CHAPTER 5

Benthic Infauna

Cover photos

Images of infauna taken by Norbert Lee (Senior Laboratory Technician), 2020.

Upper Left:	*Diopatra tridentata*, a polychaete worm found in benthic sediments off Palos Verdes in 2019.
Middle:	From left to right: Brent Haggin (Biologist II), guest scientist, and Bill Furlong (Biologist II) rinsing a benthic infauna sample while aboard the R/V Ocean Sentinel.
Lower Left:	A polychaete worm, *Malmgreniella baschi*, from a benthic sample taken off Palos Verdes in 2019.
Lower Right:	*Lanice conchilega*, a polychaete worm collected in 2019 off Palos Verdes.

Chapter 5 Benthic Infauna

INTRODUCTION

The Los Angeles County Sanitation Districts (Sanitation Districts) own and operate the Joint Water Pollution Control Plant (JWPCP), which discharges secondary treated effluent into the Pacific Ocean pursuant to the Waste Discharge Requirements and National Pollutant Discharge Elimination System (NPDES) permit issued by the Los Angeles Regional Water Quality Control Board (LARWQCB Order No. R4-2017-0180; **Appendix 1.1**). Monitoring and reporting requirements for the NPDES permit are specified in the Monitoring and Reporting Program (MRP) portion of the NPDES permit. The MRP specifies monitoring elements for the JWPCP and poses the question whether benthic conditions under the influence of the discharge are changing over time. This question concerns both the physical and chemical nature of the sediments and the structure and condition of the benthic biota. Responses to this question are provided in the present chapter on benthic infauna, Chapter 4 (Sediment Condition), Chapter 7 (Invertebrate and Fish Trawls), and for portions of the shelf in 2019, Chapter 6 (Sediment Toxicity).

Benthic infauna are monitored because they live in, or on, sediments. They have limited mobility and serve as food for higher trophic levels, such as demersal fish. They are a link between toxicants in the sediments and bioaccumulation in tissues of fishes, marine mammals, birds, and humans.

Physical habitat, especially depth and substrate type (e.g. sediment texture) are important determinants of community composition. Regional environmental conditions strongly influence recruitment, dispersal, and success of the biota. Palos Verdes' marine habitats have experienced a variety of major environmental events in the decades preceding this report, including oceanographic-related cycles, severe storms, and introduction of invasive species.

Prior to the 1970s, discharges onto the Palos Verdes shelf introduced large amounts of organic material and particulates bearing toxicants that impacted benthic community structure. Despite years of improved treatment and decreasing mass emissions of contaminants, a legacy deposit of pollutants remains in Palos Verdes sediments. These legacy contaminants, in combination with oceanographic and physical factors, complicate assessment of impact from the current discharge on the resident biota.

Chapter overview

This chapter is one component of the JWPCP 2018-2019 Biennial Receiving Water Monitoring Report (LACSD 2020a). The complete report includes results and analyses for all MRP receiving water monitoring requirements as well as the associated appendices. Electronic copies of the JWPCP 2018-2019 Biennial Receiving Water Monitoring Report can be downloaded through the Sanitation Districts' website, http://www.lacsd.org/.

MATERIALS AND METHODS

Field and laboratory

The sampling sites are arranged along 11 transects (Transects 0 through 10), and four isobaths (**Figure 5.1**). Moving from shallow to deeper stations, D stations were positioned at 30 m (the inner shelf), C stations were located at 61 m (mid-shelf; discharge depth), B stations were located at 152 m (the outer shelf), and A stations were at 305 m (the upper slope). Paired sediment chemistry (Chapter 4) and benthic infauna samples were collected with a 0.1 m^2 tandem Van Veen grab during the summers of 2018 and 2019 at each of the 44 sampling sites. During 2019, additional samples were collected for sediment toxicity (Chapter 6) testing at 24 of the stations on the shelf (30-152 m) which had also been sampled for biology and chemistry.

Benthic infauna retained on a 1 mm mesh screen were relaxed in magnesium sulfate and fixed in formalin. Once returned to the laboratory, the samples were transferred from the fixative, rinsed, and preserved in 70% ethyl alcohol. The organisms were sorted from non-living materials, separated to major groups, identified to lowest practicable taxon, and counted. More detailed presentation of field and laboratory handling and analytic technique can be found in **Appendix 5.1**.

Data analysis

All 2018-2019 benthic infaunal data were reported in the annual receiving water data summary reports (LACSD 2019, 2020b). Benthic data were analyzed using both univariate and multivariate statistical techniques to assess and

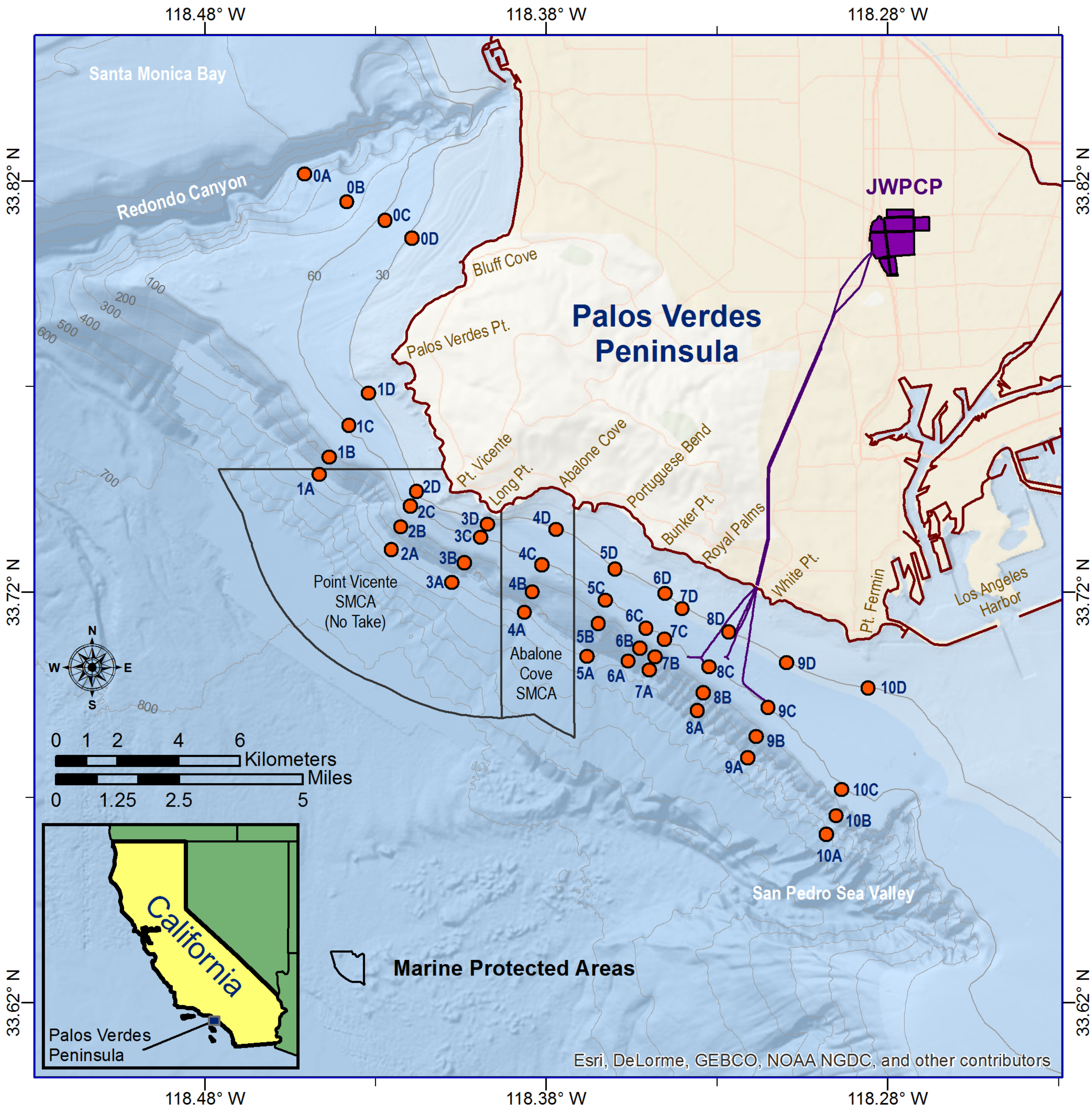

Figure 5.1 Palos Verdes Benthic Infauna Monitoring Stations
The stations are arranged along 11 transects (Transects 0 through 10), and four isobaths. D stations are positioned at 30 m (the inner shelf), C stations at 61 m (mid-shelf), B stations are located at 152 m (the outer shelf) and A stations are at 305 m (the upper slope). Benthic infauna samples were collected at 44 stations in 2018 and 2019. The Marine Protected Areas in Palos Verdes are outlined.

interpret changes over space and time. Number of individuals and species per sample, most abundant and most frequently encountered species, Shannon index (diversity, Shannon 1948), Margalef's index (species richness; Margalef 1958), Pielou's evenness index (evenness; Pielou 1969), and Simpson's dominance index (dominance; Simpson 1949) were evaluated as measures of community structure and status. An overview of all data analysis methods can be found in **Appendix 5.2**.

Biointegrity, another measure of community health, is defined as "the capability of an ecosystem to support and maintain a balanced, integrated and adaptive community of organisms, having species diversity, composition and functional organization comparable to that of the natural habitats of the region" (Karr and Dudley 1981). Biointegrity is a relative measure that assesses the degree to which the biological condition of an area has been modified relative to its natural state. The biointegrity of Palos Verdes infauna was assessed using the Benthic Response Index (BRI), an index of infaunal community response to environmental disturbance **(**Smith et al. 2001; **Appendix 5.3**). Data from the Palos Verdes shelf were instrumental in its construction, and it is useful in evaluating the biointegrity of benthic communities in the vicinity of JWPCP effluent exposure.

Spatial and temporal trends were examined by comparing the patterns of several parameters relative to sampling depth (inner shelf to upper slope), distance from the outfall, and wastewater treatment period. Wastewater treatment periods included Baseline (1972-1973), Advanced Primary (1974-1983), Partial Secondary (1984-2002), Full Secondary (2003-2017) and Current (2018-2019).

PRIMER v7 (Plymouth Routines in Multivariate Ecological Research) multivariate statistical software was used to examine the patterns of infaunal assemblages on the Palos Verdes shelf (Clarke and Gorley 2015). Multivariate analyses (Clarke et al. 2014) included hierarchical clustering based on Bray-Curtis similarity, similarity profile analysis (SIMPROF), ordination clustering using non-metric multidimensional scaling (NMDS), SIMPER ("similarity percentages") to determine inter- and intra-group species differences (Clarke 1993), and analysis of similarity (ANOSIM) to test for spatial (depth and distance from outfall) and temporal (changes over time and treatment period) differences in community composition (Appendix 5.2).

RESULTS

Samples collected in 2018 and 2019 contained 42,143 organisms representing 824 taxa (**Table 5.1**, LACSD 2019, 2020b). Averages for the two-year period are given in Table 5.1 and detailed data tables are contained in **Appendix 5.4**.

The top ten most abundant infaunal species were all polychaete worms comprising 34% of the total abundance. Eight of the top ten most frequently occurring taxa, measured as the percentage of samples in which each species occurred, were polychaete worms; the remainder were a species of bivalve mollusk, *Tellina* sp B, and one species of nemertean worm, *Tubulanus polymorphus*. Additional details can be found in Appendix 5.4.

Annelids taken during 2018-2019 were numerically dominant, representing 78% of total abundance. Arthropods were second most abundant representing 6.5% of the total. Mollusks were third most abundant, representing 5.2% of the total.

Annelids were also the most diverse infaunal group. There were approximately 423 annelid taxa, representing over half of all taxa. Arthropods were the second most diverse group. There were 153 arthropod taxa representing 18% of all taxa. Mollusks were the third most diverse with 122 mollusk taxa representing 15% of total taxa.

Taxonomic groups that have been typically less abundant (including nemerteans, echinoderms, cnidarians, chordates, platyhelminths, sipunculids, phoronids, bryozoans, brachiopods, and entoprocts) included 4,268 individuals representing 126 taxa. Of the minor phyla, nemerteans were most abundant and most diverse with 1,057 individuals, representing 29 taxa. Echinoderms were the second most abundant and second most diverse of the minor phyla, with 691 individuals representing 34 taxa. Sipunculid worms were the third most abundant with 681 individuals but represented only four taxa. (Appendix 5.4).

Table 5.1 Benthic Community Metrics, 2018-2019

Two-year average results at each station for abundance, number of taxa, Simpson Dominance Index (Dominance), Shannon Diversity (Diversity), Pielou's Evenness (Evenness) and the Benthic Response Index (BRI). Averages by depth, all of Palos Verdes, and totals are in **bold**.

Depth (m)	Transect	Abundance	Number of Taxa	Diversity	Evenness	Dominance	BRI
30	**0**	335	104	3.9	0.86	0.04	23
	1	1,152	166	3.9	0.79	0.04	23
	2	889	119	3.3	0.72	0.10	20
	3	907	177	4.2	0.83	0.03	26
	4	595	141	4.1	0.86	0.03	27
	5	638	141	3.9	0.81	0.05	29
	6	708	140	4.0	0.82	0.04	27
	7	1,112	164	3.8	0.77	0.05	25
	8	711	147	4.0	0.82	0.04	26
	9	1,058	168	4.0	0.81	0.04	24
	10	1,433	186	4.0	0.78	0.04	24
30 m Average		**867**	**150**	**3.9**	**0.81**	**0.04**	**25**
61	**0**	356	89	3.8	0.86	0.04	20
	1	446	112	3.7	0.80	0.08	17
	2	471	110	3.8	0.82	0.06	21
	3	339	94	3.6	0.82	0.06	19
	4	289	79	3.7	0.85	0.05	20
	5	378	97	3.8	0.87	0.04	22
	6	470	102	3.7	0.81	0.05	24
	7	625	129	3.9	0.82	0.04	22
	8	1232	167	3.7	0.75	0.06	24
	9	607	139	3.9	0.80	0.05	20
	10	577	145	4.2	0.86	0.03	17
61 m Average		**526**	**115**	**3.8**	**0.82**	**0.05**	**21**
152	**0**	124	39	2.7	0.76	0.16	25
	1	612	107	3.5	0.78	0.06	18
	2	547	93	3.4	0.76	0.07	21
	3	483	72	3.3	0.80	0.07	25
	4	394	72	3.5	0.83	0.06	26
	5	483	81	3.1	0.74	0.10	27
	6	331	55	3.0	0.77	0.11	29
	7	217	48	3.2	0.85	0.07	31
	8	517	68	3.1	0.76	0.09	27
	9	567	79	3.0	0.73	0.09	23
	10	437	90	3.6	0.81	0.05	20
152 m Average		**428**	**73**	**3.2**	**0.78**	**0.08**	**25**
305	**0**	44	23	2.7	0.90	0.09	24
	1	57	21	2.4	0.79	0.18	27
	2	97	38	3.1	0.88	0.07	20
	3	129	40	2.7	0.76	0.15	27
	4	134	38	2.8	0.81	0.12	29
	5	188	49	2.9	0.78	0.11	26
	6	153	35	2.8	0.83	0.09	31
	7	48	22	2.4	0.80	0.16	30
	8	58	18	2.2	0.75	0.20	35
	9	66	22	2.4	0.80	0.15	33
	10	71	29	2.8	0.83	0.11	23
305 m Average		**95**	**30**	**2.7**	**0.81**	**0.13**	**28**
Palos Verdes Average		**479**	**92**	**3.4**	**0.81**	**0.08**	**24**
Total		**42,143**	**824**				

DISCUSSION

Current condition, 2018-2019

Depth, not proximity to the discharge, was the primary determinant of infaunal community structure in 2018-2019. Mean abundance declined with increasing depth. Infaunal mean abundance at 305 m was roughly 11% of what was observed at 30 m (Table 5.1, Appendix 5.4). There were some spatial patterns across the shelf, but none of them implied a difference in overall condition of the community structure. For abundance, this pattern included a general pattern of higher abundance observed nearer the outfall with abundance generally declining downcurrent between Transect 8 and Transect 3. For the number of taxa per station, values on the shelf (30 -152 m) generally increased from Transect 7 to Transect 10 (Table 5.1, Appendix 5.4), again, with no implications for community health.

Diversity, used to describe species composition in a community, accounts for both number of species and evenness of the species present. In general, as species richness and evenness increase, diversity increases. In 2018-2019, average diversity was highest at 30 m and 61 m and declined with increasing depth. There was no discernable pattern in diversity with distance from the outfall. In a regional comparison, species diversity values were comparable to mean SCB 2013 values on the shelf and slope (Gillett et al. 2017), an indication of an unimpacted benthic community relative to the rest of the region.

Evenness is a measure of the relative abundances of species in a sample. There was no pattern to evenness by depth or transect (Table 5.1). Mean evenness values for the shelf and slope in 2018-2019 were at or above mean SCB 2013 values at the same depths (Gillett et al. 2017), further indication of an unimpacted benthic community relative to the rest of the region.

Dominance measures the probability that two individuals randomly selected from a sample are of the same species. Higher dominance equates to fewer species composing the total abundance in a sample. In 2018-2019, average dominance between stations was similar at shelf depths, and highest on the upper slope (Table 5.1, Appendix 5.4). In general, dominance followed a pattern inverse to diversity (Table 5.1), with an increase in values that was nearly linear to increasing depth.

A slightly different pattern was evident in the biointegrity data. To aid interpretation of BRI results, five thresholds of response to pollution stress are defined. The first two thresholds define Reference Condition (BRI score ≤ 25) and Marginal Deviation (BRI 26-33) from reference, the latter of which may be an indication of stress but could also be due to random variability. For the purposes of this report, and in alignment with the standards established during SCB 2008 (Ranasinghe et al. 2012), these two thresholds represent areas that are most likely unimpacted by sediment contaminants. The remaining thresholds categorize increasingly significant deviation from Reference Condition. Loss in Biodiversity, where 25% of the reference species-pool no longer occurs, was associated with BRI scores 34-43, Loss of Community Function (where 90% of echinoderms and 75% of arthropod species are not present) at BRI 44-71, and Defaunation (where 90% of the reference species-pool is lost) at BRI ≥72.

BRI values indicative of unimpacted benthic communities were found around the outfall at discharge depth and for all sites on the Palos Verdes shelf (31-152 m) in 2018-2019 (Table 5.1, **Figure 5.2**). However, one site, station 8A on the upper slope (305 m), had impacted BRI scores (Loss in Biodiversity). This station is downslope of the outfall and may be associated with remnants of legacy organics, as discussed in Chapter 4. However, BRI performance at these greater depths may be inaccurate as discussed below (Ranasinghe et al. 2012).

For a regional comparison, the SCB 2013 scoring system was used in which the BRI thresholds of Reference condition and Marginal deviation from reference (Response Level 1) indicate “good” condition (Gillett et al. 2017). The Loss in biodiversity (Level 2), Loss of community function and Defaunation (both Level 3) categories all indicate “poor” condition. BRI scores in Palos Verdes in 2018-2019 at each shelf depth (30-152 m) indicated communities were in “good” condition and were within the same category of SCB 2013 values at comparable depths (Gillett et al. 2017).

During SCB 2013, BRI scores from locations deeper than 200 m (slope and basin samples) were not evaluated due to concerns about potential inaccuracies of the BRI closer to its upper depth limit, 324 m (Ranasinghe et al. 2012). Therefore, a comparison of Palos Verdes upper slope (305 m) BRI scores to those at

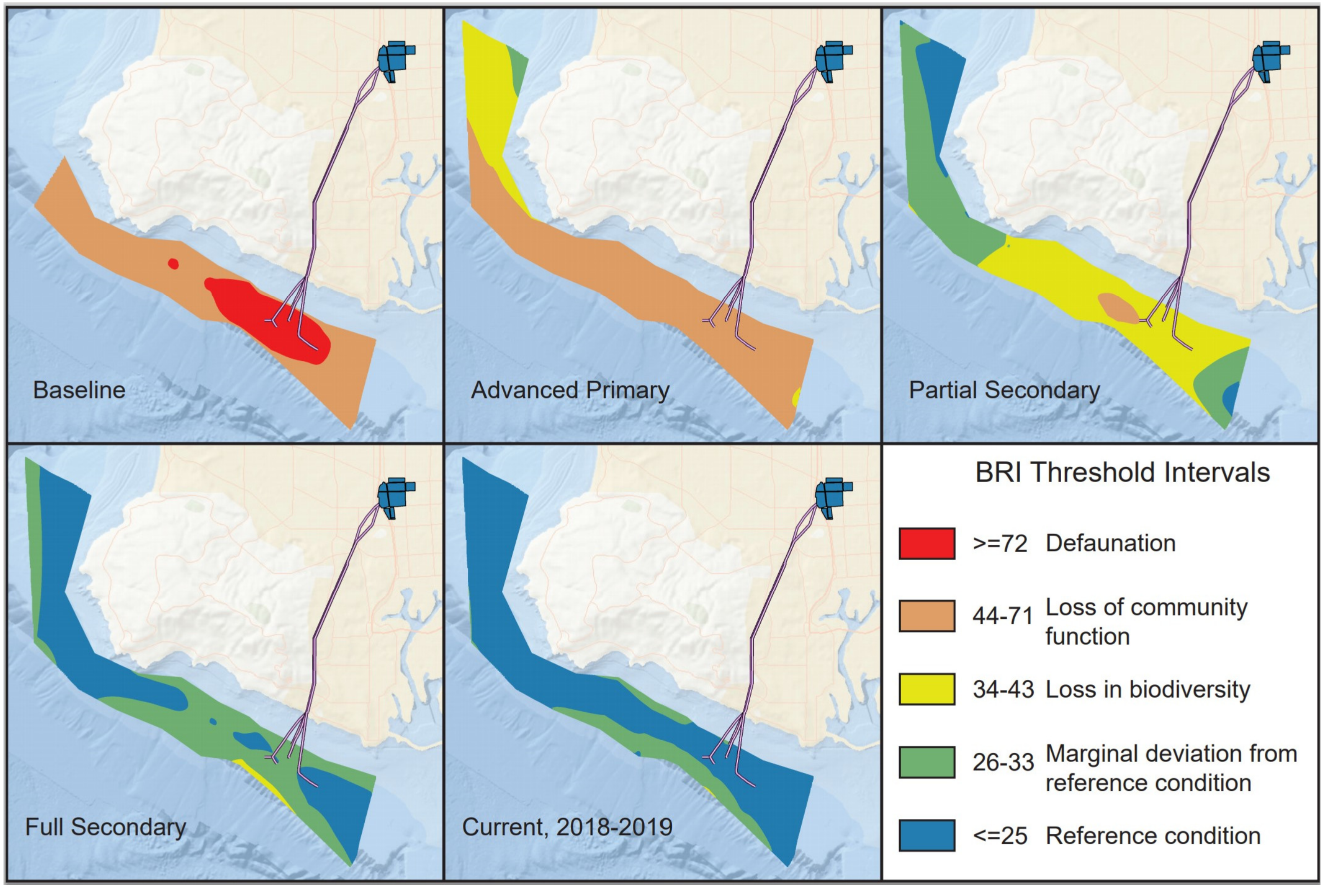

Figure 5.2 Biointegrity of Palos Verdes Benthos, 1972-2019
Temporal trends in biointegrity during each wastewater treatment period as measured by the Benthic Response Index (BRI).

similar depths in the surrounding region cannot be made at this time.

Historical trends, 1972-2019

Community structure is influenced by a variety of factors, including pollution level and species' interactions such as predation, physical disturbances, and oceanic climate fluctuations (LACSD 2012). In Palos Verdes, temporal trends in overall benthic community structure and condition relative to improving effluent discharge quality and sediment conditions are evident, with the prevailing trend of community recovery over time All community metrics including benthic infaunal abundance, number of taxa, diversity, and dominance (Appendix 5.4) indicate impacted conditions during early treatment periods, followed by recovery as treatment levels improved over time. The earliest signs of recovery were further from the outfall. By the partial secondary treatment period (1984-2002), patterns began to be more related to depth than proximity to the outfall.

A shift in benthic community structure over time was also supported in multivariate analyses of the Palos Verdes shelf (**Figure 5.3, Appendix 5.5**) which is further evidence of the recovery of the ecosystem. The relative strength of the two primary gradients, depth and outfall proximity, reversed over the monitoring history. During the baseline treatment period, the gradient of proximity to the outfall was strongest. The depth gradient is now clearly dominant, with some lesser influence associated with distance from outfall. Depth as a primary determinant of infaunal community structure has also been documented as an indicator of reference condition elsewhere in the SCB (Gillett et al. 2017). This reversal of gradient dominance reflected recovery of the ecosystem over time.

The shift is consistent with the temporal and spatial trends seen in biointegrity.

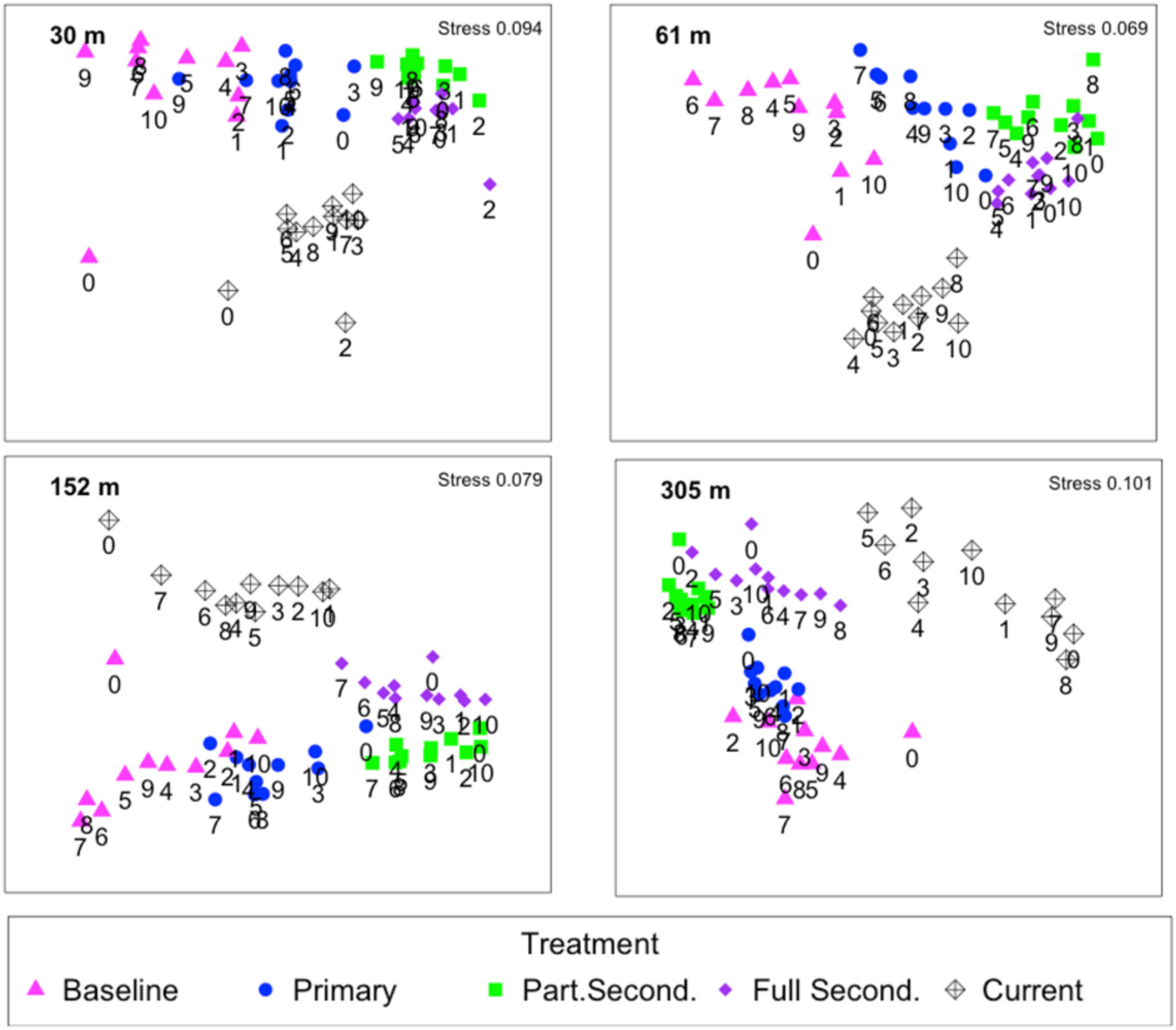

Figure 5.3 Trends in Infaunal Assemblages, 1973-2019
Non-metric multidimensional scaling (NMDS) ordination of benthic infaunal assemblages at each depth based on the Bray-Curtis similarity index of log-transformed mean abundance.
Note: There were no samples at transect 0 during the Baseline treatment period.

Examples of the recovery over time can be seen as the types of benthic species changed. In the 1970s (baseline and early advanced primary treatment periods), large numbers of deposit feeding worms and bivalves characterized the Palos Verdes benthic community. More benthic filter feeders, predators, arthropods, and burrowers, as well as higher species diversity, and greatly reduced density have characterized the past decade. In the 1980s and 1990s (advanced primary to partial secondary periods), intermediate conditions prevailed as reflected in benthic community structure and its constituent populations (Figure 5.3, Appendix 5.4, Appendix 5.5).

As sediment conditions nearer the outfall improved, many species expanded their ranges to include areas nearest the outfall, while other, more pollution-tolerant species lost their competitive advantage and declined. The individual species response is indicative of improving effluent quality and sediment conditions near the outfall. Examples of such species shifts include *Parvilucina tenuisculpta* and *Capitella capitata* Cmplx, a group of cryptic polychaete worms prevalent in the baseline and early advanced primary treatment periods and associated with impacted areas. Both have been sharply lower in abundance since the 1990's, which coincided with conditions changing during the partial secondary treatment period. Similarly, *Amphiodia* spp and *Paraprionospio alata* were absent from Palos Verdes in the 1970's (baseline and early advanced treatment periods) but became widespread in later years (Appendix 5.5).

Biointegrity

Temporal trends associated with the biointegrity of Palos Verdes infauna are discussed here using the BRI (Smith et al. 2001). The pattern of BRI values off Palos Verdes, averaged by treatment period from 1972-2019 is presented in Figure 5.2. The numeric values for all survey years are presented in Appendix 5.4. Both temporal and spatial recovery of the health of the benthic community is evident and described below.

BRI values during the Baseline treatment period were very high (poor biointegrity) and the gradient away from the outfall sites was steep (Figure 5.2). All sites, including those most distant from the outfall, were above the threshold for Loss of Community Function and over half of the stations exhibited Defaunation. During the Advanced Primary treatment period (1974-1983), the earliest recovery was seen at stations far from the discharge, followed by declining BRI values approaching the outfall transect over time.

By the start of Partial Secondary in 1984, index values had fallen and the difference between distant and near outfall sites lessened. All sites were below the Defaunation threshold, fewer stations at discharge depth (61 m) were in Loss of Community Function status. By the end of the Partial Secondary period, most 61m stations had recovered to Reference Condition, with fewer in Loss of Community Function status.

After the effluent quality was further improved to Full Secondary in late 2002, BRI numbers continued to drop (Appendix 5.4). During the Current treatment period (2018-2019) all sites at shelf depth had recovered to unimpacted categories (Table 5.1, Figure 5.2).

On the upper slope (305 m), the BRI category for two stations downslope of the outfall remains in Loss in Biodiversity condition, despite the improvements of the past few decades. However, signs of recovery continue. The number of deep stations in Loss in Biodiversity condition has consistently decreased over time. Also, during the Current treatment period (2018-2019), none of the deepest stations remain in either Defaunation or Loss of Community Function status, whereas all of them were in one of those categories during the earliest treatment periods. Although the index was calibrated with samples up to 324 m deep, there are concerns regarding regional BRI performance at slope depth which may reduce the accuracy of the BRI in some of the Palos Verdes slope stations (Ranasinghe et al. 2012). This also brings to question the validity of using the BRI scores as the sole measure of biointegrity at slope depth.

CONCLUSIONS

The structure of the infaunal community in 2018-2019 remained similar to that seen since implementation of full secondary treatment. Annelid (polychaete) worms were predominant, with arthropods and mollusks of successively less density and diversity. This is in sharp contrast to the Baseline (1972-1973) and Advanced Primary (1974-1983) treatment periods, when mollusks were far more abundant and arthropods much less abundant and diverse.

Although annelid worms have remained the most significant fraction of the community, the composition of that fraction has changed over time. Species tolerant to pollution that were once dominant during the Baseline treatment period have declined strongly in abundance or have disappeared altogether, while pollution-sensitive species found sparingly at sites distant from the outfall during the same period have become dominant across the Palos Verdes shelf. This reflects the recovery of the Palos Verdes benthic community from the impacted state exhibited during the Baseline treatment level period.

Improvements in effluent quality have contributed greatly to this recovery, as have burial of legacy toxicants, and reductions in the legacy organic enrichment of sediments. This latter change has contributed to the almost complete disappearance of toxic hydrogen sulfide from pore waters on the shelf (Chapter 4).

All of these changes have aided the recovery of the benthos.

Benthic community metrics such as diversity give further indication that the benthic community has improved over time. Similarly, the biointegrity (e.g. BRI) of the benthic community has been improving over time off Palos Verdes, which confirms that discharge influences have been greatly reduced. Trends of improving condition continue as large portions of the study area have returned to Reference Condition. This improvement accelerated following the upgrade to full secondary treatment in late 2002.

This recovery is not yet complete, despite the great improvements already evident. Residual signals of impact remain in BRI values still outside the reference range on the upper slope. These results are likely legacy effects from remnant deposits of organically enriched sediment near the discharge (Chapter 4). The current level of suspended solids discharge (Chapter 1) is extremely low making it highly unlikely that the observed response stems from current inputs.

LITERATURE CITED

Clarke KR. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18:117-143.

Clarke KR, Gorley RN. 2015. PRIMER v7: User Manual/Tutorial. Plymouth, UK: PRIMER -E.

Clarke KR, Gorley RN, Somerfield PJ, Warwick RM. 2014. Change in marine communities: an approach to statistical analysis and interpretation. 3rd ed. PRIMER-E: Plymouth, UK. 260pp.

Gillett DJ, Lovell LL, Schiff KC. 2017. Southern California Bight 2013 Regional Monitoring Program: Volume VI. Benthic Infauna. Costa Mesa, CA: Southern California Coastal Water Research Project, Technical Report 971.

Karr JR, Dudley DR. 1981. Ecological perspective on water quality goals. Journal of Environmental Management 5:55-68.

[LACSD] Los Angeles County Sanitation Districts. 2012. Joint Water Pollution Control Plant annual monitoring report 2011. Whittier, CA: Los Angeles County Sanitation Districts, Treatment Plant Monitoring Group, Technical Services Department.

[LACSD] Los Angeles County Sanitation Districts. 2019. 2018 annual receiving water data summary report [electronic file]. Whittier, CA: Los Angeles County Sanitation Districts, Ocean Monitoring and Research, Technical Services Department.

[LACSD] Los Angeles County Sanitation Districts. 2020a. Joint Water Pollution Control Plant biennial receiving water monitoring report 2018-2019. Whittier, CA: Los Angeles County Sanitation Districts, Technical Services Department.

[LACSD] Los Angeles County Sanitation Districts. 2020b. 2019 annual receiving water data summary report [electronic file]. Whittier, CA: Los Angeles County Sanitation Districts, Ocean Monitoring and Research, Technical Services Department.

Margalef R. 1958. Information theory in ecology. General Systems 3:36-71.

Pielou EC. 1969. An introduction to mathematical ecology. New York, NY: Wiley-Interscience. p. 286.

Ranasinghe JA, Schiff K, Brantley CA, Lovell LL, Cadien DB, Mikel TK, Velarde RG, Holt S, Johnson SC. 2012. Southern California Bight 2008 regional monitoring program: VI. Benthic macrofauna. Costa Mesa, CA: Southern California Coastal Water Research Project, Technical Report 665.

Shannon CE. 1948. A Mathematical Theory of Communication. The Bell System Technical Journal 27:379-423, 623-656.

Simpson EH. 1949. Measurement of diversity. Nature 163:688.

Smith RW, Bergen M, Weisberg SB, Cadien DB, Dalkey A, Montagne DE, Stull JK, Velarde RG. 2001. Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications 11(4):1073-1087.

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