2020

Annual Report of the Status of Condition C: Kelp Reef Mitigation

SAN ONOFRE NUCLEAR GENERATING STATION (SONGS) MITIGATION PROGRAM

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1.0 Executive Summary

Condition C of the San Onofre Nuclear Generating Station's (SONGS) coastal development permit requires Southern California Edison (SCE) and its partners to construct an artificial reef that is large enough to support 28 tons of reef fish and a minimum of 150 acres of functioning and sustainable kelp forest habitat as partial mitigation for the adverse impacts of SONGS operations to the San Onofre kelp forest. The artificial reef (named the Wheeler North Reef) was constructed in phases: an initial small-scale experimental phase used to test different reef designs and a larger mitigation phase used to meet the mitigation requirement of creating at least 150 acres of kelp forest habitat. Construction of the mitigation phase was completed in 2008 and monitoring of the physical and biological attributes of the Wheeler North Reef and two nearby reference reefs (San Mateo and Barn kelp beds) has been completed each year since then. Results of monitoring and additional studies showed that the combined configuration of the Phase 1 and 2 reefs was too small for the Wheeler North Reef to consistently meet the performance standards pertaining to fish standing stock and area of adult giant kelp. Consequently, the CCC required SCE to remediate this deficiency by expanding the existing Phase 1 and 2 Wheeler North Reef to include additional acreage. Construction of a 197.5-acre Phase 3 remediation reef occurred during the summers of 2019 and 2020.

Performance standards for reef substrate, giant kelp, fish, and the benthic community of algae and invertebrates are used to evaluate the success of the Wheeler North Reef in meeting the intended goal of replacing the kelp forest resources damaged or lost by SONGS operations. Absolute performance standards are evaluated only at the Wheeler North Reef, whereas relative performance standards are used to compare the Wheeler North Reef with two natural reference reefs (San Mateo and Barn) in the San Onofre region. Annual monitoring is done to determine whether the Wheeler North Reef has met these standards. The monitoring is overseen by the California Coastal Commission (CCC) and is done independently of SCE. This report summarizes the monitoring results through 2020.

Mitigation credit for meeting the relative performance standards and the absolute performance standards pertaining to hard substrate and invasive species is assigned on an annual basis and fulfillment of these requirements is achieved when the number of years of mitigation credit equals the number of years of SONGS Units 2 and 3 operations (=32 years). In 2020 the Wheeler North Reef met the absolute performance standards pertaining to hard substrate and invasive species and nine of the 11 relative performance standards, which was one less than that met by Barn, but 3 more than that met by San Mateo. Therefore, the Wheeler North Reef was deemed successful in terms of these requirements because it met the absolute standards for hard substrate and invasive species and three more relative standards than the San Mateo bed, the lower performing reference reef. Consequently, the Wheeler North Reef earned one year of mitigation credit in 2020 for meeting this collective group of performance standards for a cumulative total of two years of mitigation credit and needs another 30 years of mitigation credit to fulfill its mitigation requirement for these performance standards.

Mitigation credit for the absolute performance standards pertaining to the area of adult giant kelp and the standing stock of reef fish is assigned on a cumulative basis in which the amount supported by the Wheeler North Reef in any given year is added to the cumulative total of previous years. Fulfillment for each of these two performance standards occurs when the cumulative total for each reaches the mitigation requirement based on a desired annual value and the number of years of SONGS Units 2 and 3 operations. In 2020 the Wheeler North Reef earned credit for 4 acres of giant kelp for a cumulative total of 38 acres, and 22 tons of reef fish for a cumulative total of 40 tons. It needs an additional 4762 acres of kelp credit and 856 tons of fish standing stock credit to fulfill these two mitigation requirements.

In sum, the monitoring results to date show that the Wheeler North Reef has demonstrated considerable promise in meeting many of its objectives. Importantly, it has shown no decline in the area of hard substrate available to reef biota or loss of important reef functions due to invasive or undesirable species, and it has been shown to perform similarly to natural reference reefs across a broad suite of criteria, including kelp area and reef fish standing stock. The recently approved Phase 3 expansion should add substantial mitigation value as it has been designed to enable the Wheeler North Reef to meet the requirements for giant kelp area and reef standing stock within a time frame equivalent to the operating life of SONGS Units 2 and 3 (i.e., 32 years) with a high level of confidence.

2.0 Introduction

2.1 Purpose of Report

This report focuses on Condition C of the San Onofre Nuclear Generating Station's (SONGS) coastal development permit 6-81-330-A (California Coastal Commission 1997), which pertains to mitigation for SONGS impacts to giant kelp and associated biota. Southern California Edison (SCE) and the California Coastal Commission (CCC) have clear and distinct roles in the implementation of Condition C. Under the condition, SCE is required to construct an artificial reef that supports 28 tons of reef fish and creates a minimum of 150 acres of functioning and sustainable kelp forest habitat. The CCC is to provide scientific oversight and monitoring of the artificial reef mitigation that is independent of SCE. This report presents the results from the independent monitoring of the performance of the SONGS artificial reef (hereafter referred to as the Wheeler North Reef) from 2009 – 2020 and summarizes the status of the project's compliance with Condition C of the SONGS permit for this period.

2.2 Background

SONGS Operations

In 1974, the California Coastal Zone Conservation Commission issued a permit (No. 6-81-330-A, formerly 183-73) to SCE for Units 2 and 3 of the San Onofre Nuclear Generating Station (SONGS). SONGS is located on the coast in north San Diego County. Construction of SONGS Units 2 and 3 was completed in 1981. Operation of Units 2 and 3 began in 1982 and 1983, respectively and each unit generated up to 1,100 MW of electric power. Both reactors were shut down in January 2012 due to excessive wear in the cooling tubes of the steam generators, and in June 2013 both units were permanently retired. SCE's operating license has been modified to "possession only" and they are no longer authorized to operate the reactors. Full retirement of the units prior to decommissioning is expected to take several years in accordance with customary practices; actual decommissioning will take many years until completion.

The SONGS Unit 2 and 3 reactors are cooled by a single pass seawater system and have separate intake lines, each 18 feet in diameter, that are located in about 30 feet of water offshore of the power plant. The volume of water taken in each day by these two intake lines when Units 2 and 3 were fully operational was about 2.4 billion gallons, equivalent to a square mile 12 feet deep. Since the shutdown, the flow in each unit has been reduced to about 42 million gallons a day or roughly 2% of the normal operating flow.

The discharge pipe for Unit 2 terminates 8,500 feet offshore, while the discharge pipe for Unit 3 terminates 6,150 feet offshore. The last 2,500 feet of the discharge pipes for Units 2 and 3 consist of a multi-port diffuser that rapidly mixes the cooling water with the surrounding water. The diffusers for each unit contain 63 discharge ports angled offshore that increase the velocity of the discharge. Under normal operations the discharge water was approximately 19°F warmer than the intake water temperature. The diffusers were designed to cool the discharge water by increasing its mixing with ambient seawater at a rate of about ten times the discharge flow. The surrounding water was swept up along with sediments and organisms and transported offshore at various distances. Mixing caused by the diffuser system resulted in the formation of a turbid plume in the vicinity of the San Onofre kelp forest, which is located adjacent and south of the two diffuser lines.

SONGS Impacts

A condition of the SONGS permit required study of the impacts of the operation of Units 2 and 3 on the marine environment offshore from San Onofre and mitigation of any adverse impacts. The impact assessment studies found that the SONGS cooling water system for Units 2 and 3 had major adverse impacts to living marine resources, which included:

- Projected reductions in populations of adult fish throughout the Southern California Bight based on losses of fish eggs and immature fish entrained by the cooling water intakes and killed inside the power plant.
- Measured reductions in local populations of adult fished caused by the mortality of fish impinged against the cooling water screens inside the power plant.
- A substantial reduction in the size of the giant kelp forest and its associated community adjacent to the SONGS diffusers.

Mitigation Requirements

As a result of the impact studies, in 1991 the CCC added new conditions to mitigate the adverse impacts of the power plant on the marine environment that require SCE and its partners to: (1) create or substantially restore at least 150 acres of southern California wetlands as out-of-kind mitigation for the losses of immature fish to entrainment in the power plant’s cooling water system (Condition A), (2) install fish barrier devices at the power plant to reduce the losses of adult fish killed in the plant (Condition B), and (3) construct a 300-acre kelp reef as in-kind mitigation for the loss of giant kelp forest habitat (Conditions C). The 1991 conditions also required SCE and its partners to provide the funds necessary for CCC to contract marine scientists to perform technical oversight and independent monitoring of the mitigation projects (Condition D). In 1993, the CCC added a requirement for SCE to partially fund construction of an experimental white sea bass hatchery. Due to the experimental nature of the hatchery, the CCC did not assign mitigation credit to its operation.

After extensive review of new kelp impact studies, in April 1997 the CCC approved amended conditions that revised the kelp mitigation requirements in Condition C. Specifically, the revised Condition C requires SCE to construct an artificial reef large enough to sustain 150 acres of medium to high density kelp bed that supports 28 tons of reef fish (which could result in a reef larger than 150 acres) together with funding for a mariculture/marine fish hatchery as compensation for the estimated loss of 179 acres of a medium to high density kelp bed and associated community resulting from the discharge of cooling water from SONGS Units 2 and 3. Condition C requirements for the artificial reef consist of two phases, an initial small experimental reef (~24 acres) and a subsequent mitigation reef that is large enough to meet the 150-acre kelp and 28 ton fish standing stock requirements. The purpose of the Phase 1 Experimental Reef was to determine which combinations of substrate type and substrate coverage would most likely achieve the performance standards specified in the permit. The design of the Phase 2 Mitigation Reef was to be contingent on the results of the Phase 1 Experimental Reef.

The CCC also confirmed in April 1997 its previous finding that independent monitoring and technical oversight were required in Condition D to ensure full mitigation under the permit. Condition D requires SCE and its partners to fund scientific and support staff retained by the CCC to oversee the site assessments, project design and implementation, and monitoring activities for the mitigation projects. Scientific expertise is provided to the CCC by a technical oversight team hired under contract. The technical oversight team members include three Research Biologists from UC Santa Barbara: Steve Schroeter, Ph.D., marine ecologist, Mark Page, Ph.D., wetlands ecologist, and Dan Reed, Ph.D., kelp forest ecologist. In addition, a science advisory panel advises the CCC on the design, implementation, monitoring, and remediation of the mitigation projects. Current science advisory panel members include Richard Ambrose, Ph.D., Professor, UCLA, Peter Raimondi, Ph.D., Professor, UC Santa Cruz, and Russell Schmitt, Ph.D., Professor, UC Santa Barbara. In addition to the science advisors, the technical oversight team is aided by a crew of marine biologists hired under a contract with the University of California, Santa Barbara to collect and assemble the monitoring data. The technical oversight team is also assisted by independent consultants and contractors on an as need basis when expertise for specific tasks is required. Of particular note in this regard are Drs. Mark Steele and Mia Adreani of California State University Northridge who have contributed to studies of fish growth and reproduction since 2009. The CCC's permanent staff also spends a portion of their time on this program, but their costs are paid by the CCC and are not included in the SONGS budget.

3.0 Project Description

Mitigation for SONGS impacts to the San Onofre kelp forest through the construction of an artificial reef is being done in phases: a short-term, small-scale experimental phase for testing different reef designs, followed by a longer-term, larger-scale mitigation phase that is intended to compensate for the kelp forest resources lost due to SONGS' operations. The implementation of an additional remediation phase is to be contingent on whether the mitigation phase fully compensates for the lost resources. The information gained from the Phase 1 Experimental Reef was used to design the larger Phase 2 Mitigation Reef. The mitigation phase is to have a minimum duration equivalent to the operating life of SONGS Units 2 and 3 including the decommissioning period to the extent there are continuing discharges.

SONGS Unit 2 began operations in 1982 and Unit 3 in 1983. Both Units ceased operations in 2013, but continue to discharge approximately 2% of the volume of their full operational flow, resulting in a significantly reduced turbidity plume extending from the discharge pipes. This turbidity plume was the primary cause for the reduction in the San Onofre kelp bed as determined by the Marine Review Committee in the initial SONGS impact assessment studies (MRC 1989). In March 2019 the CCC concluded that it is unlikely that the greatly reduced flow would continue to cause significant adverse impacts to the kelp bed community off San Onofre and thus defined the operating life of SONGS as the beginning of 1982 to the end of 2013 (= 32 years).

The CCC decided that the goal of in-kind compensation for kelp forest resources lost due to SONGS operations will most likely be met if: (1) The artificial reef is built near SONGS, but outside its influence in order to ensure that the compensation for the lost resources will occur locally rather than at a distant location far from the impacts, and (2) The artificial reef is configured to mimic the natural reef at San Onofre, which is a low relief boulder field.

3.1 Experimental Phase

The Phase 1 Experimental Reef was constructed in August and September 1999 on a mostly sand bottom at 13 to 16 m depth approximately 1 km offshore of the city of San Clemente, CA, USA (Figure 3.1.1). It consists of 56 modules clustered at seven

Figure 3.1.1 Location of the artificial reef mitigation site (shown as the yellow rectangle) in relation to SONGS (shown as a red circle) and the impacted San Onofre kelp forest and the naturally occurring kelp forests at San Mateo and Barn (shown as green circles).

locations (eight modules / location) spaced relatively evenly along 3.5 km of coastline encompassing an area of approximately 144 ha (Figure 3.1.2). Each artificial reef module measured roughly 40m x 40m and the 56 modules collectively covered about nine hectares (22.2 acres) of the sea floor when initially constructed.

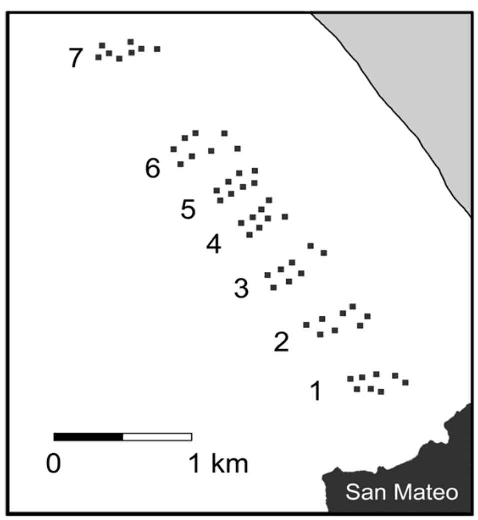

Figure 3.1.2. Design of the Phase 1 Experimental Reef. The black squares represent the 56 modules. Numbers indicate the seven locations.

The modules at each location were built from either quarry rock or concrete rubble and were constructed to form low-lying reefs (i.e., <1 m tall) that mimicked natural reefs in the region. These two types of materials were chosen because: (1) they are the two materials most preferred by the California Department of Fish and Wildlife for building artificial reefs in California, and (2) little information existed on their relative effectiveness in supporting reef biota. Four modules at each location were built from quarry rock and four were built from concrete rubble. These two construction materials differed with respect to their size, shape and specific gravity; the heavier quarry rock was boulder-like in appearance, while the less dense concrete rubble consisted primarily of pieces of flat slabs that tended to be longer, wider, and slightly shorter than quarry rocks (Reed et al. 2004). The different sizes and shapes of the two materials caused rock and concrete modules to differ somewhat with respect to small-scale topography. The slabs used to build concrete modules resulted in modules that had a greater proportion of horizontal substrate and a surface that was slightly more regular than modules constructed from quarry rock (Reed et al. 2004). By design, the amount of quarry rock and concrete rubble used to build the modules was systematically varied to produce a wide range in the bottom coverage of hard substrate (~30 to 90%) on modules of the two reef types within each location. This was done to evaluate the extent to which the bottom coverage of reef substrate influenced the abundance and species richness of colonizing biota.

Five years of post-construction monitoring were completed in December 2004. Results from the five-year experimental phase of the artificial reef mitigation project were quite promising in that all of the artificial reef designs and all seven locations tested showed nearly equal tendencies to meet several of the performance standards established for the mitigation reef (Reed et al. 2005). It was concluded from these findings that a low relief concrete rubble or quarry rock reef constructed off the coast of San Clemente, California had a good chance of providing adequate in-kind compensation for the loss of kelp forest biota caused by the operation of SONGS Units 2 and 3. These findings formed the basis of the CCC Executive Director's determination that: (1) the mitigation reef be built of quarry rock or rubble concrete having dimensions and specific gravities that are within the range of the rock and concrete boulders used to construct the SONGS experimental artificial reef, and (2) the percent of the bottom covered by quarry rock or rubble concrete on the mitigation reef average at least 42%, but no more than 86%. The CCC concurred with the Executive Director's determination for the type and percent cover of hard substrate on October 12, 2005.

3.2 Mitigation Phase

On April 17, 2006 the California State Lands Commission acting on a request from SCE adopted a resolution declaring that the SONGS Mitigation Reef be named in honor of Dr. Wheeler North, a renowned kelp forest ecologist. Construction of Wheeler North Reef was completed in 94 days on September 11, 2008 (Coastal Environments 2008). Approximately 126,000 tons of boulder-sized quarry material was deposited in 18 polygons that collectively covered 152 acres of sea floor as determined from a bathymetric survey using multibeam sonar (Figure 3.2.1).

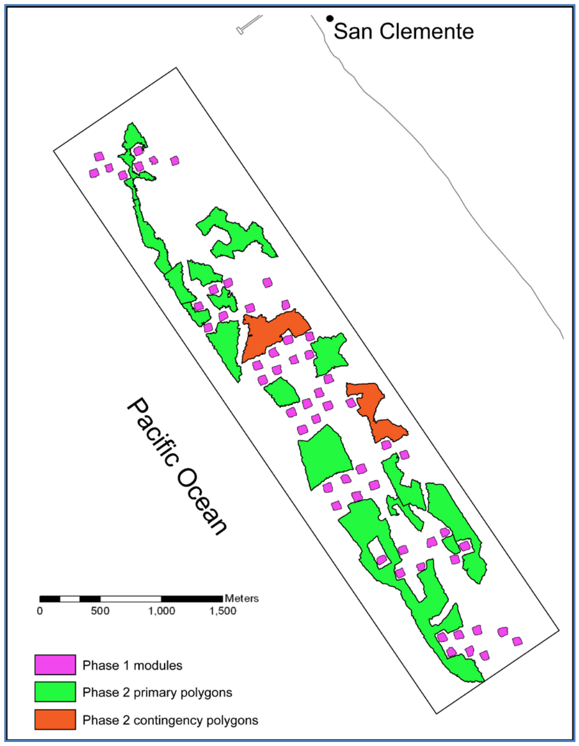

Figure 3.2.1. The 176-acre Wheeler North Artificial Reef, which includes the Phase 1 modules and the Phase 2 primary and contingency polygons.

Boulder length varied from 1 to 4 ft., with an average length of 2.3 ft.; width varied from 0.5 to 3 ft., with an average width of 1.8 ft.; and height varied from 0.5 to 2.5 ft., with an average of 1.4 ft. When added to the experimental reef a total of 176 acres (as estimated from multibeam sonar surveys in 2008 and 2009) of artificial reef were constructed. The CCC found that the average cover of quarry rock on the Phase 2 reef was slightly below the 42% minimum requirement specified in SCE's Coastal Development Permit (CDP 6-81-330-A). To address this inadequacy, the Executive Director of the CCC accepted a scenario in which 16 of the 18 polygons of the Phase 2 reef comprising 130 acres (hereafter referred to as primary polygons) were combined with the 24 acres of the Phase 1 reef (as determined in 2009, Elwany et al. 2009) to fulfill SCE's permit requirement that they construct a minimum of 150 acres of reef with an average of at least 42% cover.

3.3 Remediation Phase

The SONGS Coastal Development Permit requires that independent studies be conducted to develop recommendations for appropriate remedial measures in the event that the Wheeler North Reef fails to meet its mitigation requirements. These studies determined that the current configuration of the Wheeler North Reef (Phase 1 + Phase 2) was too small for it to meet the mitigation requirement for fish standing stock (Reed et al. 2015). Based on these results, the Executive Director of the CCC notified SCE in May 2016 that that remediation of the Wheeler North Reef was necessary for it to meet the conditions of the SONGS permit. On March 7, 2019 following extensive consultation and environmental review the CCC approved a coastal development permit for the expansion of the Wheeler North Reef to bring it into compliance with the performance standards required by the SONGS permit (California Coastal Commission 2019). The approved remediation plan included the construction of up to 210 acres of low-relief, low coverage (~41%) reef in state waters offshore of the City of San Clemente (Coastal Environments 2017). Construction of a 197.5-acre remediation reef occurred during the summers of 2019 and 2020 and consisted of approximately 151,000 tons of quarried rock covering an average of 45% of the bottom in 20 irregular shaped polygons located at depths of 28 – 49 feet north and inshore of the existing Wheeler North Reef (Figure 3.3.1). Construction of the Phase 3 reef was planned for June through September of 2019 and 2020 to avoid lobster season.

Figure 3.3.1. Map showing the locations of the polygons of the three phases of the Wheeler North Artificial Reef. Phase 1 was constructed in 1999, Phase 2 in 2008 and Phase 3 in 2019 and 2020.

4.0 Methods of Project Evaluation

This section briefly describes the general approach used to evaluate the success of the Wheeler North Reef in meeting its objective of compensating for the kelp forest resources lost due to SONGS' operations. A more detailed account of the approach and specific methods used can be found in the monitoring plan for the SONGS' reef mitigation project (Reed et al. 2021).

4.1 Performance Standards

Performance standards for reef substrate, giant kelp, fish, and the benthic community of algae and invertebrates specified in Condition C are used to evaluate the success of the Wheeler North Reef in meeting the intended goal of replacing the kelp forest resources damaged or lost by SONGS operations. Monitoring independent of the permittee is done in accordance with Condition D of the SONGS permit to: (1) determine whether the performance standards established for Condition C are met, (2) determine, if necessary, the reasons why any performance standard has not been met, and (3) develop recommendations for appropriate remedial measures. The performance standards fall into two categories: absolute standards, which are measured only at the Wheeler North Reef and require that the variable of interest attain or exceed a predetermined value that is linked to the impacts measured at the San Onofre kelp forest, and relative standards, which require that the value of the variable of interest on Wheeler North Reef be similar to that measured at nearby natural reference reefs. Among other things these performance standards require the Wheeler North Reef to support at least 150 acres of medium to high density kelp, 28 tons of fish, and assemblages of algae, invertebrates and fishes that are similar to nearby natural reference reefs.

<u>Absolute performance standards</u>

Prior to the construction of the Phase 3 remediation reef the evaluation of each absolute performance standard in any given year was based on the greater value obtained from either: (1) data collected at the Wheeler North Reef that year, or (2) a four-year running average calculated from data collected at the Wheeler North Reef for that year and the previous three years. A running average recognizes that short-term fluctuations in kelp forest biota are the norm, and it is used to allow mitigation credit to be given for excess reef biota in good years to compensate for occasional years when values for the biota are slightly below those required by the absolute standards. All absolute standards had to be met in a given year in order for that year to receive mitigation credit.

The manner in which mitigation credit is assigned for the absolute performance standards pertaining to fish standing stock and giant kelp area was changed by the CCC in March 2019 when it approved SCE's plans to construct the Phase 3 remediation reef (California Coastal Commission 2019). The size of the Phase 3 reef was based on calculations of the additional area of reef needed for the expanded Wheeler North Reef (Phases 1, 2, and 3) to eventually sustain a fish standing stock of 28 tons and 150 acres of medium to high density giant kelp with 95 % confidence. The expectation is that it would take some unknown period of time for the stock of fish and kelp to build up to the required levels during which SCE would receive no mitigation credit. To address the uncertainty in this timeline for receiving mitigation credit, the CCC changed the assignment of mitigation credit for the fish standing stock and kelp area performance standards from an all or nothing annual assessment to a cumulative approach that assigned mitigation credit for the biomass of fish and area of kelp supported by the expanded Wheeler North Reef in any given year. Using this approach fish biomass and kelp area would be measured each year and the annual total for that year would be added to the cumulative total of previous years. Fulfillment of the mitigation requirement for the fish standing stock occurs when the total accrued tons of fish equals the targeted annual value of 28 tons x the 32 years of operation of SONGS Units 2 & 3 (= 896 tons of reef fish). Similarly, the mitigation requirement for area of giant kelp is fulfilled when the total area of accrued giant kelp equals the targeted annual value of 150 acres x the 32 years that SONGS Units 2 and 3 were operating (= 4800 acres of giant kelp). The CCC determined that the implementation of this cumulative approach to assigning mitigation credit is to begin upon the installation of the expanded Phase 3 remediation reef. The manner in which mitigation credit is assigned for the other two absolute performance standards (i.e., hard substrate availability and invasive and undesirable species) was not changed and both of these standards must be met in a given year for that year to receive mitigation credit.

Relative performance standards

The evaluation of each relative performance standard is based solely on a four-year running average calculated from data collected at the Wheeler North Reef and the two reference reefs for that year and the previous three years. Only data collected from the Phase 1 modules and the Phase 2 primary polygons are used to evaluate whether the Wheeler North Reef meets the relative performance standards. This is because the combination of the Phase 1 modules and the Phase 2 primary polygons fulfills SCE's permit requirement to construct a minimum of 150 acres of reef with an average of at least 42% cover of rock, (2) this configuration is sufficient for determining whether the Wheeler North Reef is performing similarly to natural reefs in the region, and (3) the sole regulatory requirement for constructing the Phase 3 reef was to increase the aggregate fish standing stock and giant kelp acreage of Wheeler North Reef.

An either / or criterion (i.e., using data from either a single year or a 4-year running average) is not appropriate in this case because the desired goal for the relative standards is not to achieve a specified value that is linked to estimated losses at the San Onofre kelp forest, but rather to evaluate whether the abundances and numbers of species of kelp forest biota at the Wheeler North Reef are similar to those at the reference reefs. This is best accomplished using a short-term (4-year) running average that accounts for natural variation in time. Natural kelp forests vary greatly in their species composition and abundance and it is likely that even the reference reefs will not consistently meet all the relative standards in a given year.

To avoid requiring the Wheeler North Reef to perform better than the reference reefs, the Wheeler North Reef is required to meet at least as many of the relative standards as the lowest performing reference site (which, by definition is an acceptable measure of comparison) in a given year for that year to count towards compliance with Condition C.

4.2 Reference Sites

Requiring resource values at Wheeler North Reef to be similar to those at natural reefs is based on the rationale that to be successful, the Wheeler North Reef must provide similar types and amounts of resources that occur on natural reefs. Resources on natural reefs, however, vary tremendously in space and time. Differences in physical characteristics of a reef (e.g., depth and topography) can cause plant and animal assemblages to differ greatly among reefs while seasonal and inter-annual differences in oceanographic conditions can cause the biological assemblages within reefs to fluctuate greatly over time. Ideally, the biological assemblages at a successful artificial reef should fluctuate in a manner similar to those at the natural reefs used for reference. One way to help ensure this is to select reference reefs that are physically similar to Wheeler North Reef and located relatively close to it. The premise here is that nearby reefs with similar physical characteristics should support similar biota that are more likely to fluctuate similarly over time. Thus in addition to proximity, other criteria used to select the reference reefs included that they: (1) not be influenced by the operation of SONGS, (2) be located at a depth similar to Wheeler North Reef, (3) be primarily low relief, preferably consisting of cobble or boulders, and (4) have a history of sustaining giant kelp adults at medium to high densities. The criterion that the reference reefs have a history of supporting persistent stands of giant kelp is important because communities on reefs without giant kelp can differ dramatically from those with kelp. Based on these criteria, the San Mateo kelp bed (located adjacent to the southern end of Wheeler North Reef) and the Barn kelp bed (located approximately 12 km south of San Mateo kelp bed) were chosen as reference reefs for evaluating the performance of the Wheeler North Reef (Figure 4.2.1).

Figure 4.2.1. Map showing the locations of the Wheeler North Artificial Reef and the two natural reefs San Mateo and Barn that are used as reference sites.

Temporal variability, especially of the sort associated with changes in oceanographic conditions, can be accounted for more easily by sampling Wheeler North Reef, San Mateo and Barn concurrently. Concurrent monitoring of the mitigation and reference reefs helps to ensure that regional changes in oceanographic conditions affecting Wheeler North Reef will be reflected similarly in the performance criteria at the reference reefs, since nearby San Mateo and Barn will be subjected to similar regional changes in oceanographic conditions.

4.3 Determination of similarity

A requirement of the SONGS permit is that as many of the response variables used to assess the relative performance standards of the Wheeler North Reef (hereafter referred to as “relative performance variables”) be “similar” to those at nearby natural reference reefs. Evaluating whether the performance of Wheeler North Reef is similar to that at the San Mateo and Barn reference reefs requires that the mean (or in some cases the median) value for a given relative performance variable at Wheeler North Reef not be significantly lower than the mean (or median) value at the lower performing of the two reference reefs. We use a one sample, one tailed approach for all comparisons. Significance is determined using an approach that utilizes both a formal probability value (i.e. p-value) and an effect size. This is generally done by means of a t-test except in the case of the performance standards pertaining to fish reproductive rates and food chain support for fish. For these two standards significance is determined by a resampling procedure in which the effect size is calculated as the proportional difference in the medians of the resampled distributions of the Wheeler North Reef and the lower performing reference reef, and the p-value is the percentile in the distribution of the lower performing reference reef that is equal to the median value of the Wheeler North Reef.

The performance at Wheeler North Reef with respect to a given relative performance standard is considered to be worse than the lower of the two reference reefs if the p-value for the comparison is ≤ to the proportional effect size (i.e., the proportional difference between the Wheeler North Reef and the lowest performing reference reef (see Reed et al. 2021 for details). The rationale for using the lower of the two reference reefs is that both reference reefs are considered to be acceptable measures of comparison for Wheeler North Reef. Hence, if Wheeler North Reef is performing at least as well as one of the reference reefs, then it should be judged successful. The scaling of the p-value (α) to the effect size recognizes sampling error when estimating mean values and balances the probability of a Type I error (falsely concluding that Wheeler North Reef is not similar to the reference reefs when it is) with the probability of a Type II error (falsely concluding that the Wheeler North Reef is similar to the reference reefs when it is not).

To ensure that the Wheeler North Reef is not held to a higher standard than the reference reefs the above procedure is also applied to San Mateo and Barn to evaluate whether they would have met the relative performance standards. This is done by treating San Mateo (or Barn) as the mitigation reef and using the Wheeler North Reef and Barn (or San Mateo) as the two reference reefs. The Wheeler North Reef is considered similar to the reference reefs if the number of relative standards met by the Wheeler North Reef is equal to or greater than the number of relative standards met by either San Mateo or Barn.

The above approach ensures that the assessment of similarity is consistent with the SONGS permit requirement that the performance standards be met without the unreasonable requirement that Wheeler North Reef outperform San Mateo and Barn for every performance standard. Importantly, this approach deals realistically with the inherent variability of nature in a manner that best serves the interests of the public and SCE.

4.4 General Sampling Design

151 sampling locations, each defined by a fixed 50 m x 20 m area, were established at the Wheeler North Reef; 12 transects are in Phase 1, 70 in the primary polygons of Phase 2, 10 in the contingency polygons of Phase 2, and 59 in Phase 3 (Figure 4.4.1). An additional 82 transects were established at both San Mateo and Barn in areas that are known to support persistent kelp.

Transects on each reef are arranged in pairs with the two transects in each pair spaced 25 m apart. The exceptions to this are transects located on the Phase 1 and Phase 3 Wheeler North Reef, which are not paired. Pairing of transects is done to increase sampling efficiency. Maps of kelp persistence and hard substrate were used to strategically distribute the 41 transect pairs at San Mateo and Barn across areas of reef known to support giant kelp. Transects at Wheeler North Reef were allocated to the polygons and the existing experimental reef modules in proportion to their area.

Figure 4.4.1. Schematic map of the Wheeler North Reef showing the location of the transects (shown as black lines) that are monitored to assess the performance standards.

Sampling of the Wheeler North Reef, San Mateo and Barn is done concurrently from late spring to early autumn on an annual basis. Each sampling area is identified by unique differential GPS coordinates that marks the “zero end” of a 50 m transect and a compass heading along which divers lay out a 50 m measuring tape. A 20 m wide swath centered along the 50m transect defines the sample area at each sampling location. Different sized sampling units (e.g., 0.5 m^2, 1 m^2, 20 m^2, and 150 m^2) within this sampling area are used to evaluate different performance variables (Figure 4.4.2).

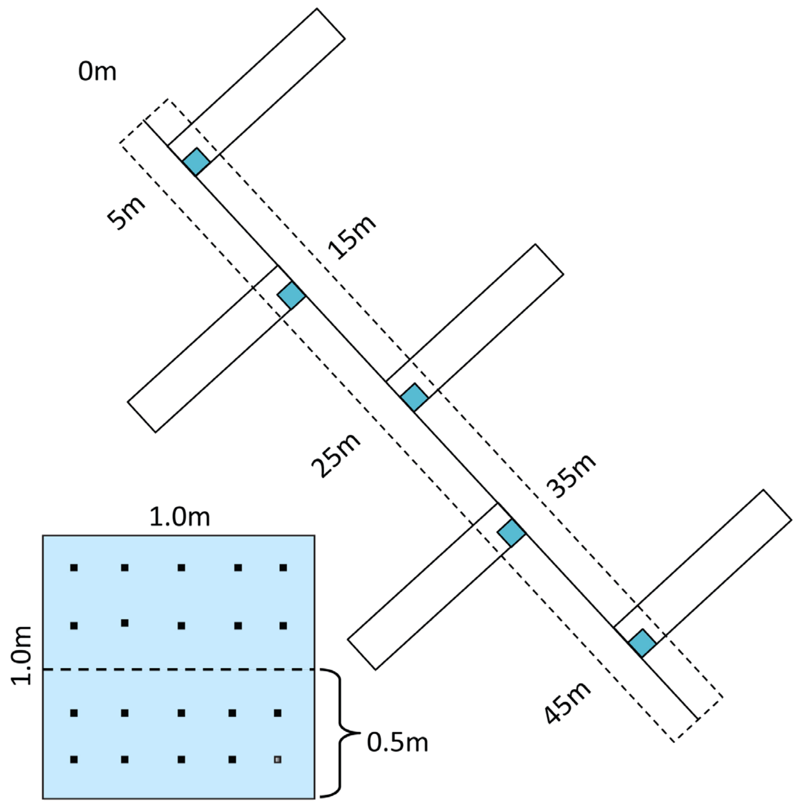

Figure 4.4.2. Schematic diagram of a sampling station. Fish are sampled in 50 m x 3 m band transects that extend 1.5m off the bottom (outlined with a dotted line). Adult giant kelp > 1 m tall, large understory algae, and large mobile invertebrates are counted in the five 10 m x 2 m rectangular quadrats positioned perpendicular to the main transect at 10 m intervals (outlined with solid lines). The percent cover of invertebrates, algae and bottom substrate is estimated using a grid of 20 points in the five 1 m x 1m quadrats (shown in blue). Smaller mobile invertebrates and small cryptic fish are counted either in 1 m x 1 m or 1 m x 0.5 m quadrats depending on their size and abundance.

University sponsored research was shut down from mid-March to mid-July 2020 in response to the COVID-19 pandemic, which delayed the start of the 2020 performance monitoring by two months. New health and safety protocols were established by UCSB in July 2020 that allowed research to resume in a limited capacity, which effectively reduced the amount of sampling that could be completed in 2020. As a result, the number of sampling stations at Wheeler North Reef, San Mateo and Barn that were used to evaluate the relative performance standards and the absolute standards for hard substrate and undesirable and invasive species was reduced from 82 to 15, which increased the level of uncertainty in assessing these performance standards.

5.0 Trends in the Physical and Biological Structure of the Wheeler North Reef

This section provides a brief summary of temporal patterns of change in the physical and biological attributes of the Wheeler North Reef from 2009 – 2020, which represents the 12-year period following the construction of the 152-acre Phase 2 mitigation reef and the 1-year period following the construction of the Phase 3 remediation reef.

5.1 Physical Characteristics

Exposed hard reef substrate is necessary for the establishment and persistence of giant kelp and other reef biota. The percent cover of exposed rock on the bottom can decline because of sedimentation and burial, or increase due to scour caused by waves and currents. Knowledge of the extent, type and persistence of exposed rock is essential to understanding how the Wheeler North Reef will function over the long term. The mean percent cover of exposed rock averaged over 82 transects located on the Phase 1 modules and the primary polygons of Phase 2 of the Wheeler North Reef was relatively constant from 2009-2019 ranging from a low of 42% in 2011 to a high of 48% in 2017 (Figure 5.1.1). In 2020, when only 15 of the 82 transects were sampled (due to restrictions resulting from COVID -19) the mean percent cover of exposed hard substrate increased to 57%. More detailed examination of the data suggests that the abrupt increase in 2020 reflects higher interannual variation in hard substrate among the 15 transects sampled in 2020 rather than an actual increase in the mean percent cover of hard substrate across all 82 transects.

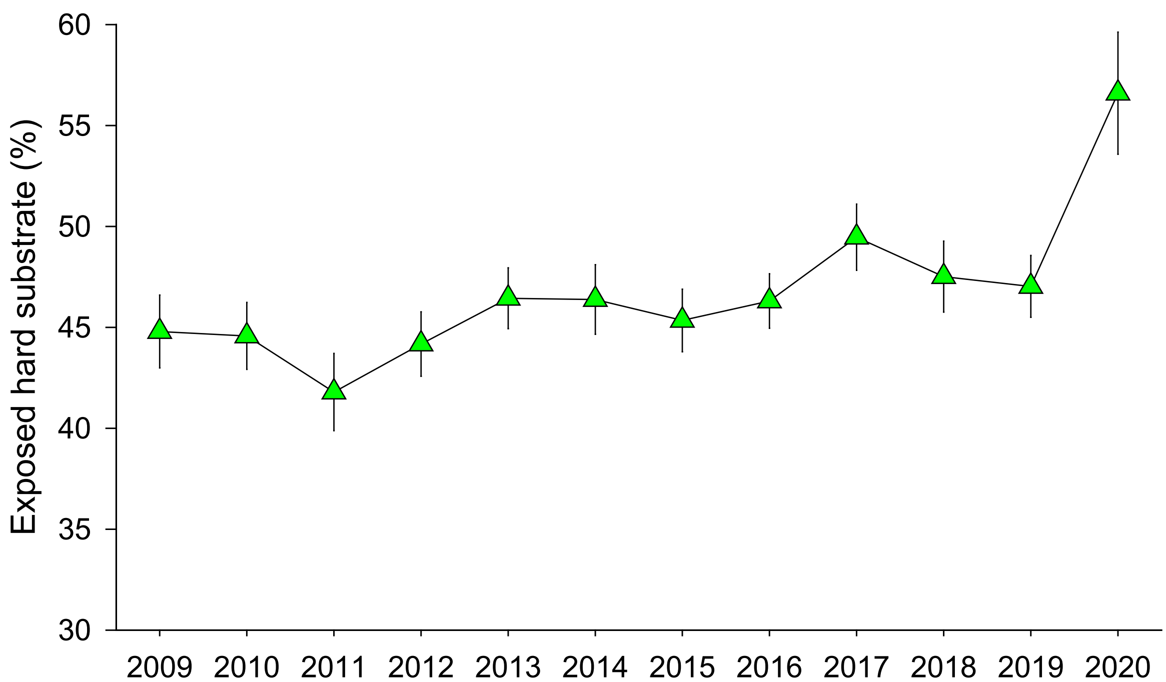

Figure 5.1.1. Mean percent cover (± standard error) of exposed hard substrate at Wheeler North Reef from 2009 – 2020.

The percent cover of exposed rock at Wheeler North Reef is spatially heterogeneous (Figure 5.1.2). Some of this spatial variability is by design as the cover of hard substrate on the Phase 1 modules has consistently ranged from ~ 25 to 85%. However, the cover of hard substrate also varied substantially among the Phase 2 polygons (27-66%), which reflects adjusting the amount of rock deployed during construction in order to meet the permit requirement of an average rock coverage of at least 42%.

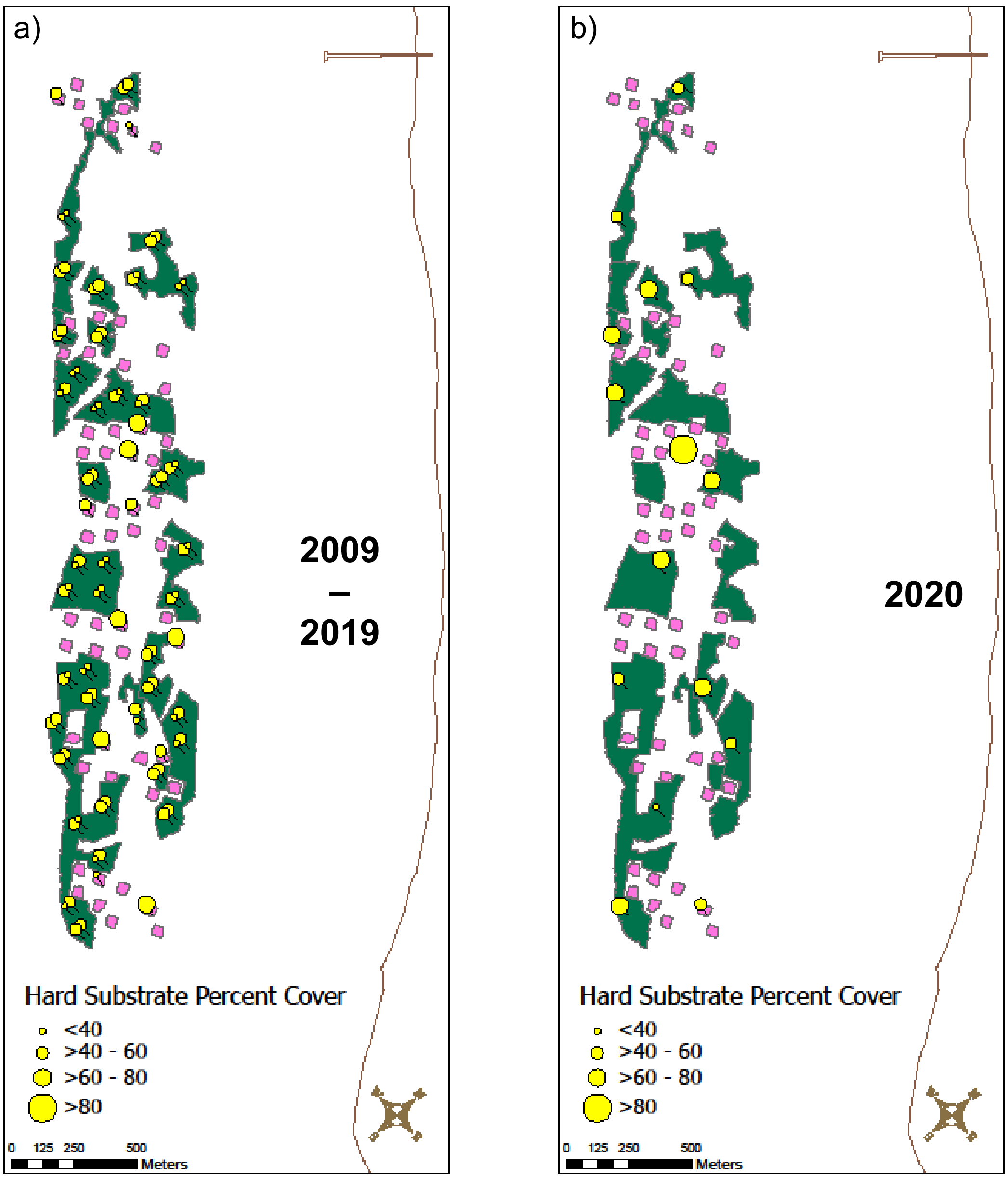

Figure 5.1.2. Percent cover of exposed hard substrate on transects of the Phase 1 modules (pink) and Phase 2 polygons (green) of Wheeler North Reef. (a) Average of 2009 – 2019, and (b) 2020. Size of bubble corresponds to percent cover of hard substrate.

Not surprisingly, the hard substrate at Wheeler North Reef consists mostly of boulder, which is what was intentionally produced at the quarries that supplied the rock for the construction of the reef (Figure 5.1.3). A small amount of cobble (much of which is a by-product of the quarry rock preparation) and natural bedrock also contributes to the hard substrate on the Wheeler North Reef. Soft substrates, consisting primarily of sand and a smaller amount of shell hash, cover approximately half the bottom within the footprint area of the Wheeler North Reef. The relative amounts of the different bottom substrates have changed little since 2009.

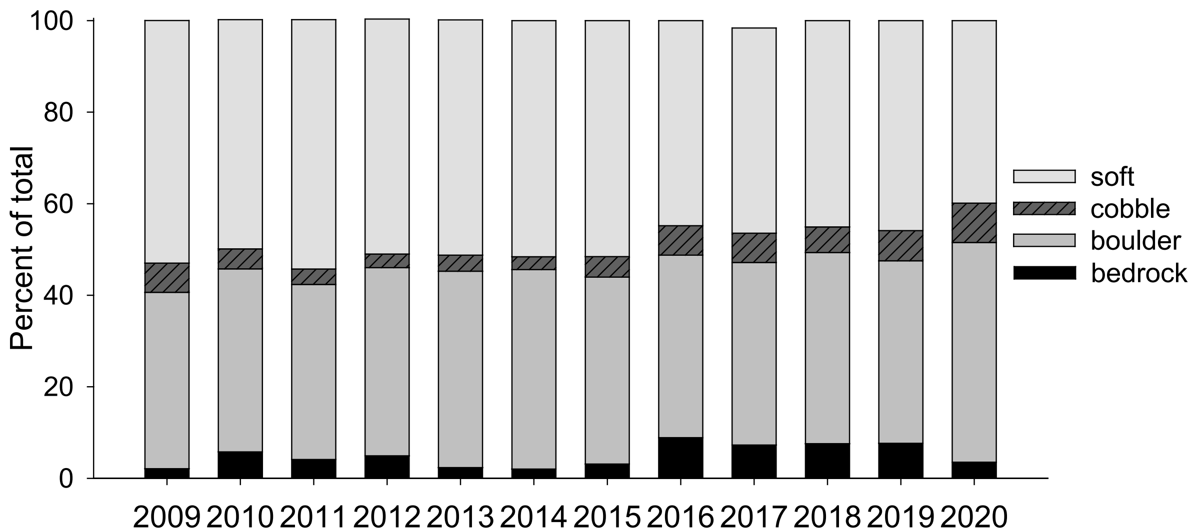

Figure 5.1.3. Distribution of substrate types on Wheeler North Reef from 2009 – 2020.

5.2 Biological Characteristics

<u>Giant kelp</u>

The giant kelp, *Macrocystis pyrifera* is the world's largest alga and it displays some of the fastest elongation rates of any autotroph on Earth. Once established, small plants grow rapidly into large adult plants that extend through the water column to produce a floating canopy at the sea surface. It is considered the foundation species of the kelp forest because it provides food and structure for a wide diversity of species. A primary goal in designing the Wheeler North Reef was to make it suitable for the establishment, growth, and persistence of giant kelp.

Results from the Phase 1 reef indicated that giant kelp would readily colonize the newly constructed Phase 2 reef and that transplanting kelp would not be needed to ensure its establishment on Wheeler North Reef (Reed et al. 2006). This prediction proved to be true as very high densities of giant kelp recruits were observed at Wheeler North Reef in the summer of 2009, one year after construction (Figure 5.2.1). Densities of newly recruited giant kelp (i.e. individuals < 1 m tall) at Wheeler North Reef had been near zero since the initial colonization event of 2009 until 2014 when low densities (~0.2 m^{-2}) of kelp recruits were observed. A similar pattern of extremely low recruitment of giant kelp in years following initial high rates of colonization was also observed during the development of the Phase 1 reef (Reed et al. 2006). This pattern is a common occurrence in kelp forests generally as the canopy formed by large plants suppresses the development of small young plants by reducing the amount of light reaching the bottom. 2015 marked a significant change as high numbers of kelp recruits were once again observed at Wheeler North Reef with mean densities averaging 50% higher than in 2009 (Figure 5.2.1). Densities of giant kelp recruits declined sharply in 2016 and were near zero from 2017 – 2019 before increasing slightly to 0.4 individuals m^{-2} in 2020.

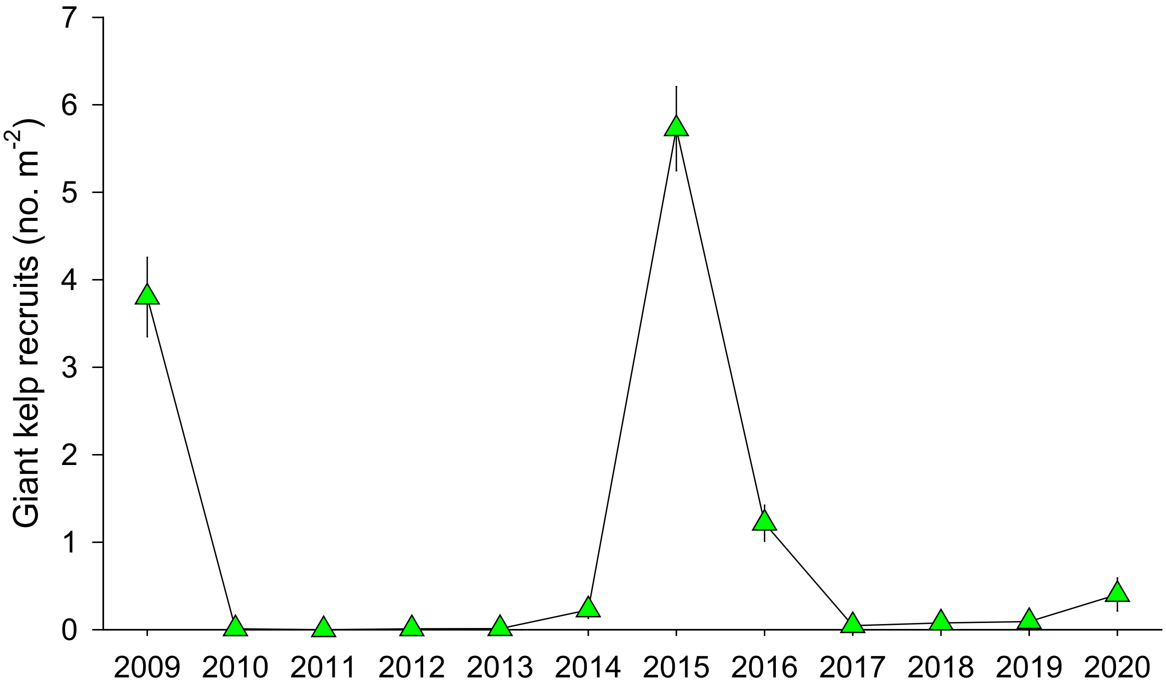

Figure 5.2.1. Mean density (±1 standard error) of newly recruited giant kelp plants (*Macrocystis pyrifera*) at Wheeler North Reef from 2009 – 2020.

Recruitment of giant kelp at Wheeler North Reef was uniformly low in 2020 when densities averaged 1 m^{-2} or fewer in all but one of the 15 transects that were sampled (Figure 5.2.2b). This was generally lower than the long-term average of the previous 11 years and contrasts greatly with 2009 and 2015 when much high densities were observed across the entire Wheeler North Reef (Figure 5.2.2a).

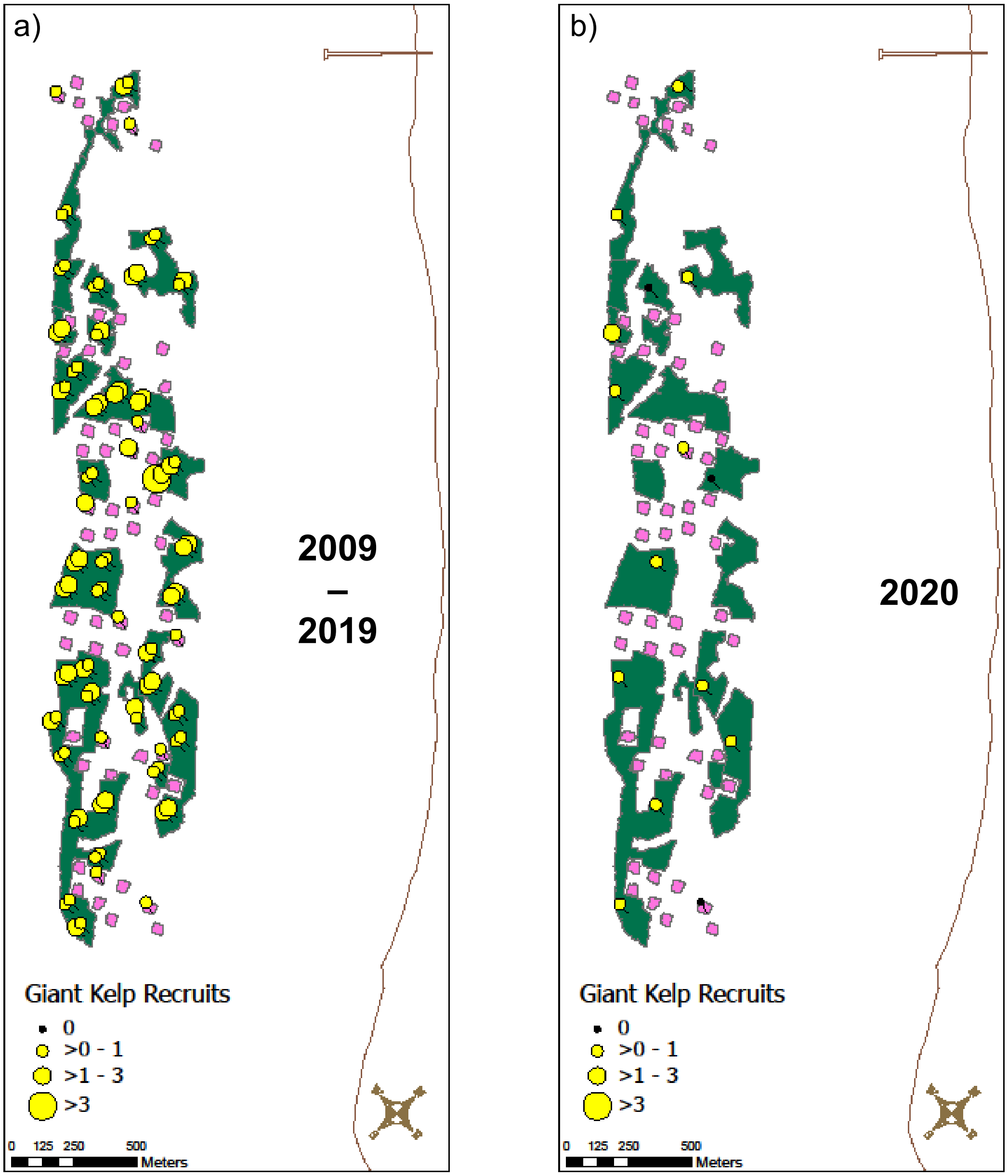

Figure 5.2.2. Density (no. 1 m^{-2}) of newly recruited giant kelp (*Macrocystis pyrifera*) on transects of the Phase 1 modules (pink) and Phase 2 polygons (green) of Wheeler North Reef. (a) Average of 2009 – 2019 and (b) 2020. Size of bubble corresponds to the density of giant kelp < 1 m tall.

The large kelp recruitment event at Wheeler North Reef in 2009 led to a large cohort of older large 'adult' plants in 2010, which declined to approximately 2 individuals per 100 m^2 in 2012 – 2014 (Figure 5.2.3). Mean densities of adult giant kelp (defined as individuals with 8 or more fronds) on Wheeler North Reef and elsewhere throughout the region declined precipitously in 2016 during prolonged anomalous conditions of warm, nutrient-poor water. Adult density increased in in 2017 when cooler waters prevailed, but has consistently declined since then in the absence of appreciable recruitment. In 2020 the overall density of adult kelp at Wheeler North Reef declined to the lowest level ever recorded as no adult kelp were observed in 90 of the 92 transects sampled (Figure 5.2.4b).

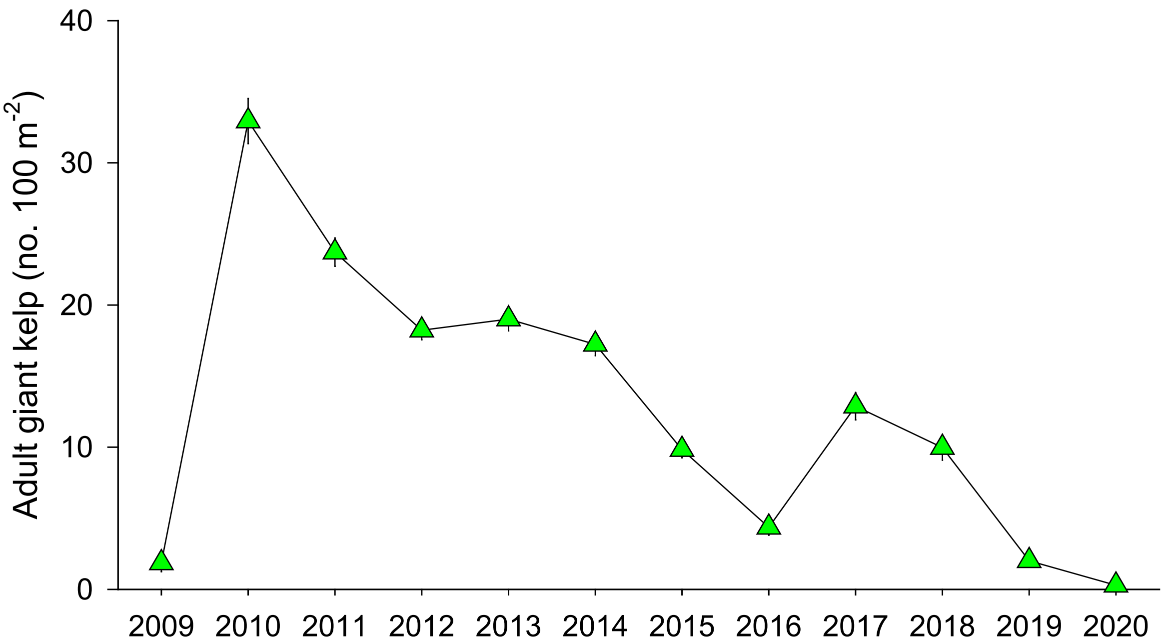

Figure 5.2.3. Mean density (± 1 standard error) of adult giant kelp (*Macrocystis pyrifera*) at Wheeler North Reef from 2009 – 2020.

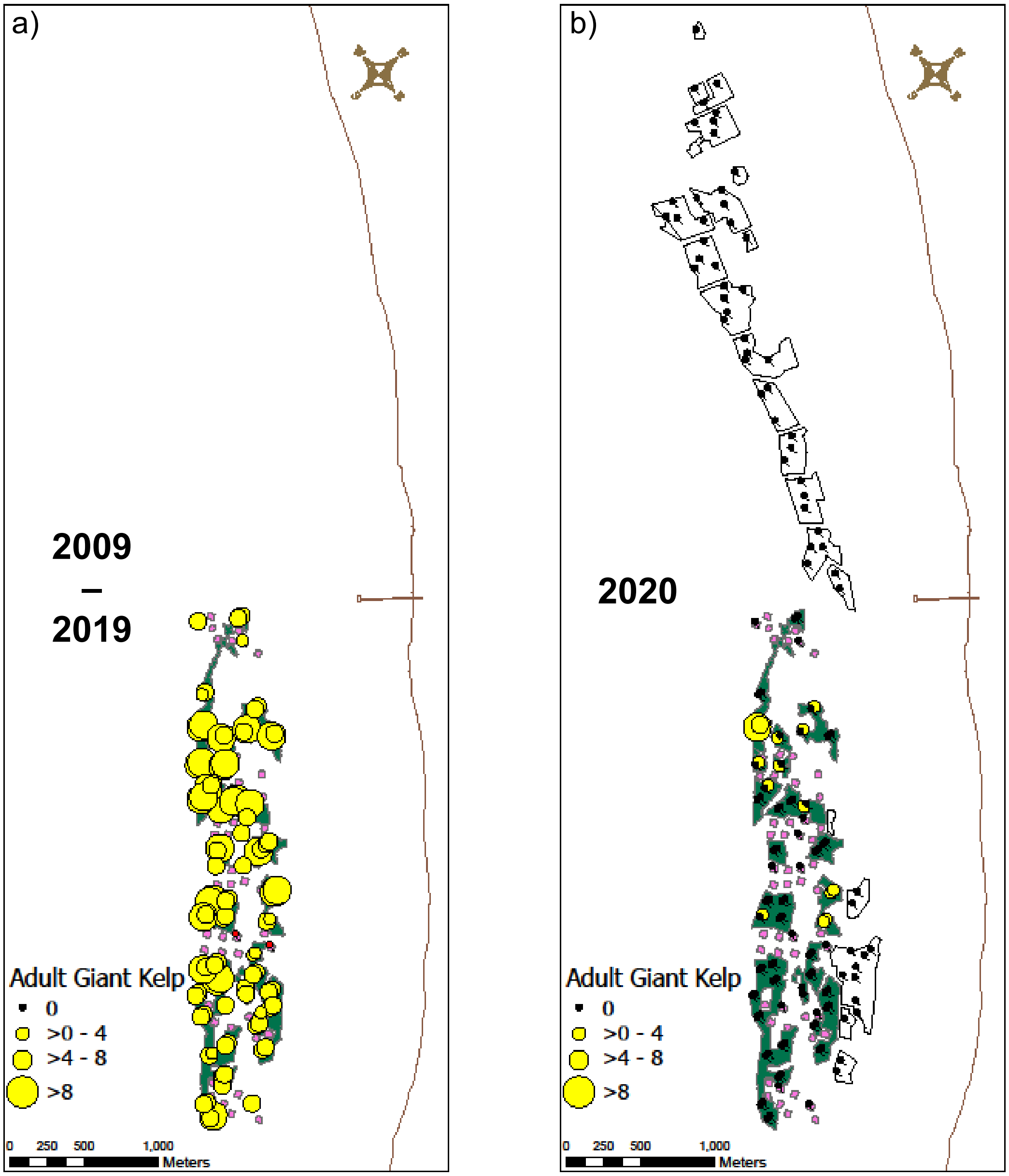

Figure 5.2.4. Density (no. 100 m^{-2}) of adult giant kelp plants (*Macrocystis pyrifera*) on the Phase 1 modules (pink), Phase 2 polygons (green) and Phase 3 polygons (white) of the Wheeler North Reef. (a) Average of 2009 – 2019, and (b) 2020. Size and color of bubbles correspond to density of giant kelp plants with 8 or more fronds.

Giant kelp plants are made up of individual fronds that consist of a vine-like stipe to which blades are attached via a small gas-filled float. The number of fronds per plant is a good indication of a plant's size. As expected, the average size of kelp plants increased dramatically at Wheeler North Reef between 2009 and 2010 as small plants grew into adults (Figure 5.2.5). By 2011, giant kelp > 1 m tall averaged about 21 fronds per plant and plant size remained relatively steady through 2015 before declining precipitously to 8 fronds per plant in 2016 (Figure 5.2.5). The relatively low numbers of fronds per plant observed in 2016 was indicative of the poor growing conditions associated with unusually high ocean temperatures throughout the region. Cooler conditions prevailed in 2017 and the average number of fronds per plant at Wheeler North Reef steadily increased to 24.5 by 2019. The average number of fronds per plant dropped precipitously to 3.3 in 2020. The low number of fronds per plant observed at this time appeared to reflect the senescence of older individuals rather than the emergence of younger (i.e., smaller) individuals as most plants had relatively large holdfasts indicative of older individuals.

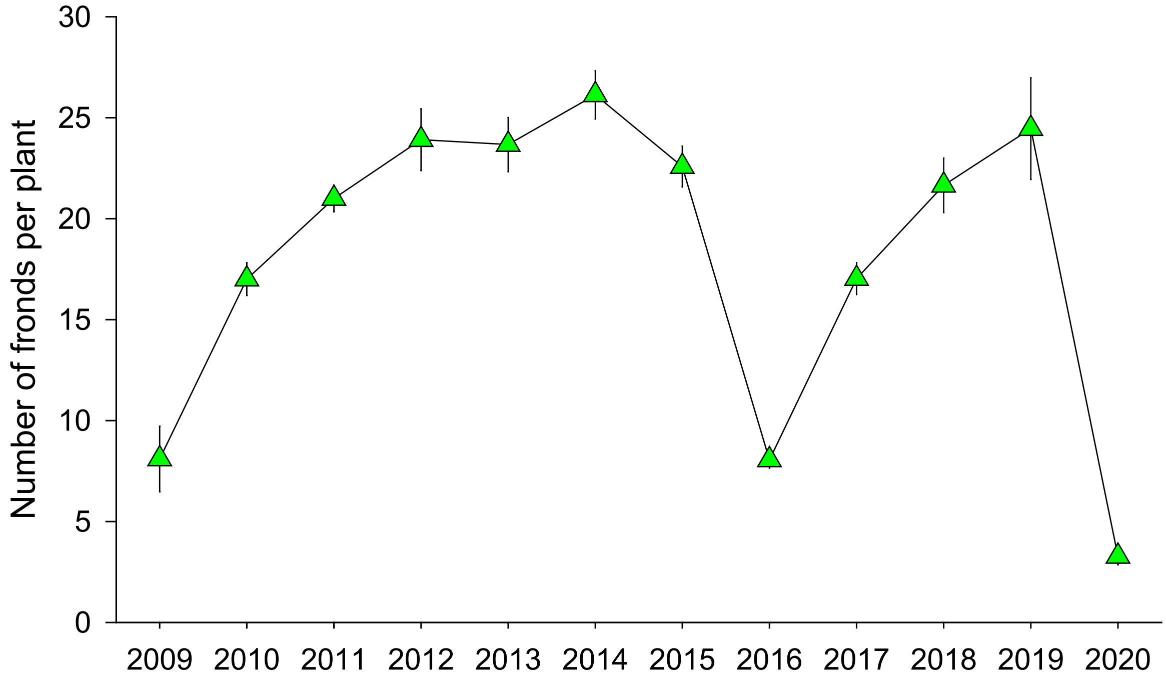

Figure 5.2.5. Mean number (± 1 standard error) of fronds per *Macrocystis* plant at the Wheeler North Reef from 2009 – 2020.

Because giant kelp plants can differ greatly in size from small recruits to large adults, the density of fronds tends to be a better predictor of its standing biomass than the density of plants (Reed et al. 2009). The biomass of kelp as indicated by the density of fronds increased six-fold at Wheeler North Reef from 2009 to 2010, and remained relatively high at between 5.5 fronds m^{-2} through 2014 (Figure 5.2.6). Frond density progressively declined to < 1 frond m^{-2} during the warm water of 2016, reflecting the lower density and size of adult plants (Figures 5.2.3 and 5.2.5). The increase in the size and density of adult plants observed in 2017 and 2018 led to an increase in the mean frond density at Wheeler North Reef, however, this increase was short lived and frond density in 2020 declined to < 0.1 m^{-2}, its lowest level ever (Figures 5.2.6).

Figure 5.2.6. Mean density (± 1 standard error) of giant kelp fronds at Wheeler North Reef from 2009 – 2020.

Benthos

The benthic community on the shallow reefs off California typically include a diverse group of low-lying red, brown and green algae that occur on the bottom beneath the canopy of giant kelp (often referred to as understory algae) and a large number of sessile and mobile species of invertebrates. Like understory algae, sessile invertebrates attach themselves to the reef. However, unlike algae that obtain their nutrition via photosynthesis, sessile invertebrates (which include organisms such as sponges, sea anemones, feather duster worms, bryozoans, bivalves and sea squirts) feed by filtering plankton from the water column. The amount of the rock that becomes occupied by algae and sessile invertebrates increases over time during the normal succession of a kelp forest community.

Such has been the case for Phases 1 and 2 of the Wheeler North Reef, which showed a dramatic increase in the percent cover of the benthic community since it was constructed (Figure 5.2.7). Within three years of Phase 2 construction >90% of the rock surface of Wheeler North Reef was covered by algae and sessile invertebrates; The fraction of rock covered by reef biota has been relatively constant since then and averaged 97% in 2020.

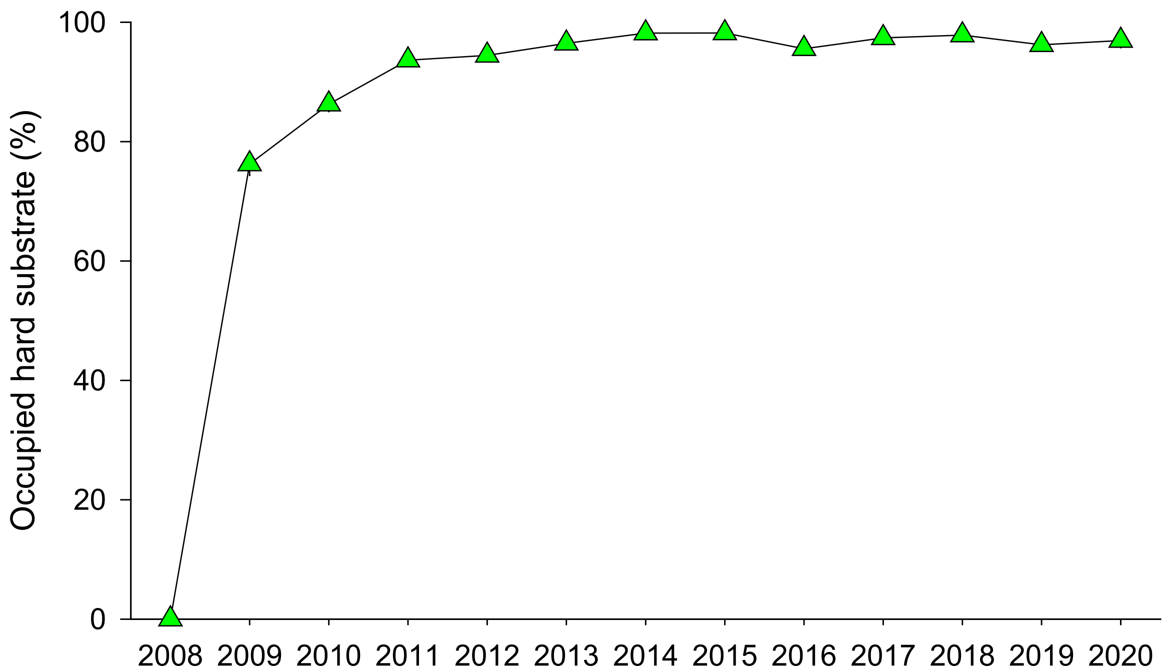

Figure 5.2.7 Mean percent cover of hard substrate occupied by sessile reef biota (i.e. understory algae and sessile invertebrates) at Wheeler North Reef from 2009 – 2020.

As occupiers of primary space, understory algae and sessile invertebrates compete for hard substrate on the bottom. Understory algae tend to be the stronger competitor except in low light environments where photosynthesis and growth are suppressed. Such is the case under a dense canopy of the giant kelp, which has a negative effect on understory algae by significantly reducing the amount of light reaching the bottom (Reed and Foster 1984). Experiments done at the Phase 1 reef found that giant kelp had an indirect positive effect on sessile invertebrates due to its direct negative effect on understory algae (Arkema et al. 2009). These experiments demonstrated that the relative abundance of understory algae and sessile invertebrates on a reef is greatly affected by the presence of giant kelp. Understory algae are favored in the absence of giant kelp, while sessile invertebrates tend to be favored in the presence of giant kelp.

The percent cover of algae at Wheeler North Reef declined three to four-fold from 2009 to 2011, remained relatively low at ~ 10% through 2013, and increased to 62% in 2020 (the highest cover of algae ever reported for Wheeler North Reef) (Figure 5.2.8a). The sharp increase in the mean percent cover of algae observed in 2020 likely reflects high variability associated with a small sample size as the percent cover of algae on the 15 transects sampled in 2020 ranged from a low of 23% in polygon 2 to a high of 121% on one of the Phase 1 modules (Figure 5.2.9b; cover > 100% indicates that layering of multiple species was common). The number of species of algae increased from a low of 18 species per 82 transects in 2011 to a high of 54 species in 2019 (Figure 5.2.8b). As might be expected, this number declined by 15 species in 2020 when only 15 transects were sampled.

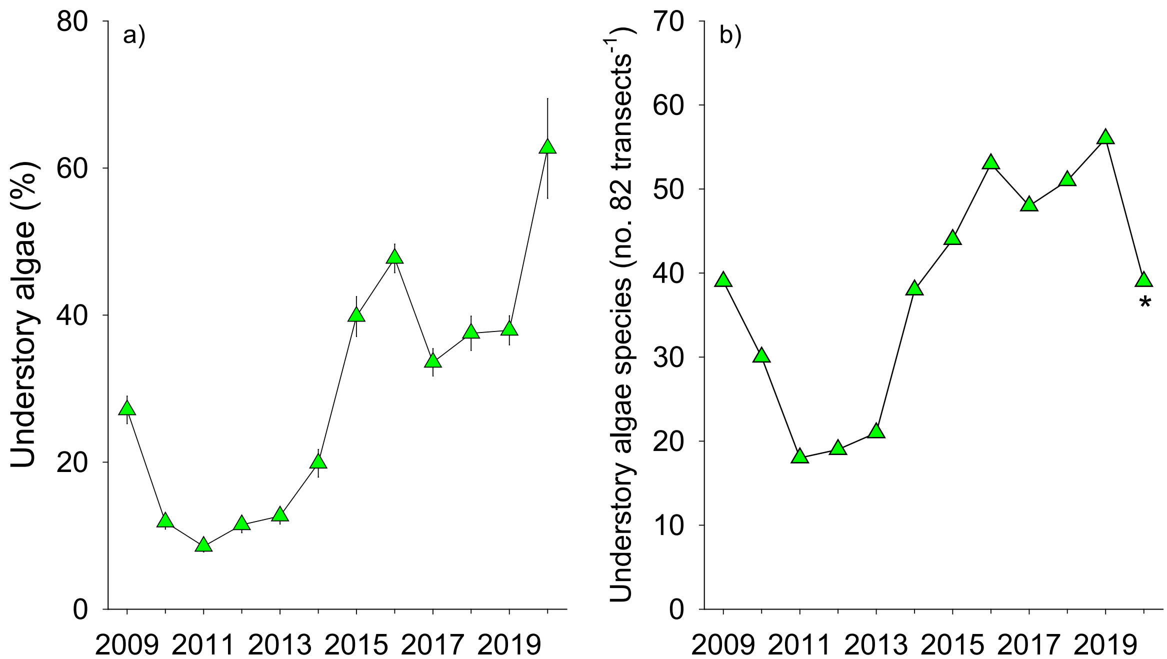

Figure 5.2.8. (a) Mean percent cover (± 1 standard error) and (b) total number of species of understory algae at Wheeler North Reef (n=82) from 2009 – 2020. * denotes reduced monitoring (n=15 transects).

The small foliose red alga *Rhodymenia* accounted for 26% of the total cover of algae on Wheeler North Reef in 2020 (Figure 5.2.10). Other prominent species of algae in 2020 included the foliose red algae *Acrosorium uncinatum* (10%), *Botryocladia pseudodichoma* (7%), and various species of small filamentous and polysiphonous red algae (7% and 10% respectively). None of the other 34 taxa of algae recorded on the 15 transects sampled at Wheeler North Reef in 2020 accounted for more than 5% of the total algal cover. The algal assemblage in 2020 differed from the previous 11-year average when giant kelp holdfasts accounted for a greater percentage (23%) of the total algal cover on Wheeler North Reef than any other species.

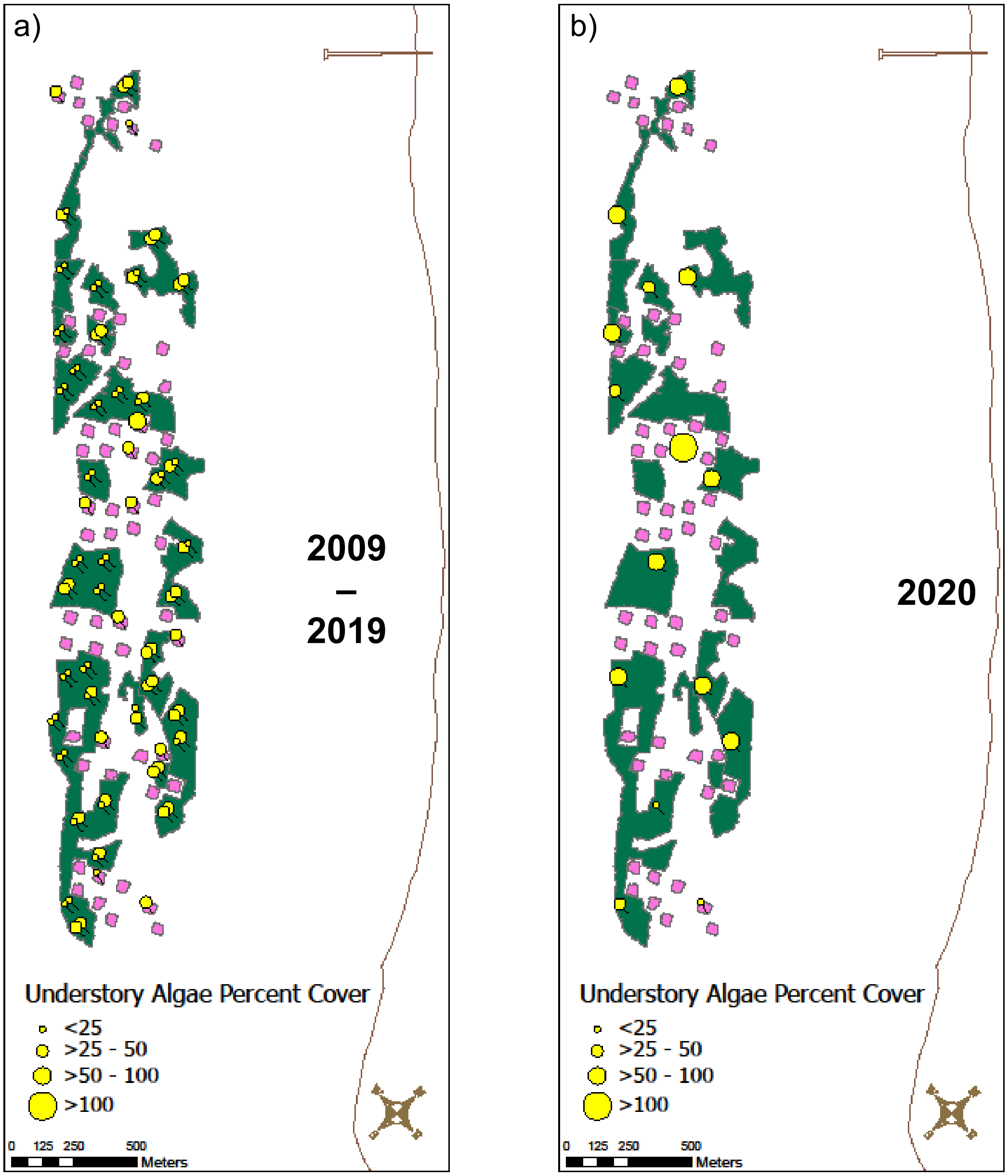

Figure 5.2.9. Percent cover of understory algae on transects of the Phase 1 modules (pink) and Phase 2 polygons (green) of Wheeler North Reef. (a) Average of 2009 – 2019, and (b) 2020. Size of bubble corresponds to level of percent cover of understory algae.

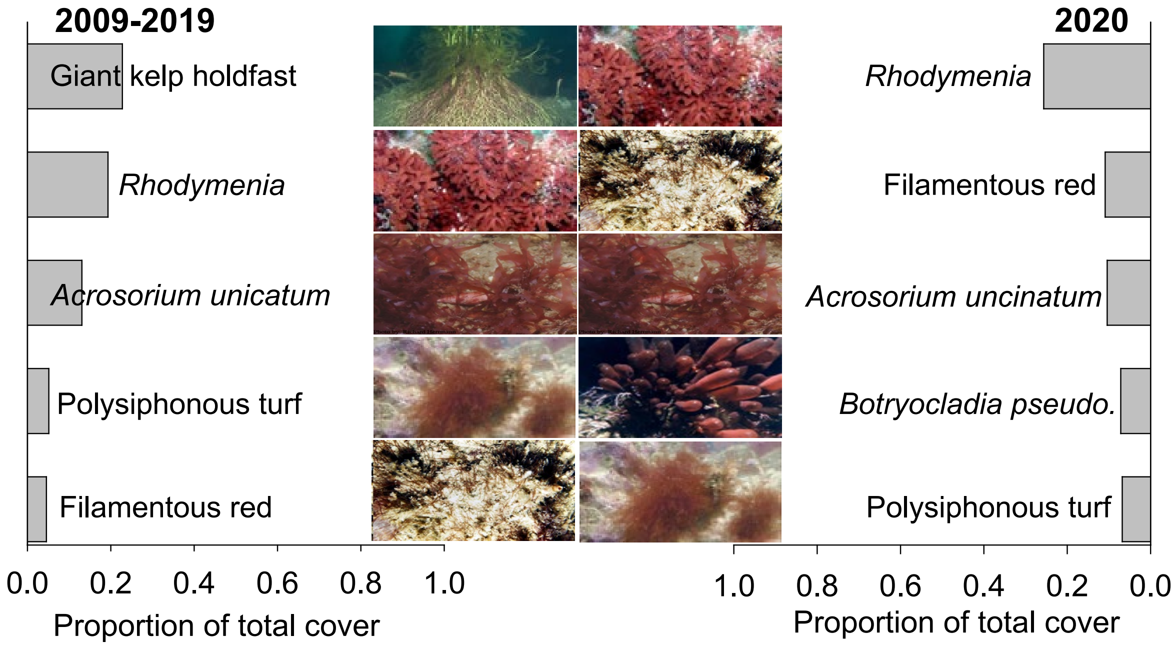

Figure 5.2.10. Proportion of the total percent cover of algae contributed by the five most abundant understory algal species at Wheeler North Reef averaged for 2009 – 2019 and 2020.

The abundance of sessile invertebrates at Wheeler North Reef showed an opposite pattern to that of understory algae; their percent cover more than doubled to ~ 50% between 2009 – 2014 (Figure 5.2.11a). In 2015 the percent cover of sessile invertebrates began to decline reaching a low of 27% in 2016. Algal cover increased in 2017 to 39% and has remained relatively constant since then. In contrast to percent cover, the total number of species of sessile invertebrates observed within the 82 transects at Wheeler North Reef increased from ~ 65 species in 2009 and 2010 to 80-88 species between 2011 – 2019 (Figure 5.2.11b). The number of species of sessile invertebrates declined to 64 in 2020 when only 15 transects were sampled.

Strong asynchrony in abundance between sessile invertebrates and understory algae, and between understory algae and giant kelp, has been observed at the Wheeler North Reef since 2009 (Figure 5.2.12). The negative covariance observed between the cover of sessile invertebrates and understory algae (its primary competitor for space) and the positive covariance between the cover of sessile invertebrates and the density of giant kelp (which outcompetes understory algae for light) is indicative of the direct and indirect effects of competition among these three groups of primary space holders (Arkema et al. 2009).

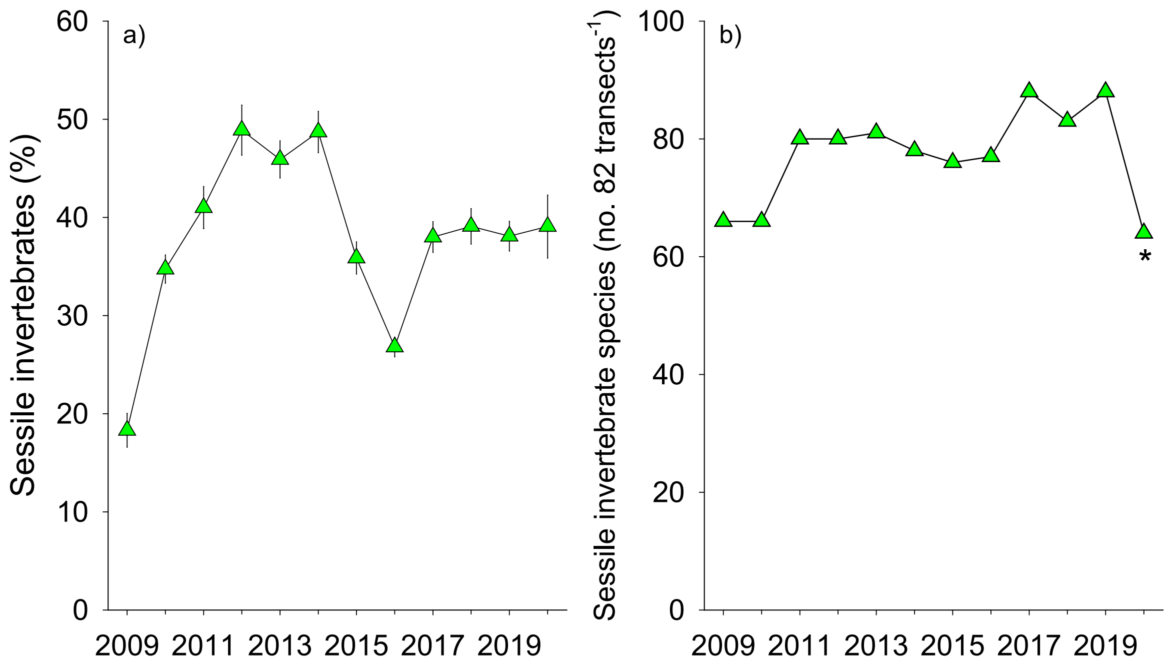

Figure 5.2.11 (a) Mean percent cover (± 1 standard error) and (b) total number of species of sessile invertebrates at Wheeler North (n=82) from 2009 – 2020. * denotes reduced monitoring (n=15 transects).

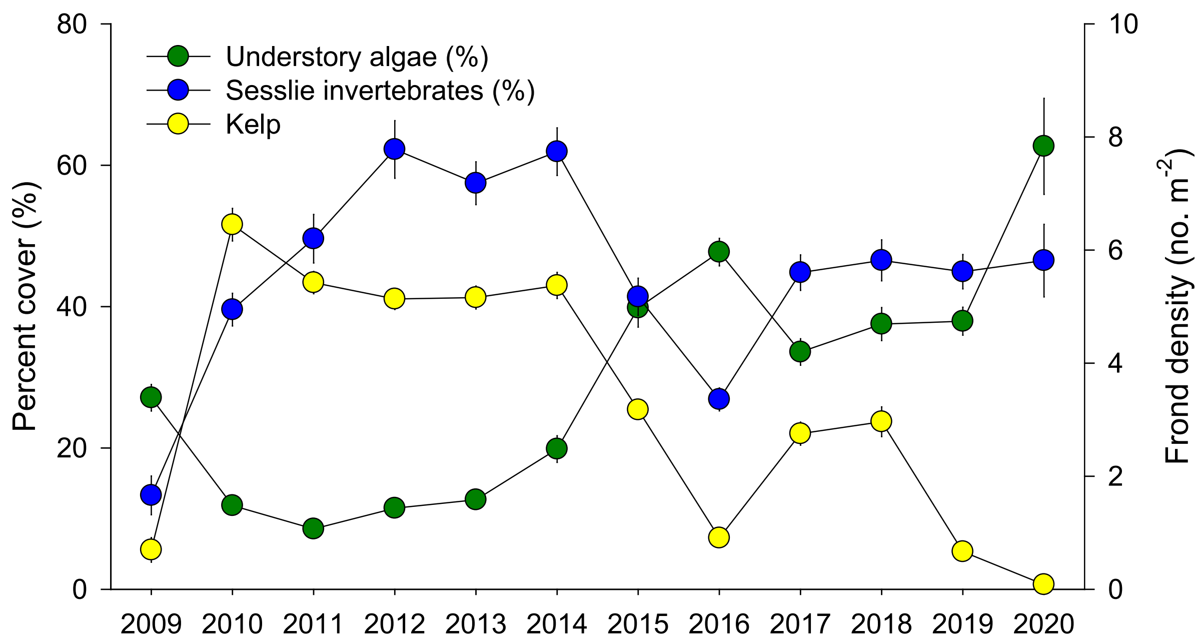

Figure 5.2.12. Comparison of mean percent cover (± 1 standard error) of understory algae (green) and sessile invertebrates (blue) on left axis and mean frond density (± 1 standard error) of adult giant kelp (yellow) on the right axis at Wheeler North Reef from 2009 – 2020.

The percent cover of sessile invertebrates varied substantially among the 15 transects sampled in 2020, ranging from 22% to 61% (Figure 5.2.13b). This range was considerably larger than that averaged over the previous 11 years (14% to 29%; (Figure 5.2.13a vs. 5.2.13b).

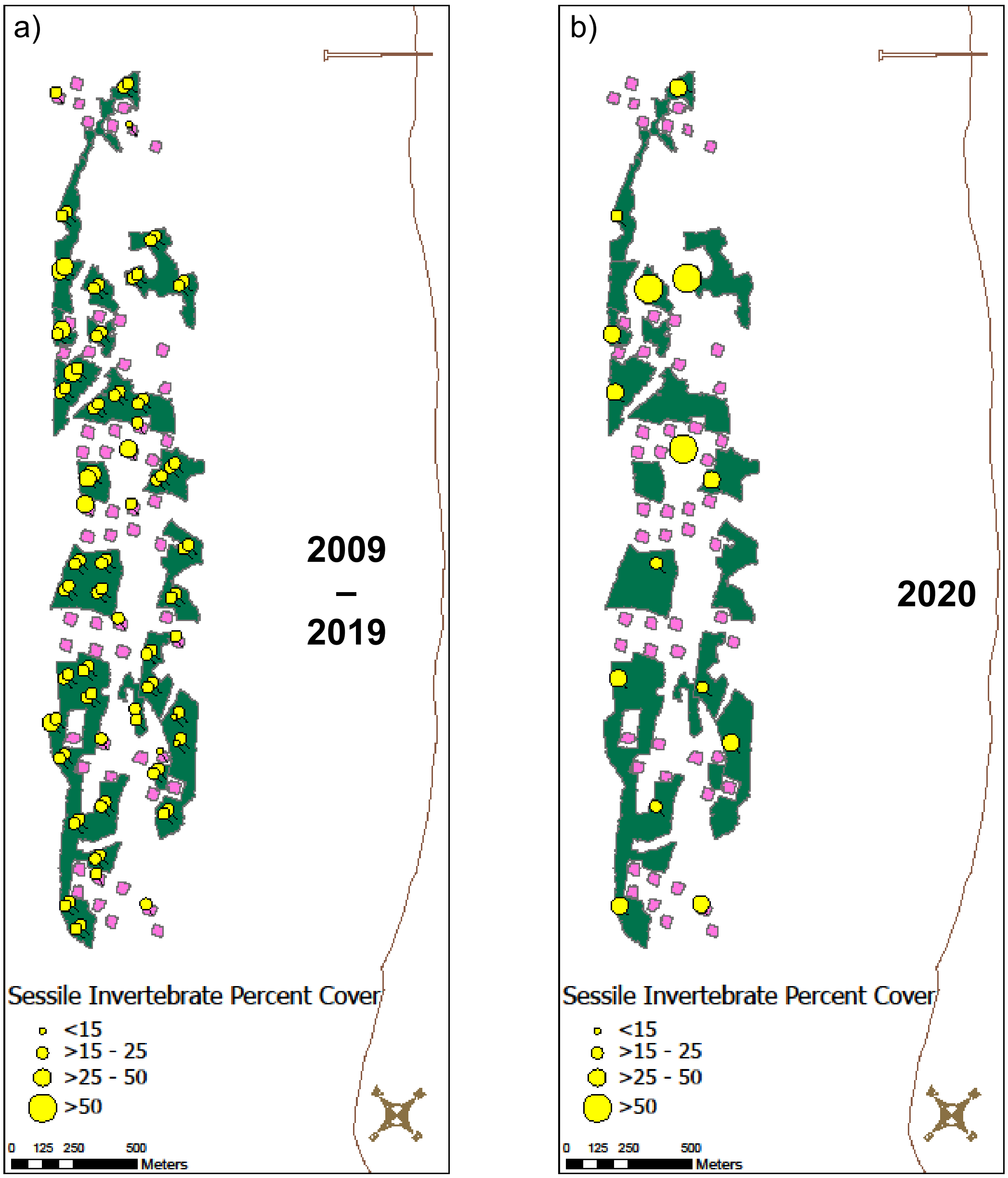

Figure 5.2.13. Percent cover of sessile invertebrates on transects of the Phase 1 modules (pink) and Phase 2 polygons (green) of Wheeler North Reef. (a) Average of 2009 – 2019, and (b) 2020. Size of bubble corresponds to level of percent cover of sessile invertebrates.

The mix of common species of sessile invertebrates at Wheeler North Reef in 2020 differed from average of the previous 11 years, in that the sea fan *Muricea californica* was the most dominant species on the reef in 2020 accounting for 15% of the total cover of sessile invertebrates (Figure 5.2.14). *Muricea* along with encrusting bryozoans and sponges, the erect bryozoan *Diaperoforma californica* and the hydroid *Plumularia* spp. accounted for 50% of the sessile invertebrate cover in 2020, In previous years (2009-2019) the colonial tunicate *Chelyosoma productum,* and encrusting sponges, foraminifera and bryozoans collectively accounted for ~ 50% of the total cover of all sessile invertebrates.

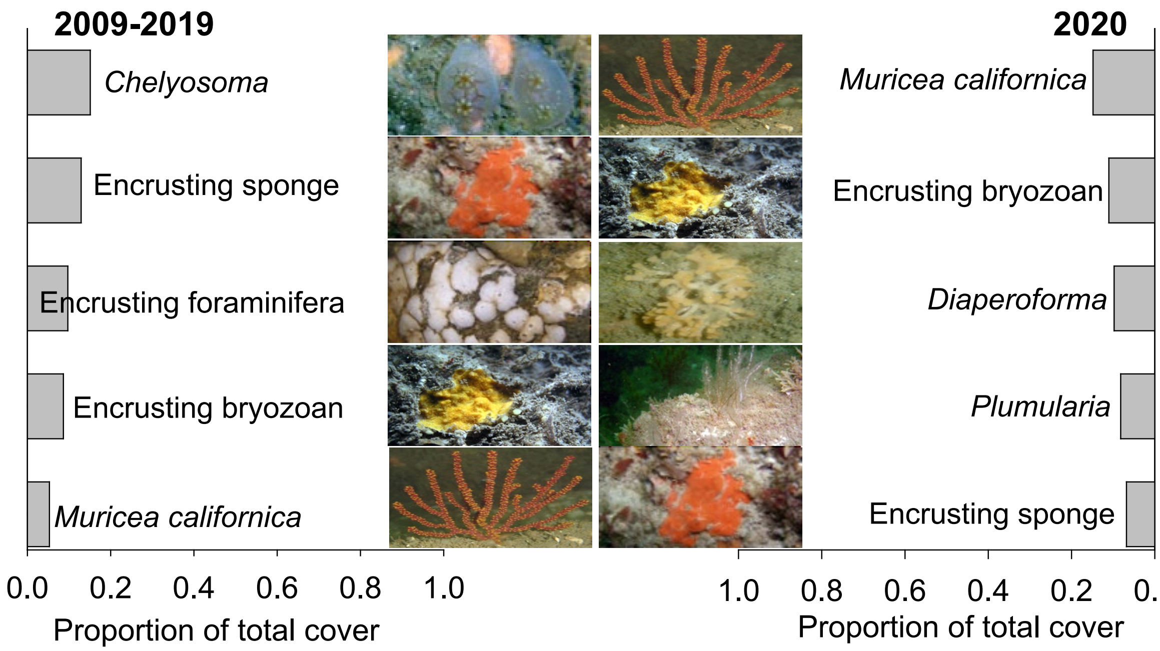

Figure 5.2.14. Proportion of the total percent cover contributed by the five most abundant sessile invertebrate species at Wheeler North Reef averaged for 2009 – 2019 and 2020.

A diverse array of mobile invertebrates is also common in southern California kelp forests including a variety of herbivorous and predatory snails, octopus, crabs, lobster, and many different kinds of echinoderms (e.g., brittle stars, sea stars, sea urchins, sea cucumbers). Like sessile invertebrates, the abundance of mobile invertebrates at Wheeler North Reef increased dramatically (~10 fold) during the first few years following its construction (Figure 5.2.15a). Mean densities of mobile invertebrates at Wheeler North Reef peaked at 109 per m^2 in 2012, before steadily declining to 18 per m^2 in 2016, which is the lowest level recorded since the first post-construction survey in 2009. Much like the cover of sessile invertebrates the density of mobile invertebrates displayed a marked increase in 2017 to 41 per m^2, however, this number declined to ~28 per m^2 in 2019 and 2020. Unlike abundance, the total number of species of mobile invertebrates observed in the 82 transects at Wheeler North Reef increased over time from 43 species in 2009 to about 72 species in 2019 (Figure 5.2.15b). As seen with algae and sessile invertebrates the number of species of mobile invertebrates declined substantially in 2020 when only 15 transects were sampled.

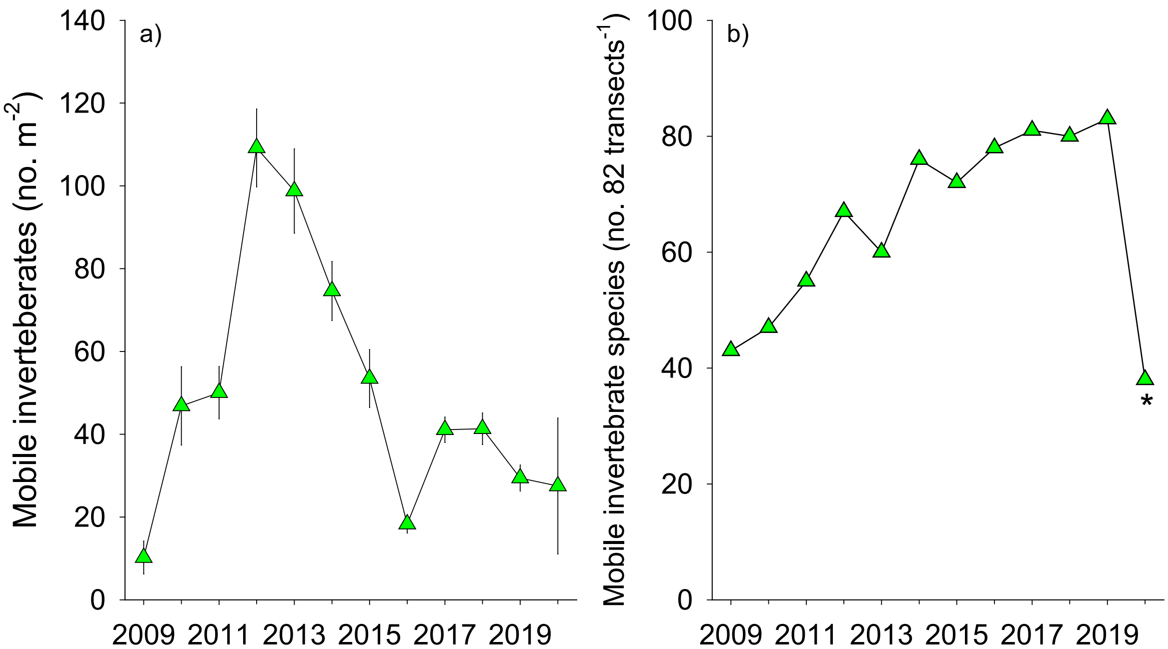

Figure 5.2.15. (a) Mean density (± 1 standard error) and (b) total number of species of mobile invertebrates at Wheeler North Reef from 2009 – 2020. * denotes reduced monitoring (n=15 transects).

The five most abundant mobile invertebrates recorded at Wheeler North Reef in 2020 did not differ appreciably from those averaged over the previous 11 years. The brittle star *Ophiothrix spiculata,* has consistently been the most abundant species accounting for 54% of all mobile invertebrates counted in 2020, which is less than the 11-year average of 80% (Figure 5.2.16). Brittle stars commonly inhabit the holdfasts of giant kelp and the changes in the density of brittle stars at Wheeler North Reef has been associated with a corresponding decrease in the percent cover of kelp holdfasts (Figure. 5.2.10). The cone snail *Conus californicus,* hermit crabs and the whelk *Pteropurpura festiva* have consistently been among the most abundant mobile invertebrates at Wheeler North Reef. Their densities have remained relatively constant over time, but their proportional abundance has shifted with fluctuations in the densities of brittle stars. Collectively these four species accounted for 82% of all mobile invertebrates recorded in 2020, which is ~10% less than their average during the previous 11 years.

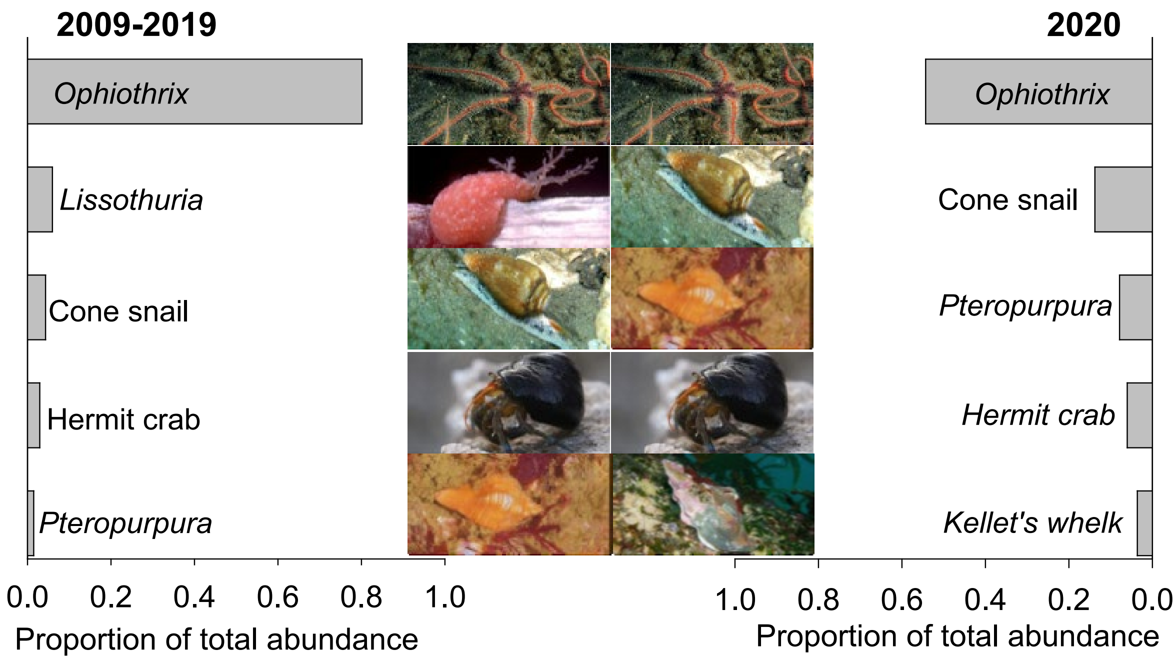

Figure 5.2.16. Proportion of the total abundance of mobile invertebrates contributed by the five most abundant mobile invertebrate species at Wheeler North Reef averaged for 2009 – 2019 and 2020.

Larger, economically important species of mobile invertebrates such as lobster, warty sea cucumbers, giant keyhole limpets and red sea urchins, while not as abundant as smaller species of mobile invertebrates, are common at Wheeler North Reef and often in greater abundance than at the nearby natural reefs at San Mateo and Barn (Figure 5.2.17). Of particular note is the California spiny lobster *Panulirus interruptus* a top predator in the kelp forest that is actively targeted by commercial and recreational fishermen. Lobster densities at Wheeler North Reef have increased nearly 20-fold since 2009 to 4.8 individuals per 100 m^2 in 2019, which was more than twice the densities observed at San Mateo and Barn. The average density of lobsters declined to 3.3 individuals per 100 m^2 in 2020, but the large variation observed among transects in 2020 (Figure 5.2.17a), indicates there is considerable uncertainty associated with this estimate, which most likely reflects the smaller sample size in 2020 (n=15) compared to previous years (n= 82).

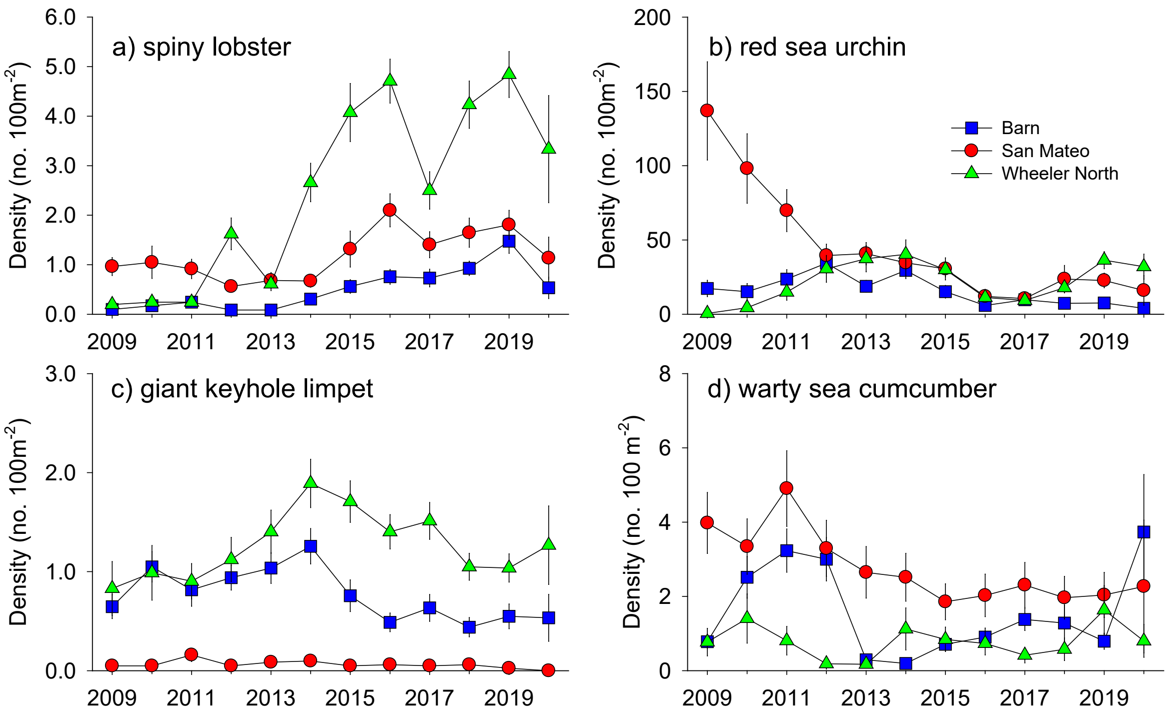

Figure 5.2.17. Mean densities (± 1 standard error) of (a) spiny lobster, (b) red sea urchin, (c) giant keyhole limpet, and (d) warty sea cucumber at Wheeler North Reef, Barn and San Mateo from 2009 – 2020.

Fish

Abundances of fishes living near the bottom at Wheeler North Reef have fluctuated greatly during the 12 years of monitoring. Fish rapidly colonized the Phase 2 Wheeler North Reef with densities reaching about 70 per 100 m^2 in the first year following construction (2009), which is the highest level observed to date (Figure 5.2.18a). Fish densities declined precipitously in 2010 and have fluctuated between 10 – 50 per 100 m^2 since then. Fish density averaged 11 individuals per 100 m^2 in 2020, which was only slightly less than that observed in the previous four years. Year-to-year variation in the number of fish species at Wheeler North Reef has fluctuated less compared to fish density. The total number of species of reef fish observed on the 82 transects nearly doubled between 2010 and 2012, remained relatively high at approximately 40 species between 2012 – 2014 and has gradually declined since then to 23 species in 2020 (Figure 5.2.18b).

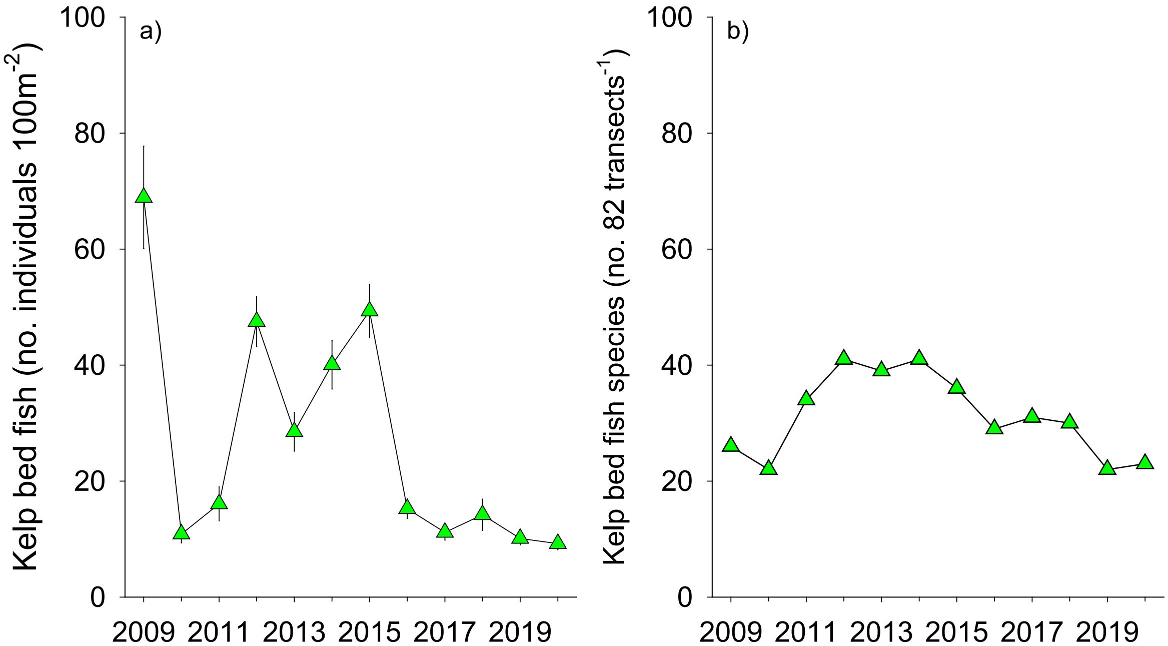

Figure 5.2.18. (a) Mean density (± 1 standard error) and (b) total number of species of kelp bed fish near the bottom at Wheeler North Reef from 2009 – 2020.

The sharp decline in the mean density of fish at Wheeler North Reef in 2016 (Figure 5.2.18a) occurred throughout the Phase 1 and Phase 2 reefs, with a few exceptions (Figure 5.2.19a vs 5.2.19b). Overall, fish densities at the smaller Phase 1 modules have been similar to those at the larger Phase 2 polygons, suggesting that reef footprint area (or reef perimeter to edge ratio) has not profoundly influenced the abundances of reef fish at Wheeler North Reef. As seen on the Phase 1 and Phase 2 reefs, fish rapidly recruited to the Phase 3 reef within days to a few weeks of its construction. As a result, densities of fish on the Phase 3 reef in 2020 were comparable to those observed on the older Phase 1 and 2 reefs (Figure 5.2.19b).

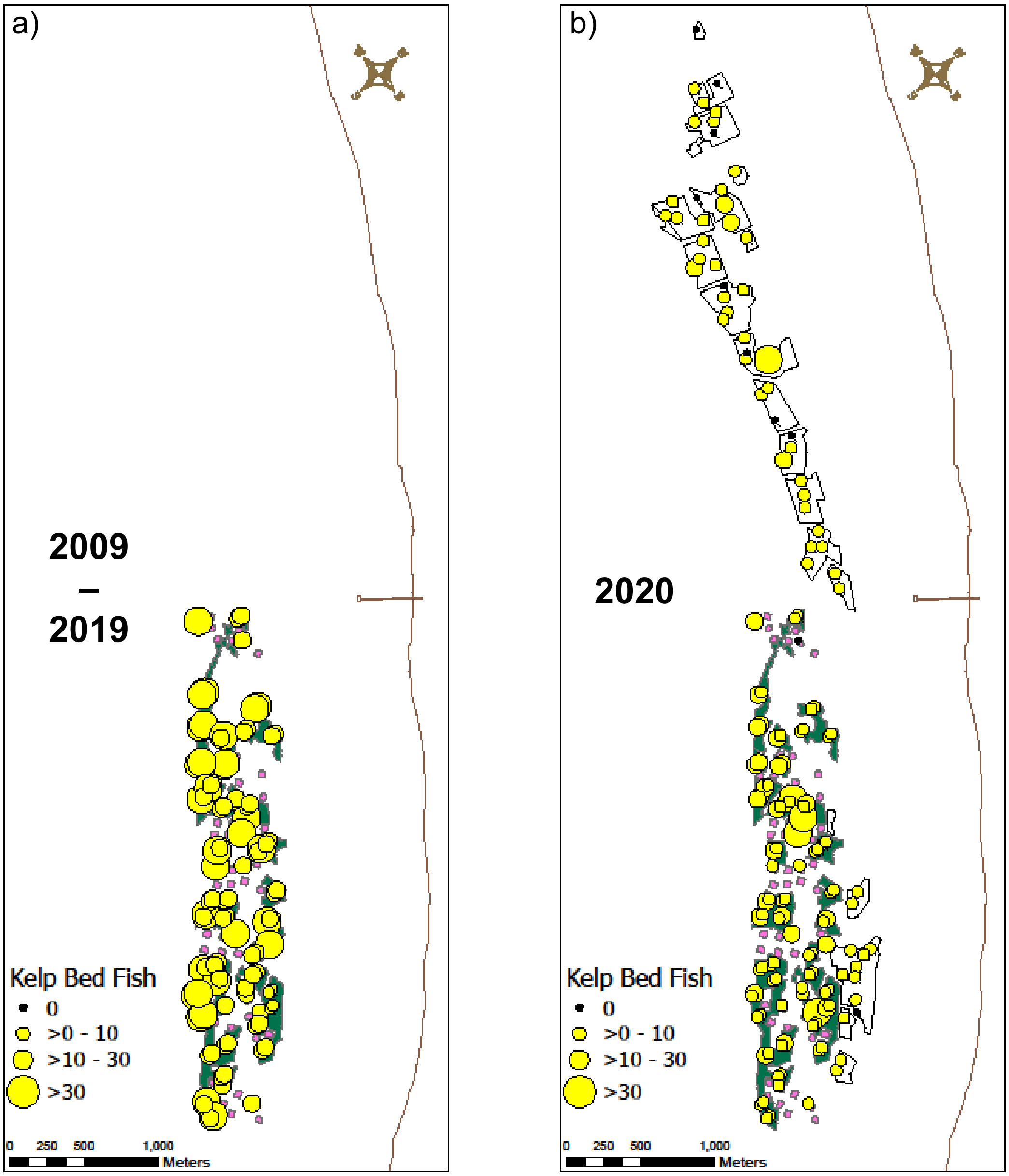

Figure 5.2.19. Density (no. 100 m^{-2}) of kelp bed fish in transects of the Phase 1 modules (pink), Phase 2 polygons (green) and Phase 3 (white) polygons of Wheeler North Reef. (a) Average from 2009 – 2019, and (b) 2020. Size of bubble corresponds to density of fish.

The species composition of reef fish at Wheeler North Reef in 2020 was dominated by species with warm-water affinities such as basses (i.e., barred sand bass, and kelp bass), wrasses (i.e., the senorita and California sheephead) and damselfish (i.e., blacksmith). These five species collectively accounted for 73% of all fish observed on the reef in 2020 (Figure 5.2.20). The blackeye goby, a short-lived (~ 2 years), cool water species that lives on the bottom and feeds on small crustaceans, had consistently been the most numerically abundant species at Wheeler North Reef through 2015, accounting for about 70% of the fish observed on the reef from 2009 –

2015. However, its proportional abundance declined to 8% during the anomalously warm water in 2016 and has remained relatively low since then. This reduction in the abundance of blackeye gobies accounts for the low overall densities of fish observed since 2016 (Figure 5.2.18a).

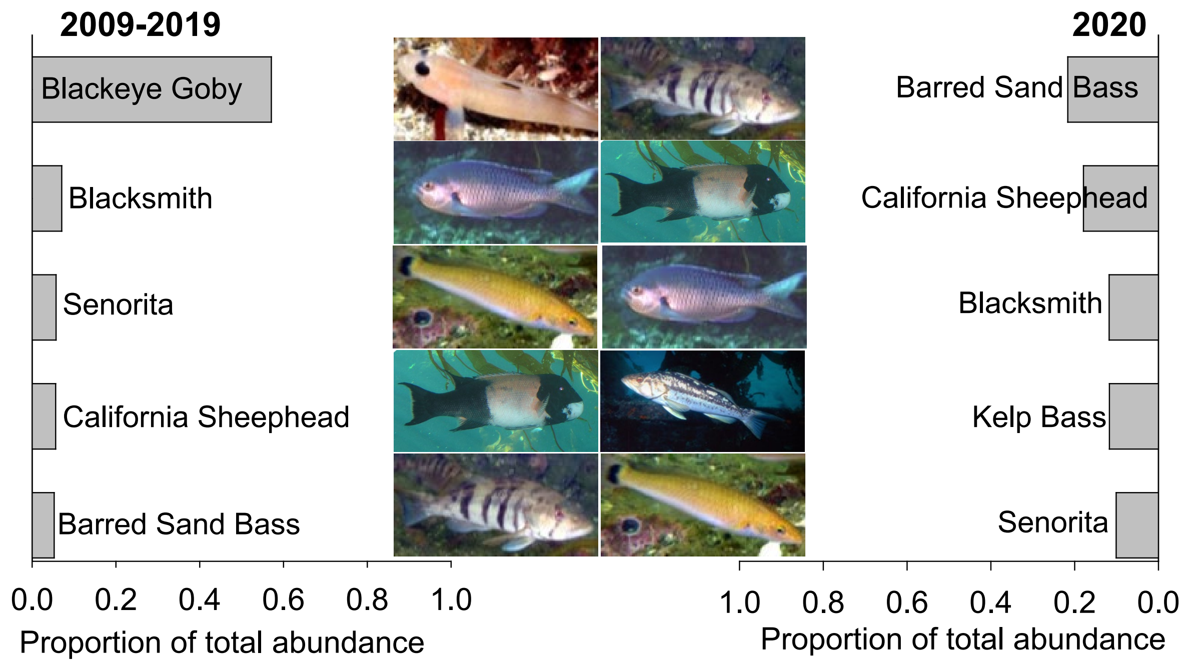

Figure 5.2.20. Proportions of total abundance contributed by the five most numerically abundant species of kelp bed fish at Wheeler North Reef averaged for 2009 – 2019 and 2020.

Large predatory species of fish that are valued ecologically and/or economically such as the giant sea bass (*Stereolepis gigas*) and California halibut (*Paralichthys californicus*) are also observed at Wheeler North Reef, but because of their large size and high trophic status they are not numerically abundant.

Because different species of fish vary tremendously in size, it is often desirable to have information on the amount of biomass of fish in a given area. This term is often referred to as biomass density to distinguish it from numerical density, which is the number of individuals per unit area. As observed for numerical density, the biomass density of fish declined at Wheeler North Reef in 2010, but did so at a lower rate than numerical density (Figure 5.2.21 vs. Figure 5.2.18a). Fish biomass density increased nearly continuously from 2010 – 2014 to a maximum of 33 g m^{-2}. Biomass density declined to ~25 g m^{-2} in 2015 and has remained relatively constant since then.

The relatively low biomass density of fish at Wheeler North Reef in 2009 when the numerical density was extremely high can be explained by the fact that blackeye gobies, which were the most numerically abundant species in 2009, are relatively small (~ 3 grams in weight) and composed a small proportion of the biomass (~ 10 % in 2009). Larger common species such as the California sheephead, barred sand bass, and kelp bass, along with smaller black perch which are numerically abundant, and the much larger but much less abundant giant sea bass have consistently been the most dominant species of reef fish at Wheeler North Reef in terms of biomass density, and in 2020 they collectively accounted for 86% of the total reef fish biomass (Figure 5.2.22).

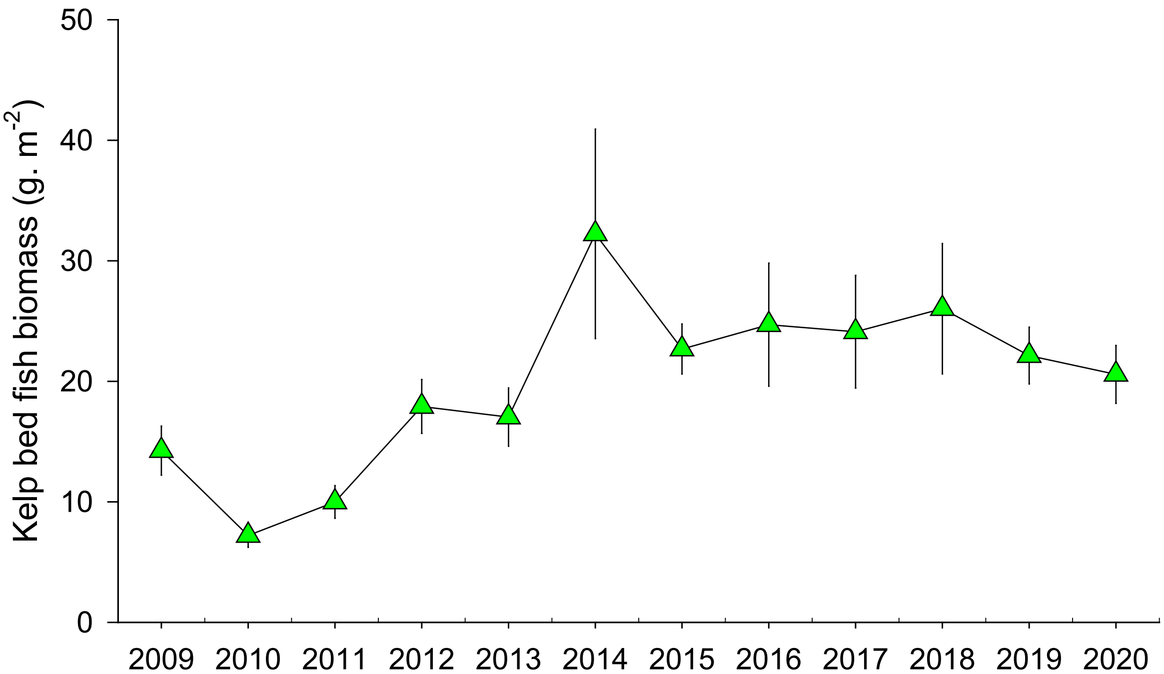

Figure 5.2.21. Mean biomass density (± 1 standard error) of kelp bed fish within 2 m of the bottom at Wheeler North Reef from 2009 – 2020.

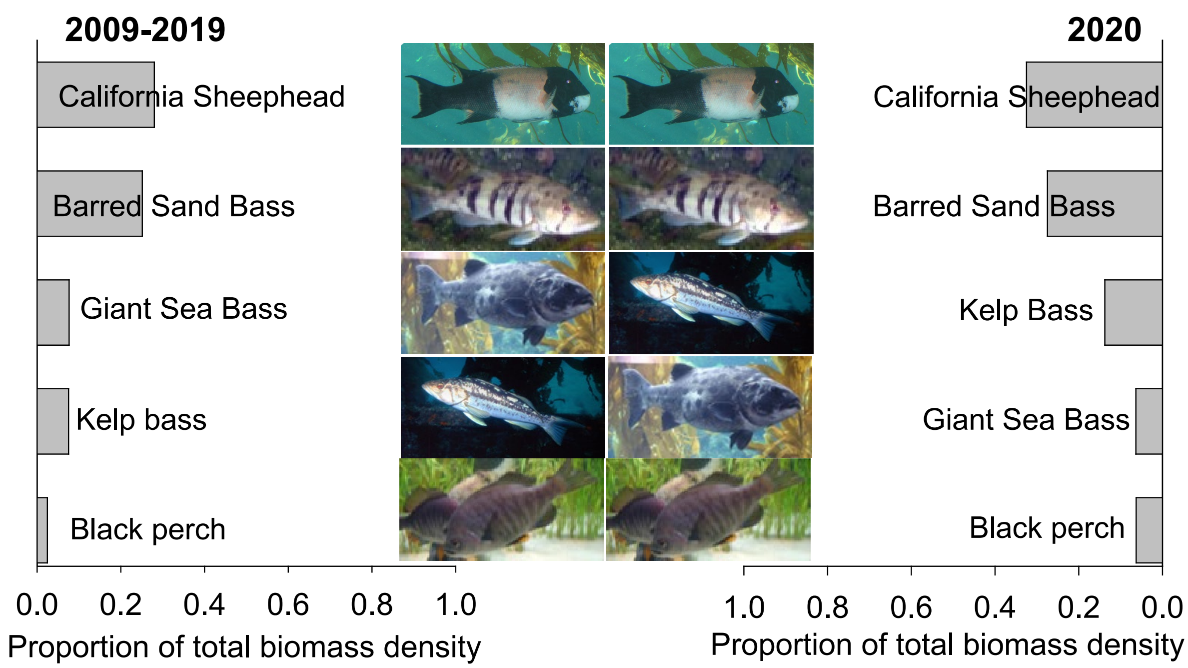

Figure 5.2.22. Proportions of total biomass density contributed by the five most dominant species of kelp bed fish at Wheeler North Reef averaged for 2009 – 2019 and 2020.

Similar to numerical density, the biomass density of kelp bed fish varied across the 151 transects sampled on the three phases of Wheeler North Reef in 2020 (Figure 5.2.23). Two transects averaged relatively high biomass (> 80 g m^{-2}) for the first 11 years (Figure 5.2.23a). In one case this resulted from 3 giant seabass and a large leopard shark in a single survey (2014). The other incidence of high average biomass density resulted from large numbers of smaller reef associated species observed in multiple years. Similarly, the high fish biomass (> 80 g m^{-2}) observed on two transects in 2020 resulted from a single giant seabass in one case, and large numbers of sand bass, kelp bass and black surfperch in the other case.

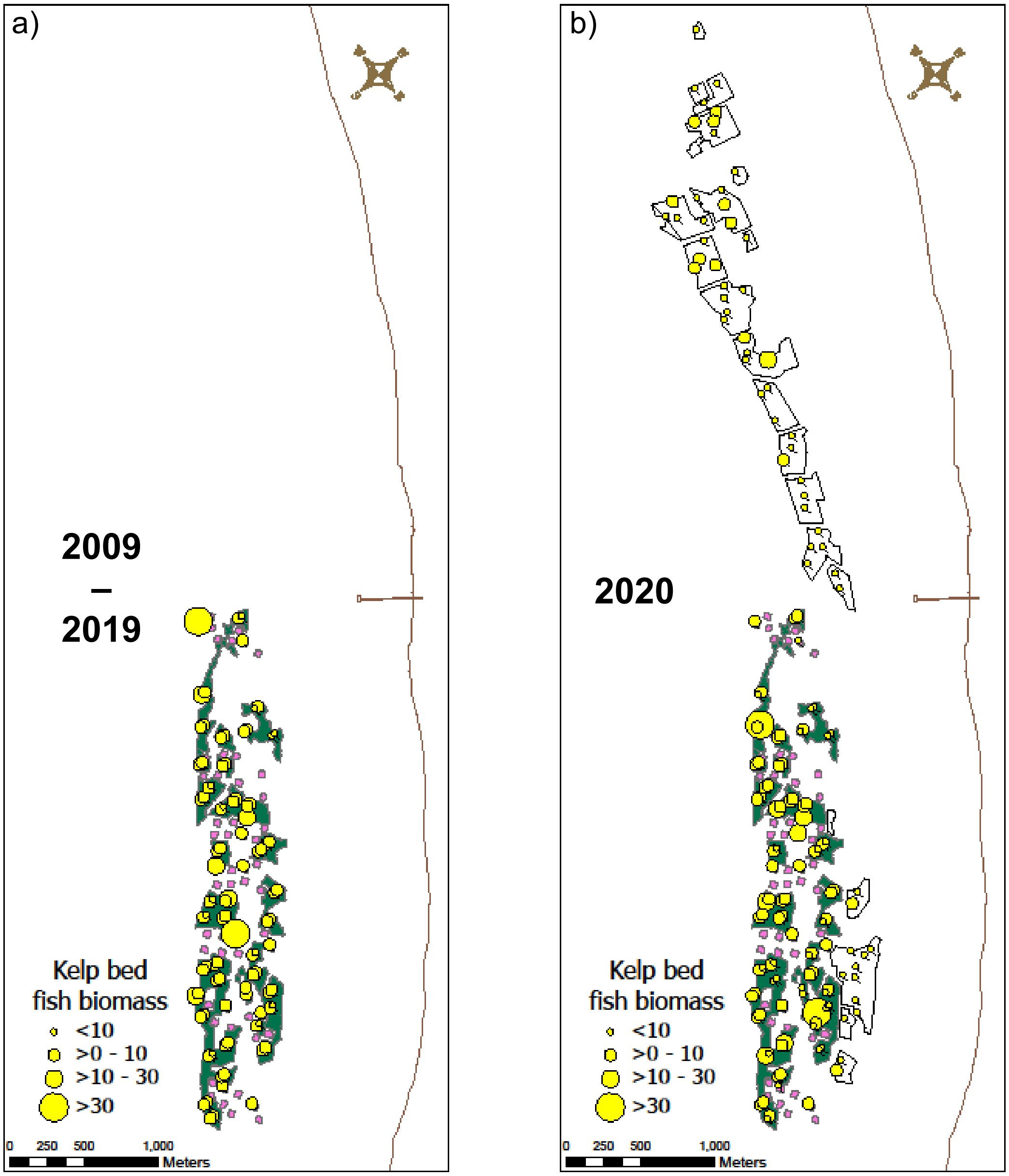

Figure 5.2.23. Biomass density (g m^2) of kelp bed fish on transects of the Phase 1 modules (pink) Phase 2 polygons (green) and Phase 3 polygons (white) of Wheeler North Reef. (a) Average of 2009 – 2019, and (b) 2020. Size of bubble corresponds to biomass density of fish.

6.0 Performance Assessment of Wheeler North Reef

Listed below are the absolute and relative performance standards that are used to evaluate whether the Wheeler North Reef meets the goals and objectives of the reef mitigation set forth in Condition C of the SONGS coastal development permit. We describe the methodological approach used to monitor and evaluate each performance standard and present a determination of the performance of Wheeler North Reef for each standard based on the results obtained from these sampling methods. More detailed methods can be found in the monitoring plan for the SONGS reef mitigation project (Reed et al. 2021).

6.1 Absolute Performance Standards

1. AT LEAST 90 PERCENT OF THE EXPOSED HARD SUBSTRATE MUST REMAIN AVAILABLE FOR ATTACHMENT BY REEF BIOTA

Approach*:* The percent cover of hard substrate is measured using a uniform grid of 20 points placed within the five 1m^2 quadrats uniformly positioned along each of the 50m long transects in the primary polygons of Wheeler North Reef (Figure 4.4.2). The observer sights along an imaginary line through each of the points that is perpendicular to the bottom and records the substrate type intercepted by the line extending below the point. Substrates are classified as natural or artificial and categorized as bedrock (continuous rocky reef), mudstone, large boulder (largest diameter ≥ 100 cm), medium boulder (≥ 50cm and < 100cm), small boulder (≥ 26cm and < 50cm), cobble (≥ 7cm and ≤ 25cm), pebble (≥ 2mm and < 7cm), sand (< 2mm), and shell hash. Only bedrock, boulders and cobbles are considered as exposed hard substrate when assessing this performance standard. Hard substrates covered with a thin layer of silt or sand are noted as being silted, but are nonetheless considered available for the attachment of reef biota for the purpose of evaluating this performance standard.

The total area of the exposed hard substrate (*S*) that is available for the attachment of reef biota during any given year *t* is determined as:

$$S_t = A_t P_t$$

where A_t is the total area of the footprint of the Wheeler North Reef in year *t,* and P_t is the proportion of the Wheeler North Reef covered by hard substrate in year *t*. A_t is determined from backscatter in the most recent multibeam sonar survey using a horizontal grid size of 0.25 meters with an isobath interval of 0.5 meters as described in Elwany et al. (2014). P_t is determined from data collected in diver surveys. The proportion of area covered by hard substrate in the as-built condition in 2008 immediately after construction ($S_0 = A_0P_0$) that is remaining at time *t* can be expressed as S_t/S_0. The value of S_t/S_0 based on the current year or a four-year running average of the current year and the preceding three years (whichever is larger) must be ≥ 0.9 for the Wheeler North Reef to successfully meet this standard.

The reef footprint area used to evaluate this standard includes the Phase 1 modules and the Phase 2 primary polygons, which collectively met the construction criteria of

≥ 42% cover of rock. The area of the Phase 2 primary polygons in the as-built survey done immediately after construction in 2008 was 130 acres (Elwany et al. 2009). Because the footprint area of the Phase 1 modules was not measured during the 2008 as-built survey, their footprint area measured in 2009 (25 acres) is used as their footprint area in 2008. Hence the initial footprint area of the Wheeler North Reef that is used to evaluate this performance standard (A_o) is 155 acres. The mean percent cover of rock of this initial footprint area in 2008 (P_0) was 45.6%.

Because the footprint area of the artificial reef is not expected to change much from year-to-year, multi-beam sonar surveys are done only once every five years and the value for reef footprint area is assumed to remain constant between sonar surveys. Multibeam sonar surveys of the Wheeler North Reef were completed in 2009, 2014 and 2020. Unlike footprint area, the percent of the bottom covered by rock is measured every year by divers.

Results: There was a slight decrease in the combined footprint area in 2009, the year following construction (Figure 6.1.1a), which is not unexpected as rocks settle into the soft sandy bottom. Since then, the footprint area of the Phase 1 modules and the Phase 2 primary polygons of Wheeler North Reef has remained relatively constant ranging from 152.1 to 153.8 acres. The percent cover of rock within the footprint areas of the Phase 1 modules and the Phase 2 primary polygons also remained relatively constant until 2020 when it unexpectedly increased from 47% to 56% cover. (Figure 6.1.1b).

The initial amount of hard substrate at Wheeler North Reef used to judge this performance standard was 70.6 acres in 2008 (Figure 6.1.1c). The 2-acre decrease in footprint area in 2009 coupled with a decline in the percent cover of hard substrate through 2011 (Figure 6.1.1b) resulted in nearly a 10% decrease in the total area of hard substrate on Wheeler North Reef by 2011 (Figure 6.1.1c). The total area of hard substrate returned to near as-built levels by 2013 following an increase in rock coverage, and remained near as-built levels until 2020 when it increased sharply to 87 acres, which is 17 acres more than initially constructed. (Figure 6.1.1c). The dramatic increase in the amount of hard substrate in 2020 resulted in a four-year running average of 76.5 acres, which is six acres more than that initially constructed (Figure 6.1.1d). Thus Wheeler North Reef met the performance standard for reef area in 2020 regardless of whether the evaluation was based on data from 2020 alone or the 4-year running average.

The large increase in the area of hard substrate at Wheeler North Reef in 2020 likely reflects less certainty in estimates of percent cover of rock associated with reduced sampling in 2020 as opposed to an actual increase in the total amount of hard substrate available on the reef. This is supported by the observation that a time series (2009-2019) of the subset of 15 stations sampled in 2020 showed greater temporal variability than that of the 82 stations that are normally sampled. If this hypothesis is correct, then the expectation is that the percent cover of hard substrate (and the corresponding area of available hard substrate) will decline to a coverage closer to the as-built level in 2021 when full monitoring of the 82 transects is expected to resume.

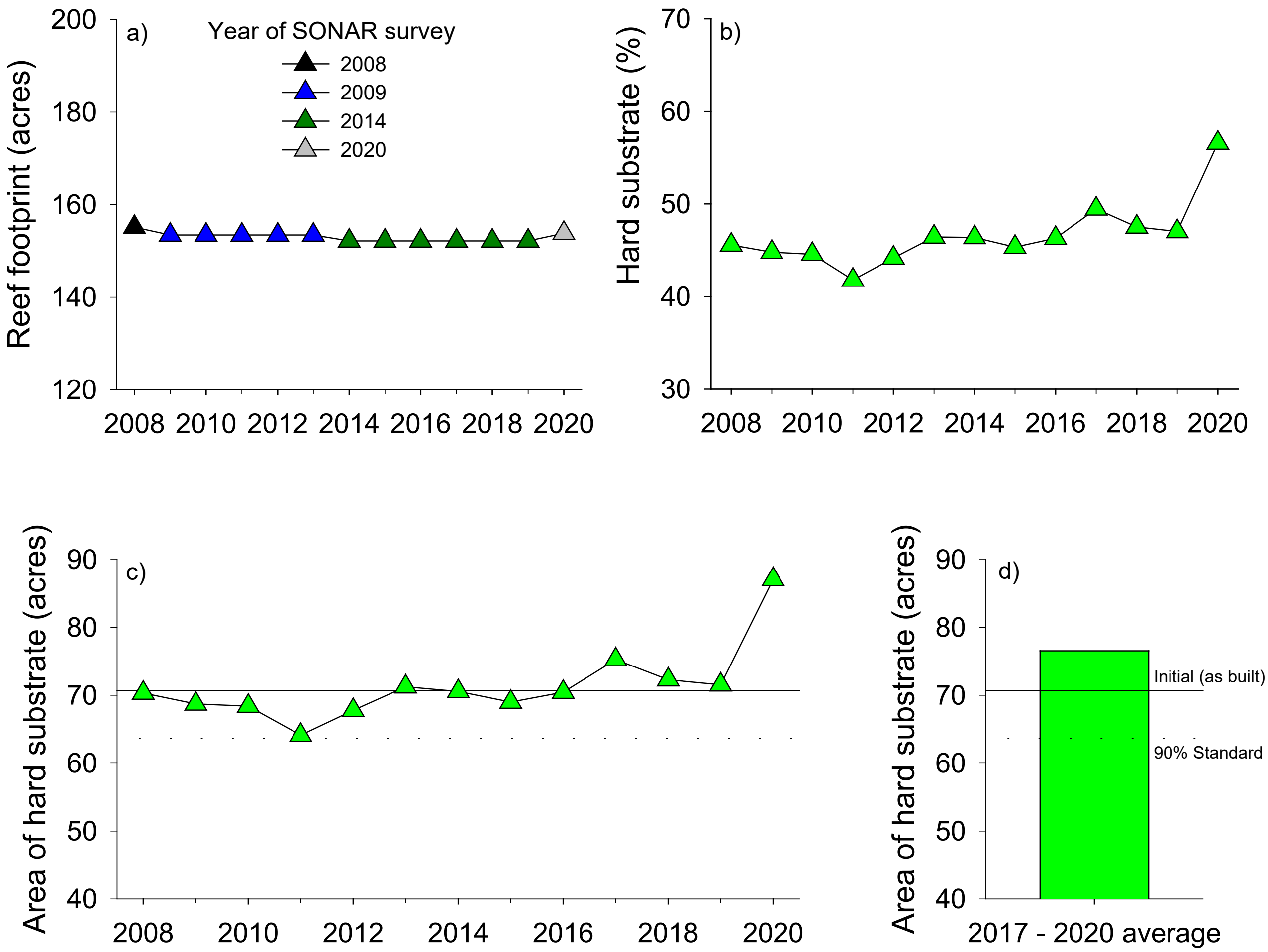

Figure 6.1.1. Variables used to calculate exposed hard substrate. (a) Reef footprint area, (b) Percent cover of hard substrate, (c) Area of exposed hard substrate and (d) 4-year running average of the area of exposed hard substrate.

2. THE ARTIFICIAL REEF(S) SHALL SUSTAIN 150 ACRES OF MEDIUM-TO-HIGH DENSITY GIANT KELP.

Approach: The abundance of giant kelp *Macrocystis pyrifera* is monitored by divers once per year in the summer in five replicate 10m x 2m plots arranged at 10m intervals along each of the ninety-two 50m transects at Wheeler North Reef (Figure 4.4.2). For the purpose of this performance standard, medium-to-high density giant kelp is defined as more than four adult plants per 100m^2 of ocean bottom and adult giant kelp plants are defined as having eight or more fronds (these criteria are the same as those used to assess the impacts of SONGS on giant kelp). The summed total of adult plants in the five 10m x 2m quadrats provides an estimate of the number of adult plants per 100m^2 at each transect. The proportion of transects with a density >4 adult plants per 100m^2 is used as an estimate of the proportional area of the artificial reef occupied by medium to high density giant kelp.

The total area A_k of Wheeler North Reef occupied by medium to high density giant kelp in a given year is determined as:

$$A_k = \sum_{i=1}^{n} \left(\frac{N_{ki}}{N_{ri}}\right) * A_i$$

where n = total number of polygons at the Wheeler North Reef (Phases 1+2+3), A_i is the area of a polygon or module based on the most recent sonar survey, N_{ki} = number of transects in that polygon with >4 plants per 100m^2, and N_{ri} is the total number of transects sampled in that polygon. For the purpose of this calculation all 56 Phase 1 modules are considered to be a single polygon.

Unlike the absolute performance standard for hard substrate, the data used to evaluate the absolute performance standard for giant kelp and fish standing stock (see below) are collected over the entire Wheeler North Reef (Phases 1+2+3). The reason for this is that the requirement for sustaining 150 acres of giant kelp and a fish standing stock of 28 tons is not tied to a specific coverage of hard substrate.

The value of A_k is calculated each year of the monitoring period and summed to that measured in previous years beginning in 2019. The mitigation requirement for giant kelp area will have been met when the total acres of giant kelp accrued by Wheeler North Reef equals the targeted annual value (i.e., 150 acres) x the total years of operation of SONGS Units 2 & 3 (= 32), which amounts to 4800 acres of medium-high density adult giant kelp.

Results: The area of medium-to-high density adult kelp on Wheeler North Reef in 2019 and 2020 was estimated to be 34 and 4 acres, respectively (Figure 6.1.2a), substantially less than the target of 150 acres established by the CCC. Nonetheless the average density of adult kelp at the Wheeler North Reef has been within the range or higher than that at the two reference reefs in all but 1 year since 2009 (Figure 6.1.3). Time series data show that the 174-acre Phase 1 and 2 Wheeler North Reef supported at least 150 acres of giant kelp from 2010 - 2015, before declining precipitously to 52.8 acres in 2016 following the onset of anomalously warm water (Reed et al. 2020). The area of kelp increased to 136 acres in 2017 when cooler waters prevailed, and subsequently declined to 4 acres in 2020. Similar declines were observed at San Mateo and Barn suggesting that the low kelp acreage observed at Wheeler North Reef since 2016 is due to unfavorable conditions for giant kelp growth and recruitment throughout the region rather than unsuitable conditions specific to Wheeler North Reef.

In 2020 the Wheeler North Reef had earned credit for 38 of the 4800 acres of medium-to-high density giant kelp required for this performance standard (Figure 6.1.2b).

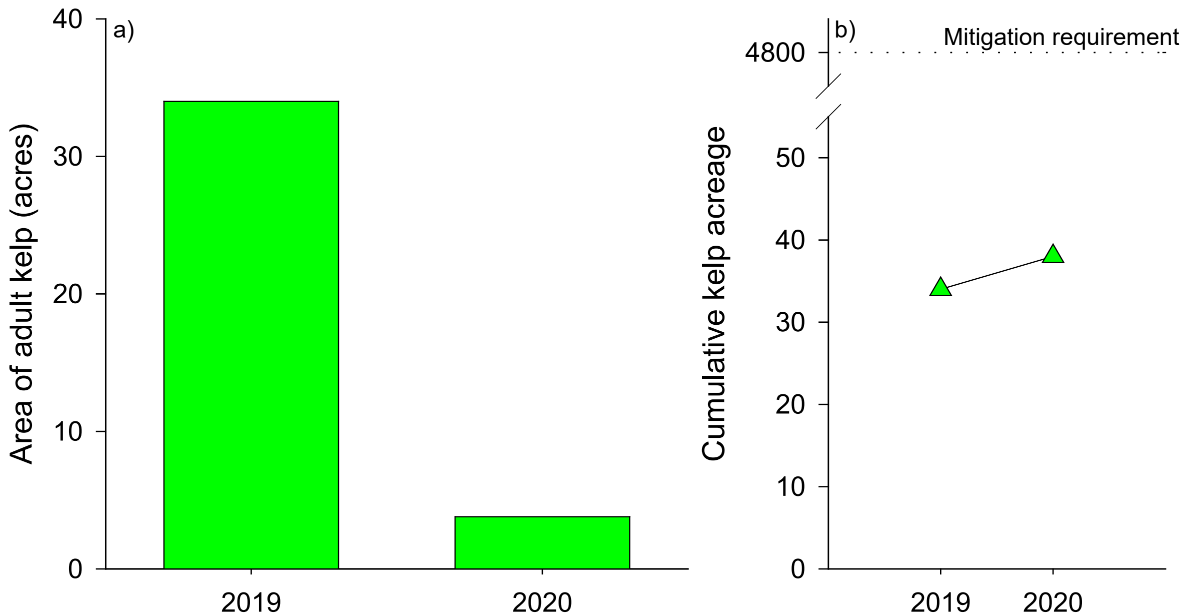

Figure 6.1.2. (a) The number of acres of medium to high density adult kelp at Wheeler North Reef in 2019 and 2020. (b) Cumulative acres of medium to high density adult kelp at Wheeler North Reef in 2019 and 2020.

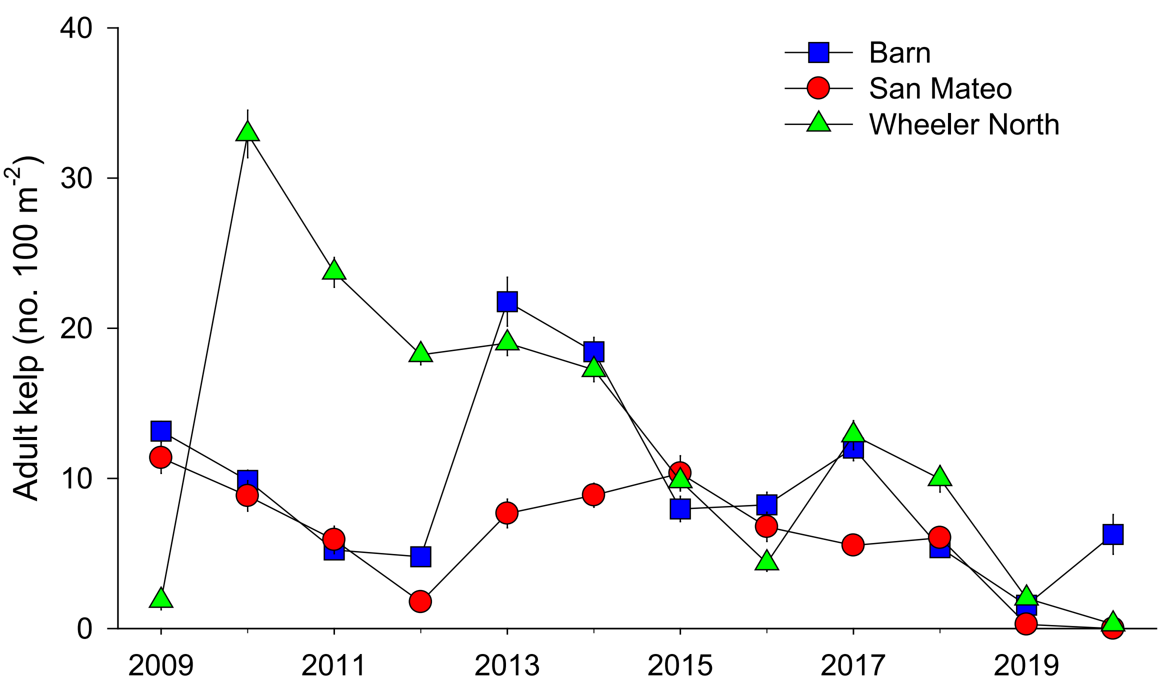

Figure 6.1.3. Mean (± 1 standard error) density of adult giant kelp (*Macrocystis pyrifera*) at Wheeler North Reef, San Mateo and Barn from 2009 – 2020.

3. *THE STANDING STOCK OF FISH AT THE MITIGATION REEF SHALL BE AT LEAST 28 TONS.*

Approach: The standing stock of fish at Wheeler North Reef is estimated using data on the density of bottom-dwelling fish, individual lengths, and the relationships between fish length and fish mass. Data on fish density and length are recorded on the bottom along replicate fixed transects at Wheeler North Reef in summer to early autumn of each year. Divers count, identify to species and estimate the total length (to the nearest cm) of each fish observed in a 3m wide x 1.5m high x 50m long volume centered above a measuring tape placed along the bottom and extending the length of each replicate 50 m transect (Figure 4.4.2). For aggregating species such as the blacksmith (*Chromis punctipinnis*) and salema (*Xenistius californiensis*), the number and mean length of individuals in a group are estimated. Smaller fish that shelter on or near the bottom are recorded in a 2m wide swath centered along the transect as divers return after completing the sampling of larger more visible fish. Small cryptic species (e.g. cottids, gobies, blennies) are recorded in the five $1m^2$ quadrats used to sample invertebrates and algae. These data are occasionally augmented with data from additional surveys of fish lengths when more information is needed to accurately characterize population size structure.

Length data are used to assign each fish to one of three life stages (juvenile, subadult, and adult) using data from the literature (e.g. Love 2011) or best professional judgment by reef fish experts (e.g., Milton Love UCSB and Mark Steele CSUN). The biomass of each species within a transect is calculated by multiplying the number of fish in each life-stage by the average weight of the life stage and summing over all life stages. Fish weights are estimated from fish lengths using species-specific length-weight regressions obtained either from the literature (Gnose, 1967; Quast, 1968a, 1968b; Mahan, 1985; Wildermuth, 1983; Stepien, 1986; DeMartini et al., 1994, Love, 2011) or from data collected as part of this project.

The biomass densities of all species encountered on a transect are summed to produce an estimate of the total biomass of fish within each transect in units of g wet weight m^{-2}. The biomass density of all transects in a polygon are then averaged, converted to US tons per acre, and multiplied by the total area of the polygon (in acres) to obtain the standing stock of fish in that polygon. The standing stock of fish on all polygons (Phases 1, 2 and 3) is summed to obtain an estimate of the total standing stock of fish at the Wheeler North Reef. For the purpose of this calculation all 56 Phase 1 modules are considered to be a single polygon. The sampling methods and calculations for determining fish standing stock described above are the same as those used by the Marine Review Committee (MRC, 1989) when they determined that SONGS operations caused a 28-ton reduction in the standing stock of bottom-dwelling kelp bed fish.

The standing stock of reef fish calculated for a given year is added to the cumulative total of previous years. The mitigation requirement for fish standing stock will have been met when the total tons of fish accrued by Wheeler North Reef equals the targeted annual value (i.e., 28 tons) x the total years of operation of SONGS Units 2 & 3 (= 32), which amounts to 896 tons of reef associated fish.

Results: The standing stock of reef fish on Wheeler North Reef in 2020 was estimated to be 22 tons, which was four tons more than that estimated for 2019 (Figure 6.1.4a).

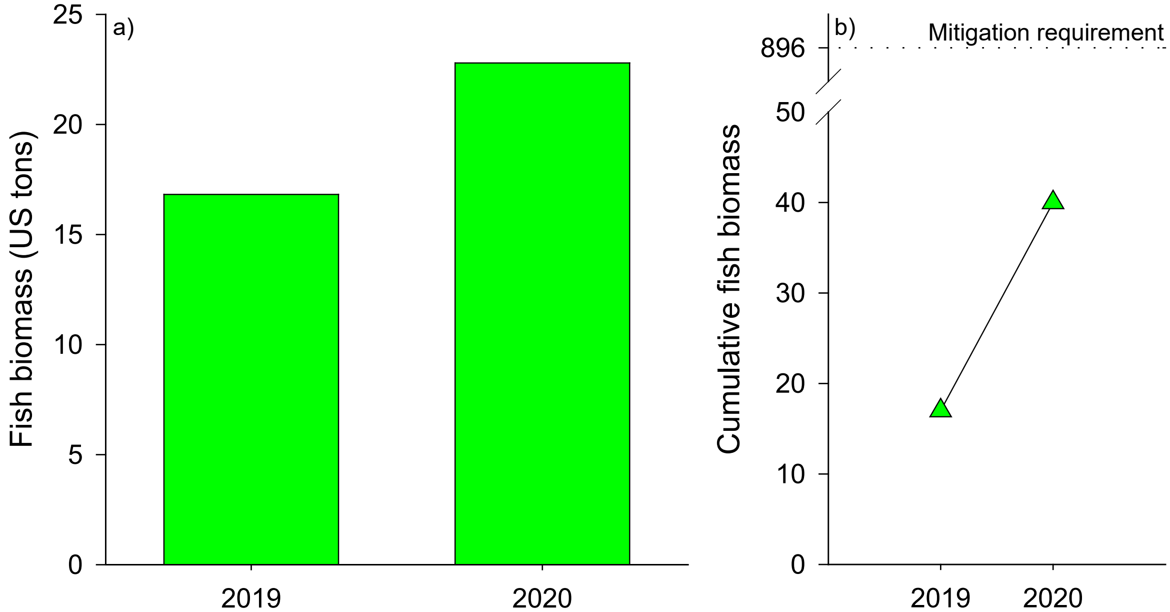

Figure 6.1.4. (a) Estimated standing stock of fish at Wheeler North in 2019 and 2020 and (b) cumulative fish biomass at Wheeler North Reef in 2019 and 2020.

The biomass density of fish at the Wheeler North Reef has been consistently within the range estimated for the two reference reefs (Figure 6.1.5). The same six species comprised more than 80% of the total fish biomass on all three phases of the Wheeler North Reef in 2020 (Figure 6.1.6) despite differences in the age and community development of the three reef phases. That this was true for the Phase 3 polygons constructed in 2020 just weeks prior to sampling suggests that these species are influenced more by physical rather than biological features of the reef, especially during times of low giant kelp abundance as was the case in 2020.

In 2020 the Wheeler North Reef had earned credit for 40 of the 856 tons of fish required for this performance standard (Figure 6.1.4b).

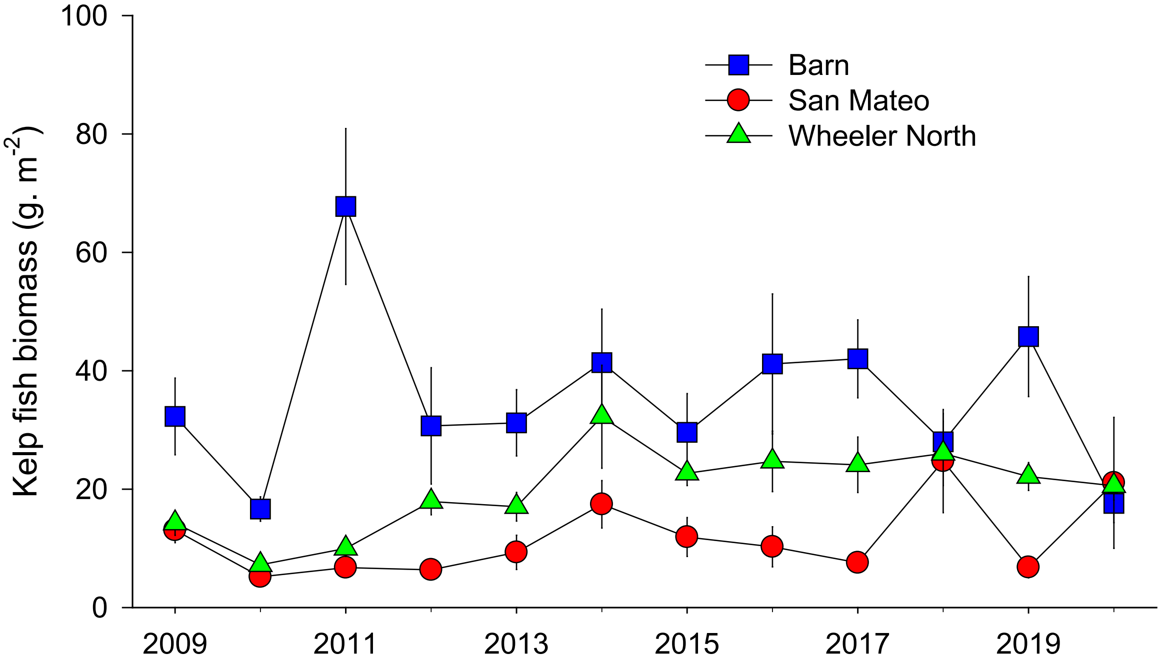

Figure 6.1.5. Mean (± 1 standard error) biomass density of kelp bed fish within 2 m of the bottom at Wheeler North Reef, San Mateo and Barn from 2009 – 2020.

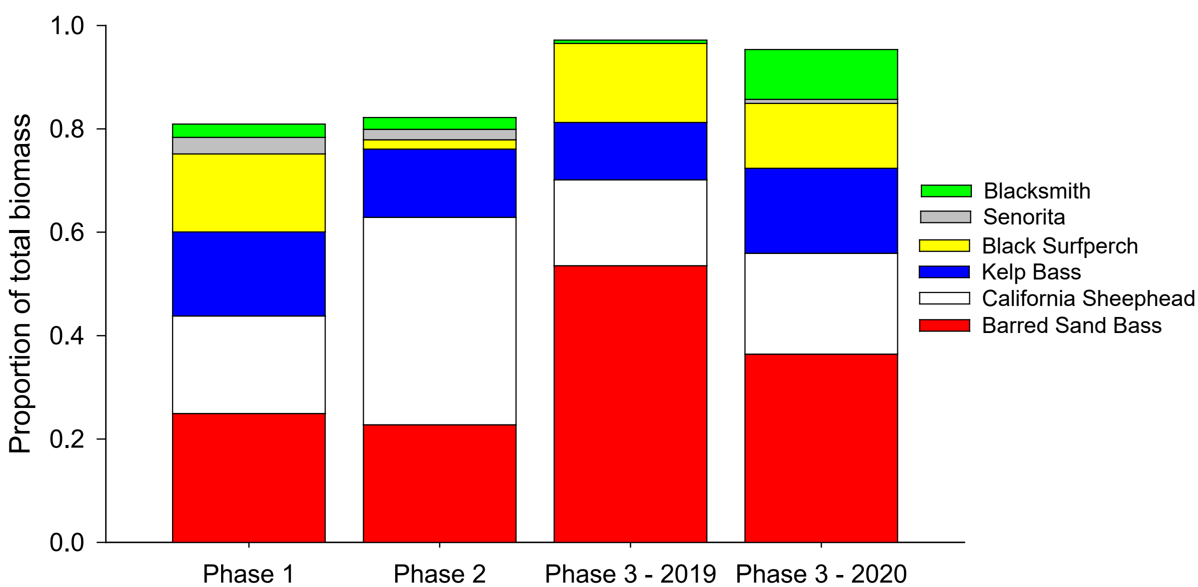

Figure 6.1.6. Proportion of total biomass in 2020 of blacksmith, señorita, black surfperch, kelp bass, California sheephead and barred sand bass on each of the three phases of Wheeler North Reef. Separate values are provided for the Phase 3 polygons built in 2019 and 2020.

4. THE IMPORTANT FUNCTIONS OF THE REEF SHALL NOT BE IMPAIRED BY UNDESIRABLE OR INVASIVE BENTHIC SPECIES (E.G., SEA URCHINS OR CRYPTOARACHNIDIUM).

Approach: Reefs in southern California provide many important ecological functions that pertain to the production of food and the provision of habitat for reef associated species. Undesirable outbreaks of native species along with the introduction of invasive non-indigenous species have the potential to impair these functions and thus prevent the Wheeler North Reef from attaining its mitigation goal of compensating for the loss of marine resources caused by SONGS' operations. Invasive reef species may include non-native taxa such as the green seaweed *Caulerpa taxifolia,* which escaped from the aquarium trade to invade many marine habitats worldwide, including some in southern California, and the brown seaweed *Sargassum horneri,* which was accidentally introduced from Asia and has become increasingly abundant at some reefs off southern California. Native species that become undesirable when they attain very high abundances include dense aggregations of sessile invertebrates such as sea fans that monopolize space and exclude other species, and starved sea urchins that overgraze the bottom and create large deforested areas commonly called sea urchin barrens. Data on the abundance of undesirable and invasive species are collected as part of the monitoring done to evaluate the biological performance standards pertaining to the benthic community of reef algae, invertebrates and fish.

Examples of key ecological functions provided by shallow reefs of southern California include the provision of nursery habitat for fishes and primary production by macroalgae. The provision of nursery habitat for fishes can be assessed using data collected for the purpose of evaluating the performance standard pertaining to the abundance of young-of-year fish and thus incurs no added cost to evaluate. By contrast, measuring primary productivity by reef macroalgae is very time consuming (e.g., see Harrer et al. 2013, Rassweiler et al. 2018) and is not required for evaluating the performance of Wheeler North Reef. However, net primary production (NPP) by giant kelp (which constitutes the vast majority of macroalgal biomass on reefs in California; Graham et al. 2007) can be predicted from more easily obtained measurements of kelp frond density (Rassweiler et al. 2018), which are made as part of the evaluation of the performance standard pertaining to giant kelp area.

The evaluation of the performance standard pertaining to undesirable and invasive species involves a two-step approach. First, the performance of Wheeler North Reef with respect to young-of-year fish and giant kelp NPP is assessed relative to the two reference reefs to determine whether these important functions of Wheeler North Reef are impaired. Second, data collected on the abundance of sea urchins, sea fans or other potentially undesirable or invasive species are used to evaluate whether their abundances reach levels that have been shown to impair reef functions and to assess whether key reef functions are negatively related to their abundance.

Results: We found little indication that important ecological functions of Wheeler North Reef were impaired in 2020. Results from monitoring showed that annual net primary production by giant kelp at Wheeler North Reef in 2020 was within the range of the two reference sites (Figure 6.1.7a), while the four-year average from 2017-2020 was slightly above the range (Figure 6.1.7b).

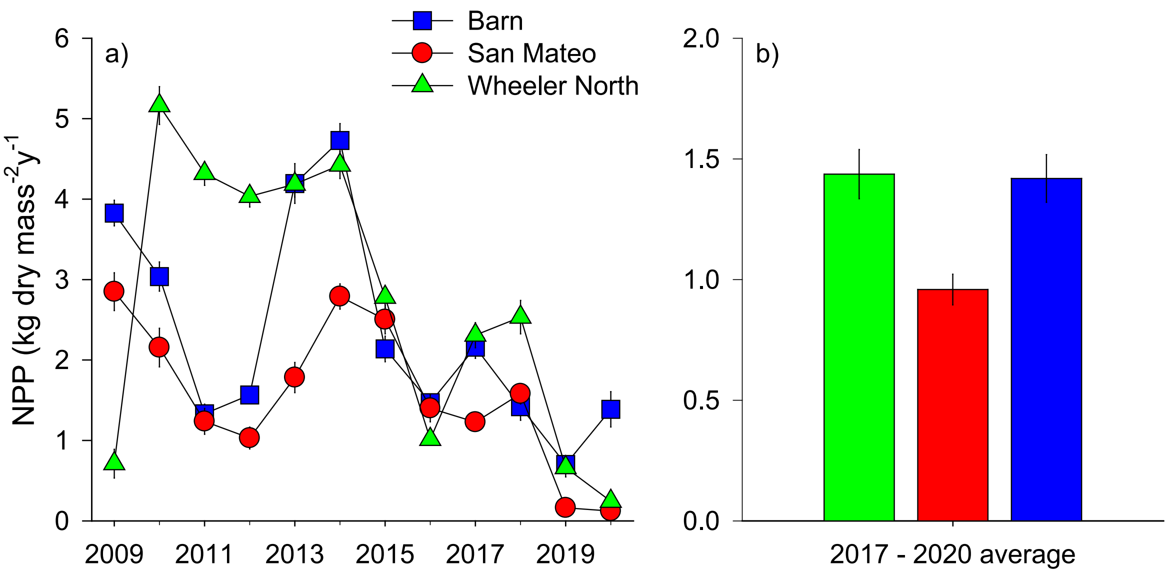

Figure 6.1.7. Mean (± 1 standard error) giant kelp net primary production at Wheeler North Reef, San Mateo and Barn (a) annual values for 2009 – 2020 and (b) 4-year running average.

Data collected on the density of young-of-year fishes indicated that the capacity of the Wheeler North Reef to function as nursery habitat for fishes has been on average similar to that of the reference reefs over the last four years (see section 6.2.7).

Invasive and potentially undesirable species of particular interest are native sea fans (*Muricea* spp.), which are known to attain high abundances on artificial reefs in California and exclude other species, including giant kelp (Ambrose et al. 1987). The percent cover of sea fans at Wheeler North Reef has steadily increased since the first year of monitoring in 2009 (Figure 6.1.8a). A particularly large increase in percent cover was observed in 2020, which may be an artifact of reduced sampling caused by restrictions imposed by COVID-19. If this is true, then a slowing or reduction in sea fan cover is expected in 2021. While the cover of sea fans is high at Wheeler North Reef relative to San Mateo and Barn it does not appear to be sufficient to substantially impact the abundances of other species in the benthic community. Importantly, we found no relationship between the percent cover of *Muricea* on a transect and the net primary production of giant kelp (Figure 6.1.9a) or young-of-year fish indicating that *Muricea* had little to no impact on these important ecological functions of Wheeler North Reef (Figure 6.1.9b).

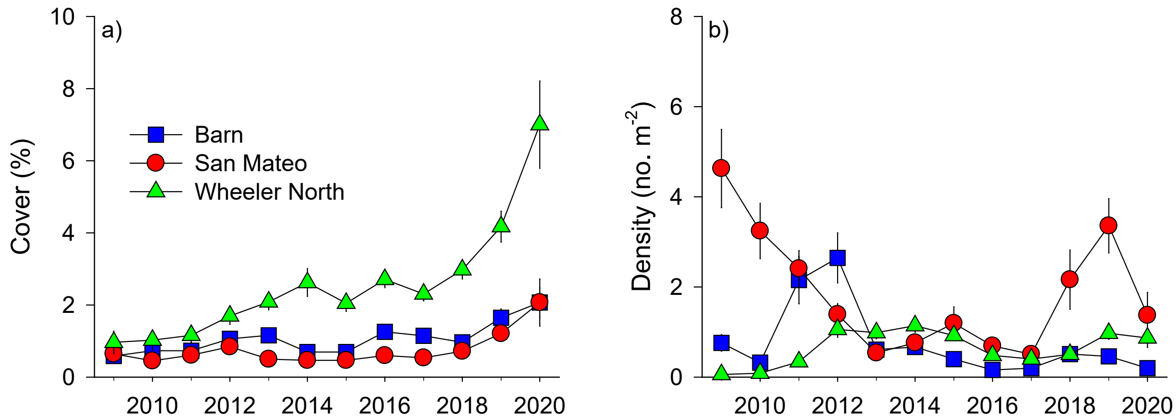

Figure 6.1.8. Mean (± 1 standard error) for (a) the percent cover of the sea fan *Muricea* spp. and (b) the density of sea urchins at Wheeler North Reef, San Mateo and Barn for 2009 – 2020.

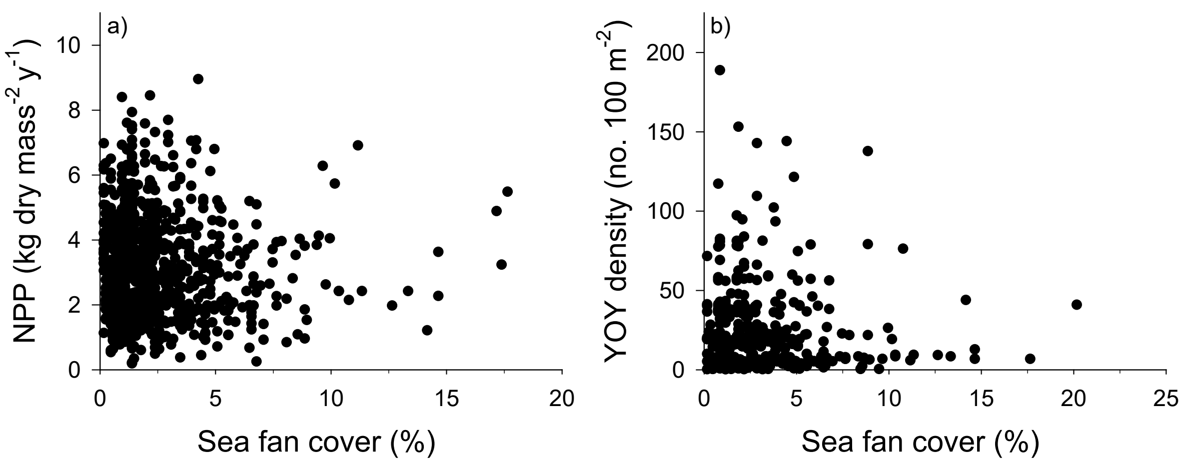

Figure 6.1.9. Percent cover of sea fans vs. (a) the net primary production (NPP) by giant kelp and (b) the abundance of young-of-year fishes at Wheeler North Reef. Data represent values for a given transect in a given year (2009-2020) that have been de-trended for changes over time.

As with sea fans, high densities of sea urchins can prevent the establishment of giant kelp and other organisms. For example, Arkema et al. (2009) found that giant kelp was absent on reefs where sea urchin densities exceeded 35 m^{-2}. Monitoring data from 2009 – 2020 show that sea urchin densities have been consistently low at Wheeler North Reef averaging about 1 individual m^{-2} (Figure 6.1.8b). This density is far below that needed to significantly impact giant kelp and other components of the benthic community.

The observation that giant kelp NPP and the abundance of young-of-year fish were both unrelated to the density of sea urchins at Wheeler North Reef (Figure 6.1.10a,b) provides further evidence that sea urchins did not impair the important ecological functions of the Wheeler North Reef.

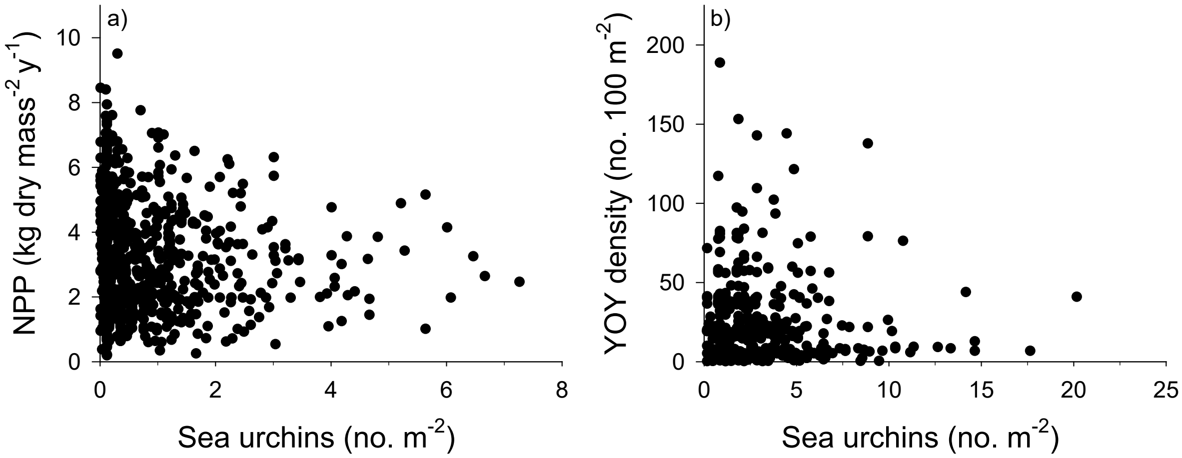

Figure 6.1.10. Density of sea urchins vs. (a) net primary production (NPP) by giant kelp and (b) the density of young-of-year fishes at Wheeler North Reef. Data represent values for a given transect in a given year (2009-2020) that have been de-trended for changes over time.

No non-native species of invasive algae were observed at Wheeler North Reef in 2020, which was also the case from 2009 – 2013. A single non-reproductive individual of *Sargassum horneri*, a non-native brown alga that has been expanding throughout southern California and Baja California (Marks et al. 2015), was observed in 2014 and a few more individuals of this species were observed in 2015 – 2018. Furthermore, very few non-native invertebrate species and no non-native fishes have been recorded at Wheeler North Reef since it was constructed.

Based on the above results we conclude that invasive or undesirable species did not impair important ecological functions of Wheeler North Reef. Thus the Wheeler North Reef met this performance standard in 2020.

6.2 Relative Performance Standards

1. THE BENTHIC COMMUNITY OF MACROALGAE SHALL HAVE A COVERAGE SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: The coverages of reef associated algae and sessile invertebrates provide a measure of the biomass of the benthic community attached to the hard substrate of a reef. Because many species of algae are difficult to count as individuals their abundance is estimated as percent cover. The percent cover of benthic macroalgae at Wheeler North Reef, San Mateo, and Barn is measured annually in the summer in five replicate 1m^2 quadrats located at 10m intervals along each of the eighty-two 50m transects. At the Wheeler North Reef, these transects are located in the Phase 1 modules and the Phase 2 primary polygons (Figure 4.4.2). Percent cover is estimated using a uniform point contact method that consists of noting the identity and relative vertical position of all organisms intersecting 20 uniformly placed points within each of five quadrats located along each transect. Using this method, the total percent cover of all species combined can exceed 100%, however, the maximum percent cover possible for any single species cannot exceed 100%. Because the abundance of macroalgae is expressed as percent cover of the bottom (rather than percent cover of the rock on the bottom) the ability of the Wheeler North Reef to meet this standard is not only influenced by biological processes that regulate species abundance (i.e., recruitment, growth, mortality), but also by the percent of the bottom covered by rock. For Wheeler North Reef to meet this performance standard the four-year running average of the percent cover of macroalgae calculated from the current year and the three preceding years must not be significantly less than that of the reference reef with the lower four-year running average of macroalgal cover (i.e. the p-value for the t-test must be less than the proportional difference between the two reefs).

<u>Results:</u> The percent cover of macroalgae at Wheeler North Reef was about 27% in 2009 and decreased to about 9% in 2011 after the surface canopy of giant kelp became fully established (Figure 6.2.1a). It steadily increased to 48% in 2016 coincident with the decline in the abundance of giant kelp and remained at ~ 40% though 2019. In 2020 when sampling was reduced from 82 to 15 transects the mean percent cover of macroalgae at Wheeler North Reef increased to 63%, which is the highest ever recorded. In spite of the increasing trend in the percent cover of macroalgae at the Wheeler North Reef since 2011, it has been consistently lower than that at the two reference reefs. As a result, its four-year running average from 2017-2020 was significantly lower than that of the two reference reefs (Figure 6.2.1b). Consequently, the Wheeler North Reef did not meet this performance standard in 2020.

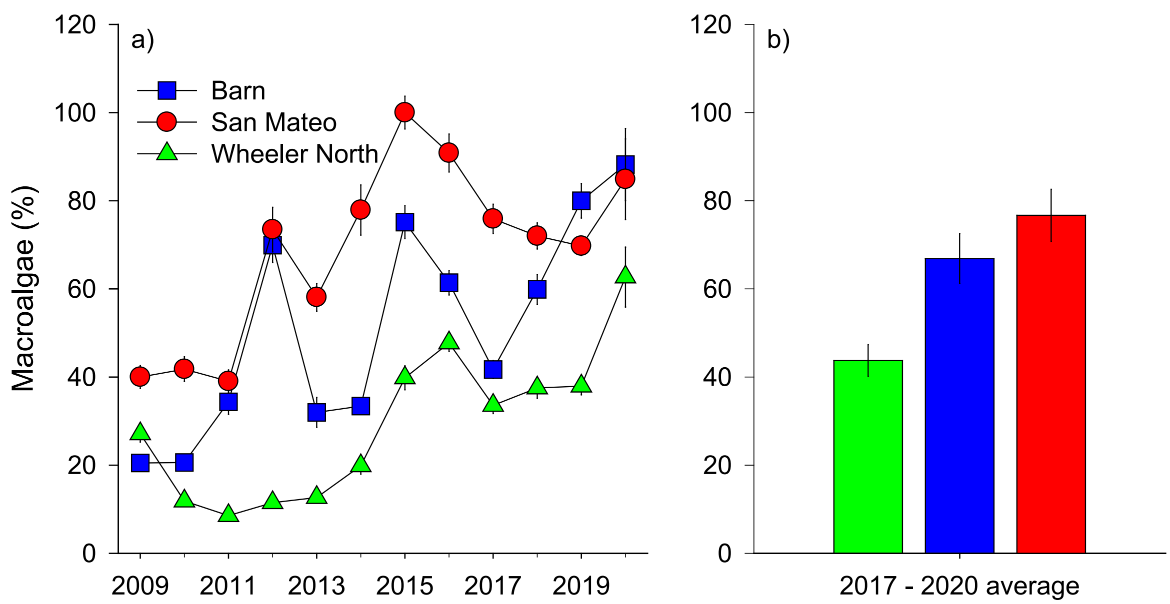

Figure 6.2.1. Mean percent cover (± 1 standard error) of macroalgae at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

2. THE NUMBER OF SPECIES OF BENTHIC MACROALGAE SHALL BE SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: Data on the percent cover data of macroalgae in the 1 m^2 quadrats are combined with data on the density of larger algal species sampled in the 20 m^2 quadrats to determine the total number of species per transect on the Wheeler North Reef, San Mateo, and Barn. These values are averaged over the 82 transects on each reef to provide an estimate of average species density of macroalgae per reef. For Wheeler North Reef to meet this performance standard, its four-year running average of number of species of macroalgae per transect must not be significantly less than that of the reference reef with the lower four-year running average of the number of species of macroalgae per transect.

Results: Temporal fluctuations in the average number of macroalgal species per transect at the Wheeler North Reef, Barn and San Mateo largely mirrored those of macroalgal percent cover (Figure 6.2.2a vs. Figure 6.2.1a). Macroalgal species richness at the two reference reefs has been consistently and substantially higher than at Wheeler North Reef since 2010 (Figure 6.2.2a). Consequently, the Wheeler North Reef did not meet the performance standard for algal diversity in 2020 as its four-year running average of the number of species of algae per transect was significantly lower than that of both reference reefs (Figure 6.2.2b).

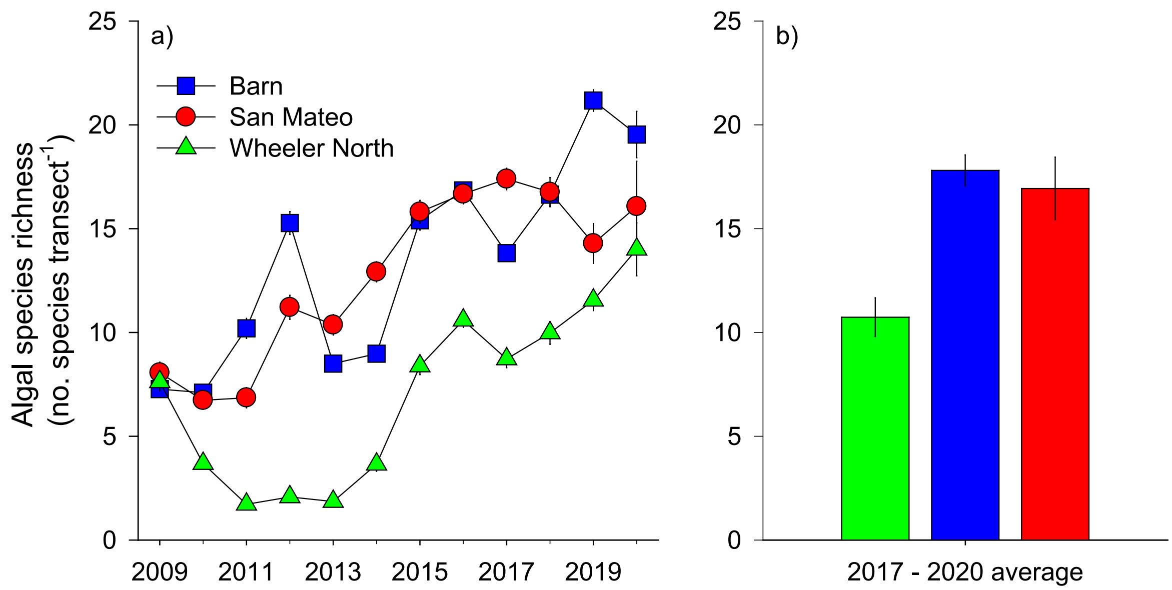

Figure 6.2.2. Mean (± 1 standard error) number of species of understory algae per 100 m^{-2} at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

3. THE BENTHIC COMMUNITY OF SESSILE INVERTEBRATES SHALL HAVE A COVERAGE SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: The percent cover of sessile invertebrates is measured at the same time and in the same way as the percent cover of benthic macroalgae. For Wheeler North

Reef to meet this performance standard the four-year running average of the percent cover of sessile invertebrates calculated from the current year and the three preceding years must not be significantly less than that of the reference reef with the lower four-year running average of sessile invertebrate cover.

Results: As described in section 5.0, sessile invertebrates and algae compete for space on the bottom and as a result, increases in the percent cover of one group are typically accompanied by decreases in the percent cover of the other (Figure 5.2.12). This is the pattern that we have seen at Wheeler North Reef, Barn and San Mateo. The percent cover of sessile invertebrates at Wheeler North Reef in 2009 was about half that at the reference reefs, but increased nearly three-fold by 2012 as the percent cover of algae declined (Figure 6.2.3a vs. Figure 6.2.2a). The percent cover of sessile invertebrates and algae remained relatively constant from 2012 – 2014, but changed dramatically in 2015 and 2016 as the percent cover of algae doubled while that of sessile invertebrates was halved. By contrast, the percent cover of sessile invertebrates remained relatively constant at Barn and San Mateo from 2009 to 2011 before decreasing sharply in 2012 (Figure 6.2.3a); the exact opposite pattern that was observed for the percent cover of macroalgae at these sites (Figure 6.2.2a). All three sites showed a sharp increase in the percent cover of sessile invertebrates in 2017 to ~ 40%. The cover of sessile invertebrates has remained at this level at the Wheeler North Reef through 2020, but declined at San Mateo and Barn to ~ 26% (Figure 6.2.3a). In 2020 the four-year running average of the percent cover of sessile invertebrates was higher at the Wheeler North Reef compared to San Mateo and Barn (Figure 6.2.3b). As a result, the Wheeler North Reef met this performance standard in 2020.

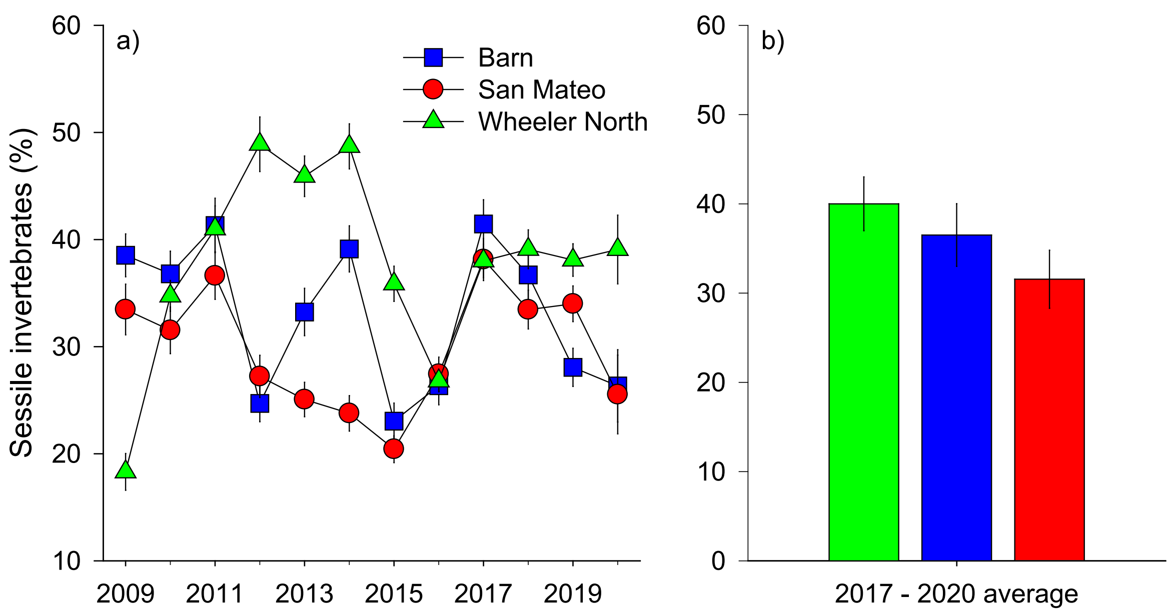

Figure 6.2.3. Mean percent cover (± 1 standard error) of sessile invertebrates at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

4. THE BENTHIC COMMUNITY OF MOBILE MACROINVERTEBRATES SHALL HAVE A DENSITY SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: The number of large solitary mobile invertebrates (e.g. sea stars, sea urchins, and lobsters) are counted in the five 10m x 2m plots centered along each 50m transect. Depending on their size and abundance, smaller solitary mobile invertebrates (e.g., brittle stars, nudibranchs, sea cucumbers) are counted in either a $1m^2$ or a $0.5m^2$ area created by dividing the $1m^2$ quadrats in half using an elastic cord stretched across the frame of the quadrat. Densities are expressed as number per m^2 of bottom. For Wheeler North Reef to meet this performance standard the four-year running average of the density of benthic mobile invertebrates calculated from the current year and the three preceding years must not be significantly less than that of the reference reef with the lower four-year running average of mobile invertebrate density.

Results: Much like the percent cover of sessile invertebrates, the density of mobile invertebrates at Wheeler North Reef was initially low (< 10 m^{-2}) in 2009 and increased dramatically (> 100 individuals m^{-2}) by 2012 (Figure 6.2.4a). Mobile invertebrate density steadily declined at Wheeler North Reef from 2012 – 2016, largely due to a decrease in the density of brittle stars, which associate with the holdfasts of giant kelp and are the most numerous mobile invertebrate on the reef. As kelp increased in 2017 so did the density of brittle stars and the overall density of mobile invertebrates reached 40 m^{-2} in 2017 and 2018 before declining to 27 m^{-2} in 2020 with the decline in giant kelp. Since 2012 temporal trends in the density of mobile invertebrates at San Mateo and Barn have mirrored those at the Wheeler North Reef (Figure 6.2.4a). The four-year running average of mobile invertebrate density at Wheeler North Reef in 2020 was similar to that at San Mateo and significantly greater than that at Barn (Figure 6.2.4b).

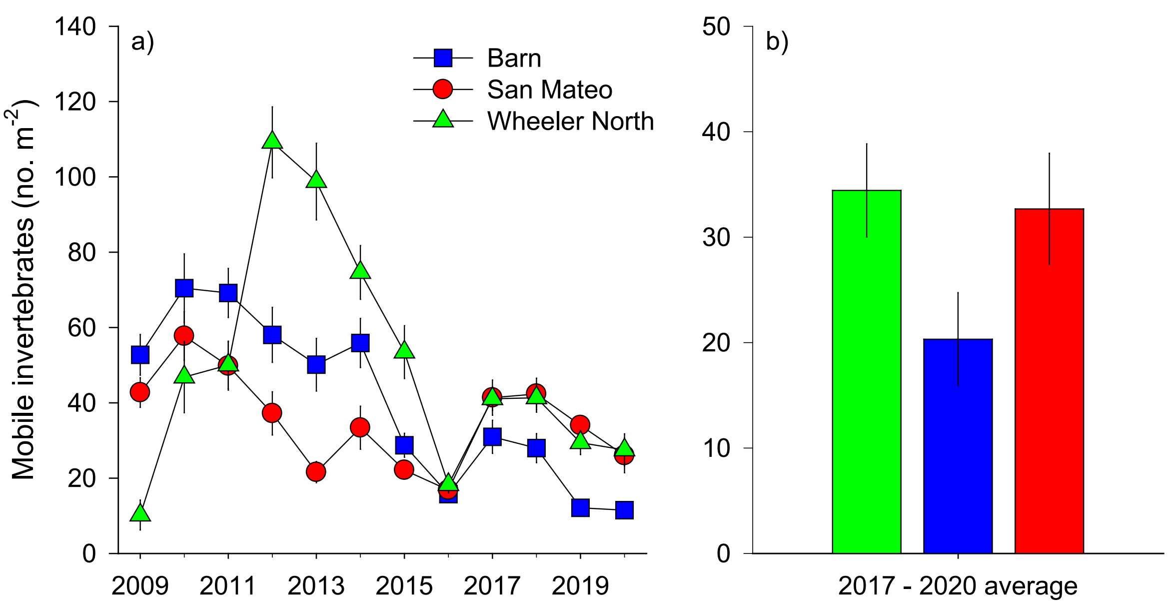

Figure 6.2.4. Mean density (± 1 standard error) of mobile invertebrates at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

As a result, the Wheeler North Reef met this performance standard in 2020.

5. THE COMBINED NUMBER OF SPECIES OF BENTHIC SESSILE AND MOBILE INVERTEBRATES SHALL BE SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: Data on the percent cover of sessile invertebrates are combined with data on the density of mobile invertebrates to determine the total number of species of benthic invertebrates on each transect at the Wheeler North Reef, San Mateo, and Barn. These values are averaged over the 82 transects on each reef to provide an estimate of average species density of benthic invertebrates per transect at each of the three reefs. For Wheeler North Reef to meet this performance standard its four-year running average of number of species of benthic invertebrates per transect must not be significantly less than that of the reference reef with the lower four-year running average of number of species of benthic invertebrates per transect.

Results: The average number of species of benthic invertebrates per transect at the two reference reefs declined slightly from 2009 to 2016, whereas it increased dramatically at Wheeler North Reef from a low value of 14 species per transect in 2009 to ~35 species per transect in 2012 (Figure 6.2.5a). It has remained near this high level except in the warm water years of 2015 and 2016 when invertebrate diversity declined on all three reefs. In 2020 the four-year running average of the number of invertebrate species per transect was 33.6 (±1.3) species per transect, which was slightly, but not significantly lower than the 34.2 (± 1.6) species per transect recorded at San Mateo, the lower performing reference reef (Figure 6.2.5b). As a result, the Wheeler North Reef met this performance standard in 2020.

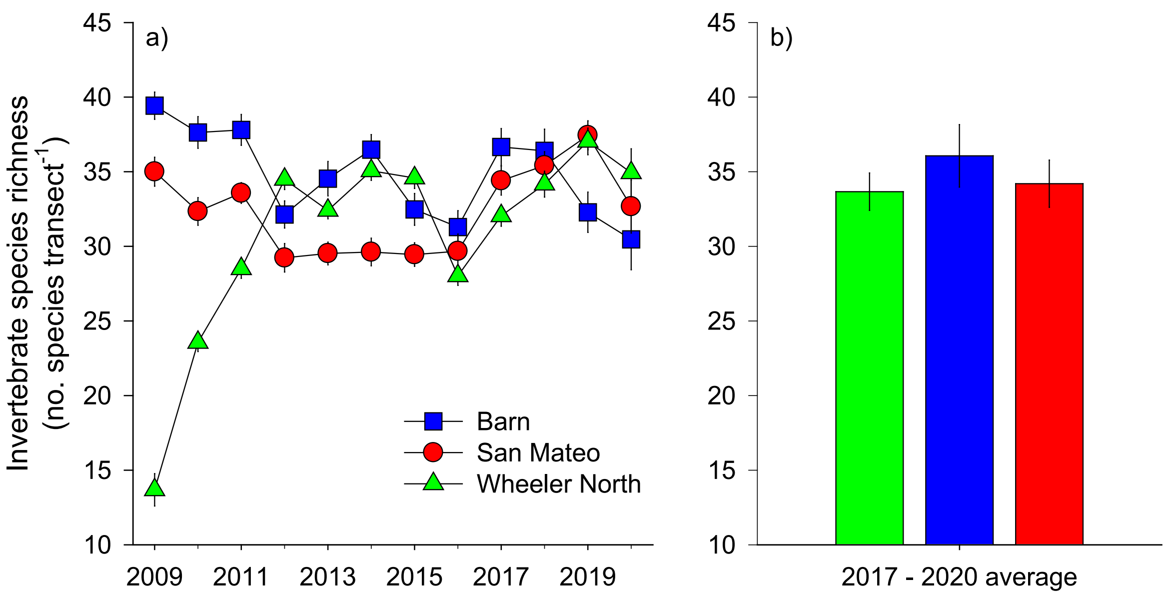

Figure 6.2.5. Mean species density (± 1 standard error) of invertebrates at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

6. THE RESIDENT FISH ASSEMBLAGE SHALL HAVE A TOTAL DENSITY SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: Data on the density and lengths of resident fishes at San Mateo and Barn are collected using the same methods described above for estimating the standing stock of fish at Wheeler North Reef. Resident fish are defined as reef associated species > 1-year old (fish <1-year old are termed young-of-year). Data on fish lengths are used to classify each individual fish counted as a resident or young-of-year based on published size classes and/or expert knowledge. The total density of resident fishes at Wheeler North Reef, San Mateo, and Barn is calculated as the mean density of resident fishes near the bottom averaged over the 82 replicate 50m x 3m x 1.5m transects sampled on each reef. For Wheeler North Reef to meet this performance standard the four-year running average of the density of resident fish calculated from the current year and the three preceding years must not be significantly less than that of the reference reef with the lower four-year running average of resident fish density.

Results: In 2009, 1 year after its construction, the density of resident fish at the Wheeler North Reef was 50% - 300% greater than that at the reference reefs (Figure 6.2.6a). Since then, fish densities have been relatively similar among the three reefs. The lone exception was a spike in resident fish density at Barn in 2011 when large schools of señorita were observed on several transects and the relatively low densities of fish observed at San Mateo from 2015-2019. In 2020 the four-year running average of resident fish at the Wheeler North Reef was ~20% lower than that at Barn and 50% higher than that recorded at San Mateo (Figure 6.2.6b). Thus, Wheeler North Reef met the performance standard for resident fish density in 2020.

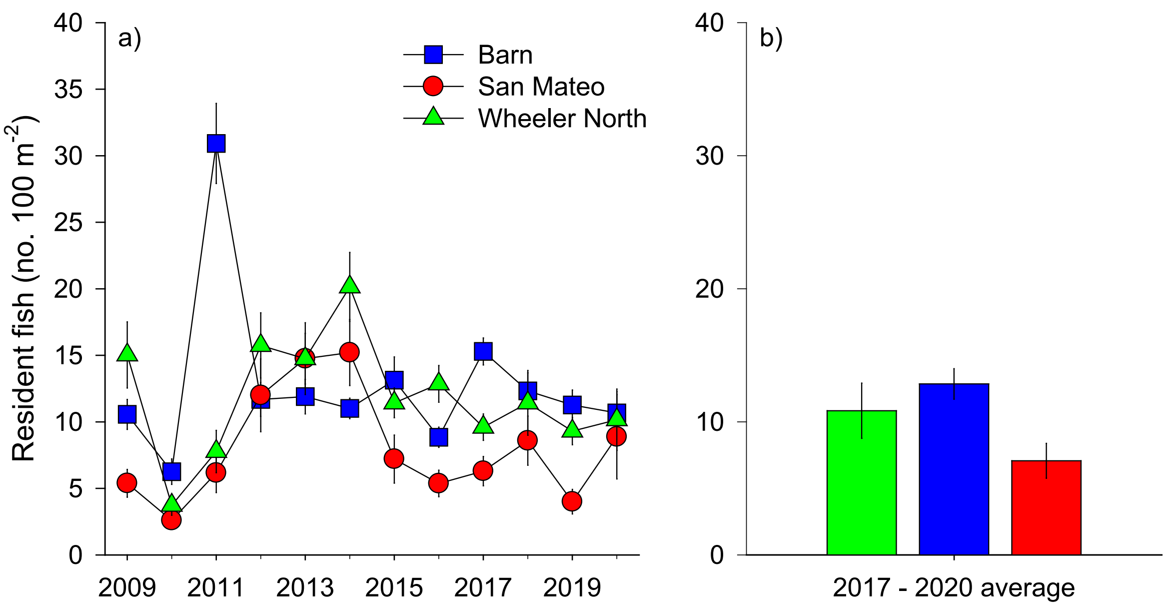

Figure 6.2.6. Mean density (± 1 standard error) of resident fish at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

7. THE DENSITY OF YOUNG-OF-YEAR FISHES (INDIVIDUALS LESS THAN 1-YEAR OLD) SHALL BE SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: Giant kelp forests serve as nursery habitat for a variety of nearshore fishes, and full compensation for the loss of kelp forest habitat caused by the operation of SONGS requires the Wheeler North Reef to provide this important ecological function at a level that is similar to that of natural reefs in the region. Data on the density of young-of-year (YOY) fishes at the Wheeler North Reef and the reference reefs are collected using the same methods and at the same time as data for resident fishes. The approach used for determining whether the density of YOY fishes at Wheeler North Reef is similar to that on the reference reefs is the same as that used for resident fishes.

Results: Densities of YOY fishes in 2009 were 1.7 – 5 times higher at Wheeler North compared to San Mateo and Barn (Figure 6.2.7a) due to a large recruitment of the blackeye goby, *Rhinogobius nicholsii*. Since then mean densities of YOY fish at Wheeler North Reef have fluctuated within the range set by San Mateo and Barn. YOY densities declined precipitously at all three reefs in 2016 and have remained low through 2020 reflecting the near absence of blackeye gobies. This cool-water species has a life span of about two years and its low abundance the past five years may be linked to anomalously warm water in 2014 – 2016. The four-year average for YOY density at Wheeler North Reef was within the range observed at San Mateo and Barn (Figure 6.2.7b). Thus, the Wheeler North Reef met the performance standard for YOY density in 2020.

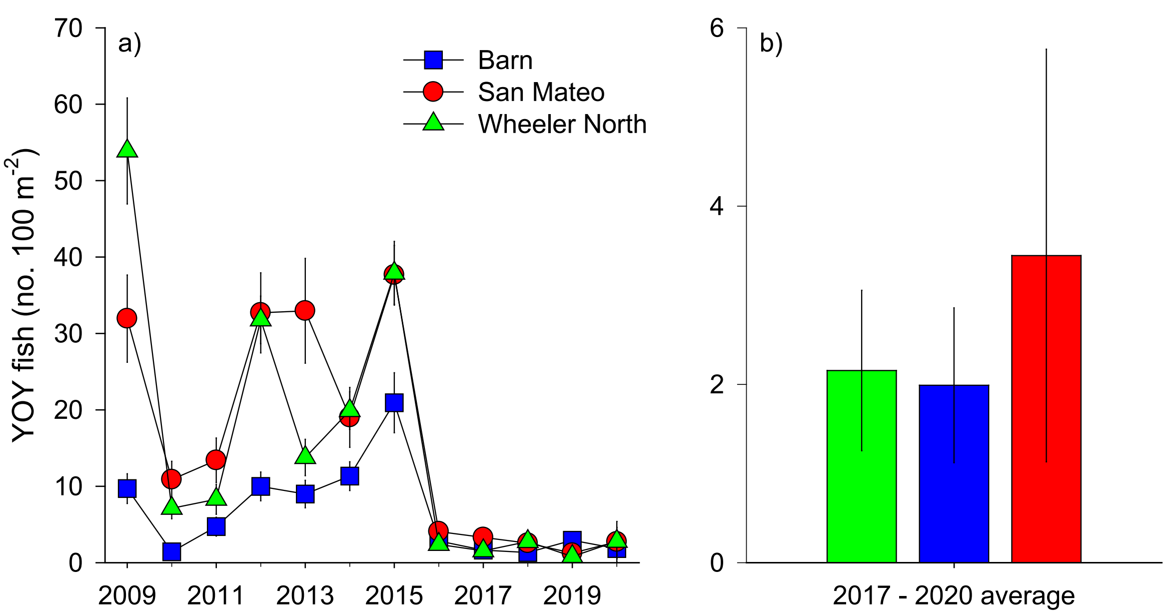

Figure 6.2.7. Mean density (± 1 standard error) of young-of year fish at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

8. THE COMBINED NUMBER OF SPECIES OF RESIDENT AND YOUNG-OF-YEAR FISH SHALL BE SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: All fish counted to assess the abundance of resident and young-of-year fish are identified to species. These data are used to calculate the number of species of resident and young-of-year fish combined per transect on each reef. These values are then averaged over the 82 transects on the Wheeler North Reef, San Mateo, and Barn to provide an estimate of average species density of kelp bed fishes per reef. For Wheeler North Reef to meet this performance standard its four-year running average of number of species of kelp bed fish per transect must not be significantly less than that of the reference reef with the lower four-year running average of the number of species of kelp bed fish per transect.

Results: The mean number of fish species per transect has largely fluctuated synchronously over time at the three reefs (Figure 6.2.8a). In general, Barn and Wheeler North Reef have displayed the highest diversity of fishes and San has consistently displayed the lowest diversity. Consequently, the 4-year average of the mean number of fish species per transect at Wheeler North Reef in 2020 was within the range set by the two reference reefs (Figure 6.2.8b). Thus the Wheeler North Reef met the performance standard for fish species richness in 2020.

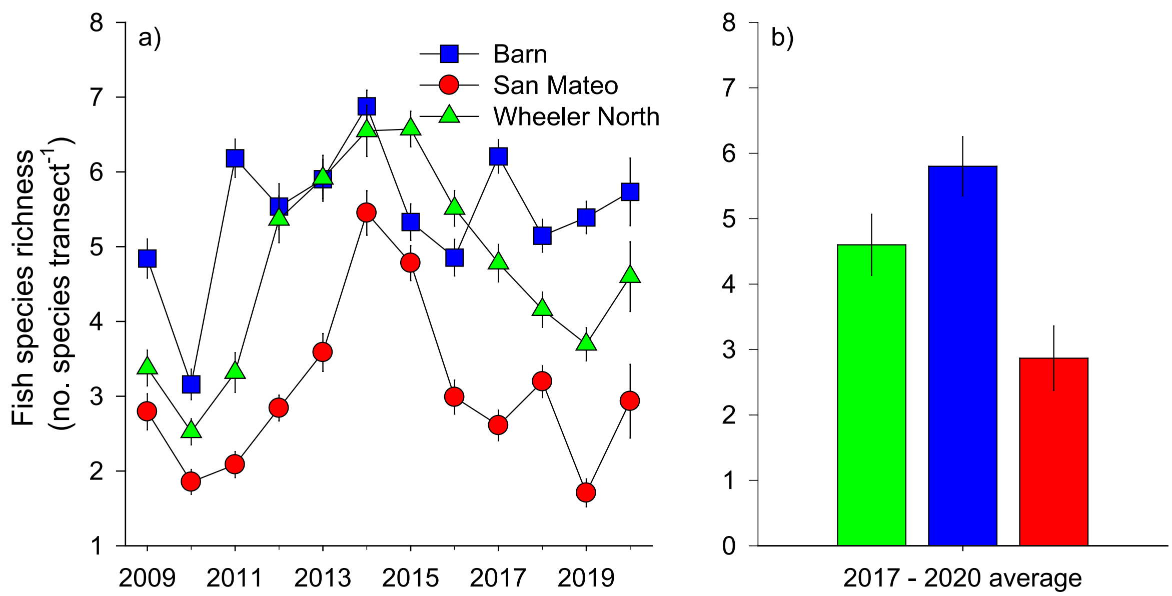

Figure 6.2.8. Mean species density (± 1 standard error) of fish at Wheeler North Reef, San Mateo and Barn. (a) annual values for 2009 – 2020 and (b) 4-year running average.

9. FISH PRODUCTION SHALL BE SIMILAR TO NATURAL REEFS WITHIN THE REGION

Approach: Estimating fish production on a reef is a difficult and potentially expensive task because it requires knowledge (or scientifically defensible assumptions) of the abundance and size structure of the fish standing stock, coupled with size-specific rates of growth, mortality, reproduction, emigration and immigration. For this reason, a great deal of thought has gone into developing a precise and cost-effective way to evaluate this performance standard. The method selected for estimating fish production to assess this performance standard involves the use of data on biomass and gonadal growth collected for the purpose of the performance standards pertaining to fish density, fish standing stock, and fish reproductive rates, in combination with data of somatic growth rates obtained from otolith studies. Importantly, this method of estimating fish production assumes no net migration (i.e., the immigration of fish to a reef is assumed to be equal to the emigration of fish from a reef). Details of the method used to estimate fish production are provided in the monitoring plan for the SONGS' reef mitigation project (Reed et al. 2021).

Fish production is estimated for five target species: blacksmith, black perch, señorita, California sheephead and kelp bass. These species represent the major feeding guilds of fishes in southern California kelp forests and are common to the study region. Blacksmith eat plankton during the day and seek shelter on the reef at night, black perch and señorita feed on small invertebrates that live on or near the bottom, California sheephead feed on larger benthic invertebrates, and kelp bass feed on other species of fish. The annual production for each of these species is averaged to obtain an overall mean and standard error of fish production for each of the three reefs. For Wheeler North Reef to meet this performance standard the four-year running average of fish production calculated from the current year and the three preceding years must not be significantly less than that of the reference reef with the lower four-year running average of fish production.

<u>Results:</u> Temporal patterns of reef fish production at the Wheeler North Reef mirrored those at San Mateo, but with slightly higher values from 2009 through 2013 and significantly higher values from 2014 – 2019 and less so in 2020 (Figure 6.2.9a). Fish production at Barn has followed a similar trajectory but, with a notable spike in all five target species in 2011. The Wheeler North Reef met the performance standard for fish production in 2020 as its mean four-year running average was greater than Barn and San Mateo (Figure 6.2.9b).

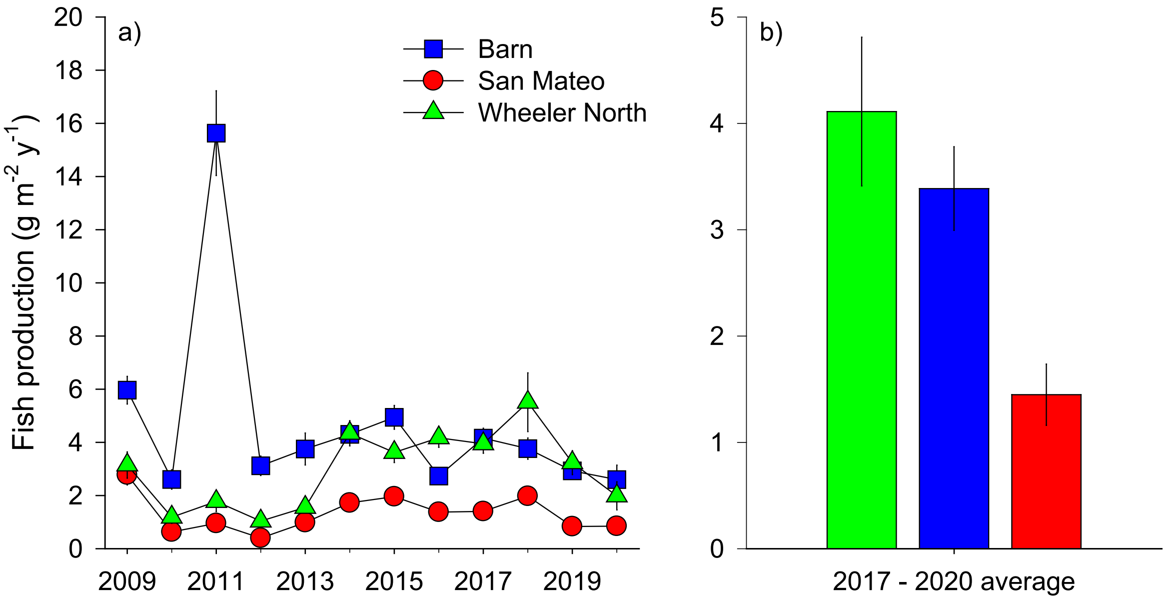

Figure 6.2.9. Mean fish production (± 1 standard error) at Wheeler North Reef, San Mateo and Barn. (a) annual values from 2009 – 2020 and (b) 4-year running average.

10. FISH REPRODUCTIVE RATES SHALL BE SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: The rationale for the performance standard pertaining to fish reproductive rates is that for artificial reefs to be considered successful, fish must be able to effectively reproduce at a level similar to that on the reference reefs. Data on per capita egg production of a select group of targeted reef fish species collected throughout the spawning season (summer through autumn) are used to determine whether fish reproductive rates at Wheeler North Reef are similar to those at San Mateo and Barn for similar sized individuals. The targeted species used to evaluate this performance standard are the California sheephead, señorita and kelp bass. These species represent different feeding guilds of reef fishes in southern California and are sufficiently abundant to facilitate their collection with minimal impact to their local populations.

A resampling approach is used to statistically determine whether the Wheeler North Reef met this performance standard for a given year (see Appendix 1 in Reed et al. 2021 for details). Resampling provides a method to estimate the variance and provides a basis for the calculation of a p-value. Because larger individuals tend to produce more eggs, the production of eggs is scaled to the body length and used to obtain a standardized measure of fecundity for each species at each reef.

For each reef, a species-specific estimate of standardized fecundity is combined with a species-specific estimate of the proportion of individuals spawning to obtain a four-year running average of the Fecundity Index that is averaged across all target species in a manner that weights each species and year equally. The four-year running average of the Fecundity Index for each reef for a given year is calculated as the median of the resampled distribution of the four-year running average for that year. In order for fish reproductive rates at Wheeler North Reef to be considered similar to that at natural reference reefs the median of the four-year running average of its Fecundity Index (based on the current year and the previous three years) must not be significantly lower than that of the reference reef with the lower four-year running average Fecundity Index.

Results: The value of the Median Fecundity Index varied inconsistently among the three reefs during the 11 years of monitoring (Figure 6.2.10a). This included a three-fold increase at Barn in 2016 that was not observed at San Mateo and Wheeler North Reef. Despite the erratic and somewhat asynchronous fluctuations in fish reproductive rates at the three sites, the median values of the 4-year running averages of their Fecundity Index have been relatively constant over time and in 2020 did not differ significantly among the three reefs (Figure 6.2.10b). Consequently, the Wheeler North Reef met this performance standard in 2020.

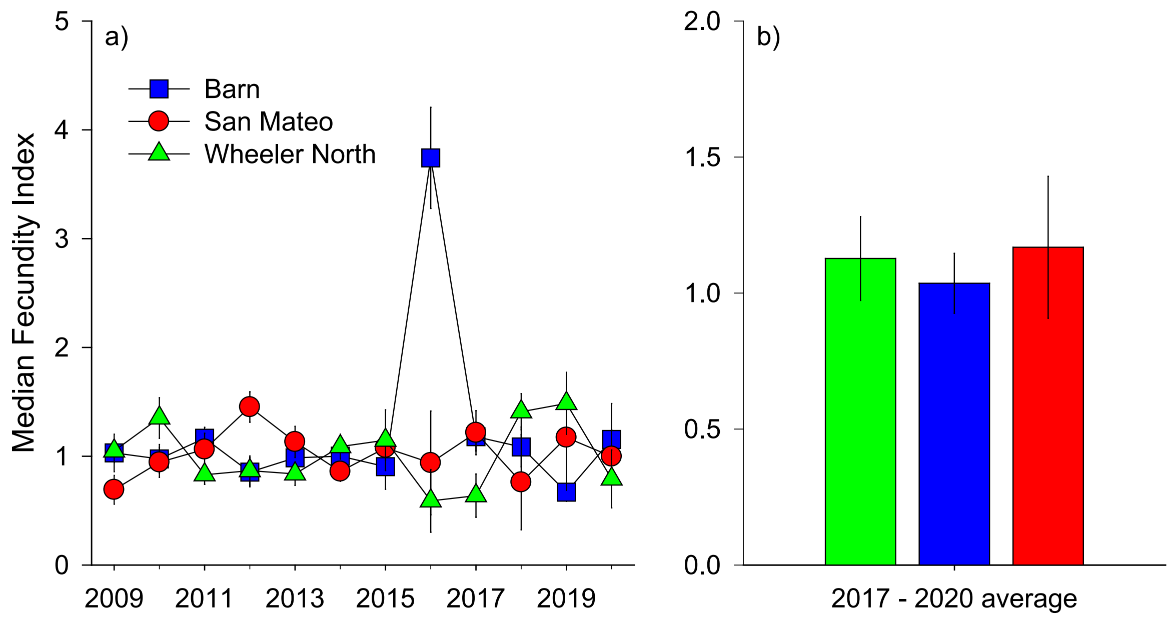

Figure 6.2.10. Median fecundity index (± 1 standard deviation) at Wheeler North Reef, San Mateo and Barn (a) annual values for 2009 – 2020 and (b) 4-year running average.

11. THE BENTHIC COMMUNITY SHALL PROVIDE FOOD-CHAIN SUPPORT FOR FISH SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: Several different approaches could be taken to evaluate the contribution of the benthic community in supporting the nutritional needs of reef fishes, but the most direct and cost efficient of these approaches involves sampling gut contents in reef fishes that feed on the bottom and are collected for other purposes. Such is the case for the black surfperch and the California sheephead. Both species feed almost exclusively on benthic prey, and individuals of these species are collected for purposes of evaluating the performance standards pertaining to fish reproductive rates and fish production. Once collected, black surfperch and sheephead specimens are placed on ice and transported to the laboratory where they are either immediately dissected and processed or frozen for processing at a later date.

Sample processing for both species involves removing the entire tubular digestive tracts and weighing the contents, either before or after preservation by fixation in 10% formaldehyde and storage in 70% ethanol. These measurements are used to calculate an index of food chain support (FCS) that is based on the mass of the gut contents relative to the body mass of the fish

$$FCS = \frac{g}{b - (r + g)}$$

Where g=gut content mass, b=body mass, and r=gonad mass.

Because the number of specimens of each species collected inevitably varies between species and among reefs the FCS values must be standardized to ensure each species and reef are weighted equally. To accomplish this standardization, FCS values for each species and reef in a given year are resampled with replacement 100 times (100 being the targeted sample size) and this process is iterated 1000 times. The mean for each iteration is calculated to produce a dataset of 1000 FCS values for each species x reef combination for a given year. For each species and year, we calculate the mean and standard deviation of the FCS values averaged over all 3000 iterations (= 1000 values for 3 reefs). We use these means and standard deviations to calculate the z-scores for each combination of year x species x iteration number for each reef yielding 1000 z-scores for each species x year x reef combination. We then average the z scores of the two species for each of the 1000-year x reef combinations to produce a data set of 1000 standardized FCS values for each reef in any given year.

The four-year running average of the standardized FCS index for each reef is calculated using a four-year mean of each iteration based on the current year and the previous three years producing 1000 values of the four-year average of the standardized FCS index for each reef. The four-year mean and variance of the standardized FCS index for each reef is calculated from the resampled distribution of these 1000 values. The four-year running average of the standardized FCS index at Wheeler North Reef must be similar to that at the reference (as per the methods described in section 4.3) in order for the Wheeler North Reef to meet this performance standard for any given year.

Results: The three reefs have shown very different and asynchronous temporal patterns in the values of their standardized FCS index (Figure 6.2.11a). Erratic fluctuations in the index have been observed at all three reefs at some point in the 12-year time series. This was especially true in 2020 when Barn showed a dramatic increase and San Mateo showed a dramatic decrease. These large fluctuations in 2020 resulted from the fact that FCS values for both species were highest at Barn and lowest at San Mateo, which has not been observed before.

The four-year running average of the FCS at Wheeler North Reef was within the range set by the two reference reefs in 2020 (Figure 6.2.11b). Consequently, the Wheeler North Reef met this performance standard in 2020.

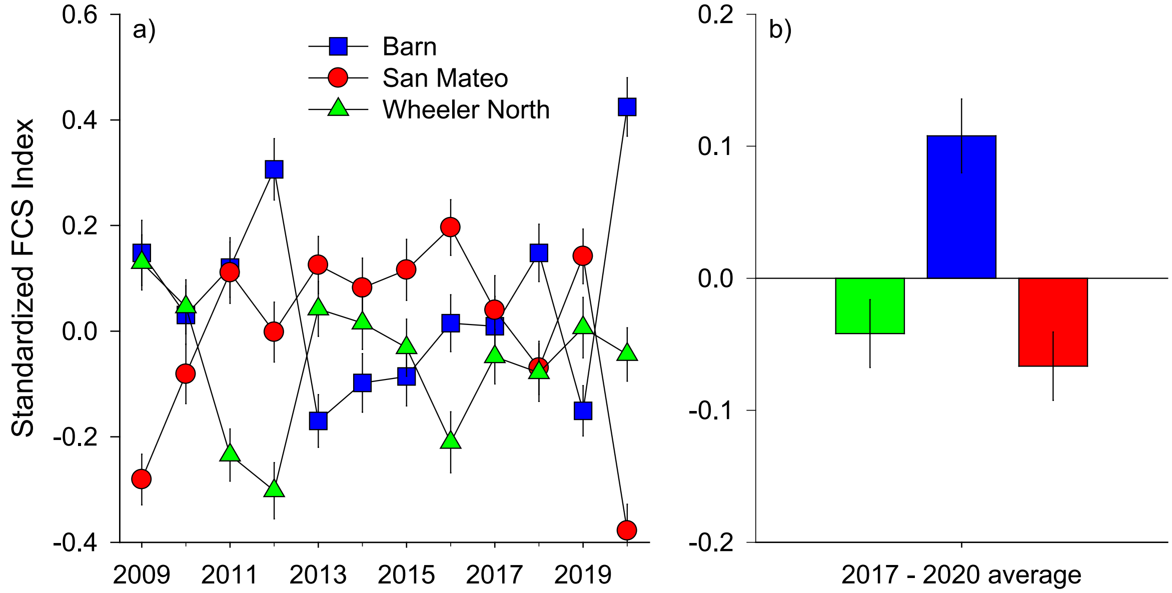

Figure 6.2.11. Food chain support (FCS) index (± 1 standard error) at Wheeler North Reef, San Mateo and Barn (a) annual values for 2009 – 2020 and (b) 4-year running average.

7.0 Permit Compliance

7.1 Summary of the performance of Wheeler North Reef and earned mitigation credit

Annual mitigation credit

Mitigation credit for the Wheeler North Reef with respect to the absolute performance standards for hard substrate and invasive/undesirable species and the relative performance standards is assigned on an annual basis. To receive mitigation credit for a given year the Wheeler North Reef must meet the absolute performance standards for hard substrate and invasive and undesirable species, and at least as many relative standards as the lower performing reference reef. The two absolute performance standards are measured only at the Wheeler North Reef and they are assessed using values from either the current year (i.e., 2020) or the most recent four-year running average, whichever is higher. The relative performance standards are evaluated at Wheeler North Reef, San Mateo and Barn using only the most recent four-year running average (see Section 4.1). Fulfillment of the mitigation requirement for this collective group of performance standards occurs when the number of years of mitigation credit accrued by the Wheeler North Reef equals the total years of operation of SONGS Units 2 & 3 (= 32 years). The accrual of mitigation credit began in 2019 upon installation of the Phase 3 remediation reef.

A summary of the performance of the Wheeler North Reef in 2020 with respect to the absolute performance standards for hard substrate and undesirable/invasive species and the 11 relative performance standards is shown in Table 7.1.1. In 2020 the Wheeler North Reef met the two absolute standards and 9 of the 11 relative performance standards, which was one less than Barn, but three more than San Mateo. The Wheeler North Reef underperformed relative to the reference reefs with respect to the percent cover and number of species of understory algae (Figures 6.2.1 and 6.2.2), which is not surprising given its generally greater abundance of giant kelp (Figure 6.1.2) and the negative covariance observed between giant kelp and understory algae (Figure 5.2.12).

The Wheeler North Reef earned one year of mitigation credit in 2019 and 2020 for meeting the absolute standards for hard substrate and invasive/undesirable species and as many relative standards as San Mateo, the lower performing reference reef. It needs another 30 years of mitigation credit to fulfill its mitigation requirement for this collective group of performance standards.

		WNR		San Mateo	Barn
		2020	4-yr avg	4-yr avg	4-yr avg
	ABSOLUTE STANDARDS				
1.	Hard substrate	YES	YES		
2.	Undesirable and invasive species	YES	YES		
	Number of Absolute Standards met	**2**	**2**		
	RELATIVE STANDARDS				
1.	Algal cover		NO	YES	YES
2.	Algal species richness		NO	YES	YES
3.	Sessile invertebrate cover		YES	NO*	YES
4.	Mobile invertebrate density		YES	YES	NO
5.	Invertebrate species richness		YES*	YES	YES
6.	Resident fish density		YES	NO	YES
7.	YOY fish density		YES	YES	YES*
8.	Fish species richness (all ages)		YES	NO	YES
9.	Fish reproductive rates		YES	YES*	YES
10.	Fish production		YES	NO	YES
11.	Food chain support		YES*	NO*	YES
	Number of Relative Standards met		**9**	**6**	**10**

Table 7.1.1 Summary of the performance of Wheeler North Reef in 2020 with respect to the absolute performance standards pertaining to hard substrate and undesirable/invasive species and the 11 relative performance standards that are used to judge whether it is performing similar to natural reefs in the region. YES means that the standard was met in 2020, NO means that the standard was not met in 2020. * indicates a change from 2019.

Cumulative mitigation credit

The absolute performance standards established for giant kelp area and fish standing stock are evaluated on a cumulative basis in which full compensation is based on mitigation for total losses rather than for annualized losses. In this case the area of giant kelp and the standing stock of fish is measured each year and the annual total for each is added to the cumulative total of previous years. Each standard is evaluated independently, and their mitigation requirement is fulfilled when their cumulative total equals the target value (150 acres for kelp and 28 tons for fish standing stock) x the total years of operation of SONGS Units 2 and 3 (= 32). Using this approach, the mitigation requirement for giant kelp area will have been fulfilled when the cumulative kelp area provided by the Wheeler North Reef equals 4800 acres (i.e., 150 acres x 32 years). Similarly, the mitigation requirement for reef fish standing stock will have been fulfilled when the Wheeler North Reef's cumulative fish standing stock reaches 896 tons (i.e. 28 tons x 32 years).

In 2020 the Wheeler North Reef earned credit for 4 acres of giant kelp for a cumulative total of 38 acres and 22 tons of reef fish for a cumulative total of 40 tons. It needs an additional 4762 acres of kelp credit and 856 tons of fish standing stock credit to fulfill these two mitigation requirements.

7.2 Verification that the Phase 3 mitigation reef was built according to approved specifications

Special Condition 8 of the coastal development permit that allowed SCE to construct a low-relief remediation reef up to 210.6 acres offshore of San Clemente (CDP 9-19-0025), requires SCE to complete an As-Built Construction Sonar Verification Survey of all polygons in the remediation reef and submit a final post-construction survey report to the Executive Director.

Specific requirements for construction of the remediation reef identified in CDP 9-19-0025 include:

a) Up to 210.6 additional acres of low-relief kelp reef using up to 175,000 tons of quarried rock in 22 new polygons
b) Quarry rock placed at water depths ranging from 28 to 49 feet to achieve low rock coverage (42 percent at 790 tons per acres) and low relief (< 3 feet in height)
c) Designated polygon areas to contain < 30 % cover of natural exposed hard substrate and sited to avoid known areas of kelp forest including maintaining a minimum distance of 23 feet from existing reef areas
d) Sand thickness in each of the polygons < 2.3 feet (±20 percent) to minimize the potential that newly placed rock will sink into the ocean floor and become buried
e) All rock used will meet the CDFW Material Specification Guidelines for artificial reefs
f) Construction methods that are similar to those used to construct Phase 2 of the Wheeler North Reef

CDP 9-19-0025 also requires SCE to submit a final post-construction survey report to the Executive Director that contains information demonstrating:

a) The position, perimeter and area of each polygon;
b) The average topographic relief and average percentage of the seafloor covered with quarry rock within each polygon;
c) An estimate of the uniformity of rock coverage within the perimeter of each polygon as well as rock overlap; and
d) The location, perimeter, area, average relief and average percent cover of any polygon that is significantly different from the specifications set forth in the CDP Application.

We reviewed SCE's final post-construction survey report (Coastal Environments Inc. 2020) for consistency with CDP 9-19-0025. The report demonstrated that the remediation reef was constructed of 150,974 tons of quarry rock deployed to depths of 34-49 feet across 20 polygons located in areas < 30% cover of hard substrate that collectively encompassed a total of 197.52 acres with an average height < 3 feet and an average rock coverage of 45.1%. Sub-bottom profiling data presented in SCE's CDP application verified that the sand thickness in each of the polygons averaged < 2.3 feet (± 20 percent). Two of the planned 22 polygons (numbers 35 and 36) were located in areas surrounded by intermittent natural rock, which made them less preferable. These two polygons were not needed to achieve the combined acreage and rock cover required for the remediation reef and were therefore not constructed.

Polygon ID	Footprint area (acres)	Natural rock area (acres)	Natural rock coverage (%)
29	18.83	0.01	0.07
31	14.09	0.53	3.75
33	14.85	0.43	2.89
34	2.42	0.17	6.99
37	13.37	0.45	3.38
38	2.82	0.15	5.26
39	7.46	0.35	4.68
40	1.51	0.05	3.38
Total	75.35	2.14	

Table 7.2.1. The total footprint area and the area covered by natural rock in the eight polygons identified as containing natural rock.

Upon reviewing SCE's application for CDP 9-19-0025 and the 2016 pre-construction sonar bathymetry maps we discovered that there were small areas of natural hard substrate in 8 of the 20 Phase 3 polygons (Table 7.2.1). All of these polygons were in the northern portion of the lease area and were constructed in the summer of 2020. In the fall of 2020 we conducted surveillance dives in these polygons and verified the presence of natural hard substrate in the suspected areas identified from bathymetry maps. Upon verifying the existence of natural rock in the polygons we calculated the area covered by natural rock in each of eight polygons from the sonar bathymetry maps using ArcInfo GIS.

The total area of natural rock summed across the eight polygons was 2.14 acres, which amounted to 2.9% of the 75.35 acres comprised by the eight polygons (Table 7.2.1). The bottom coverage of natural rock in any one of the eight polygons ranged from 0.07% - 6.99% which was far less than the allowed specification of < 30% coverage of natural rock. Thus, our finding of small amounts of natural rock within 8 of the 20 constructed polygons did not constitute a deviation from the approved specifications that significantly compromised the value of the remediation reef. We note that in their staff report approving CDP 9-19-0025, the Commission recognized the possibility that a small amount existing rocky substrate could be crushed or covered with new rock during the construction of the proposed reef. However, they concluded that any impacts in such small areas would be temporary and minor and would be replaced with similar rocky habitat that would in time develop the same biotic community. We agree with this assessment.

8.0 Future Monitoring Plans

Monitoring of the performance standards at the Wheeler North Reef, San Mateo and Barn will continue in 2021 as required by the SONGS permit. A return to full monitoring consisting of 151 transects at Wheeler North Reef and 82 transects at each of the two reference reefs is anticipated in 2021.

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