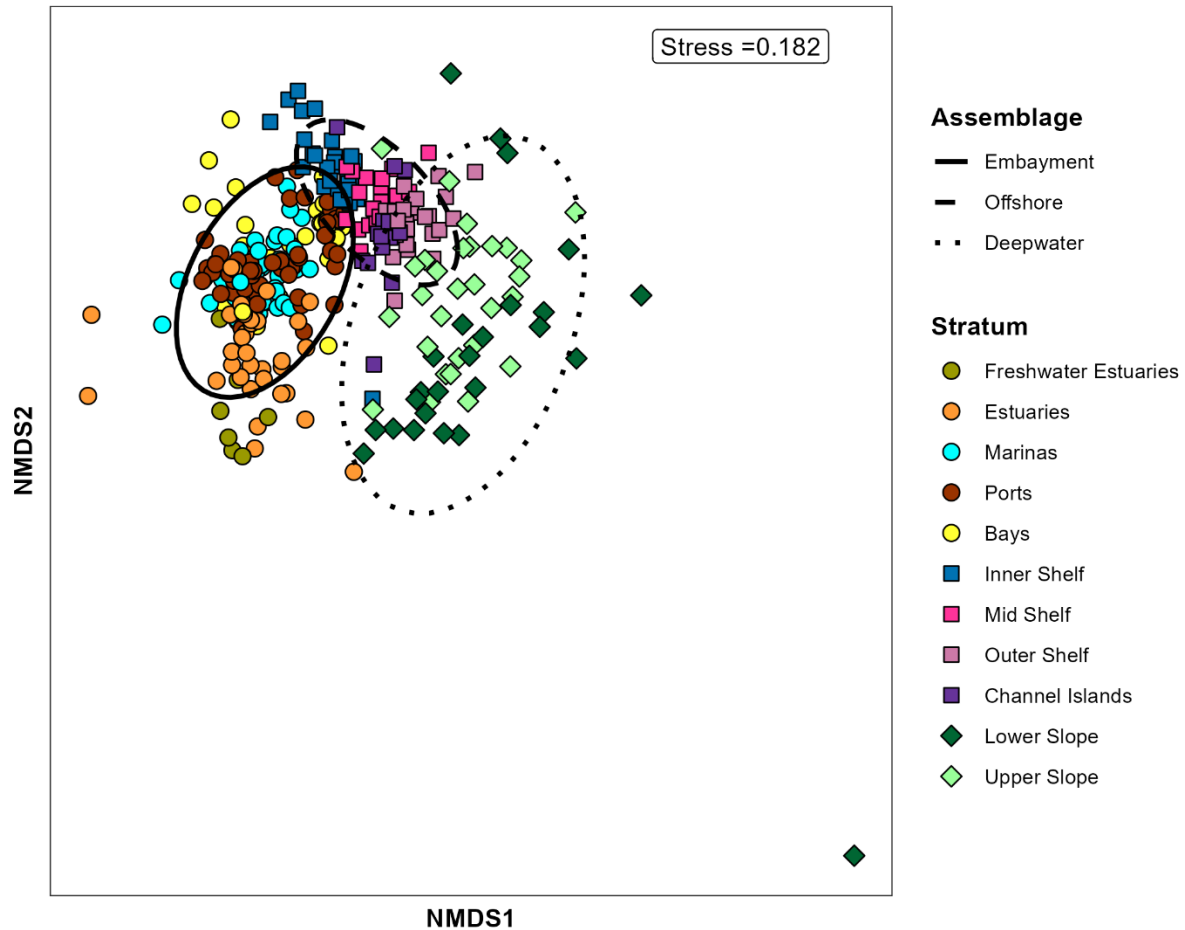
While all of the DQOs were met across the dataset, a small number of samples failed to meet the objectives for sorting or identification. These failures resulted from the lack of experienced sorters and some counting discrepancies. Just a few errors in samples with few individuals have a big impact on quality assurance and quality control measures. However, the ability of most labs to reach the established DQOs across the width and breadth of their samples indicated very high performance in the bulk of the data and should impart similarly high confidence in the quality of the data for all subsequent analyses.

One of the common types of changes made to the dataset during the Synoptic Data Review was the “rolling back” of an identification to a higher taxonomic level to ensure consistency of effort across the dataset. A large number of these changes were due to differences in standard practices between labs in dealing with higher-level taxonomic designations (e.g., the use of sub-family vs. family designations on polychaetes that cannot be identified to species). This aspect of taxonomic standardization is currently not considered in the creation of the pre-survey lab manual. We would recommend including group-specific guidance on the “Bight-recommended” level of taxonomic effort in future Bight Program lab manuals to help expedite the re-ID and Synoptic Data Review processes.

## IV. RESULTS

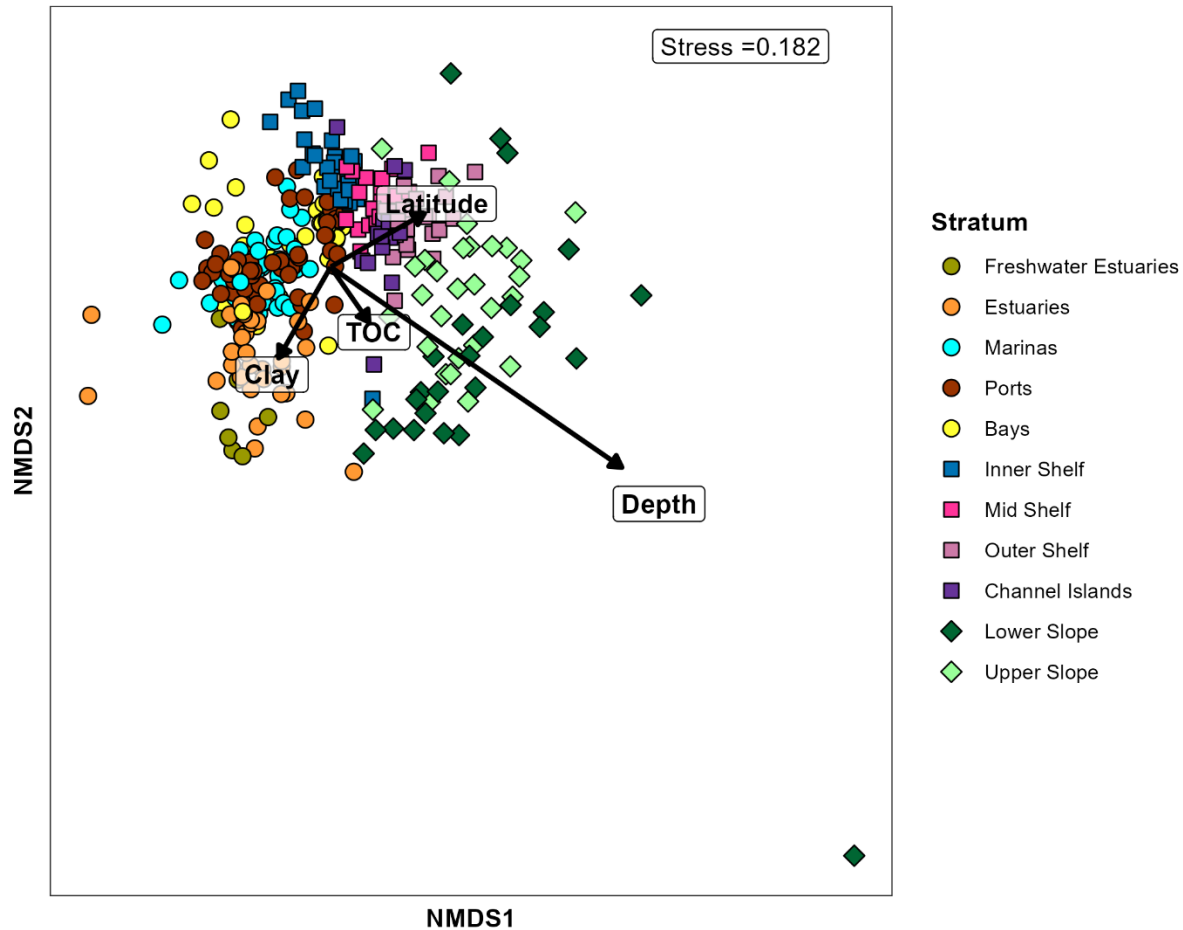
### Community Composition

The nMDS ordination illustrates that all of the samples clustered into three, relatively contained groups (stress = 0.182): embayment, offshore, or deepwater assemblages (Figure 2). A visual inspection of Figure 2 shows that the embayment cluster (circles) comprised samples from the Freshwater Estuaries, Estuaries, Marinas, Ports, and Bays strata. The Estuaries and Freshwater Estuaries were somewhat separated from the other types of embayments but were generally still part of the larger embayment assemblage group, possibly representing a gradient of salinity and upland influence. The offshore assemblage cluster (squares) comprised samples from the Inner Shelf, Mid Shelf, Outer Shelf, and Channel Islands strata. As indicated by the clustering and overplotting in Figure 2, the macrobenthic fauna of offshore community samples were very similar to each other and displayed a moderate gradient into the deepwater assemblage samples. The third group, a deepwater assemblage (diamonds), comprised samples from Upper Slope and Lower Slope strata. As illustrated by the broad dispersal of points across the outer portions of ordination in Figure 2, these samples – especially those from the lower slope – showed the greatest amount of taxonomic heterogeneity of the different habitats sampled in the survey; they were not particularly similar to each other, but they were quite dissimilar to all of the other samples. This pattern echoes that detailed across the continental slope of the region by Gillett et al. (2021), which suggested that these communities may be organized according to neutral (stochastic) principles instead of the niche differentiation patterns observed in shelf and embayment habitats. Note that for ease of interpretation, the ordination, SIMPER, and multivariate correlation analyses, five outlier samples (4 from the Lower Slope and 1 from the Freshwater Estuaries) were removed from these analyses for being azoic, having low abundance, or other types of anomalous composition.



**Figure 2. Two-dimensional nMDS ordination illustrating benthic infaunal community similarity of samples from the 11 different sampling strata. The three different assemblages are denoted with shapes and strata are denoted by color. The ellipses represent 95% of the data for each assemblage.**

Station water depth ( $r=0.67$ ) and station latitude ( $r=0.21$ ) were the two most important environmental variables that correlated to the separation of samples in the nMDS ordination (Figure 3). Sediment variables – Total Organic Carbon content ( $r=0.12$ ) and clay content ( $r=0.18$ ) – had a weaker relationship to the ordination of the sample. Other grainsize variables (% sand, % silt, and total nitrogen) did not have meaningful relationships ( $r<0.1$ ) to the ordination of samples.

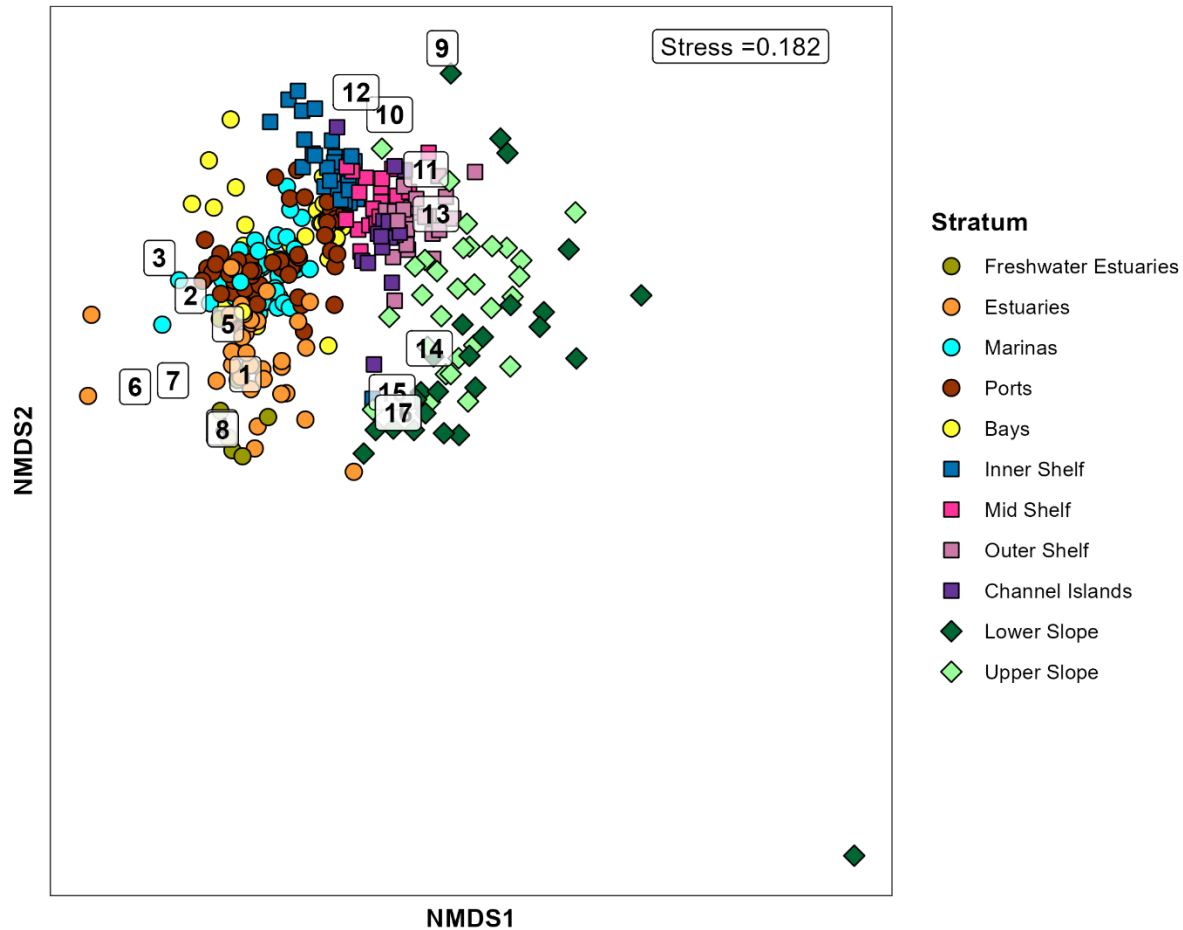


**Figure 3. Two-dimensional nMDS ordination of Bight 23 macrobenthic samples from Figure 2 with environmental vectors overlaid. The length of the vectors is proportional to the strength of their correlation to the ordination pattern.**

There were 16 different taxa that had comparatively strong ( $r > 0.2$ ) correlations to the sample patterns in the 2-d ordination of the samples collected in the survey (Table 7). These taxa could be grouped into those that clearly distinguished the embayment assemblage and those that identified with the offshore or deepwater assemblages (Figure 4). This clear separation was logical given the distinct differences in salinity and water depth between the embayment strata and other strata sampled in the survey. The differences between those taxa associated with the deepwater and offshore assemblages was less distinct than that with the embayments. A nice illustration of this “in-between assemblage” pattern was *Paraprionospio alata*, which plotted out on the ordination between deepwater and offshore samples. This pattern was likely reflective of the more subtle changes in depth and temperature along the continental shelf-slope continuum, as well as the north-south biogeographic separation in deepwater community composition (see the latitude vector in Figure 3) detailed in Gillett et al. (2023).

**Table 7. Taxa with strongest explanatory value ( $r > 0.2$ ) in the 2-dimensional nMDS ordination shown in Figures 2-4. The labels of the taxa vectors in Figure 4 correspond to the Vector IDs in this table. The assemblage association indicates the direction of that taxon's vector to the assemblages defined in Figure 2. Note that the points for *Oligochaeta* (4) and *Grandidierella japonica* (8) plotted on top of each other, as did the points for *Astyris permodesta* (15), *Amage longibranchiata* (16), and *Sosane* sp (17).**

<b>ID</b>	<b>Taxon</b>	<b>Assemblage</b>
1	<i>Acteocina inculta</i>	Embayment
2	<i>Exogone lourei</i>	Embayment
3	<i>Leitoscoloplos pugettensis</i>	Embayment
4	<i>Oligochaeta</i>	Embayment
5	<i>Prionospio newportensis</i>	Embayment
6	<i>Pseudopolydora paucibranchiata</i>	Embayment
7	<i>Arcuatula senhousia</i>	Embayment
8	<i>Grandidierella japonica</i>	Embayment
9	<i>Paraprionospio alata</i>	Offshore/Deep
10	<i>Glycinde armigera</i>	Offshore
11	<i>Glycera nana</i>	Offshore
12	<i>Spiophanes duplex</i>	Offshore
13	<i>Maldane sarsi</i>	Offshore
14	<i>Prionospio lobulata</i>	Deepwater
15	<i>Astyris permodesta</i>	Deepwater
16	<i>Amage longibranchiata</i>	Deepwater
17	<i>Sosane</i> sp	Deepwater



**Figure 4. Two-dimensional nMDS ordination of Bight 23 macrobenthic samples from Figure 2 with taxa overlaid. Numbers correspond to taxa in Table 8.**

SIMPER analysis of the samples grouped by their distribution within the three assemblages depicted in Figure 2 determined that the average community Bray-Curtis percent similarity was 20.4 among the embayment samples, 20.7 among the offshore samples, and only 9.2 among the deepwater samples. Twenty different taxa contributed just over 60% to the similarity values within the embayment assemblage (Table 8). The orbiniid polychaete *Leitoscoloplos pugettensis*, capitellid polychaetes from the genus *Mediomastus*, spionid polychaetes *P. paucibranchiata*, and lumbrinerid polychaetes of the genus *Scoletoma* were identified as the taxa most associated with the embayment samples, with each taxon contributing > 5% to the similarity values among the samples. In contrast, samples from the offshore group had 48 different taxa that represented 60% of the within group similarity, reflecting the greater species richness traditionally observed in the continental shelf of the region compared to the embayments or deepwater habitats (see below; Ranasinghe et al. 2012). No one taxon contributed more than %5 to the within group similarity of the assemblage; the spionid polychaete *Paraprionospio alata* represented the maximum at 4.4% (Table 9). Eighteen taxa

contributed to 60% of the similarity within the deepwater samples (Table 10). The polychaetes *Prionospio lobulata*, *Paraprionospio alata*, and *Maldane sarsi* each contributed > 5% to the within group similarity of the deepwater assemblages. The full, assemblage vs assemblage comparison output of the SIMPER analysis can be found in Appendix D.

**Table 8. Similarity (%) for taxa contributing to the top 60% of within-group similarity of the samples from the embayment group. Average within-group Bray-Curtis similarity was 20.4.**

Taxon	% Contribution to Similarity	% Cumulative Contribution
<i>Leitoscoloplos pugettensis</i>	6.98	6.98
<i>Mediomastus</i> sp	6.34	13.32
<i>Scoletoma</i> sp	5.74	19.06
<i>Pseudopolydora paucibranchiata</i>	5.68	24.74
<i>Exogone lourei</i>	3.91	28.65
<i>Theora lubrica</i>	3.37	32.02
Oligochaeta	3.32	35.35
<i>Arcuatula senhousia</i>	3.1	38.44
<i>Phoronis</i> sp	2.35	40.8
<i>Grandidierella japonica</i>	2.34	43.14
<i>Cossura</i> sp A	2.2	45.33
<i>Prionospio</i> sp	2.15	47.48
<i>Scoletoma</i> sp C	1.88	49.36
<i>Scoletoma</i> sp A	1.84	51.2
<i>Amphipholis squamata</i>	1.76	52.96
<i>Prionospio newportensis</i>	1.76	54.72
<i>Lyonsia californica</i>	1.71	56.43
<i>Amphideutopus oculatus</i>	1.71	58.14
<i>Acteocina inculta</i>	1.18	59.32
Maldanidae	1.1	60.42

**Table 9. Similarity (%) for taxa contributing to the top 60% of within-group similarity of the samples from the offshore group. Average within-group Bray-Curtis similarity was 20.7.**

<b>Taxon</b>	<b>% Contribution to Similarity</b>	<b>% Cumulative Contribution</b>
<i>Paraprionospio alata</i>	4.37	4.37
<i>Spiophanes duplex</i>	3.94	8.31
<i>Mediomastus</i> sp	3.39	11.7
<i>Glycinde armigera</i>	2.53	14.23
<i>Glycera nana</i>	2.36	16.6
<i>Pectinaria californiensis</i>	1.99	18.58
Lineidae	1.97	20.55
Euclymeninae sp A	1.96	22.51
<i>Paradiopatra parva</i>	1.95	24.46
<i>Spiophanes berkeleyorum</i>	1.93	26.39
<i>Tellina cadieni</i>	1.83	28.22
<i>Lumbrineris</i> sp	1.67	29.88
<i>Phoronis</i> sp	1.48	31.36
<i>Prionospio jubata</i>	1.42	32.78
Amphiuridae	1.19	33.97
<i>Caecognathia crenulatifrons</i>	1.16	35.13
<i>Chondrochelia dubia</i> Cmplx	1.13	36.26
<i>Parvilucina tenuisculpta</i>	1.09	37.35
<i>Amphiodia urtica</i>	1.07	38.42
<i>Lumbrineris cruzensis</i>	1.01	39.43
<i>Westwoodilla tone</i>	0.99	40.42
<i>Tubulanus polymorphus</i>	0.93	41.34
<i>Euphilomedes carcharodonta</i>	0.91	42.26
Maldanidae	0.91	43.17
<i>Amphiodia</i> sp	0.89	44.06
<i>Spiophanes kimballi</i>	0.89	44.95
<i>Prionospio dubia</i>	0.87	45.82
Euclymeninae	0.87	46.69
<i>Ampelisca careyi</i>	0.82	47.51
<i>Axinopsida serricata</i>	0.78	48.29
<i>Kirkegaardia cryptica</i>	0.77	49.06
<i>Praxillella pacifica</i>	0.74	49.8
<i>Laonice nuchala</i>	0.72	50.52
<i>Notomastus hemipodus</i>	0.71	51.22
<i>Phyllodoce hartmanae</i>	0.69	51.92
<i>Onuphis</i> sp A	0.69	52.61

<i>Terebellides californica</i>	0.68	53.29
<i>Scoletoma</i> sp	0.68	53.97
<i>Rhepoxynius menziesi</i>	0.67	54.64
<i>Nereis</i> sp A	0.65	55.29
<i>Nephtys ferruginea</i>	0.64	55.94
<i>Maldane sarsi</i>	0.64	56.58
<i>Sternaspis affinis</i>	0.62	57.2
<i>Tellina carpenteri</i>	0.62	57.82
Ophiuroidea	0.6	58.42
<i>Ampelisca brevisimulata</i>	0.59	59.02
Ampharetidae	0.58	59.59
<i>Spiophanes norrisi</i>	0.56	60.16

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**Table 10. Similarity (%) for taxa contributing to the top 60% of within-group similarity of the samples from the deepwater group. Average within-group Bray-Curtis similarity was 9.18.**

<b>Taxon</b>	<b>% Contribution to Similarity</b>	<b>% Cumulative Contribution</b>
<i>Prionospio lobulata</i>	12.35	12.35
<i>Paraprionospio alata</i>	6.28	18.63
<i>Maldane sarsi</i>	5.4	24.03
<i>Eclysippe trilobata</i>	4.68	28.71
<i>Limifossor fratula</i>	3.82	32.54
<i>Bipalponephtys cornuta</i>	3.66	36.2
<i>Pectinaria californiensis</i>	3.21	39.4
<i>Falcidens hartmanae</i>	2.39	41.79
Ampharetidae	2.32	44.12
<i>Phyllochaetopterus limicolus</i>	2.3	46.42
<i>Glycera nana</i>	2.04	48.46
<i>Astyris permodesta</i>	2.03	50.49
Euclymeninae	2.01	52.5
<i>Ampelisca unsocalae</i>	1.73	54.23
Lineidae	1.69	55.92
<i>Glycinde armigera</i>	1.63	57.55
<i>Stereobalanus</i> sp	1.57	59.12
<i>Aphelochaeta</i> sp	1.23	60.36

Within the embayment assemblage, samples from the Marinas, Ports, and Bays strata had relatively similar species diversity, richness, and evenness, while the Estuaries samples had lower values for both taxa richness and diversity (Table 11). The targeted Freshwater Estuaries samples had even lower diversity and taxa richness than the Estuaries stratum samples. Despite the similarity of the univariate metrics, the community composition data served to highlight the differences in taxonomic composition of the different strata born out in the multivariate analyses described above. A full list of all taxa, their abundance, and frequency of occurrence within each stratum are presented in Appendix C. Estuaries and Freshwater Estuaries strata were dominated by typical estuarine endemic taxa – the amphipod *Grandidierella japonica*, oligochaetes, the mussel *Arculatula senhousia*, as well as the spionid polychaete *Pseudopolydora paucibranchiata* and the capitellid polychaetes in the *Capitella capitata* Cmplx and the genus *Mediomastus* (Appendix C1 and C2). Marina samples were dominated by the spionid polychaete *Pseudopolydora paucibranchiata*, the orbiniid *Leitoscoloplos pugettensis*, and the syllid *Exogone lourei* (Appendix C3). The Ports samples were dominated by polychaetes – *Scoletoma* sp, *Mediomastus* sp, and *P. paucibranchiata* (Appendix C4). Similar to the Ports,

the most frequently observed taxa in the Bays samples were polychaetes - *Scoletoma* sp, *Mediomastus* sp, and *L. pugettensis*. Unlike the other embayment strata, the most abundant taxon in the Bays samples – the gastropod mollusc *Barleeia haliotiphila* – were found in less than 25% of the samples, indicating a patchy, high-density distribution (Appendix C5).

**Table 11. Mean (min - max) abundance, species richness, diversity, and evenness for all samples (probabilistic and non-probabilistic) for each stratum from the Bight 23 survey. Strata are grouped by their primary assemblage association noted in the nMDS ordination**

Assemblage	Stratum	Abundance	Shannon-Weiner Diversity (H')	Pielou's Evenness (J)	Species Richness (S)
Embayment	Freshwater Estuary n=(8)	274.3 (2 - 1,042)	1.3 (0.5 - 2.6)	0.7 (0.2 - 1)	12.2 (2 - 35)
	Estuaries n=(33)	719.5 (5 - 2,763)	1.9 (0.6 - 2.8)	0.6 (0.2 - 1)	24.8 (4 - 61)
	Marina n=(46)	675.3 (58 - 4,844)	2.3 (1 - 3.1)	0.7 (0.2 - 0.8)	36.7 (7 - 82)
	Port n=(55)	350.0 (17 - 1,529)	2.8 (1.3 - 4)	0.8 (0.3 - 1)	43.8 (12 - 105)
	Bay n=(47)	513.9 (17 - 2,134)	2.8 (1.6 - 3.9)	0.8 (0.5 - 1)	43.1 (11 - 89)
Offshore	Inner Shelf n=(30)	279.5 (65 - 764)	3.5 (1.4 - 4.3)	0.8 (0.5 - 0.9)	69 (19 - 144)
	Mid Shelf n=(27)	343.2 (107 - 957)	3.9 (2.7 - 4.4)	0.9 (0.7 - 0.9)	92 (46 - 169)
	Outer Shelf n=(30)	237.0 (40 - 566)	3.1 (1.6 - 4)	0.8 (0.5 - 0.9)	56.6 (21 - 100)
	Channel Islands n=(14)	370.4 (134 - 1,094)	3.4 (1.5 - 4.1)	0.8 (0.4 - 0.9)	75.8 (40 - 122)
Deepwater	Upper Slope n=(29)	59.0 (11 - 184)	2.3 (1.3 - 3.3)	0.8 (0.5 - 1)	19.6 (8 - 37)
	Lower Slope n=(29)	38.7 (0 - 108)	2.1 (0 - 3.3)	0.8 (0 - 1)	16.4 (0 - 36)

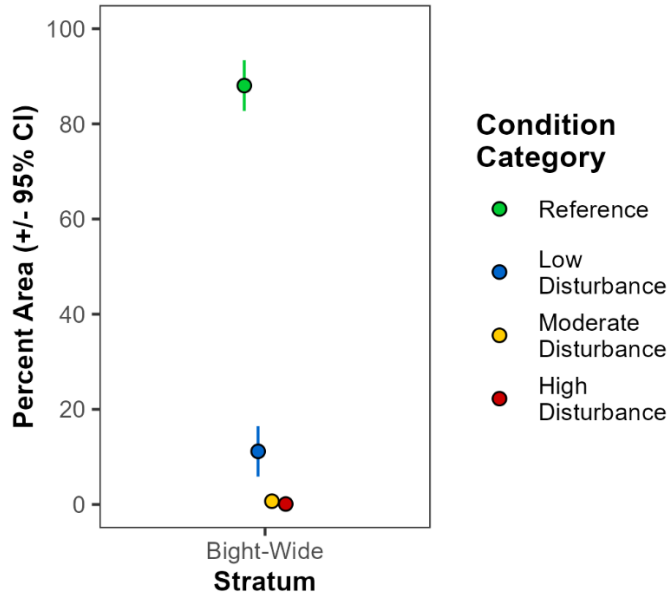
Samples from the offshore strata had greater species richness and diversity than embayment or deepwater strata (Table 11). Species diversity and evenness were relatively similar among the samples from the offshore strata. Species richness, however, varied among the offshore strata, with the Mid Shelf samples having the highest average species richness (92.0), while the Outer

Shelf samples had the lowest (56.6). The Inner, Mid, and Outer Shelf samples all had relatively similar dominant taxa, characteristic of the coastal ocean: a mix of polychaetes - the spionid polychaetes *Spiophanes duplex*, *S. kimballi*, *Paraprionospio alata*, and *P. dubia*, the glycerid *Glycera nana*, the goniadid *Glycinde armigera*, and capitellids of the genus *Mediomastus* – plus the tellinid bivalve *Tellina cadieni* and the phoxocephalid amphipod *Rhepoxynius menziesi* (Appendices A6-8). As Figure 2 would suggest, the samples from the Channel Islands stratum shared many of the same dominant taxa as those from the other offshore strata. Interestingly among the Channel Islands samples, the most abundant (~400 individuals), yet infrequently observed ( $\leq 2$  samples) taxa were the onuphid polychaete *Mooreonuphis* sp LA1 and the oweniid polychaete *Myriochele striolata* (Appendix C9).

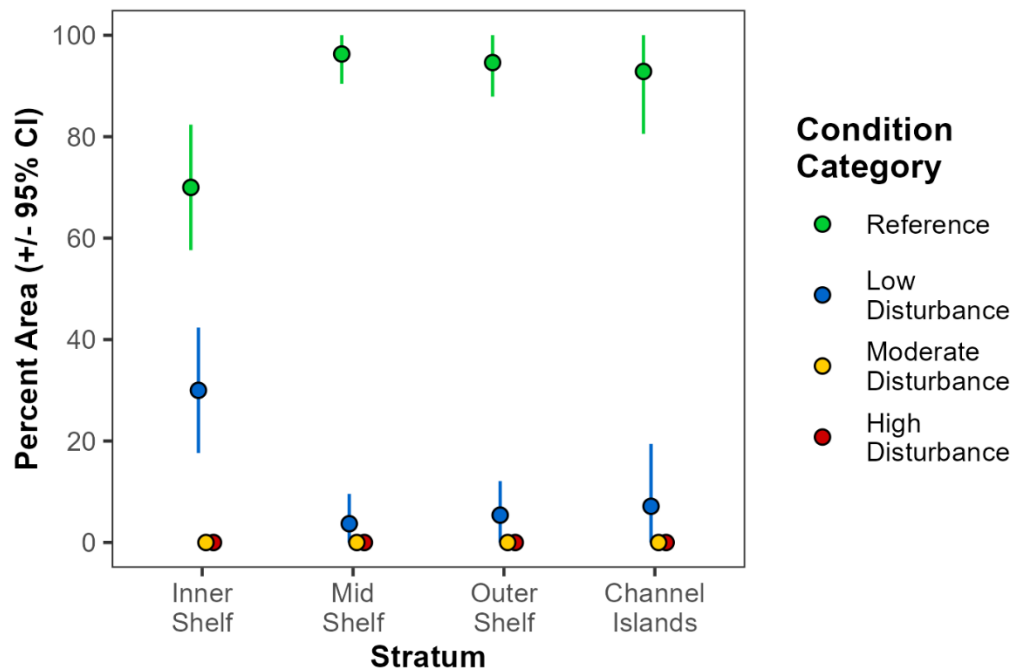
Species diversity and evenness of the deepwater strata samples were similar to samples from the embayments (Table 11). The species richness values were lower than nearly all the other strata, with the Lower Slope samples having the lowest richness (16.4) of any strata, except the Freshwater Estuaries (12.2). As suggested by Figure 2, the fauna from the Upper Slope stratum samples were relatively dissimilar from each other. As an illustration, the spionid polychaetes *Paraprionospio alata* and *Prionospio lobulata*, plus the maldanid polychaete *Maldane sarsi* were the only taxa observed in more than 50% of the samples (Appendix C10). Conversely, the most abundant taxon, the spionid polychaete *Phyllochaetoperus limicolus* was only observed in 24% of Upper Slope samples. The relative dissimilarity among samples was even more pronounced among the Lower Slope stratum samples, where the most frequently observed taxa, *P. lobulata*, the enteropneust *Stereobalanus* sp, and the chaetoderm mollusc *Falcidens hartmanae* were only found in 42 – 30% of samples (Appendix C11).

### **Condition assessment in 2023**

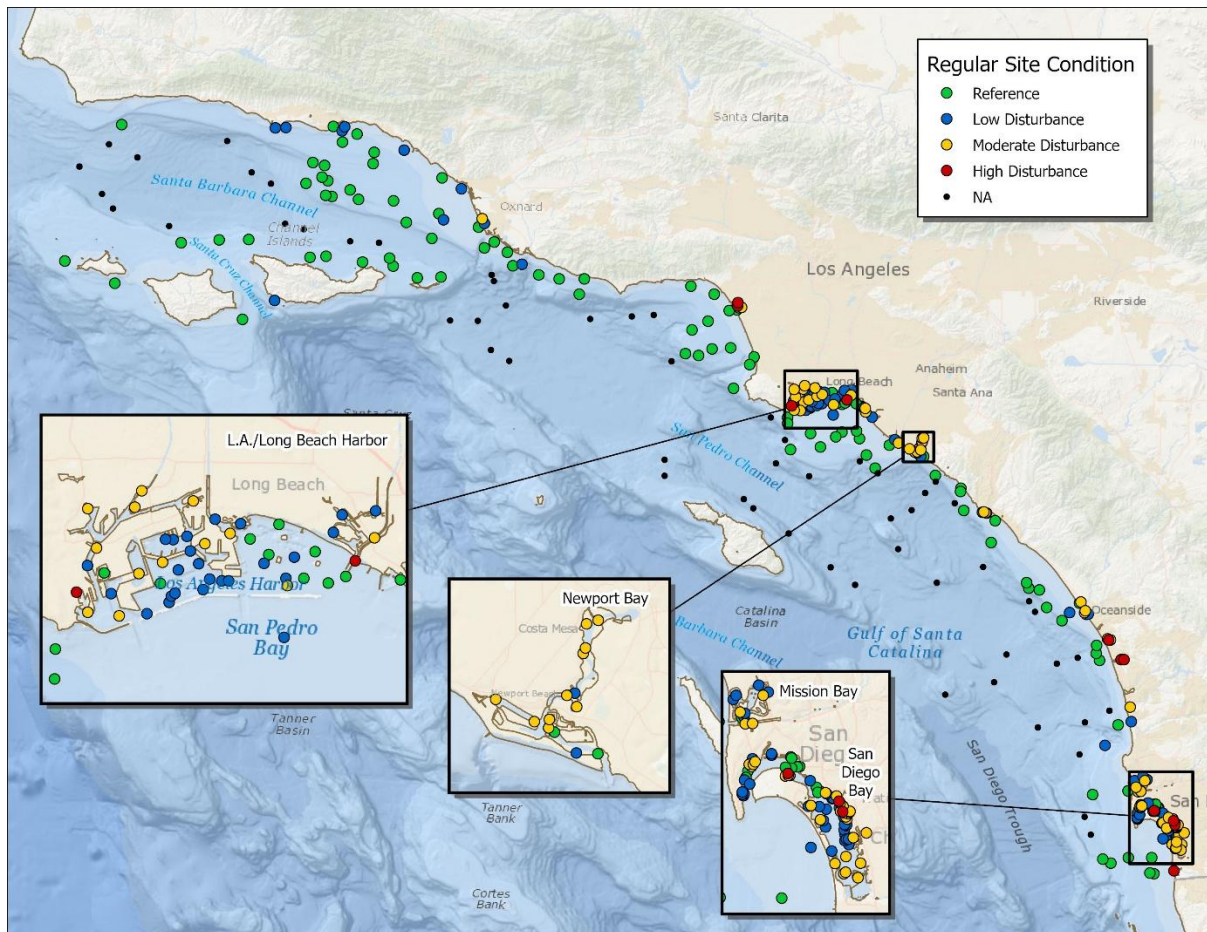
More than 99% of the assessable portions of the region (i.e., non-slope strata) were in good condition (88.1% reference condition + 11.2% low disturbance condition) and less than 1% were in poor condition (Figure 5). Of the four offshore strata, there were no areas in poor condition (Figure 6). Within the good condition category, the four offshore strata had varying levels of condition within the reference and low disturbance categories. Ninety-three percent of the Channel Islands stratum was in reference condition, while the Inner Shelf, Mid Shelf, and Outer Shelf strata had 70, 96, and 95% in reference condition, respectively. Full details of the condition extent estimates for all of the assessable strata can be found in Appendix E and are mapped in Figure 7.



**Figure 5. Percent area estimates (w/ 95% confidence intervals) of the assessable portions of the Southern California Bight in each of the four condition categories. The dots depict the estimate and the whiskers depict the local neighborhood-based confidence intervals.**



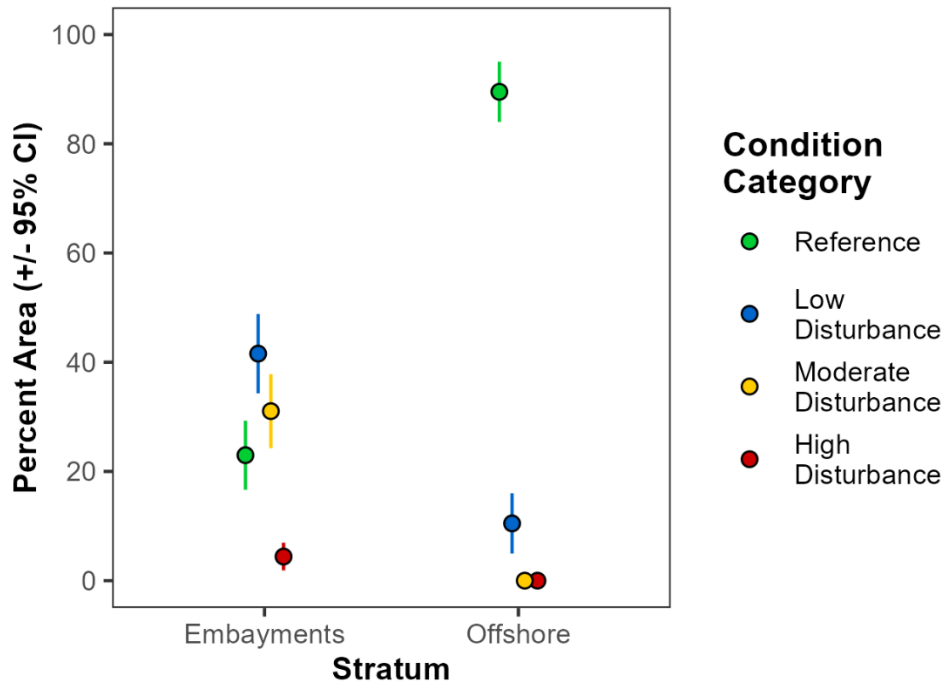
**Figure 6. Percent area estimates (w/ 95% confidence intervals) of the four offshore strata in each of the four condition categories. The dots depict the estimate and the whiskers depict the local neighborhood-based confidence intervals. Note: no area was in the moderate or high disturbance category.**



**Figure 7. A map of the Southern California Bight depicting the distribution of samples and their condition collected across the eleven strata of the survey. The insets depict the distribution of samples from Ports of LA and Long Beach, Newport Bay, Mission Bay, and San Diego Bay. The color of the dots indicate their condition and the small black dots represent samples whose condition could not be assessed (Upper Slope and Lower Slope).**

The embayment strata had a greater relative extent of area in poor condition (35.5%) compared to the offshore strata (0%) (Figure 8). The largest percentage of the area in the embayment strata was in the low disturbance category (41.6%), followed by the moderate disturbance category (31.0%). When comparing different embayment strata (Figure 9), Bays and Ports strata were in relatively better condition than the Estuaries and Marinas strata. Most of the area in Bays and Ports strata was in good condition (14-28% reference and 45-48% low disturbance condition) with less area in poor condition (25-37% moderate disturbance and 1-2% high disturbance). The Marinas stratum was in the middle between the Bays or Ports and Estuaries, with the most amount of area in moderate disturbance condition (33%), but similar amounts of area in reference or low disturbance (28% and 30%, respectively). The Estuaries stratum had the smallest extent of area in reference condition (3%) relative to the other strata

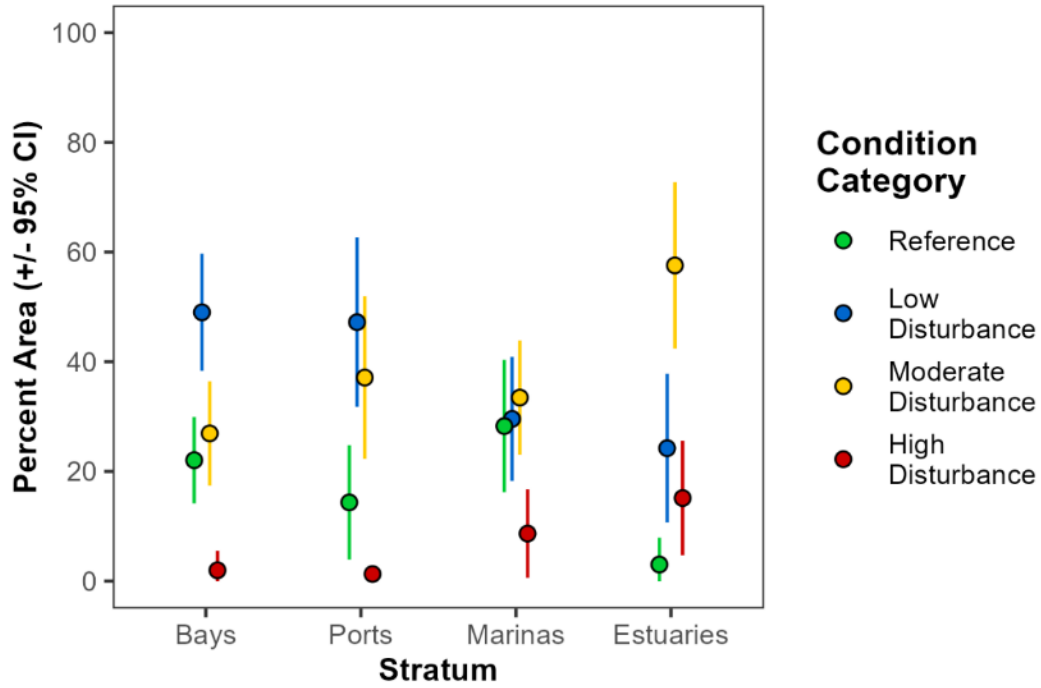
coupled with greatest extent of area in both the moderate (51%) and high (21%) disturbance categories.



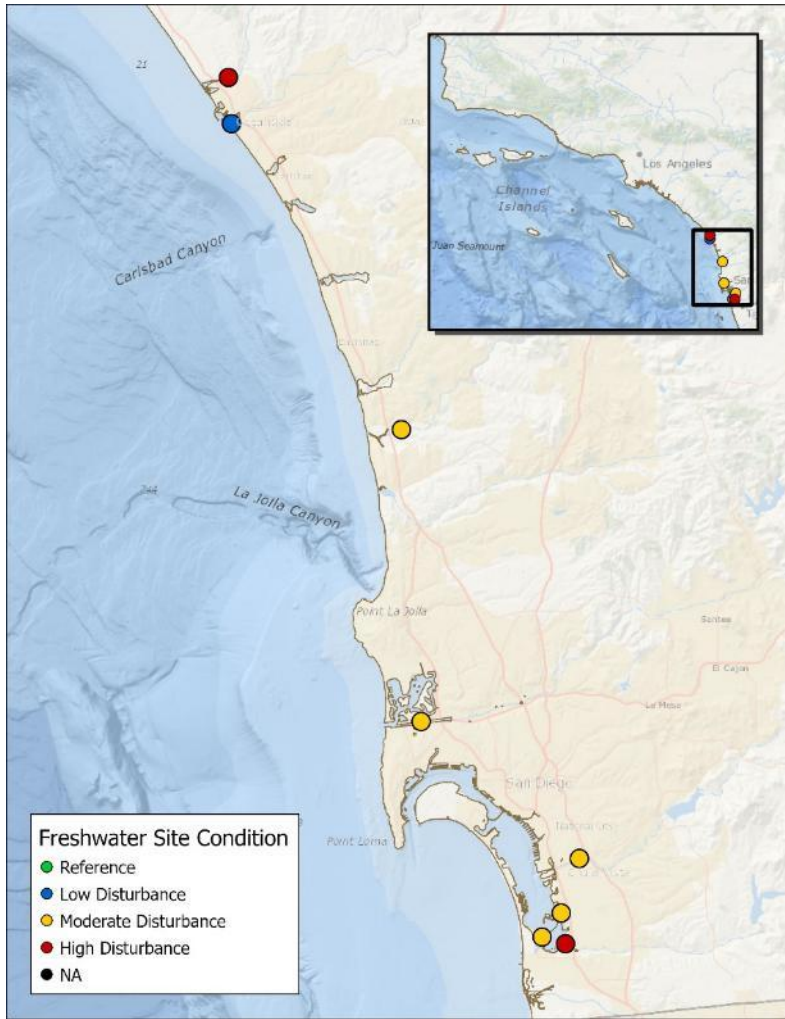
**Figure 8. Percent area estimates (w/ 95% confidence intervals) of the combined embayment and offshore strata in each of the four condition categories. The dots depict the estimate and the whiskers depict the local mean confidence intervals.**

### Condition of Freshwater Estuary Sites

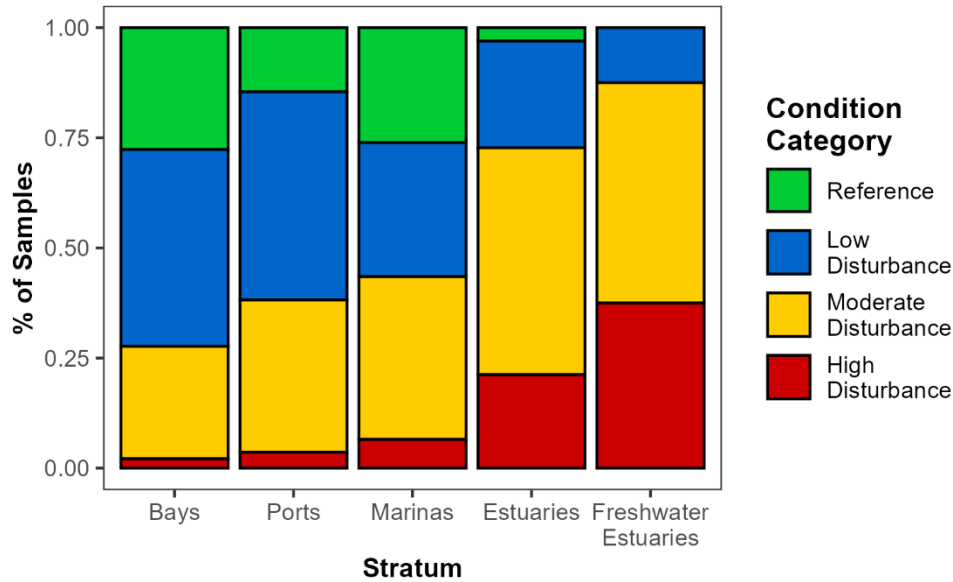
The sites sampled within the Freshwater Estuary stratum (Figure 10) were targeted rather than randomly selected. Consequently, the condition data was presented relative to the number of samples rather than the percent area estimates. The samples from the Freshwater Estuary stratum were in poorer condition than those from the other embayment strata (Figure 11). There were no samples in reference condition and 37.5% of samples were in the high disturbance category. As a point of comparison, no other stratum had more than 21% of the samples in the high disturbance category. The largest amount of Freshwater Estuary stratum samples (50%) were in the moderate disturbance category.



**Figure 9 Percent area estimates (w/ 95% confidence intervals) of the four embayment strata in each of the four condition categories. The dots depict the estimate and the whiskers depict the local mean confidence intervals**



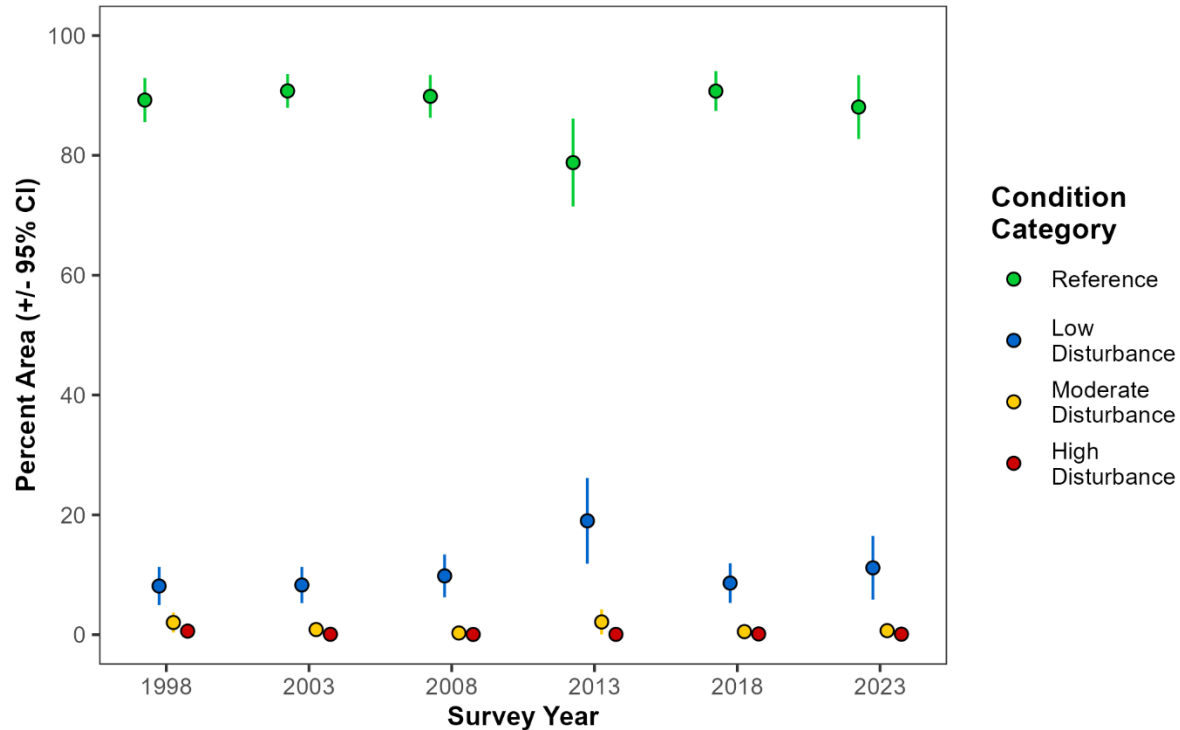
**Figure 10 -A map depicting the location and condition of the samples collected from the Freshwater Estuaries stratum. The inset shows their location relative to the whole of the Southern California Bight**



**Figure 11. Stacked bar chart presenting the percent of samples from the Freshwater Estuaries stratum in each of the four condition categories. The distribution of condition categories among the samples (i.e., non-weighted) other embayment strata are presented for context.**

### Multi-survey temporal trend

A comparison of survey data from 1998-2023 shows a relatively stable trend in the proportions of the Southern California Bight in each of the four condition categories from 1998 through 2008. In 2013, there was a change in the percent area in the reference and low disturbance condition categories relative to previous surveys. However, this change in the pattern did not persist in either the 2018 or 2023 surveys. In the most recent surveys, the distribution of condition categories looks more like 2008 and prior (Figure 12). For the 1998-2008 and 2018-2023 surveys, nearly 90% of the assessable area was in reference condition and approximately 9% in low disturbance condition; contrasted with 78% and 21% respectively during the 2013 survey. Despite the anomaly observed in 2013, the areal extent of good condition habitat (i.e., reference + low disturbance) has remained stable – around 99% of the total assessable area – between 1998 and 2023. Likewise, the sum amount of moderate and high disturbance condition area bight-wide has remained stable at  $\leq 2\%$  from 1998 to 2023. Full details of the multi-survey areal extent estimates of habitat condition within each stratum can be found in Appendix E2.



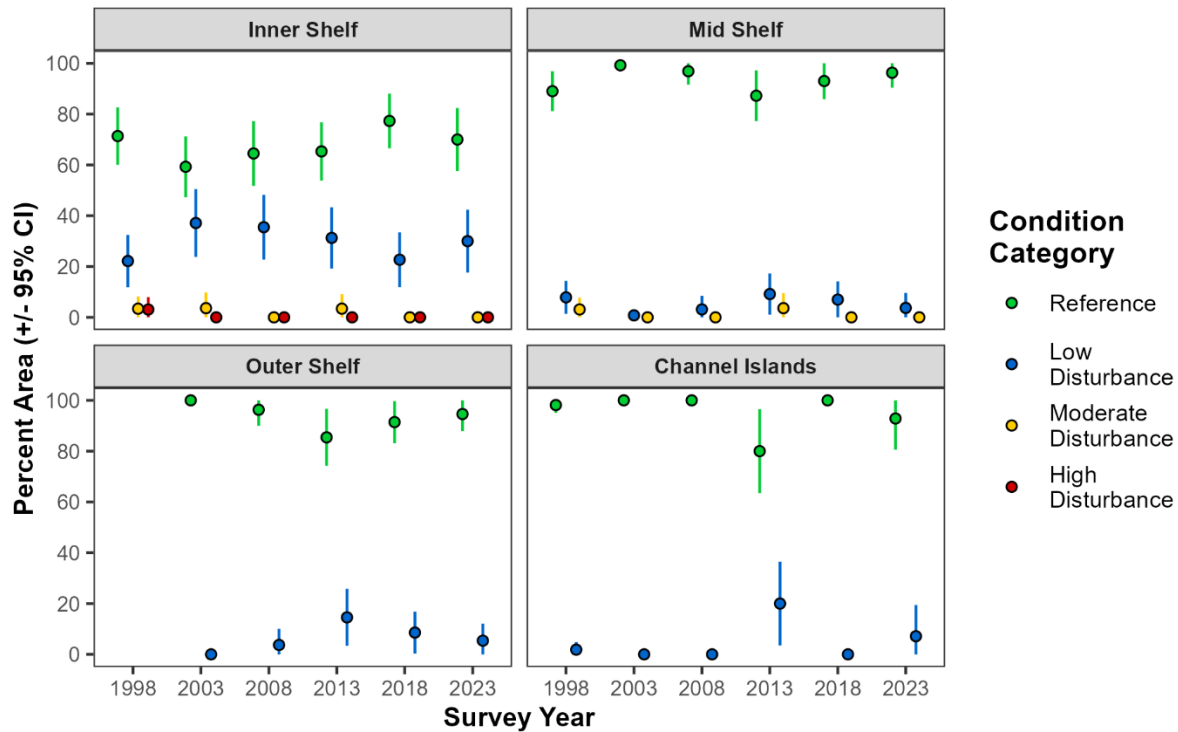
**Figure 12. Percent area estimates (w/ 95% confidence intervals) for the entire Southern California Bight in each of four condition categories from the six regional surveys. The dots depict the estimate and the whiskers depict the local mean confidence intervals.**

When comparing the individual offshore strata, the multi-survey trend was not uniform (Figure 13). The Mid Shelf and Outer Shelf strata have been relatively stable throughout since the 1998 survey. The majority of their area has been in reference condition, with small amounts in the low disturbance category. There was a small increase in the percent of areas of both the Mid Shelf and Outer Shelf strata in the low disturbance category paired with a decline in the area in reference condition in 2013. However, by 2023 patterns have returned to the pre-2013 pattern.

The pattern on the Inner Shelf showed more survey-to-survey change than the other strata. There was a downward shift (decline in reference area and increase in low disturbance) from 1998 to 2003. Post-2003 the trend on the Inner Shelf was towards an increase in the amount of reference area, a decline in the amount of low disturbance, and the disappearance of the small amounts of moderate disturbance area. The 2023 survey showed a small potential downturn in the percent of area of the Inner Shelf in reference condition, but it is still within the values observed in previous studies.

In the 2013 and 2018 Bight Benthic Report, it was highlighted that the Channel Islands stratum showed a notable change in condition in 2013 compared to previous surveys. From 1998 to 2008, nearly 100% of the area was in reference condition. In 2013, however, there was a 20% decrease in the amount of area in reference condition accompanied by an increase in low

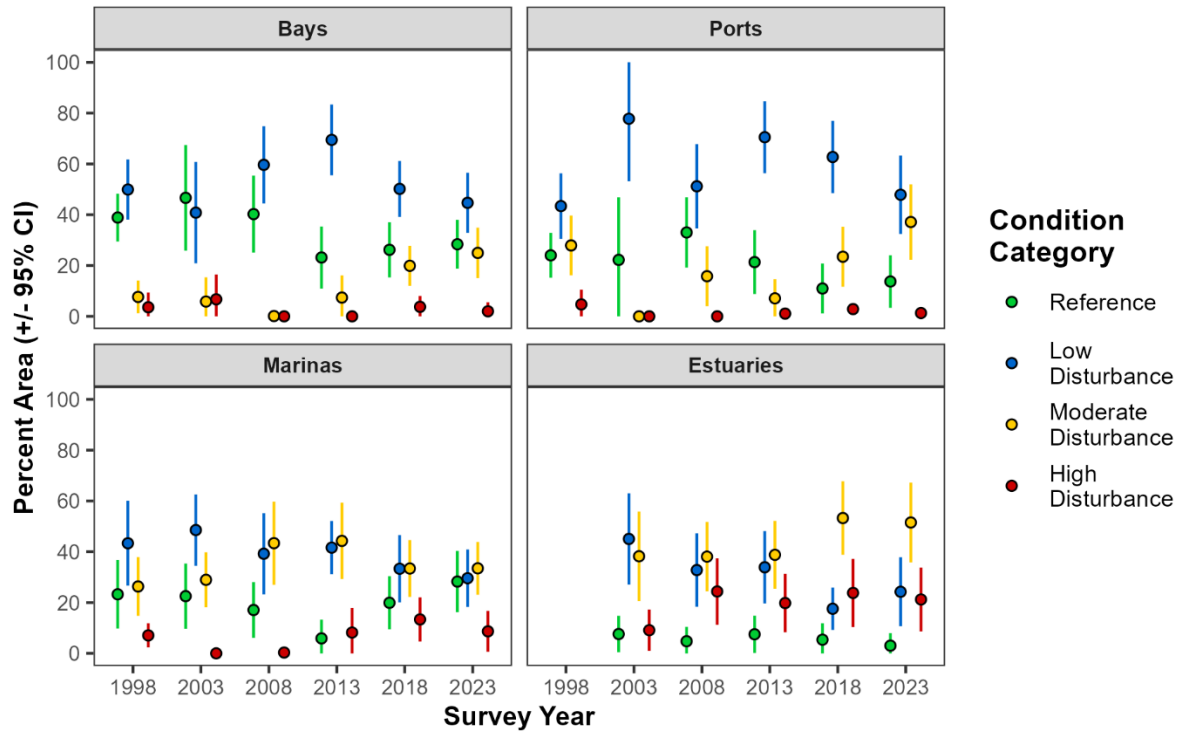
disturbance condition. The 2018 survey showed a return to 100% of the area in the reference condition category. In contrast, the 2023 survey showed a slight decline again, though not as drastic as in 2013. It is important to note that since 2013 there has been a reduction in sampling effort within the Channel Islands stratum relative to the other strata (Table 3). This smaller sample size therefore results in a greater influence of any single sample on the pattern of the stratum as a whole (Appendix E2).



**Figure 13. Percent area estimates (w/ 95% confidence intervals) in each of four condition categories for the four offshore strata sampled in the six regional surveys. The dots depict the estimate and the whiskers depict the local mean confidence intervals. Note that no Outer Shelf samples were collected in 1998.**

Relative to the offshore strata, there was less consistency in the multi-survey trends in condition among the four embayment strata (Figure 14). In general, all but the Marinas stratum have seen increases in either moderate or high disturbance condition since the 1998 survey. The percent area of the Ports stratum in the reference and high disturbance categories was relatively stable, however, there was a ~20% increase in moderate disturbance condition from 2013 to 2023 that was paired with a decline in the percent area in the low disturbance category. Since 2008, the amount of high disturbance and reference areas in the Estuaries stratum was relatively stable. However, there has been an increase in the percent area in moderate disturbance condition paired with a decline in low disturbance condition area. The trend in the Bays stratum appears to have stabilized across the 2018 and 2023 surveys with small increases and decreases in moderate disturbance and reference area, respectively. The

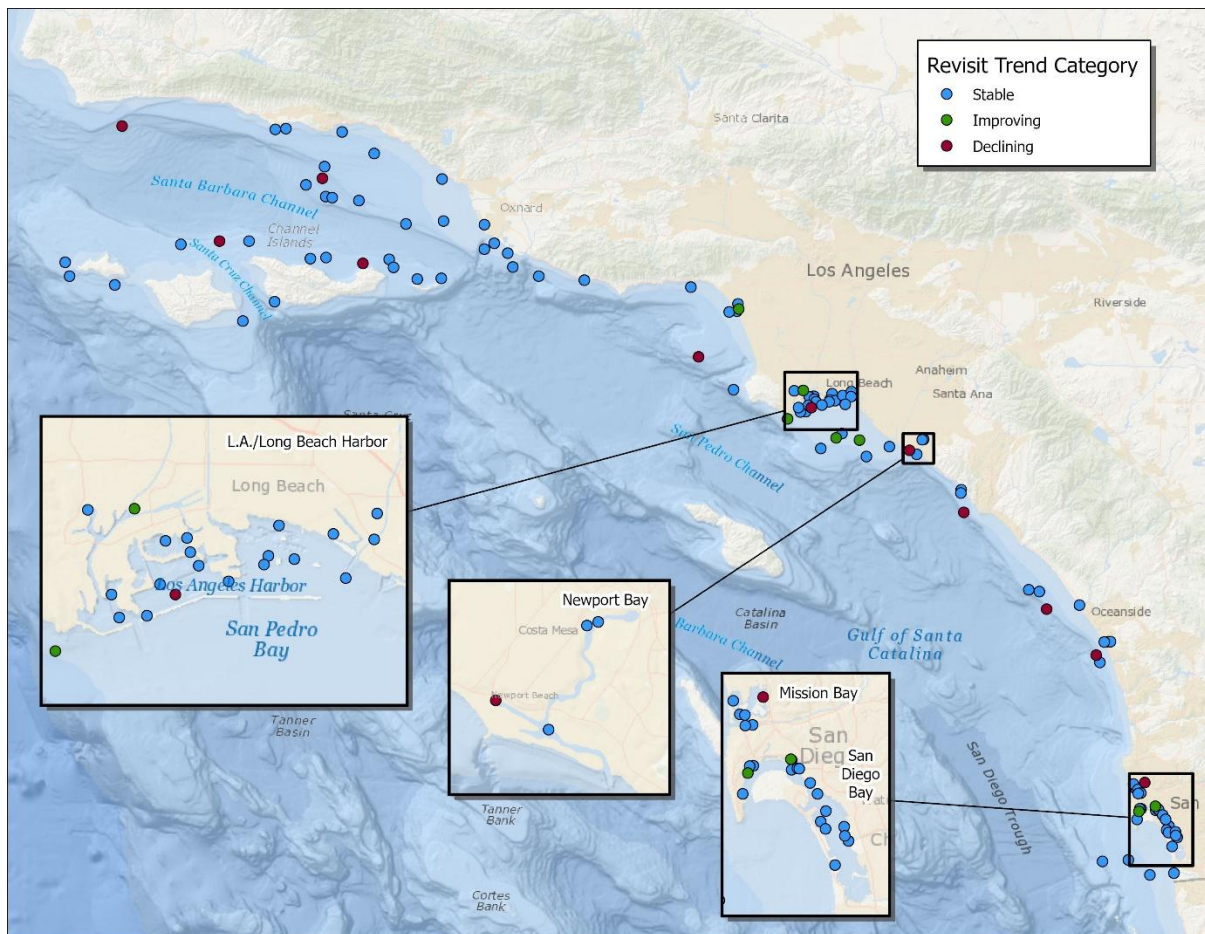
Marinas stratum was the most stable of the embayment strata, with there being a relatively similar amount of area in the reference, low disturbance, and moderate disturbance categories since 2013.



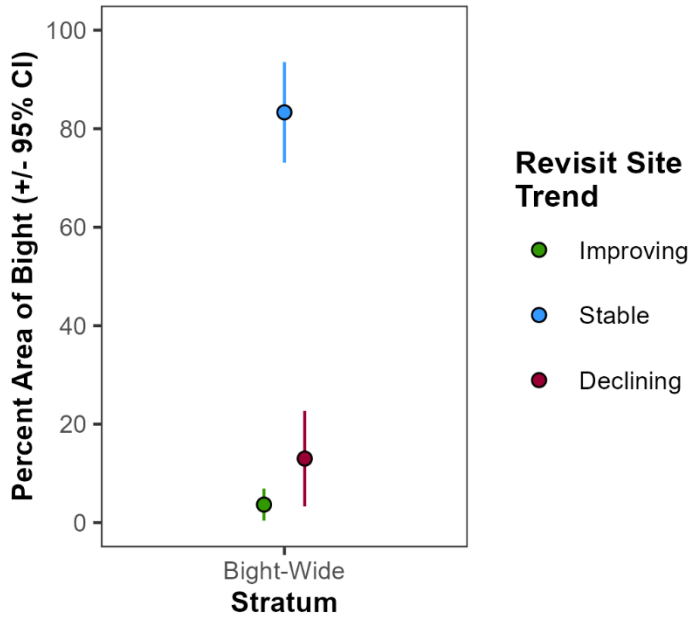
**Figure 14. Percent area estimates (w/ 95% confidence intervals) in each of four condition categories for the four embayment strata sampled in the six regional surveys. The dots depict the estimate and the whiskers depict the local mean confidence intervals. Note that no Estuaries samples were collected in 1998.**

## Site revisit temporal trends

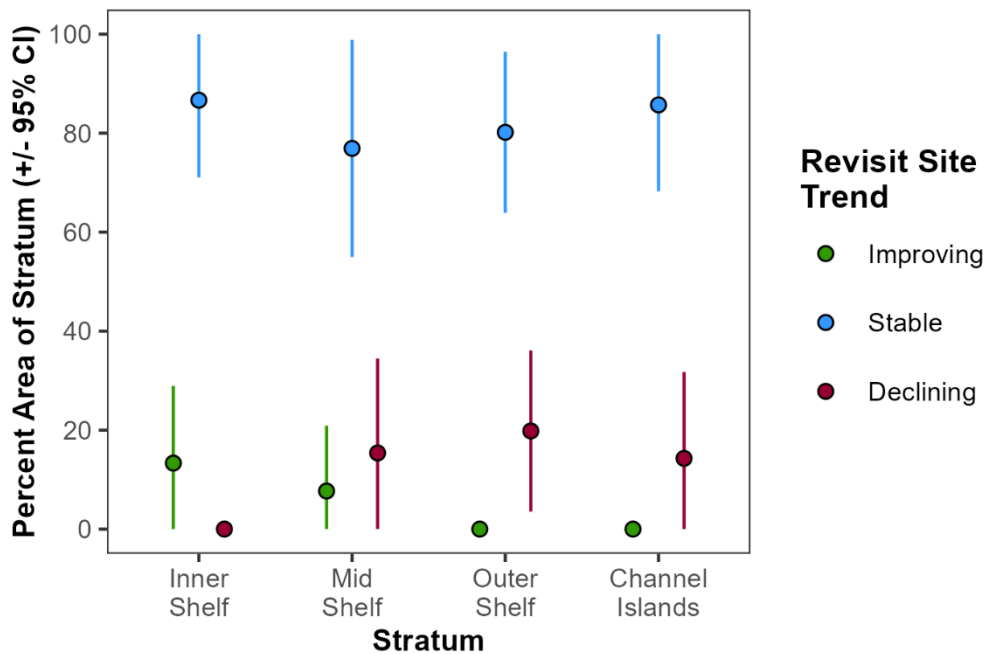
Based upon sites revisited from 1998 through 2023 (Figure 15), 3.7% of the assessable portions of the Southern California Bight showed a trend towards improving condition (i.e., better BRI scores), 83.3% had a stable trend, and 13.0% had a trend of declining condition (Figure 16; Appendix E3). Compared to the other offshore strata, the Outer Shelf had the greatest amount of area (20%) in a declining trend with 0% in improving condition (Figure 17). Most of the area in the Inner Shelf, Mid Shelf, and Channel Islands strata had a stable (77-87%) or declining (0-16%) trend in condition. The Mid Shelf and Inner Shelf had 8% and 13% in improving condition, while the Channel Islands and Outer Shelf had no area in improving condition. Within these temporal trends in index score from 1998-2023 (Appendix F), only 4 sites within the offshore strata changed condition categories between the Bight 18 and Bight 23 (Table 12) and no sites crossed over from good to poor or poor to good.



**Figure 15. A map of the Southern California Bight depicting the distribution of revisit samples and their trend in condition between 1998/2003 and 2023. The insets depict the distribution of samples from the Ports of LA and Long Beach, Newport Bay, Mission Bay, and San Diego. The color of the dots indicate the nature of the trend.**

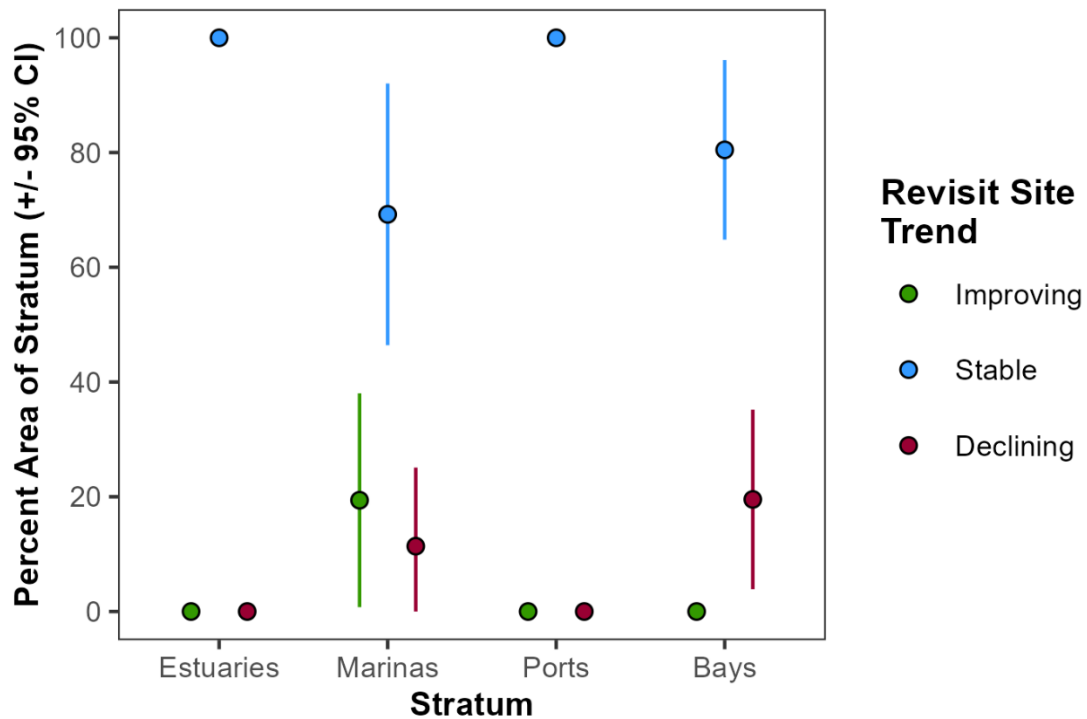


**Figure 16. Percent area estimates (w/ 95% confidence intervals) of the assessable portions of the Southern California Bight with an improving, stable, or declining trend in condition score derived from revisited sites sampled from 1998 to 2023. The dots depict the estimate and the whiskers depict the local mean confidence intervals.**



**Figure 17. Percent area estimates (w/ 95% confidence intervals) of the four offshore strata with an improving, stable, or declining trend in condition score derived from revisited sites sampled from 1998 to 2023. The dots depict the estimate and the whiskers depict the local mean confidence intervals.**

The majority trend in condition at the revisit sites among the embayment strata was stable. In both the Estuaries and Ports strata, 100% of their respective areas had a stable trend in condition from 1998 to 2023 (Figure 18). Among the embayment strata, the Marinas stratum had the largest amount of area with an improving trend, in condition (19%), 11% in declining trend in condition, and the remaining 69% with a stable trend in condition. The trend in the Bays stratum was largely stable (81%), with 0% of area with an improving trend in condition and 20% of the area with a declining trend in condition. Among the revisit sites within the Marinas stratum, two of the sites with an improving trend in condition transitioned from the poor category (high or moderate disturbance) to the good category (low disturbance or reference) over the span of the Bight Program (Appendix F). Among the sites (in the Bays stratum) with a declining trend in condition, two crossed over from the good to poor category (Appendix F). Seventeen revisit sites from the embayment strata changed categories between the 2018 and 2023 Bight Surveys, with 10 improving and 7 declining in condition (Table 12). Full details of the temporal trend areal extent estimates using the revisit sites can be found in Appendix E3 and the detailed results of the trend analysis can be found in Appendix F.



**Figure 18. Percent area estimates (w/ 95% confidence intervals) of the four embayment strata with an improving, stable, or declining trend in condition score derived from revisited sites sampled from 1998 to 2023. The dots depict the estimate and the whiskers depict the local mean confidence intervals.**

**Table 12. A comparison of condition categories among revisit sites in each stratum between Bight 2023 and Bight 2018. A cell highlighted in green indicates an improvement in condition category between 2018 and 2023. A cell highlighted in red indicates a decline in condition category between 2018 and 2023.**

Stratum	Bight 18 Condition	B23 Condition			
		Reference	Low Disturbance	Moderate Disturbance	High Disturbance
Estuaries	Reference	0	0	0	0
	Low Disturbance	0	1	1	0
	Moderate Disturbance	1	0	5	1
	High Disturbance	0	0	0	1
Marinas	Reference	2	1	1	0
	Low Disturbance	1	3	0	0
	Moderate Disturbance	0	0	5	0
	High Disturbance	1	0	0	1
Ports	Reference	1	0	0	0
	Low Disturbance	2	7	0	0
	Moderate Disturbance	0	3	1	0
	High Disturbance	0	0	0	0
Bays	Reference	4	0	0	0
	Low Disturbance	3	4	3	0
	Moderate Disturbance	0	1	1	0
	High Disturbance	0	0	0	0
Inner Shelf	Reference	11	0	0	0
	Low Disturbance	1	3	0	0
	Moderate Disturbance	0	0	0	0
	High Disturbance	0	0	0	0
Mid Shelf	Reference	11	0	0	0
	Low Disturbance	1	1	0	0
	Moderate Disturbance	0	0	0	0
	High Disturbance	0	0	0	0
Outer Shelf	Reference	14	0	0	0
	Low Disturbance	1	0	0	0
	Moderate Disturbance	0	0	0	0
	High Disturbance	0	0	0	0
Channel Islands	Reference	13	1	0	0
	Low Disturbance	0	0	0	0
	Moderate Disturbance	0	0	0	0
	High Disturbance	0	0	0	0

## V. DISCUSSION

Bight 23 represents the sixth full regional survey of the area's macrobenthic infauna. The probabilistic sampling design, with a subset of fixed-position revisit sites woven among new randomly selected sites, provided us with a powerful analytical framework to measure spatial extent and temporal changes in condition of the region and its different habitats. Multi-survey comparisons provided a stratum-level assessment that was easier to quickly communicate temporal patterns in habitat condition. Analysis of the revisit sites allowed for an assessment of habitat condition that minimizes spatial variability to focus on temporal trends in the region's waterbodies (Urquhart and Kincaid 1999). Furthermore, the high-quality taxonomic data generated by the survey, as well as abiotic data generated by the other components of the Bight Program, allowed for investigation of the underlying ecology of the region's benthic communities in 2023 and across the 25 years of the Bight Program. These patterns are touched upon in this report but will be invaluable to scientists across the region beyond the scope of the 2023 survey and this report.

From the perspective of macrobenthic community composition, the assessable portions of the Southern California Bight continued to be doing well in 2023. More than 99% of the assessable portions of the region were in good condition (88% reference condition + 11% low disturbance condition) and less than 1% were in poor condition. However, conditions were not uniform across the region. As was observed in previous Bight surveys (Ranasinghe et al. 2007, Ranasinghe et al. 2012; Gillett et al. 2017; Gillett et al. 2022), the benthic habitat of the offshore strata (Inner Shelf, Mid Shelf, Outer Shelf, and Channel Islands) was in much better condition than that in the embayment strata (Estuaries, Marinas, Ports, and Bays). The offshore strata were largely all in reference condition, with a relatively small area in low disturbance condition. The only small deviation in this offshore strata pattern was the Inner Shelf stratum, which had proportionally smaller amounts of reference condition habitat and more than 30% of area in low disturbance condition. In contrast to the offshore strata, the embayment strata were largely comprised of areas with low to moderate levels of disturbance and relatively small areas with reference conditions. Among the embayment strata, the Bays and Ports strata were in relatively better condition than the Marinas and Estuaries strata.

As a whole, the assessable portions of the Southern California Bight were in proportionally similar condition in 2023 as they were in 2018. In 2013, there was a noticeable increase in the amount of area in Low Disturbance condition compared to previous surveys. As detailed in the Bight '18 benthic report, this pattern from 2013 was most likely a product of cold, low oxygen, low pH deep basin waters anomalously shoaling up into shallower depths of the Channel Islands and Outer Shelf strata versus any change in sediment contaminant load or apparent toxicity of the sediments (Gillett et al. 2022). Conditions Bight-wide and within the Channel

Islands stratum in 2018 bounced back to more closely resemble those from Bight Surveys prior to 2013. This return to the “normal” regional pattern continued in the 2023 survey.

One of the lessons reinforced by the temporal patterns in benthic community condition across Bight surveys is that sediment contaminants are not the only anthropogenic factor influencing macrobenthic community composition (e.g., Gillett et al. 2023) and condition scores. Basin-scale oceanographic shifts in ocean acidification, dissolved oxygen, and temperature shape the benthic communities – especially in the offshore strata where sediment contamination has been a very minor factor at regional scales over the last three to four decades. One of the recommendations in the 2018 benthic report (Gillett et al. 2022) was to pursue better integration of oceanographic data and climate change patterns into the Bight Program as a whole. Patterns in the present survey continue to reinforce this notion that future Bight surveys could provide a better, more holistic understanding of the coastal zone by incorporating oceanographic and climatic factors into the thorough sediment contaminant focus of the program.

For the most part, the spatial pattern of condition that was observed in Bight 23 – poorer condition in the marinas and estuaries strata moving towards better conditions in the offshore strata – was similar to observations from previous surveys (Ranasinghe et al. 2007; Ranasinghe et al. 2012, Gillett et al. 2017; Gillett et al. 2022). The general pattern that emerges is that more enclosed waterbodies, which are also more intimately associated with upland anthropogenic activities, are in poorer condition than more open waterbodies further removed from anthropogenic activities, such as bays and the continental shelf. This pattern extends through the offshore strata as well. The Inner Shelf stratum, the stratum immediately adjacent to the coast and upland development, has been more variable and in slightly poorer condition than the increasingly further afield and deeper offshore strata across the history of the Bight Program.

This spatial pattern in habitat condition is not unique to Southern California and has been similarly observed in other systems (Holland et al. 2004; Llansó et al. 2015). Unfortunately, beyond the broad catch-all of “proximity to anthropogenic activities”, we cannot confidently identify the reasons for any instances of disturbed benthic communities observed across the region. In embayments, the CA SQO framework was designed to assess the impact of toxic compounds in the sediment on the benthic fauna, but it was not intended to assess the impacts from eutrophication, poor water quality (e.g., low dissolved oxygen, non-tidal salinity fluctuation), physical disturbance, or climate change. Much of the data produced by the Southern California Bight Monitoring Program could be used to begin identifying the pressures on the benthic fauna in different parts of the region. However, we lack a fully realized causal assessment framework (e.g., Norton et al. 2015) that can be applied in marine and estuarine

settings (Newman et al. 2007; Davis and Kidd 2012). More detailed, site-specific studies are needed to identify the specific causes of impacted macrobenthic communities observed in Bight 23 and potentially take actions to improve conditions in the future.

The regional pattern among the four condition categories from all of the sites in 2023 was similar to that of 2018 and the years prior to 2013, which was mirrored in the trends among the revisited sites. More than 83% of the region was in stable condition and approximately 4% in improving condition. This region-wide pattern was echoed in most of the offshore strata, which have generally been in stable condition from 1998-2023. Interestingly, the strata most removed from the mainland – the Mid Shelf, Outer Shelf, and Channel Islands – all had more (15-20%) area with a trend towards declining condition. The trends were largely within the reference or low disturbance category and are subtle. However, the consistent changes in condition scores that were observed across 5 revisit events were not accompanied by similar changes in sediment contaminants. As such, they may reflect a response to shifts in oceanographic conditions at the shelf/slope boundary, similar to what may have happened, in a more acute fashion, at the Channel Islands in 2013. It is important to note that these trends were all within the reference or low disturbance categories. As such, drastic action is not warranted. However, it is advisable to continue to revisit these trend patterns with subsequent surveys in the Bight 2028 survey.

Within the embayments, the relative proportion of area with stable, increasing, or declining trends in condition from 1998-2023 was consistent among the strata. Most or all of the area of these strata were in stable condition, with relatively small and equivalent amounts of increasing or declining areas. However, given that nearly 80% of these strata were not in the reference condition categories in 2023, a stable trend in condition indicates that disturbed areas have remained impacted over time. Furthermore, it would suggest that the types of disturbances impacting these waterbodies are either persistent legacy factors (e.g., legacy sediment contaminants or shoreline hardening) or frequently and consistently occurring factors (e.g., watershed eutrophication or physical disturbance). Development of a causal assessment program for diagnosing the nature of the disturbance(s) affecting sites within the region's embayments would help to inform management strategies to potentially intercede and change the condition at certain sites through time.

As has been noted in previous Bight Regional Monitoring reports, we can only assess the condition of approximately 36% of the 16,676 km<sup>2</sup> surveyed by the program. The macrobenthic-based assessment tools that have been validated for use in this region (offshore BRI, SQO benthic indices, and M-AMBI) are limited by design or standard practice to waters 6 – 200m deep in continental shelf habitats and embayment waters. These traditional limitations excluded continental slope habitats, which are too deep. Since the Bight 18 survey, the lower

salinity (<27 PSU) portions of embayments have been assessed using a United States version of the M-AMBI bioassessment tool (Pelletier et al. 2018) adjusted to fit into the traditional SQO benthic indices (Gillett et al. 2019). However, we would suggest that in following the best practices associated with applying a bioassessment index to any new location (e.g., Gillett et al. 2019), it be validated in the embayments and estuaries of Southern California – possibly as part of the 2028 Bight Survey – to ensure consistent evaluation across the different strata of the Bight Program.

The continental slope provides a more challenging problem. Gillett et al. (2021) suggested that the BRI scores could be derived within habitats equivalent to the Upper Slope stratum, but that the thresholds used to categorize those scores into the different condition classes should be done carefully. Caution is needed as water depth and, most likely, the natural gradients associated with increasing water depth (e.g., temperature, dissolved oxygen, and pH) are an important structuring element of benthic communities in the region (Gillett et al. 2021; Bergen et al. 2001). Additionally, and the effects of depth on BRI category threshold have not been calibrated nor validated at depths below 300m. As part of the Bight 18 survey, the BRI was experimentally applied to the Upper Slope stratum. While the index provided reasonable coverage of the taxa collected in the survey, the lack of validated tolerance scores and category thresholds at depths beyond 300m did not leave the index as a viable option for regular application to Upper Slope samples in the Bight Program (Gillett et al. 2022). Our continued inability to fully assess the condition of the Upper Slope and to provide any insight into condition of the Lower slope reinforces the notion that an assessment tool, calibrated and validated for application on the continental slope habitats of the region, is a pressing need if we are to fully understand the condition of the Southern California Bight.

As has been observed in previous Bight Surveys (e.g., Gillett et al. 2022), the benthic communities of the region fell into three relatively distinct assemblages we have termed embayment, offshore, and deepwater. Within those assemblages, the fauna from the different sampling strata were separated from each other along environmental gradients of depth, sediment composition, and salinity. From a decadal perspective, the composition of the macrobenthic communities of the Southern California Bight has been slowly changing across the breadth of the Bight Surveys since 1998 (Gillett et al. 2023). Though not directly related to understanding the health of the region's waters, the benthic ecology data produced by the Bight Program is key to understanding the progression of the region's biological resources (e.g., Gillett et al. 2021; Leonard-Pingel et al. 2019; Tomašových and Kidwell 2017; Simons et al. in 2023).

## **VI. CONCLUSIONS**

### **1. Macrobenthic community composition indicates the Southern California Bight was largely in good condition during 2023**

Approximately 99% of the assessable portions of the region (i.e., continental shelf and embayment soft bottom habitat) were in good condition (89% reference and 10% low disturbance) and less than 1% in poor condition (moderate or high disturbance).

### **2. Not all habitats were in equally good condition**

The offshore strata were predominantly in reference condition, with some low disturbance areas. The embayment strata, in contrast, were composed of predominantly low and moderate disturbance areas with small amounts of reference and highly disturbed areas. Of the embayment strata, Estuaries were in the poorest condition, with nearly 73% of their area in the moderate (52%) or highly (21%) disturbed categories. There was a pattern, even among the generally high-quality offshore strata, of decreasing overall condition with greater proximity to upland development.

### **3. Most of the region was in stable condition**

The trend in habitat condition from 1998-2023 was relatively stable at both the regional (~80%) and stratum-scale (60-80%). Among the offshore strata, that stability represents habitat that has been consistently in Reference condition. However, in much of the embayment strata the stability represents habitat that has consistently been in non-reference condition and predominantly in the Moderate or High disturbance categories.

## **VII. RECOMMENDATIONS**

### **1. Develop condition assessment framework for deepwater habitats**

The Bight Monitoring Program collects and characterizes macrobenthic infauna across the region, from nearly 1000m deep to the shallow coastal lagoons. However, the area for which there are calibrated and validated macrobenthic-based assessment tools only comprises 36% of the total area that is sampled. The largest areas where condition cannot be assessed are the deepwater (i.e., > 200 m deep) habitats of the continental slope. Given the large area the slope habitats represent, it is apparent that an assessment framework purpose built for the deeper waters of the continental slope needs to be developed. Bight 23 marks the fifth survey where macrobenthic and environmental data have been intensively collected from the deepwater habitats. These are the ideal data to be used in developing an assessment framework for these areas that would finally allow us to truly provide estimates of the condition of the region's coastal ocean versus the caveated results we presently produce.

### **2. Develop a causal assessment framework for different Southern California Bight habitats**

We have statistically rigorous bioassessment frameworks for evaluating the condition of embayment and continental shelf habitats. However, when severely impacted conditions are detected (e.g., embayment strata), or departures from reference conditions over time are observed, the Bight Regional Monitoring Program is not designed to determine the cause(s) of the alterations to community composition. However, Bight data combined with that from other more localized and frequent monitoring programs (e.g., Publicly Owned Treatment Works (POTWs), Water Quality Improvement Plans (WQIP), estuarine Marine Protected Areas), could provide a reasonable platform upon which a causal assessment framework could be built. Developing a causal assessment framework would assist ecosystem managers in understanding why sites are in poor condition so they could plan remediation actions. At a minimum, a coastal causal assessment framework should be able to distinguish between basin-scale (e.g., ENSO-PDO, climate change, ocean acidification) and local-scale (e.g., eutrophication, contaminants, physical disturbance) impacts. If developed, a coastal causal assessment program could be applied to help diagnose condition patterns observed during future Bight Surveys.

### **3. More fully incorporate climate and oceanographic change measures into the sediment quality components of future Bight surveys**

The Bight Program has traditionally been centered around assessing the condition of the region's soft sediment habitats, with an emphasis on the effects of legacy toxic chemicals and, to a lesser degree, eutrophication. Historically this made sense, as chemicals and excess nutrients have been important drivers of the health of the region's benthic and demersal biotic resources. However, with improvements in managing local anthropogenic discharges and land use, these types of stressors have become less important to the composition and abundance of the biota – especially in the offshore environment. Instead, changes in oceanographic circulation, water temperature, acidification, and dissolved oxygen appear to be impacting the biota, as illustrated by the decline in benthic community condition at the Channel Islands observed in Bight 13. Characterizing these aspects of regional water quality and composition have been included in recent Bight Programs, but they have tended to be collected spatially and temporally asynchronous to the benthic and demersal biological measurements. This disconnect makes it difficult to accurately interpret patterns of benthic community change and condition. We would recommend that *a priori* considerations are made in the design of future Bight surveys to better synchronize and incorporate water quality and oceanographic elements of the program with the sediment quality elements to provide a more holistic interpretation of patterns in condition of the region.

**4. Continue to update the taxonomy associated with the condition indices every Bight survey**

The taxonomic nomenclature of benthic infauna is a continuously evolving paradigm, where naming conventions improve over time as more information about the animals becomes available from the literature or the efforts of local SCAMIT taxonomists. As such, there is a high likelihood that the names of some of the taxa used in calculating benthic condition will change between Bight 23 and Bight 28. Before the present survey, the last consensus effort to update the taxonomy associated with the benthic indices was done during Bight 08. As such, there were a large number of taxa whose names needed to be updated. This effort took a number of people upwards of 10 work days to resolve.

Our recommendation is that if name changes are addressed every Bight survey, then the number of changes that need to be made will be relatively small. Furthermore, since a routine for checking and updating names has been created already, it can be replicated. Therefore, the process of addressing name changes in future Bight surveys should proceed much quicker and efficient manner. This will allow us to provide the most precise estimates of benthic habitat condition going forward.

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## **APPENDIX A – UPDATING OFFSHORE BENTHIC RESPONSE INDEX (BRI) TAXA**

Appendix A can be accessed here:

[https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486\\_B23BenthicInfaua\\_AppendixA.pdf](https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486_B23BenthicInfaua_AppendixA.pdf)

This appendix represents the best efforts of the Bight 23 Infauna Benthic Index Taxonomy subcommittee to update the taxa used in the offshore BRI (Benthic Response Index) (Smith et al. 2001) to match the taxonomic standards of 2023 (i.e., SCAMIT list Edition 14). This list, colloquially referred to as the p-code list, links organism names to specific p-codes, which connect to numeric pollution tolerance values created and detailed in Smith et al. (2001).

As part of this work, we did not change the p-code/tolerance values of any given taxon. Rather, the committee only updated the names associated with a given p-code to match present day taxonomic practice.

The taxonomy of benthic infauna is an evolving science, where names and relationships periodically change as better information becomes available in the literature or through day-to-day practice. As a consequence, users of the BRI and other benthic indices have periodically updated their own p-code lists. However, these local, or in-house changes most often happened independent of each other, which introduces the potential for small errors or differences in opinion to creep into the benthic indices.

The last concerted effort to update the p-code list using group consensus among the benthic ecologists and taxonomists of the region was in 2010, the BATMAN group, and this was used as the baseline to which changes would be made. Copies of the 2010 p-code list were provided by SCCWRP, ABC Labs, OCSan, and CLAEMD. These lists were all identical in content.

It is our intention that, in lieu of waiting another 13 years, a similar updating effort will take place every 5 years during a given Bight survey. We assume that this 2023 vintage list will then be updated, as needed. Our general approach was to compare the taxa names on the 2010 p-code list to the 2023 SCAMIT ed 14 list. Names that were on the 2010 list but not in SCAMIT ed 14 were deemed to have changed in some fashion. Potential replacements for those changed taxa were determined through an iterative process.

First, the 2010 name was compared to the SCAMIT ed 14 synonym list, which provides a history of name changes by SCAMIT - linking older, previously valid names to a 2023 standard. Where there were matches, the 2023 name was substituted onto the p-code list. Second, any 2010 name without a SCAMIT ed 14 synonym was searched for in the online WoRMS database (<https://www.marinespecies.org/index.php>) and the accepted synonym there was substituted onto the p-code list. Lastly, any remaining 2010 taxa deemed to have changed, but without a

clear 2023 name on either the SCAMIT list or WoRMS database were discussed among the subcommittee members.

Changes were characterized into one of 5 categories:

- **one-to-one:** changes where a 2010 name was changed/updated to a single new name - species A is now species B
- **split:** changes where a single 2010 name was changed into multiple new names - species A is now species B or species C
- **lump:** changes where multiple 2010 names were changed into a single new name - species A and species B are now species C
- **complex:** a catch all category for changes that do not fit into the previous three categories, most often complex splitting patterns - some specimens of species A are still species A, but others are now species B
- **spelling/convention:** changes where a spelling error was identified or there have been changes in naming convention - Species AA is supposed to be Species A or Species B is now Species cf. B

Each potential change was reviewed by the members of the subcommittee and approved by a simple majority vote before changes were recorded onto the 2023 p-code list.

An important additional piece of information associated with p-codes and the associated transition of their names from 2001 was the assignment of p-codes to higher taxonomic levels (e.g., genus or family). This propagation of a p-code to all, or some, daughter taxa was explicitly clarified in the 2010 updating of p-codes. We have preserved these propagation rules in the present update. Each instance of a propagation was reviewed by the subcommittee to make sure it made sense from a modern taxonomic perspective.

Table A1 - B23 BRI taxa history file represents the evolution of names associated with a given p-code from the 2001 original to 2010 to our present update. It contains the taxonomic definitions for each p-code from 2001 and 2010, the names from 2010, a yes/no indicator if the 2010 name was changed, a description of the type of change, the 2023 name, and the propagation rule.

Table A2 - ed14 p-code taxa is a simple table of p-codes and the SCAMIT ed14 standard name, including all propagations noted in the p-code definitions of Table 1. This is the file that is used by the new Bight 23 Rcode BRI calculator.

For context, the 2010 p-code review changed approximately 83 taxa (15%) from the original 2001 list. The present update changed 105 taxa (16%) from the 2010 list. Of the changes, 66%

were one-to-one, 19% were split, 4% were lump, 7% were complex, and 5% were spelling/convention changes.

#### **Members of the Bight 23 Benthic Index Subcommittee**

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## **APPENDIX B – UPDATING SQO BENTHIC INFAUNA LOOK-UP LIST TAXA**

Appendix B can be accessed here:

[https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486\\_B23BenthicInfana\\_AppendixB.pdf](https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486_B23BenthicInfana_AppendixB.pdf)

This appendix represents the best efforts of the Bight 23 Infauna Benthic Index Taxonomy subcommittee to update the taxa used in the Southern California Sediment Quality Objectives Benthic Line of Evidence (Bay et al 2021) to match the taxonomic standards of 2023 (i.e., SCAMIT list Edition 14). This list, colloquially referred to as the SQO look-up list, links organism names to specific sensitivity codes, taxonomic designations (mollusc or crustacean), SQO BRI tolerance values, and RIVPACS designations.

As part of this work, we did not change the designations or tolerance values of any given taxon. Rather, the committee only updated the names associated with a given assignment to match present day taxonomic practice. Taxonomy is an evolving science, where names and relationships periodically change as better information becomes available in the literature or through day-to-day practice. As a consequence, users of the SQO benthic indices and other benthic indices have periodically updated their own lookup lists. However, these local, or in-house changes most often happened independent of each other, which introduces the potential for small errors or differences in opinion to creep into the benthic indices.

The last concerted effort to update the SQO look-up list using group consensus among the benthic ecologists of and taxonomists of the region was in 2008 when the SQO BLOE was finalized and therefore this was used as the baseline to which changes would be made. A copy of the original 2008 look-up list associated with the Microsoft Excel-based SQO calculator was used as the baseline to which changes would be made. ABC and WSP provided copies of their most recent updated in-house look-up lists used for their SQO calculations. It is our intention that, in lieu of waiting another 15 years, a similar updating effort will take place every 5 years during a given Bight Survey and this 2023 vintage list will then be updated, as needed.

Our general approach was to compare the taxa names on the 2008 look-up list to the 2023 SCAMIT ed 14 list. Names that were on the 2008 look-up list but not in SCAMIT ed 14 were deemed to have changed in some fashion. Potential replacements for those changed taxa were determined through an iterative process. First, the 2008 name was compared to the SCAMIT ed 14 synonym list, which provides a history of name changes by SCAMIT - linking older, previously valid names to a 2023 standard. Where there were matches the 2023 name was substituted onto the list. Second, any 2008 name without a SCAMIT ed 14 synonym was searched for in the online WoRMS database (<https://www.marinespecies.org/index.php>) and the accepted synonym there was substituted onto the list. Lastly, any remaining 2008 taxa deemed to have

changed, but without a clear 2023 name on either the SCAMIT list or WoRMS database were discussed among the subcommittee members.

Changes were characterized into one of 5 categories:

- **one-to-one:** changes where a 2008 name was changed/updated to a single new name - species A is now species B.
- **split:** changes where a single 2008 name was changed into multiple new names - species A is now species B or species C.
- **lump:** changes where multiple 2008 names were changed into a single new name - species A and species B are now species C.
- **complex:** a catch all category for changes that do not fit into the previous three categories, most often complex splitting patterns - some specimens of species A are still species A, but others are now species B.
- **spelling/convention:** changes where a spelling error was identified or there have been changes in naming convention - Species AA is supposed to be Species A or Species B is now Species cf. B.

Each potential change was reviewed by the members of the subcommittee and approved by a simple majority vote before and changes were recorded onto the 2023 look-up list.

An important additional piece to consider with the SQO BLOE look-up list are the instances where values were assigned to higher taxonomic levels (e.g., genus or family) but not to individual daughter taxa. Due to the way the new Rcode SQO BLOE calculator works - transforming modern taxa back to the 2008 standard of the look-up list, values assigned to a parent taxon can be propagated to daughter taxa not already included on the look-up list

. By the nature of the look-up list's construction, if a binomial species (Genus A species 1) is on the list, as well as its parent genus (Genus A sp), the parent genus is retained for taxa richness/diversity counts but typically does not have any other tolerance or RIVPACS values associated with it.

Table B1 - Bight 23 SQO Appendix presents the name of a taxon on the original 2008 look-up list, an indication if it was changed, the type of change, and the new SCAMIT ed 14 standard name. Specifically, for each taxon from the 2008 SQO BLOE look-up list the table indicates if the name was changed (yes/no), the type of change, the new name that is used and then the BLOE-related designations: Designation as sensitive (S) or not (blank) under the IBI, its designation as a mollusc or crustacean for the IBI or RBI, its BRI tolerance score, whether the taxon is used in the RIVPACS model.

With this update, 203 taxa were changed (21%) from the original 2008 Southern California SQO BLOE look-up list. Among those taxa that were changed, 59% were one-to-one, 14% were split, 15% were lump, 5% were complex, and 6% were spelling/convention.

#### **Members of the Bight 23 Benthic Index Code Subcommittee**

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## **APPENDIX C – ENCOUNTERED TAXA LIST**

Appendix C can be accessed here:

[https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486\\_B23BenthicInfana\\_AppendixC.pdf](https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486_B23BenthicInfana_AppendixC.pdf)

## **APPENDIX D – DISSIMILARITY SIMPER OUTPUT**

Appendix D can be accessed here:

[https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486\\_B23BenthicInfana\\_AppendixD.pdf](https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486_B23BenthicInfana_AppendixD.pdf)

## **APPENDIX E – CONDITION CATEGORY AND REVISIT SITE CONDITION TREND EXTENT DETAILS**

Appendix E can be accessed here:

[https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486\\_B23BenthicInfana\\_AppendixE.pdf](https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486_B23BenthicInfana_AppendixE.pdf)

## **APPENDIX F – REVISIT SITE TREND REGRESSIONS**

Appendix F can be accessed here:

[https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486\\_B23BenthicInfana\\_AppendixF.pdf](https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1486_B23BenthicInfana_AppendixF.pdf)