MONITORING PLAN FOR THE SONGS REEF MITIGATION PROJECT

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Updated November 2023

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EXECUTIVE SUMMARY

Condition C of the coastal development permit (no. 6-81-330) for the San Onofre Nuclear Generating Station (SONGS) requires Southern California Edison (SCE) and its partners to select a site and construct an artificial reef as partial mitigation for impacts to living marine resources in the San Onofre kelp forest caused by the operations of SONGS Units 2 and 3. The artificial reef is to be located in the vicinity of SONGS (but outside of its influence) with the goal of replacing a minimum of 150 acres (= 60.7 hectares) of kelp forest community that includes 28 tons of reef associated fishes. Mitigation for losses of kelp forest resources through the construction of an artificial reef is to be done in two phases; an initial five-year experimental phase followed by a mitigation phase having a duration equivalent to the operating life of SONGS Units 2 and 3 (= 32 years). The primary purpose for the experimental phase was to determine the substrate types and configurations that best provided adequate conditions for establishing and sustaining giant kelp and other reef-associated biota during the mitigation phase. Data collection on the experimental phase was completed in December 2004, and on October 12, 2005 the California Coastal Commission (CCC) concurred with the CCC's Executive Director's determination for the type and percent cover of hard substrate to be used to build the mitigation reef. Construction of the mitigation phase of the SONGS artificial reef was completed in September 2008. The combined 177-acre experimental and mitigation reef complex was named in honor of Wheeler North. In July 2020 the construction of a 198-acre expansion of Wheeler North Reef (referred to as Phase 3) was completed to ensure that the requirements for fish standing stock and kelp area were met in a timely fashion.

Monitoring by independent contract scientists working for the CCC is being done during the mitigation phase to: (1) determine whether the performance standards established for the mitigation reef are met, (2) determine, if necessary, the reasons why a performance standard has not been met, and (3) develop recommendations for appropriate remedial measures. The SONGS coastal development permit requires the CCC's contract scientists to develop a monitoring plan for the mitigation reef that describes the sampling methodology, analytical techniques and methods for measuring the success of the mitigation reef in terms of meeting the performance standards identified in the SONGS coastal development permit. This document serves as that monitoring plan. It contains: (1) a description of the process used to evaluate compliance with Condition C of the SONGS coastal development permit, including a list of the performance standards by which Wheeler North Reef is judged and the general approach that is used to evaluate its overall success in compensating for the loss

of kelp forest resources caused by SONGS operations, (2) descriptions of the specific sampling methods and analyses that are used to evaluate each performance standard, (3) an explanation of how project data are managed, archived and accessed for future use, and (4) a description of how the results from the monitoring program are being disseminated to the CCC, SCE, and all other interested parties.

This monitoring plan is a living document that will be modified as needed to ensure and maintain rigorous monitoring and evaluation of Condition C in the most cost-effective manner possible. A chronology of changes to the monitoring plan is provided in Appendix 5 of this document.

1.0 INTRODUCTION

Through its 1991 and 1997 coastal permit actions, the California Coastal Commission (CCC) amended Southern California Edison's (SCE) coastal development permit for the San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 (permit no. 6-81-330, formerly 183-73, hereafter SONGS permit) to include permit Condition C, which requires SCE and its partners to select a site and construct an artificial reef as partial mitigation for the resource losses at the San Onofre kelp forest caused by SONGS operations[1]. The reef is to be located in the vicinity of SONGS with the goal of replacing a minimum of 150 acres (= 60.7 hectares) of kelp forest community. Condition D of the SONGS permit adopted by the CCC establishes the administrative structure to fund the independent monitoring and technical oversight of the artificial reef mitigation project. Specifically, Condition D: (1) enables the CCC to retain contract scientists and technical staff to assist them in its oversight and monitoring functions, (2) provides for a scientific advisory panel to advise the CCC on the design, implementation, monitoring, and remediation of the SONGS mitigation projects, (3) assigns financial responsibility for the CCC's oversight and monitoring functions to the permittee and sets forth associated administrative guidelines, and (4) provides for periodic public review of the performance of the SONGS mitigation projects.

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

[1] The amount of kelp forest habitat lost due to SONGS operations was estimated at 179 acres. To fully mitigate this loss, the CCC required SCE and its partners to build an artificial reef that replaced 150 acres of kelp forest habitat and to establish an interest-bearing account in the amount of $3.6 million for a mariculture/fish hatchery program operated by the State of California through the Ocean Resource Enhancement and Hatchery Program (OREHP). The purpose of this fund was to compensate for losses to the kelp forest community at SONGS that are not mitigated by the artificial reef.

experimental phase for testing different reef designs (Phase 1), followed by a longer-term, larger-scale mitigation phase that is intended to compensate for the kelp forest resources lost due to SONGS operations (Phase 2). The information gained from the Phase 1 experimental reef was used to design the larger Phase 2 mitigation reef (Reed et al. 2005). An additional remediation phase (Phase 3) was constructed in the summers of 2019 and 2020 after it was determined that the combined area of the Phase 1 and 2 reefs was insufficient to fully compensate for the resources damaged or lost by SONGS operations. The design of the Phase 3 Reef mirrored that of the Phase 2 Reef. On April 17, 2006 the California State Lands Commission acted on a request from SCE to adopt a resolution declaring that the SONGS artificial reef complex be named in honor of Dr. Wheeler North.

The CCC decided that the goal of in-kind compensation for kelp forest resources damaged or lost due to SONGS operations would most likely be met if the artificial reef: (1) was built near SONGS but outside its influence to ensure that the compensation for the lost resources occurs locally rather than at a distant location far from the impacts, (2) was configured to mimic the impacted natural reef at San Onofre, which is a low relief boulder field, and (3) replaced the lost resources for a period of time that is at least as long as the operating life of SONGS Units 2 and 3, which was determined to be 32 years.

The Phase 1 Reef was built during summer 1999 on a mostly sand bottom at 13 to 16 m (42 to 52 feet) depth approximately 1 km (0.6 miles) offshore of the city of San Clemente, CA. It tested eight different reef designs that varied in substrate composition (quarry rock boulders or recycled concrete rubble), substrate coverage (~ 30 - 90%), and presence of transplanted kelp. It consists of 56 low-relief modules clustered at seven locations (eight modules / location) spaced relatively evenly along 3.5 km of coast (Figure 1). Each artificial reef module measures roughly 40 m x 40 m and the 56 modules collectively cover about 25 acres (~ 9 ha) of the sea floor.

Construction of the Phase 2 Reef was completed in September 2008 and consisted of boulder-sized quarry rock deposited in a mono-layer in 18 irregularly shaped polygons of varying size that collectively covered 150 acres (~ 62 ha) of sea floor (Figure 1). The CCC found that the average cover of quarry rock in the Phase 2 polygons was slightly below the 42% minimum requirement specified in the SONGS permit. To address this inadequacy, 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 25 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. The acreage associated with the two Phase 2 polygons not used to meet the 150-acre requirement (hereafter referred to as the

Phase 2 contingency polygons) are used when evaluating the requirements pertaining to giant kelp area and fish standing stock (see section 2.1).

The Phase 3 Reef was built during the summers of 2019 and 2020 and consists of approximately 151,000 tons of quarried rock distributed as a mono-layer covering an average of 45% of the bottom in 20 polygons totaling 198 acres (~80 ha) at depths of 28 – 49 feet (8.5 -15 m) north and inshore of the existing Phase 1 and 2 Reefs. In 2020, the Phase 1, 2 and 3 Reefs combined (collectively known as Wheeler North Reef) encompassed 373 acres (151 ha) with an average rock coverage of 46%.

Performance standards for reef substrate, giant kelp, fish, benthic invertebrates, and macroalgae specified in Condition C are used to evaluate the success of Wheeler North Reef in meeting the intended goal of replacing the kelp forest resources damaged or lost during the 32 years that SONGS Units 2 and 3 were operational. Monitoring independent of the permittee is being done in accordance with Condition D to: (1) determine whether the performance standards established for Condition C are met, (2) determine, if necessary, the reasons why a performance standard has not been met, and (3) develop recommendations for appropriate remedial measures.

The SONGS permit requires the CCC's contract scientists to develop a monitoring plan for Wheeler North Reef that describes the sampling methodology for measuring the performance of the mitigation reef relative to the performance standards identified in Condition C. This document serves as that monitoring plan for Wheeler North Reef.

2.0 EVALUATION OF THE MITIGATION REQUIREMENTS

Condition C of the SONGS permit identifies physical and biological standards that specify how the mitigation reef should perform and the timing and level of monitoring that is needed to evaluate its performance. The performance standards fall into two categories: (1) absolute standards, which are measured at Wheeler North only and require the variable of interest attain or exceed a predetermined value that is linked to estimated losses in the San Onofre kelp forest caused by SONGS operations, and (2) relative standards, which require the value of the variable of interest at Wheeler North Reef be similar to that measured at natural reference reefs. Among other things, these performance standards require Wheeler North Reef to support at least 150 acres of medium-to-high density kelp, 28 tons of reef fish, and assemblages of benthic macroalgae, invertebrates and fishes that are similar to nearby natural reference reefs.

In this section we provide: (1) a list of the absolute and relative performance standards for Wheeler North Reef as stated in the SONGS permit, (2) the process for selecting the reference reefs used as a measure of comparison in assessing the relative performance standards, (3) a schedule for the monitoring period, (4) a description of methods used to determine whether Wheeler North Reef and the reference reefs are similar, and (5) an explanation of how mitigation credit is assigned for the different types of performance standards.

2.1 Performance standards

The following performance standards listed in the SONGS permit will be used to measure the success of Wheeler North Reef and to determine whether remediation is necessary.

1. The mitigation reef shall be constructed of rock, concrete, or a combination of these materials
2. The total area of the mitigation reef (including the experimental reef modules) shall be no less than 150 acres
3. At least 42% but no more than 86% of the mitigation reef area shall be covered by exposed hard substrate
4. At least 90 percent of the exposed hard substrate must remain available for attachment by reef biota
5. The mitigation reef shall sustain 150 acres of medium-to-high density giant kelp. For purposes of this condition, medium-to-high density giant kelp is defined as more than four adult Macrocystis pyrifera plants per 100 m2 of sea floor
6. The standing stock of fish at the mitigation reef shall be at least 28 tons
7. The resident fish assemblage shall have a total density similar to natural reefs within the region
8. The young-of-year fish assemblage shall have a total density similar to natural reefs within the region
9. The total number of species of resident and young-of-year fish shall be similar to natural reefs within the region
10. Fish reproductive rates shall be similar to natural reefs within the region
11. Fish production shall be similar to natural reefs within the region
12. The percent cover of macroalgae shall be similar to natural reefs within the region
13. The number of species of macroalgae shall be similar to natural reefs within the region

14. The percent cover of benthic sessile invertebrates shall be similar to natural reefs within the region
15. The density of benthic mobile invertebrates shall be similar to natural reefs within the region
16. The number of species of benthic invertebrates shall be similar to natural reefs within the region
17. The benthic community shall provide food-chain support for fish similar to natural reefs within the region.
18. The important functions of the reef shall not be impaired by undesirable or invasive benthic species (e.g., sea urchins or *Cryptoarachnidium*).

Performance standards 1-3 are requirements for the design of the mitigation reef and were evaluated shortly after the Phase 2 reef was constructed. Performance standards 4-6 are absolute standards measured at Wheeler North Reef only and standards 7-18 are relative performance standards measured at Wheeler North Reef and the two reference reefs. These performance standards (#s 4-18) are evaluated annually until they receive enough mitigation credit to fulfill their mitigation requirement (see Section 2.5).

2.2 Reference Reefs

2.2.1. Criteria for reference reef selection

Requiring that the value of a resource be similar to that of natural reefs is based on the rationale that to be successful, the mitigation reef must provide the same types and amounts of resources that occur on natural reefs. However, resources on natural reefs 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 whereas seasonal and inter-annual differences in environmental conditions can cause the biological assemblages within reefs to fluctuate greatly over time. Ideally, the biological assemblages on a successful artificial reef should fluctuate similarly to those on the natural reefs used for reference. One way to compare this type of similarity is to select reference reefs that are close to and physically similar to the design of Wheeler North Reef. The premise here is that nearby reefs with similar physical characteristics should support similar biota, which should 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 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, San Mateo kelp forest (located adjacent to the southern end of Wheeler North Reef) and Barn kelp forest (located approximately 12 km south of San Mateo kelp forest) were chosen as reference reefs for evaluating the performance of Wheeler North Reef.

Temporal variability can be accounted for more easily by sampling Wheeler North Reef, San Mateo and Barn concurrently. Concurrent monitoring of the mitigation and reference reefs increases the likelihood that regional changes in environmental conditions affecting Wheeler North Reef are reflected in the performance criteria, since nearby San Mateo and Barn will be subjected to similar regional changes in environmental conditions.

2.2.2 Strategy for dealing with unusual events

An issue that may occur during the monitoring period of the SONGS reef mitigation project is the loss of reef habitat and/or biota at transects on the reference reefs due to unusual or unforeseen events. Such events would render the reference sites to be an inappropriate comparison for judging the performance of Wheeler North Reef. An example of such an unusual event was the catastrophic loss of kelp forest biota at Barn during the impact assessment phase of the SONGS mitigation project (Bence et al. 1989). The loss of hard substrate due to a rapid influx of sediment caused by the construction of the Interstate-5 freeway was implicated as the cause for the loss of kelp forest resources at Barn during the 1980s (Bence et al. 1989; Kuhn and Shepard 1984). Because the loss of reef habitat at Barn was substantial and linked to human activities, it was deemed to be an inappropriate reference site for measuring SONGS impacts. Consequently, data from Barn were excluded from the analyses of SONGS impacts. This loss of reef habitat at Barn was temporary and by 1999 Barn was deemed to be a suitable reference site for the reef mitigation program.

If such unusual events occur at San Mateo and Barn during the monitoring period of Wheeler North Reef, then the usefulness of the site as a reference for Wheeler North Reef will be reassessed.

2.3 Monitoring period

Condition C of the SONGS permit requires that the SONGS mitigation reef be monitored for a period equivalent to the operating life of SONGS. “Full operating life” was defined by the CCC to include “past and future years of operation of SONGS Units 2 and 3, including the decommissioning period to the extent that there are continuing discharges”. The operation of Units 2 and 3 began in 1982 and 1983, respectively. Both reactors were shut down in January 2012 due to excessive wear in the cooling tubes of the steam generators and permanently retired in June 2013. In March 2019 the CCC determined the full operating life of SONGS to be 32 years based on the commencement of Unit 2 in 1982 through the end of 2013. The CCC ruled that the accrual of mitigation credit by Wheeler North Reef would begin upon the installation of the Phase 3 Reef (i.e., summer 2019).

Monitoring the performance of Wheeler North Reef will continue until Wheeler North Reef earns 32 years of mitigation credit for meeting the performance standards (see Section 2.5). The level of sampling for "full monitoring" may be reduced to "annual site inspections" after Wheeler North Reef has met the relative performance standards and the absolute performance standard for hard substrate for at least three consecutive years following completion of the construction of the Phase 3 Reef in 2020 (see Section 2.4.2).

2.4 Determination of similarity

Evaluating the relative performance standards requires determining the extent to which Wheeler North Reef is similar to the reference reefs with respect to the performance standards. This is accomplished using a four-year running average (based on the value of a performance standard in the current year and the previous three years) to account for short-term fluctuations in reef biota, which are the norm. Below we describe the approaches used to determine similarity between Wheeler North Reef and the reference reefs for full monitoring and for annual site inspections.

2.4.1. Full monitoring

A requirement of the SONGS permit is that the response variables used to assess the relative performance standards of Wheeler North Reef be "similar" to those at nearby natural reference reefs. Evaluating whether the performance of Wheeler North Reef is similar to that of the San Mateo and Barn reference reefs requires that the four-year running average of a given relative performance standard at Wheeler North Reef not be significantly lower than that of the lowest performing reference reef. A one-sample, one-tailed approach is used for all comparisons and statistical significance is determined using a formal probability value (i.e., p-value) and an effect size. This determination is generally done with a t-test except in the case of the performance standards pertaining to fish reproduction and benthic food chain support for fish. For these two standards a resampling procedure is used to calculate the p-value for determining statistical significance (see Appendices 2 and 4).

The level of certainty in determining whether Wheeler North Reef meets the relative performance standards is directly related to sampling effort. Data collected during the experimental Phase 1 of the reef mitigation were used to determine the level of sampling that would likely be needed to detect a 20% deviation from the relative performance standards (i.e., the "effect size", which is calculated as the proportional difference between the mean values for Wheeler

North Reef and that of the lowest performing reference reef) with statistical power ≥ 0.80 (calculated as 1- β), using a critical α = 0.2. Once data are collected and an effect size for a given relative performance standard is determined, a critical α needs to be assigned to evaluate whether Wheeler North Reef met the performance standard for the year. The monitoring philosophy for this project is to balance the risk associated with falsely concluding that the performance standard was not met (i.e., Type I error = critical α = 0.20) with the risk associated with falsely concluding that the standard was met (i.e., Type II error = β = 0.20).

As noted, the sampling program design balanced Type I and Type II errors while considering the minimum detectable effect size. Once data are collected and the results are analyzed, it is important to consider the risks of missing large effects or underestimating effect sizes due to high variance in the data. Both scenarios are unlikely given the sampling design. However, there may be a situation where variance is greater than anticipated and we are unable to assess large effect sizes (i.e. >0.20) with a power of 0.80 using a critical α = 0.20. Thus, we developed a "floating alpha" approach that links critical alpha to effect size, thereby allowing us to detect large effect sizes when the variance is unexpectedly large.

The floating alpha approach was developed because of the importance of correctly determining that Wheeler North Reef failed to meet a relative performance standard, irrespective of effect size. If the effect size is small, then it is necessary to apply a correspondingly small value for critical α to be certain that the difference between Wheeler North Reef and the reference reefs is real. By contrast if the effect size for a relative performance standard is large, then assigning a critical value of α that is too small runs the risk of concluding that the reefs are similar when they differ. Thus linking the critical value of α to the effect size reduces the probability of committing a Type I error when the effect size is small, and a Type II error when the effect size is large.

The following rules are used with the floating alpha approach when assessing whether Wheeler North Reef meets a given relative performance standard (refer to Figure 2). "Calculated α" refers to the p-value computed from the data for a given statistical test, and "critical α" refers to the threshold value of α to which the calculated α is compared for the purpose of determining statistical significance. Using these rules, critical α is set to equal the effect size for all effect sizes ≤ 0.50.

1) If for a given performance standard, the calculated α ≤ effect size for any calculated α ranging from 0.000 to 0.500, then Wheeler North Reef will be considered to have not met that performance standard (i.e., it is different from the reference reefs) for the period of assessment (α and effect size rounded to three significant figures).
2) If calculated α > effect size for any effect size ranging from 0.000 to 0.500, then Wheeler North Reef will be considered to have met that performance

standard (i.e., it is similar to at least one of the reference sites) for the period of assessment (calculated α and effect size rounded to three significant figures).

3) If effect size is > 0.500 and calculated α is > 0.500, then assessment of that performance standard for the period (based on calculated α and effect size rounded to three significant figures) will be considered inconclusive and the following steps will be taken:
    a. The sampling design may be revised to increase the statistical power to an expected value of at least 0.80. Whether this effort is necessary will be based on the history of the performance of Wheeler North Reef with respect to the performance standard. For example, if the analyses were conclusive in previous periods, then a single inconclusive analysis would not be sufficient to invoke a change in the sampling design.
    b. If needed, the revised sampling design will be implemented the following year.
    c. If in the following year the performance standard is met, then the standard will be considered to have been met the previous year as well. If in the following year the performance standard is not met, then the standard will be considered to not have been met the previous year as well.
    d. This process will continue until evaluation of the performance standard is no longer inconclusive, barring any changes in Condition C of the SONGS permit.
4) Monitoring data will be evaluated annually to determine whether changes need to be made to the sampling program to bring it closer to the design objective of detecting an effect size ≥ 0.20 with statistical power ≥ 0.80 using a critical $\alpha \leq 0.2$.

The following is an example of how these rules are implemented. If the proportional effect size for a given variable was 0.25 (i.e., the four-year average of Wheeler North Reef was 75% of the four-year average of the lower of the two reference reefs), then a t-test yielding a calculated $\alpha \leq 0.25$ would indicate Wheeler North Reef did not meet the performance standard for that year, whereas calculated $\alpha > 0.25$ would indicate that it did meet the performance standard. 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 evaluating the performance of Wheeler North Reef. Hence, if Wheeler North Reef is performing at least as well as one of the reference reefs, it would be judged successful. The scaling of the calculated α to the effect size recognizes sampling error when estimating the four-year average and balances the probability of a Type I error (i.e., falsely concluding that Wheeler North Reef is not similar to the reference reefs when it is) with the probability of a Type II error (i.e., falsely concluding that Wheeler North Reef is similar to the reference reefs when it is not).

To ensure that 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 evaluation treats San Mateo (or Barn) as the mitigation reef and uses Wheeler North Reef and Barn (or San Mateo) as the two reference reefs. Wheeler North Reef is considered similar to the reference reefs if the number of relative standards met by Wheeler North Reef is equal to or greater than the number of relative standards met by either San Mateo or Barn. This analysis does not include the relative performance standard for undesirable and invasive species (# 18), which must be met in a given year for the Wheeler North Reef to receive mitigation credit for that year (see section 2.5).

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 the reference reefs for every relative performance standard. Importantly, this approach deals realistically with the inherent variability of nature.

2.4.2. Annual site inspections

There are provisions in Conditions C and D of the SONGS' coastal development permit to reduce the level of monitoring to annual site inspections once Wheeler North Reef has demonstrated that it has successfully met the performance standards for three consecutive years upon completion of ten years of full monitoring. Because success in the SONGS permit is defined in terms of meeting the performance standards in successive years, annual site inspections are only applicable to those standards evaluated annually. These standards include all performance standards except those pertaining to the area of giant kelp and the standing stock of fish, which are evaluated on a cumulative basis. Importantly, the purpose of annual site inspections as described in the SONGS coastal development permit is to "serve to identify any noncompliance with the performance standards", but with substantially reduced sampling effort and associated costs.

As mentioned above (Section 2.4.1), the sampling effort associated with full monitoring of the relative performance standards was designed to detect a 20% difference between reefs (effect size = 0.2) with 80% statistical power (Type II error (β) = 0.2) using a Type I error (α) = 0.2. Achieving these criteria is very unlikely in a scenario in which sampling effort is substantially reduced, as is the case for annual site inspections. Therefore, rather than using probability values associated with higher Type I and Type II error rates or accepting a higher effect size to maintain desired levels of the Type I and Type II error rates, similarity for annual site inspections will be determined without inferential statistics. This approach (hereafter referred to as the “means test”) entails a simple comparison of the mean values (rounded to three significant figures) of a performance standard among the three reefs. The simplicity of the means test involves accepting less assurance of correctly determining whether two values are truly similar than that obtained with full monitoring (see Reed et al. 2006 for an example). A notable difference between the means test and the statistical approach used for full monitoring is that using the means test virtually guarantees that one of the three reefs will fail to meet each of the relative performance standards every year. It is highly unlikely that one or more reefs will have identical means when rounded to three significant figures, causing one reef to always have a lower mean than the other two reefs. This outcome contrasts with full monitoring, where the means from two or more reefs can be statistically similar when they are not identical. Analyses of the four-year running averages of the relative performance standards during the period 2012-2021 show that estimates of similarity based on the means test were similar to those based on inferential statistics for all three reefs (Appendix 1, Table S1).

2.5 Assigning mitigation credit

Mitigation credit for the Wheeler North Reef is assigned on an annual basis and how credit is assigned varies with the type of performance standard.

The absolute performance standards for fish standing stock and the area of giant kelp were designed to ensure Wheeler North Reef compensates for annual losses to fish and giant kelp caused by SONGS operations. These annual losses were estimated to be 28 US tons of fish standing stock and 150 acres of medium-to-high density adult giant kelp. Rather than requiring Wheeler North Reef to sustain these levels each year to receive mitigation credit, credit accumulates over time based on the standing stock of fish and area of giant kelp supported by the Wheeler North Reef in a given year. The CCC’s rationale for this approach is that full compensation is to be based on total accrued losses of fish and kelp during the period of SONGS operations rather than annualized losses. For example, the accrued loss of fish standing stock due to SONGS operations is estimated to be 896 tons (28 tons x 32 years). Using this approach, the standing stock of reef fish is measured each year and the annual total is added to the cumulative total of previous years. Once a cumulative total of 896 tons is reached, the requirement for mitigation of losses in fish standing stock will be satisfied. Using this same cumulative approach, the mitigation requirement for sustaining 150 acres of giant kelp is satisfied once Wheeler North Reef has supported a cumulative total 4800 acres of medium-to-high density adult giant kelp (150 acres x 32 years).

The requirement that at least 90 percent of the exposed hard substrate of the artificial reef remain available for attachment by reef biota is also an absolute performance standard that is evaluated at the Wheeler North Reef only. Because the amount of available hard substrate has a profound effect on the abundance and diversity of reef biota, this performance standard must be met in a given year for the Wheeler North Reef to receive mitigation credit for that year. The assignment of mitigation credit for this performance standard is based on the greater value obtained from either that average for that year or a four-year running average calculated from data collected that year and the previous three years. A running average recognizes that short-term fluctuations in the amount of hard substrate on a low-relief coastal reef due to scour and accretion are common, and allows credit for excess hard substrate in years when scour exceeds accretion to compensate for reduced substrate in years when accretion exceeds scour.

The remaining 12 performance standards are relative standards that are evaluated by comparing the value of the performance standard measured at Wheeler North Reef to those measured at the two reference reefs. This evaluation is based solely on a four-year running average calculated from data collected at each reef for that year and the previous three years. An either/or criterion (i.e., using data from either a single year or a 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 Wheeler North Reef and its ecological functioning are similar to those at the reference reefs. This evaluation is best accomplished using a short-term (4-year) running average that accounts for natural variation in reef biota over time.

Natural kelp forests vary greatly in their species composition and abundance through time and across space. Moreover, species interact to affect the abundance and diversity of other species (e.g., a high cover of macroalgae is likely to inhibit the cover and diversity of sessile invertebrates). Consequently, it is likely that the reference reefs will not consistently meet all the relative performance standards in a given year. Therefore, to avoid requiring Wheeler North Reef to perform better than the reference reefs, Wheeler North Reef is required to meet at least as many of the relative standards as the lowest performing reference reef (which by definition is an acceptable measure of comparison as per section 2.4) in a given year for that year to count towards compliance with Condition C. The one exception to this rule is the relative performance standard for undesirable and invasive species, which *must be met* in a given year for that year to receive mitigation credit.

Wheeler North Reef will earn one year of mitigation credit for each year that it meets the absolute performance standard for hard substrate, the relative performance standard for invasive and undesirable species, and as many of the other 11 relative performance standards as the lowest performing reference reef.

The mitigation requirement for these 13 performance standards will be met once Wheeler North Reef attains 32 years of mitigation credit. The rules for assigning mitigation credit to SCE for Wheeler North Reef are the same regardless of whether the performance standards are evaluated using inferential statistics or the means test.

3.0 SAMPLING METHODS AND DATA COLLECTION

3.1 General Sampling Design

The goal of the general sampling design is to provide a cost-efficient framework for collecting data that is suitable for accurately determining whether Wheeler North Reef has met the SONGS performance standards. To achieve this goal, the sampling design incorporates: (1) spatially distributed sampling to increase accuracy in the characterization of each reef, (2) sampling methods specifically designed for measuring each response variable and (3) different levels of sampling for full monitoring and annual site inspections that enable them to meet their respective objectives.

3.1.1 Full monitoring

The approach used to determine the sampling effort for full monitoring of the relative performance standards was based on the desire to detect a 20% difference between the mean values for the lowest and second lowest performing reefs with relatively high confidence (see Section 2.4.1). This approach resulted in a sample size of 82 sampling locations (hereafter referred to as transects) per reef. Twelve of the 82 transects at Wheeler North Reef are located at the Phase 1 modules and the other 70 transects are located at the primary polygons of Phase 2 (Figure 3a). The 82 transects at San Mateo and Barn were established in areas known to support persistent giant kelp (Figures 3b, c).

Each transect is identified by unique differential GPS coordinates that mark the “zero end” of the transect and a compass heading along which divers lay out a 50 m long measuring tape. A 20 m wide swath centered along the measuring tape defines the sample area. 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 standards (Figure 4). Each year the three reefs are sampled concurrently.

The 82 transects at each reef are arranged in pairs with the two transects in each pair spaced 25 m apart (Figures 3a - c). An exception to this design are the 12 transects located on the Phase 1 modules, 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 Phase 2 primary polygons and the experimental Phase 1 modules in proportion to their area. An additional 10 paired transects in the Phase 2 contingency polygons and 59 unpaired transects in the Phase 3 polygons are used in combination with the other 82 transects at Wheeler North Reef to evaluate the absolute performance standards for giant kelp area and fish standing stock, and the relative performance standard pertaining to undesirable and invasive species (n = 151 transects total; Figure 3a).

Evaluating the performance standards for fish production, fish reproduction and benthic food chain support for fish involves the field collection and laboratory processing of five species of fish (Black perch, Blacksmith, Señorita, Sheephead and Kelp bass). For this purpose, 75-100 individuals of each species are targeted for collection at each reef yearly. Collections are spread out evenly throughout the summer sampling season (June through September).

3.1.2 Annual site inspections

The sampling design for annual site inspections is motivated by the desire to substantially reduce the sampling effort following a period of demonstrated success in meeting the performance standards. This approach differs substantially from the sampling design for full monitoring, which is based on the ability to detect a specified difference between Wheeler North Reef and the reference reefs (i.e., effect size) with a desired level of statistical power and confidence. The rationale for this difference is that the premise during full monitoring (which was implemented immediately after artificial reef construction) is that Wheeler North Reef is not performing similar to reference reefs, whereas the premise during the period of annual site inspections is that Wheeler North Reef is performing similar to reference reefs. The goal of a substantial reduction in sample size envisioned for annual site inspections could mean that there will be less assurance of correctly identifying whether or not reefs are similar with respect to the relative performance standards than with full monitoring. This outcome would certainly be true when assessing similarity using the inferential statistical approach described above for full monitoring. As a result, reductions in the sample size for annual site inspections need to be balanced by the SONGS Permit requirement that annual site inspections “serve to identify any noncompliance with the performance standards”. To meet this need we developed a non-statistical approach for determining similarity among reefs during annual site inspections that is based on the premise that the reefs are similar. Determining how best to reduce the sampling effort for annual site inspections using this approach depends on whether a given performance standard is evaluated using data collected in transect surveys and/or data obtained from fish collections.

<u>Transect surveys</u>: Analyses of transect data from Wheeler North Reef, San Mateo and Barn collected from 2009 – 2021 were used to determine the minimum number and spatial distribution of transects needed during annual site inspections to assess the relative performance standards evaluated using transect data. Performance standard #18, which requires the important functions of Wheeler North Reef not be impaired by undesirable or invasive benthic species, was not included in this analysis because it requires a different sampling design that includes data collected from all three phases of Wheeler North Reef (unlike the other relative performance standards, the evaluation of standard #18 is based on data collected from the same suite of transects used to evaluate the absolute performance standards for kelp area and fish standing stock). In addition to optimizing the spatial distribution of sampling, transects for annual site inspections were also chosen to approximate the mean percent cover of hard substrate of each reef because many ecological attributes of kelp forests are strongly correlated with hard substrate availability (Ambrose and Swarbrick 1989, Miller et al. 2018, Castorani et al. 2021). Results from these analyses showed that a sample size of 15 spatially distributed unpaired transects reasonably accomplished the goal of determining similarity of the relative performance standards evaluated with transect data using the means test on the 4-year running average (Appendix 1; Table S2, Figures S1, S2).

As mentioned above, annual site inspections are not appropriate for evaluating the absolute performance standards for giant kelp area and reef fish standing stock, which accumulate mitigation credit incrementally over time rather than on an annual basis. Nonetheless, implementing reduced sampling for annual site inspections provides an opportunity to potentially decrease the number of transects sampled for these two performance standards. One method for accomplishing this reduction in sampling effort that maintains broad spatial coverage is to eliminate one of the transects in each of the 40 pairs in the Phase 2 primary and contingency polygons (these transects would no longer be surveyed during annual site inspections for the purpose of evaluating the relative performance standards). Reducing sampling effort in this manner decreases the number of transects surveyed for fish standing stock and giant kelp area from 151 to 111 transects. Results of analyses using data from 2009-2022 show that reducing the sample size from 151 to 111 transects would likely have little effect on reef wide estimates of the area of medium-to high density giant kelp area and fish standing stock (Figure 5).

The percent cover of hard substrate of the Phase 1 modules and Phase 2 polygons is used to evaluate the absolute performance standard requiring at least 90% of the exposed hard substrate of Wheeler North Reef to remain available for reef biota (see #4 section 3.2). This measure is obtained from 82 transects during full monitoring (12 at Phase 1 and 35 pairs at Phase 2). The elimination of one of the transects in each pair during annual site inspections will result in the evaluation of this performance standard being based on 47 transects rather than 82. This reduction in sample size has little effect on the assessment of this performance standard as evidenced by the results of regression analysis which showed that annual estimates of the mean percent cover of hard substrate based on 47 and 82 transects were nearly equal (slope = 0.93) and highly correlated ($r^2 = 0.89$, $p < 0.001$).

Transect data are also used to estimate kelp and fish production and the abundances of sea fans and sea urchins, which form the basis for evaluating the performance standard pertaining to undesirable and invasive species (see #18, section 3.2). Just as data on giant kelp and fish will be collected from 111 transects at Wheeler North Reef and 15 transects at San Mateo and Barn during annual site inspections, so will data on the abundance of sea fans and sea urchins. Thus, the evaluation of performance standard #18 during annual site inspections will be based on 111 transects at Wheeler North Reef and 15 transects at San Mateo and Barn. Analyses of data for giant kelp net primary production and fish production collected from 2009-2022 revealed that Wheeler North Reef would have met this performance standard in every year regardless of whether it was evaluated using full or reduced monitoring, which indicates that the reduction in sample size associated with annual site inspections will likely have little effect on the ability of Wheeler North Reef to meet this performance standard.

Fish collections: Several approaches were used to determine the most cost-effective means for reducing sampling effort of annual site inspections for the three performance standards evaluated using data from fish collections. First, we explored the use of easily measured proxies as a means of reducing effort and costs. We found that the cumulative biomass density of the five indicator fish species was a good predictor of the production of these species at each of the three reefs based on data collected from 2009-2021 (Appendix 1; Figure S4). Importantly, the use of biomass density as a proxy for fish production does not require the substantial effort associated with fish collections or the tedious and costly processing of samples in the laboratory. Rather, fish biomass density (which is one component of fish production along with somatic and gonadal growth; see Section 3.2.11 and Appendix 3) is derived from data already collected in transect surveys for the purpose of evaluating other performance standards, and its use to predict fish production results in a substantial reduction in effort and cost.

A key metric used to evaluate the performance standard for fish reproduction is batch fecundity, which is time consuming and costly to measure (see Section 3.2.10 and Appendix 2). Analyses of gonadal data collected from 2009-2021 from the three indicator species of fish that displayed batch spawning revealed the gonad mass of females with hydrated eggs is a good proxy for batch fecundity (Appendix 1; Figure 5). Furthermore, the annual median fecundity index based on gonad mass is a good proxy for the annual median fecundity index based on batch fecundity (Appendix 1; Figure 6). The use of gonad mass to predict batch fecundity for annual site inspections constitutes a significant reduction in effort and costs because it eliminates the need for laborious and expensive processing of gonadal samples in the laboratory.

Additional reduction in sampling effort for fish reproduction during annual site inspections is achieved by reducing the number of fish collected at each reef. Annual site inspections will target 40-50 individuals of two species (Kelp bass and Sheephead) as opposed to 75-100 individuals of four species in full monitoring. Kelp bass and Sheephead were chosen for annual site inspections because they are relatively easy to collect and process, and they provide reliable estimates of batch fecundity. Analyses of data collected from 2009 – 2021 showed that restricting the collection of Kelp bass (but not Sheephead) to July and August produces a more accurate estimate of batch fecundity when sample size is reduced (Appendix 1; Table S3).

No easily measured proxy was found for estimating benthic food chain support for fish. Furthermore, analyses showed that both species (i.e., Sheephead and Black perch) were needed to obtain a reasonable estimated of the food chain support index. However, the number of fish collected at each of the three reefs could be reduced from 75-100 of each of two species to 40-50 individuals of each species without severely compromising the ability to evaluate this performance standard (Appendix 1; Table S4).

<u>Summary of sampling design and effectiveness</u>: An assessment of reef performance during the period 2009 -2021 with respect to the 11 relative performance standards that are evaluated annually indicated the number of years that Wheeler North Reef, San Mateo or Barn passed each of these performance standards was generally similar whether based on full monitoring and inferential statistics or annual site inspections and the means test (Table 2). Thus, the methods described above for annual site inspections appear to meet the objective of substantially reducing the sampling effort and costs while retaining the ability to identify non-compliance with the performance standards. A comparison of the sampling effort for full monitoring and annual site inspections is provided in Table 3.

3.1.3. Conditions causing a return to full monitoring

SCE is required to fund additional studies in the event that annual site inspections show Wheeler North Reef is failing to meet the performance standards. The purpose of these studies is to determine the causes for this failure and appropriate remedial actions. Failure of Wheeler North Reef to meet the relative performance standards during annual site inspections suggests it is underperforming relative to the reference sites. Failure during annual site inspections could also result from less accuracy in estimating the average values for the performance standards due to a smaller sample size compared to full monitoring, which could lead to incorrect conclusions regarding similarity and the underperformance of Wheeler North Reef relative to the reference sites. If Wheeler North Reef fails enough performance standards (see below), then it will be important to distinguish between these two putative causes. This will require data from full monitoring, which has sufficient sample sizes to detect statistically acceptable differences in similarity for each of the performance standards. Data collected from full monitoring can also provide important insights into the causes of actual underperformance and thus inform potential remedial actions.

The failure of Wheeler North Reef to meet a relative performance standard during annual site inspections could include small or large differences in similarity, given that similarity during annual site inspections is based on a simple comparison of means rather than on inferential statistics (i.e., p-values) Failure can also be relatively short-lived, lasting only a year or two, or be persistent and require remediation for Wheeler North Reef to regain satisfactory performance. A prompt return to full monitoring is desirable when failure is persistent or results show clear underperformance of many performance standards because it is in the best interest of the public and SCE to determine the causes for underperformance as soon as possible. By contrast, a sudden return to full monitoring when underperformance results from short-lived differences in similarity may incur unnecessary costs. However, delaying a return to full monitoring in this situation runs the risk of SCE not receiving mitigation credit when failure is due to a small sample size rather than actual underperformance.

A decision to return to full monitoring requires balancing overreacting to potentially short-term underperformance with failing to react to persistent or extreme underperformance. Therefore, a return to full monitoring during annual site inspections will occur only if Wheeler North Reef meets fewer relative performance standards than either reference reef, and it is highly unlikely that its underperformance is due to chance. The approach used to inform this decision balances the costs of unnecessary monitoring with the failure to receive mitigation credit due to insufficient monitoring with the pressing need to determine the specific reasons for failure when caused by actual underperformance. This approach involves calculating the probability (P) that Wheeler North Reef fails to meet n relative performance standards (where n ranges from 0-11) in a given year due to chance alone, which assumes that Wheeler North Reef, San Mateo and Barn have an equal probability of failing to meet each standard. A return to full monitoring would occur when Wheeler North Reef fails to receive mitigation credit (i.e., *n* for Wheeler North Reef > *n* for San Mateo and Barn) and *P* for *n* < critical α = 0.1.

There are two possibilities where *n* for Wheeler North Reef > *n* for San Mateo and Barn in a given year and *P* for *n* > 0.1 (Table 4; *n* =5 or 6). In these two cases a decision to return to full monitoring would be delayed until the following year when *P* would be based on the number of standards not met by Wheeler North summed over both years. In the following year (Year 1 +2) there is only one possibility in which *n* for Wheeler North Reef > *n* for San Mateo and Barn and *P* in both years and *n* for Year 1+2 > 0.1 (Table 4; *n* = 10). This scenario would delay the decision to return to full monitoring until a third year (Year 1+2+3) when there is no possibility of Wheeler North Reef failing in three successive years and *P* for *n* in Year 1+2+3 > 0.1. Using this approach, a return to full monitoring would be invoked in scenarios in which it is highly unlikely that the failure of Wheeler North to receive mitigation credit resulted by chance potentially due to the small sample size associated with annual site inspections. If a return to full monitoring indicates the failure of Wheeler North Reef to meet the performance criteria was due to a small sample size rather than underperformance, then monitoring will revert back to annual site inspections. Otherwise, full monitoring will continue until Wheeler North Reef successfully meets the performance criteria for three successive years before monitoring switches back to annual site inspections.

3.2 Methods used to evaluate the performance standards

Below are the approaches used to evaluate the performance standards and judge whether Wheeler North Reef meets the mitigation requirements for Condition C of the SONGS permit. The general sampling methods follow those used during the experimental phase (Reed et al. 2005), with some modifications. Detailed information on the sampling methods and sampling locations can be found in Reed et al. 2023a-d.

1. THE MITIGATION REEF SHALL BE CONSTRUCTED OF ROCK, CONCRETE, OR A COMBINATION OF THESE MATERIALS.

Approach: SCE's final design plan for Wheeler North Reef listed quarry rock as the exclusive building material. University of California Santa Barbara (UCSB) scientists working for the CCC conducted diver surveys and reviewed SCE's final construction report for Wheeler North Reef (Coastal Environments 2008, 2020) and determined that the material used to construct Wheeler North Reef conformed to that described in the final design plan. Hence, SCE met this performance standard.

2. THE TOTAL AREA OF THE MITIGATION REEF (INCLUDING THE EXPERIMENTAL REEF MODULES) SHALL BE NO LESS THAN 150 ACRES.

Approach: Multi-beam sonar surveys of the Phase 2 Reef were done in 2008 by contractors working under a cooperative agreement with SCE and the CCC immediately after it was constructed (hereafter referred to as the as-built sonar survey). Data from the as-built sonar survey were compared to results obtained from the pre-construction multi-beam survey done in 2005 to determine whether Wheeler North Reef constitutes 150 acres of artificial reef habitat. Analyses of data obtained from these surveys were presented in the final construction report of Wheeler North Reef (Coastal Environments 2008). UCSB scientists working for the CCC reviewed this report and determined that at the time that it was built in 2008 the Phase 2 Reef consisted of 152 acre low-profile (<1 m in height) single-layer quarry rock reef arranged in 18 polygons. Because multibeam surveys of the Phase 1 portion of Wheeler North Reef were not done in 2008, bathymetry data of the Phase 1 Reef collected in 2009 (Elwany et al. 2009) were used to estimate the total as-built area of Wheeler North Reef (i.e., Phase 1 + Phase 2) in 2008. Thus, the 177 acres of mitigation reef constructed by SCE (25 acres from the Phase 1 Reef as determined from the 2009 multi-beam sonar survey + 152 acres from Phase 2 Reef as determined from the 2008 as–built multi-beam survey) met this performance standard.

3. AT LEAST 42 % BUT NO MORE THAN 86% OF THE MITIGATION REEF AREA SHALL BE COVERED BY EXPOSED HARD SUBSTRATE

Approach*:* The percent cover of hard substrate on Wheeler North Reef was measured by UCSB scientists in summer 2008. Five 1 m^2 quadrats were uniformly placed along the length of each transect. Percent cover was estimated using a uniform grid of 20 points placed within the 1 m^2 quadrats using the same technique employed during the experimental phase of the reef mitigation project. In brief, the observer sighted an imaginary line through each of the points that was perpendicular to the bottom and recorded the substrate type intercepted by the line extending below the point. Substrates were classified as natural or artificial and categorized as bedrock (continuous rocky reef), mudstone, large boulder (largest diameter ≥ 100 cm), medium boulder (≥ 50 cm and <100 cm), small boulder (≥ 26 cm and <50 cm), cobble (≥ 7 cm and ≤ 25 cm), pebble (≥ 2 mm and < 7 cm), sand (< 2 mm), and shell hash. The categories of exposed hard substrate used to assess this standard included only quarry rock in the form of cobble, small, medium and large boulders. Hard substrates covered with a thin layer of silt or sand were noted as being silted (silted artificial substrates are considered available for the attachment of reef biota for the purpose of evaluating performance standard 4 below). Results from diver surveys completed immediately after the construction of the Phase 2 Reef in 2008 showed that the mean percent cover of hard substrate averaged across all Phase 2 primary polygons and Phase 1 modules was 42.3 %, demonstrating that the as-built condition of Wheeler North Reef met this standard. Moreover, post-construction monitoring of the Phase 3 Reef demonstrated that it also met this standard as its rock coverage averaged 45%.

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

Approach*:* 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 Wheeler North Reef in year *t,* and P_t is the proportion of 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. 2009. 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 ($S_0 = A_0 P_0$) 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 Wheeler North Reef to 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 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 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%.

5. 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 10 m x 2 m quadrats arranged at 10 m intervals along each of the replicate transects at Wheeler North Reef (Figure 3). For the purpose of this performance standard, medium-to-high density giant kelp is defined as more than four adult plants per 100 m^2 of ocean bottom. Adult giant kelp is defined as individuals with eight or more fronds > 1 m tall. The summed total of adult plants in the five 10 m x 2 m quadrats provides an estimate of the number of adult kelp per 100 m^2 at each transect. The proportion of transects with a density > 4 adult kelp per 100 m^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 at Wheeler North Reef occupied by medium-to-high density giant kelp in a given year is determined as:

$$=$$

Where n = total number of polygons at Wheeler North Reef (Phases 1, 2, and 3), A_i is the area of a polygon or module based on the most recent sonar survey, N_{ki} = number of transects on that polygon with >4 plants per 100 m^2, and N_{ri} is the total number of transects sampled on that polygon. For 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, and 3). The reason for this approach 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 be met when the total acres of giant kelp accrued by Wheeler North Reef equals the targeted annual value (= 150 acres) x the total years of operation of SONGS Units 2 & 3 (= 32), which amounts to 4800 acres of medium-to-high density adult giant kelp.

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

Approach: The standing stock of fish on Wheeler North Reef is estimated using data on total fish density, individual lengths, and relationships between fish length and 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 3 m wide x 1.5 m high x 50 m long volume centered above a measuring tape placed along the bottom of each replicate transect. 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. Cryptic fishes on the bottom are recorded in a 2 m wide swath centered along the transect and in the five 1 m^2 quadrats used to sample invertebrates and algae. These data are augmented with data from additional surveys of fish lengths if more information is needed to accurately characterize the population size structures.

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 within a transect are summed to produce an estimate of the total biomass of fish within each transect in units of g wet weight per m^2. The biomass density of all transects in a polygon are 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 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 forest fishes.

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 Wheeler North Reef. For this calculation, all 56 Phase 1 modules are considered to be a single polygon. The standing stock of reef fish is calculated each year and is added to the cumulative total of previous years. The mitigation requirement for fish standing stock will be 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 (i.e., 32), which amounts to 896 tons of reef associated fish.

7. 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 in the San Mateo and Barn kelp forests are collected with the same methods described for Wheeler North Reef above (see approach for performance standard 6). Briefly, all species of resident fish are sampled on the bottom within a 3 m wide x 1.5 m high x 50 m long area of each transect at Wheeler North Reef, San Mateo and Barn (cryptic resident species are sampled in a 2 m x 50 m swath and 1 m^2 quadrats) to obtain the density of resident fish within each transect. Resident fish are defined here as reef associated species > 1-year-old. Data on fish length are used to classify each individual fish counted as a resident or young-of-year (< 1-year-old) based on published size classes and/or knowledge of local experts. The total density of resident fish for each reef is calculated as the mean density of resident fish on the bottom averaged over the replicate transects. The four-year running average of the density of resident fishes at Wheeler North Reef must be similar to that at the reference reefs (as per the methods described in Section 2.4) for Wheeler North Reef to meet this performance standard for any given year.

8. THE YOUNG-OF-YEAR FISH ASSEMBLAGE SHALL HAVE A TOTAL DENSITY SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: Data on the density of young-of-year fish (defined as reef associated fish that are < 1-year-old) at Wheeler North Reef and the reference reefs are collected during the same surveys as resident fish. The approach used for determining whether the density of young-of-year fish on Wheeler North Reef is similar to that on the reference reefs is the same as that used for evaluating the performance standard pertaining to the density of resident reef fish. The four-year running average of the density of young-of-year fish at Wheeler North Reef must be similar to that at the reference reefs (as per the methods described in Section 2.4) for Wheeler North Reef to meet this performance standard for any given year.

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

Approach: Species richness (number of species) of resident and young-of-year fish at Wheeler North Reef and the reference reefs are assessed as the mean number of species observed per transect during the same surveys used to estimate resident and young-of-year fish density. The four-year running average of the mean number of species of resident and young-of-year fish combined at Wheeler North Reef must be similar to that at the reference reefs (as per the methods described in Section 2.4) for Wheeler North Reef to meet this performance standard for any given year.

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

Approach: Data on per capita egg production of a select group of four targeted reef fish species 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. Reproductive rates are assessed for selected target species that represent different feeding guilds of reef fishes in southern California and are sufficiently abundant to facilitate collection (Table 1).

Data on per capita egg production (i.e., number of eggs in a clutch) and the proportion of individuals likely to have spawned within 24 hours of collection (as determined by the hydrated status of the eggs) are collected monthly at Wheeler North Reef, San Mateo, and Barn during summer through autumn and used to evaluate this standard. A resampling approach is used to statistically determine whether Wheeler North Reef met this performance standard for a given year (Appendix 2). This approach 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 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 to weigh each species and year equally (Appendix 2). 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. For fish reproductive rates at Wheeler North Reef to be considered similar to that at reference reefs, the four-year running average of its Fecundity Index must be similar to that at the reference reefs (as per the methods described in Section 2.4) for Wheeler North Reef to meet this performance standard for any given year.

11. 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. The method selected for estimating fish production uses information already being collected on fish abundance and size structure (for performance standards 6, 7, and 9), fish reproductive rates (standard 10), combined with estimates of somatic growth rates obtained from additional otolith studies. Importantly, this method of calculating 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 methods used to estimate fish production are presented in Appendix 3.

Production is estimated for five target species that represent the major feeding guilds of fishes in southern California kelp forests and are common to the study region (Table 1). The annual production calculated for each of the targeted species is averaged to obtain an overall mean and standard error for each of the three reefs (Wheeler North Reef, San Mateo and Barn). The four-year running average of fish production at Wheeler North Reef must be similar to that at the reference reefs (as per the methods described in Section 2.4) for Wheeler North Reef to meet this performance standard for any given year.

12-16. THE BENTHIC COMMUNITY (BOTH ALGAE AND MACROINVERTEBRATES) SHALL HAVE COVERAGE OR DENSITY AND NUMBER OF SPECIES SIMILAR TO NATURAL REEFS WITHIN THE REGION.

Approach: The benthic communities at Wheeler North Reef, San Mateo, and Barn are sampled annually in the summer within the replicate transects (n = 82) at each reef (see *3.1 General Sampling Design* for details). Several different sampling methods are used to determine density and percent cover of benthic invertebrates, and understory algae. Abundances of sessile invertebrates and understory algae that are either difficult to distinguish as individuals (e.g., colonial tunicates, foliose red algae) or lay flat on the bottom (e.g., the brown alga *Desmarestia ligulata*) are measured as percent cover in five replicate 1 m^2 quadrats located at 10 m intervals within each of the transects. Percent cover is estimated using a uniform point contact method that notes the identity and relative vertical position of all organisms under 20 uniformly placed points within each quadrat, giving a total of 100 points per 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%. Large solitary mobile invertebrates (e.g., sea stars, sea urchins, and lobsters) and large solitary understory algae (e.g., palm kelp *Pterygophora californica,* oar weed *Laminaria farlowii*) are counted in the five replicate 10 m x 2 m quadrats located at 10 m intervals along the length of each transect. Smaller solitary mobile invertebrates (e.g., nudibranchs, brittle stars, bivalves) and algae (e.g., small size classes of all kelps) that are numerous and/or time consuming to count in a 1 m^2 area are counted in a 0.5 m^2 area created by dividing the 1 m^2 quadrats in half using a bungee cord stretched across the frame of the quadrat. Percent cover data and count data are both used to determine the mean number of species of understory algae and benthic invertebrates per transect at each reef.

The following five performance standards are used to evaluate the benthic community: (#12) the percent cover of algae, (#13) the number of species of algae, (#14) the percent cover of sessile invertebrates, (#15) the density of mobile invertebrates, and (#16) the combined number of species of sessile and mobile invertebrates. The four-year running averages of these performance standardsat Wheeler North Reef must be similar to those at the reference reefs (as per the methods described in Section 2.4) for Wheeler North Reef to meet these performance standard for any given year.

17. 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 to food-chain support 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 to evaluate the performance standards for 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 remaining non-gonadal body mass of the fish.

$FCS =$

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

The overall FCS value for the reefs in a given year should represent both species and not be influenced by differences in the number of observations per species, which inevitably varies between species and among reefs due to the vagaries of collecting fish. Nor should the overall FCS value be affected by species specific differences in FCS. Hence, the average FCS values of each species are averaged to produce a mean FCS Index for each reef and year. For Wheeler North Reef to meet this performance standard, its four-year running average of the mean FCS Index must not be significantly less than that of the reference reef with the lower four-year running average. The proportional effect size is calculated using the four-year running average FCS index values of Wheeler North Reef and the lower performing reference reef using the equation below, which for the purpose of illustration assumes Wheeler North Reef (WN) has a lower value than the lower performing reference reef (RR).

Proportional effect size = $(FCS_{RR} – FCS_{WN}) / FCS_{RR}$

Testing for significant differences in the mean FCS index between the reefs with the two lowest values in any given year involves calculating the proportional effect size between the four-year running averages of the two reefs (shown above) and the probability (i.e., p-value) that they are significantly different as described in Section 2.4. The calculation of a p-value involves resampling standardized FCS values (i.e., z-transformed data by each species, reef, and year) to ensure each species and reef are weighted equally. Standardized FCS values for each species and reef in a given year are resampled with replacement and this process is iterated to ultimately produce a “null” distribution of the four-year averaged standardized FCS values from which the p-value is calculated (see Appendix 4 for details). The four-year running average of the standardize FCS index at Wheeler North Reef must be similar to that at the reference reefs (as per the methods described in Section 2.4) for Wheeler North Reef to meet this performance standard for any given year.

18. 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 including the production of food and the provision of habitat for reef associated species. Undesirable outbreaks of some native species and the introduction of invasive non-indigenous species have the potential to impair these functions and thus prevent Wheeler North Reef from attaining its mitigation goal of compensating for the loss of marine resources caused by SONGS operations. Native species that may become undesirable when they attain very high abundances include dense aggregations of sessile invertebrates that can monopolize space and exclude other species (e.g., giant kelp). For example, starved sea urchins that intensively graze the bottom can create large deforested areas commonly called sea urchin barrens (Graham et al. 2007, Schiel and Foster 2015). Invasive reef species refer to non-native taxa such as the brown seaweed *Sargassum horneri,* which was accidentally introduced from Asia and has become increasingly abundant at some reefs off of southern California. Data on the abundance of potentially undesirable and invasive species are collected as part of the monitoring to evaluate the biological performance standards for the benthic community of reef algae, invertebrates and fishes.

Important functions refer to the physical, chemical, and biological processes or services that species play in their ecosystem. Unlike discrete properties of species in an ecosystem (e.g., abundance, diversity), functional attributes emphasize rates of physiological/ecological processes (e.g., primary production, nutrient cycling) or ecological roles (e.g., the provision of structure, buffers to disturbance) that species play in defining an ecosystem. Such functions can be logistically difficult to measure and quantifying them often requires substantial effort and funding.

Reef fishes are highly valued for their ecological and socioeconomic importance and their production is a highly desirable function. This function is particularly important for artificial reefs whose role in attracting fish vs. producing fish has long been debated (Bohnsack 1989, Grossman et al. 1997, Pickering and Whitmarsh 1997). Fish production on Wheeler North Reef is one of the relative performance standards by which it is judged and using fish production to evaluate the performance standard pertaining to undesirable and invasive species incurs no additional effort or cost. Similarly, net primary production (NPP) is one of the more important functions of an ecosystem as it provides the basis for sustaining life on Earth, and NPP by giant kelp forests is among the highest of any ecosystem in the world (Reed and Brzezinski 2009). In contrast to the secondary production by reef fishes, measuring NPP by giant kelp is not required for evaluating the performance of Wheeler North Reef. Although NPP by giant kelp is time consuming to measure, it can be predicted from more easily obtained data of kelp frond density (Rassweiler et al. 2018), which are routinely collected for the evaluation of the performance standard for giant kelp area.

Secondary production by reef fishes and net primary production by giant kelp were selected as the “important functions” for evaluating this performance standard because of their important ecological roles, the minimal additional effort required to estimate them, and their overall relevance to the objectives of the reef mitigation requirement.

The evaluation of this performance standard involves a three-step process. First, the abundances of potentially undesirable native species and invasive non-native species are measured and compared at Wheeler North Reef (Phases 1, 2 and 3) and the two reference reefs to determine their potential to impair important ecological functions of Wheeler North Reef. Second, the performance of Wheeler North Reef with respect to reef fish production and giant kelp NPP is assessed relative to the two reference reefs to determine whether either of these functions at Wheeler North Reef are impaired relative to the lowest performing reference reef. This approach compares the four-year running averages of each function at Wheeler North Reef (Phases 1, 2, and 3) to those at the two reference reefs to determine whether each function at Wheeler North Reef is similar to that at the two reference reefs (i.e., = or >). If both functions at Wheeler North Reef are similar to those at the reference reefs (as per the methods described in Section 2.4), then Wheeler North Reef meets this performance standard. If, on the other hand, one or more functions at Wheeler North Reef are found to be dissimilar (i.e., <) to the reference reefs, then this finding triggers a third step that involves additional analyses and studies to determine whether undesirable or invasive species are the cause of this dissimilarity. If an undesirable or invasive species is found to be the cause of dissimilarity for either reef fish production or giant kelp NPP, then the function is considered impaired and the Wheeler North Reef would fail to meet this performance standard.

4.0 DATA MANAGEMENT

Data management protocols will follow those developed during the experimental phase of the reef mitigation project and are outlined below.

4.1 Data Verification Procedures

Data management and quality assurance procedures for the artificial reef monitoring begin in the field. Upon completion of each dive, data sheets are checked for completeness and legibility and total counts are tallied for each species. After these field checks are completed, the data sheets are filed into a field binder for transport back to the laboratory. Upon arrival at the laboratory, data sheets are checked into a survey log that contains entries for the observer, date, and survey location. The log is used to verify that all data assignments for a day have been completed and all field data have been accounted for.

Data consistency is also verified during the check-in procedure, and any anomalies are brought to the attention of the field supervisor. Senior staff members examine the data sheets for possible misidentification of species, missing data values, and invalid counts. The field supervisor decides how to rectify any errors and implements corrective action to avoid repeating mistakes in the field. Such actions have included retaking data, and providing additional field training for investigators.

4.2 Data Entry and Quality Assurance

All SONGS Mitigation Monitoring data are entered and stored in electronic relational databases based on Structured Query Language (SQL). The project's data entry procedures are designed to facilitate rapid data entry while continuing to ensure the quality and integrity of the data as they are transformed from physical to electronic form.

The vast majority of monitoring data are entered using custom designed web forms. These web forms provide an intuitive, graphical user interface to the project's databases. Each form mimics the exact layout of the data sheets taken into the field, which allows the individual entering the data to electronically transcribe a sheet without transforming the data into tabular format (e.g., spreadsheets). This method eliminates the need for users to replicate key variable entries, or manipulate columns, rows, or formats. Such tasks are processed on the project's internal application servers, which translate the form data into the appropriate format for storage on the project's data servers. In some cases, these forms can reduce the amount of data a user is required to enter by over 100 fields for a single data sheet, which translates to significant time savings and reduction in data entry errors.

The data entry schema also implements a multi-tiered data checking system. Data entered using the web forms are verified in three distinct phases before any information is considered suitable for the final databases on which all analyses are done.

1. First, a validator is incorporated into each web form used to enter data. The validator includes a number of checks that test the structural (e.g., recognizing out of range values and incorrect formats) and relational (e.g., validating that survey dates and locations match the field logs) integrity of the data. If any of these checks fail, then the user is informed of the error, and the entire form is rejected until the invalid entry is corrected. The system requires all errors to be corrected for a form to be successfully submitted.
2. Second, after a form is successfully submitted, the web server checks that each data row does not violate any constraint built into the database, and can be correctly transformed for entry into the database table. If any line of the form fails these tests, then the entire form is rejected until the invalid

entry is corrected.

3. Finally, once the data are transformed, the web server enters the values into the database tables. The database server performs the final referential integrity checks (e.g., foreign key constraints, data triggers) on each value entered into the data tables. Failure of any these causes the form to be rejected until the invalid entry is corrected.

This three phase checking system has greatly reduced the time required for post-entry data checking procedures by eliminating the most common data entry errors. This system has also substantially reduced the number of data checking programs previously required to find these problems, in some cases by as much as 75%.

Three final steps convert the electronically checked databases into the final databases. First, pairs of investigators manually check each data line of the database tables against the field data sheets for correct values. Second, following the manual check, a series of programs are run on the data to check for any inconsistencies that are not detected by referential integrity checks. For example, sampling locations in a given survey are checked against the dates recorded into the sampling log for that survey to verify that all locations have been entered. Any inconsistencies are rectified. Once these checks are complete, the data are merged onto a template that populates the data for observations with a value = 0. The templates also contain all pertinent metadata (variable descriptions and sampling methods) that are checked thoroughly prior to posting. At this stage, databases are considered to be in their final form and suitable for analysis.

4.3 Data Storage and Preservation

After the data are entered and checked, each data sheet is scanned and converted into a PDF file for electronic storage. The material sheets are then filed in binders by survey type and year and stored in the monitoring data library located at UCSB’s SONGS mitigation office and laboratory in Carlsbad, CA. The PDF data sheets are similarly filed in an electronic library located on the project's data servers.

The project employs a highly redundant, multi-server system to ensure maximum data integrity, preservation, and uptime. The system consists of a central data server, and multiple mirror and backup servers located at UCSB’s Carlsbad office, the Marine Science Institute on UCSB’s main campus in Santa Barbara, CA, and geographically distributed cloud storage.

The central server at UCSB’s Carlsbad office is the primary management point for all project-related data and files. These files fall into three distinct classes that are used to determine the method and format of automated backup and preservation:

(1) regular documents (backed up daily to local and cloud storage in native format), (2) SQL database files (backed up daily to two mirror servers using native format, and daily to cloud storage in comma delimited text), and (3) versioned documents, including statistical and database program files (central repository is backed up in real time to two mirror servers in native format).

Local daily backups are written to a redundant disk array. All valid users for the system can access daily backups of regular documents and statistical or database program files. By contrast, restoration of SQL database files must be done by the system administrator.

5.0 DISSEMINATION OF RESULTS

The following procedures are followed to ensure efficient and effective communication with SCE, state and federal resource agencies, and the general public: (1) CCC contract scientists communicate with SCE and state and federal agencies as needed via phone, email, and face-to face meetings to discuss results and any potential changes in monitoring design, (2) status reports are prepared and submitted to the CCC for public viewing on an annual basis, (3) project related documents are downloadable from the project's public website (https://marinemitigation.msi.ucsb.edu/), which also provides information on the history, current status, contact information, and other relevant material pertaining to the monitoring of the SONGS reef mitigation project, (4) all monitoring data are deposited annually into the Environmental Data Initiative (EDI) repository (https://portal.edirepository.org) after they have been verified and are freely accessible to the public via the project's website or EDI's data portal (using the Key words UCSB SONGS), and (5) as per Condition D of the SONGS permit, duly noticed annual public workshops are convened to review the overall status of the project, identify problems, and make recommendations for solving them, and review activities planned for the following year.

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Table 1. Reef fishes used as target species for estimating reproductive rates and fish production. *As live bearers, black surfperch are excluded from estimates of reproductive rates, which are based on per capita egg production.

Common Name	Scientific Name	Mode of Reproduction	Primary Diet
kelp bass	*Paralabrax clathratus*	egg layer (broadcast)	Midwater and benthic fish and invertebrates
señorita	*Oxyjulis californica*	egg layer (broadcast)	Zooplankton & small benthic invertebrates
sheephead	*Semicossyphus pulcher*	egg layer (broadcast)	Hard-shelled benthic invertebrates
blacksmith	*Chromis punctipinnis*	egg layer (demersal)	Zooplankton
black surfperch*	*Embiotica jacksoni*	live bearer	Small benthic invertebrates

Table 2. Comparison of similarity for full sampling vs. reduced sampling for annual site inspections for the 11 relative performance standards that are evaluated annually (the relative standard for undesirable and invasive species (#18) was not included in this analysis because it is evaluated using a different sampling design). Similarity for the full sampling design was assessed with inferential statistics applied to the 4-year average of each performance standard and the means test was used to assess similarity of the 4-year averages for the reduced sampling design. Shown are the number of performance standards met (i.e., deemed to be similar) by each reef for each year from 2012 to 2021. Numbers in green indicate a reef met as many or more performance standards as the lowest performing reef used as reference. Numbers in red indicate a reef met fewer performance standards that the lowest performing reef used as reference. The bottom row shows the total number of years during 2012-2021 that a reef met as many or more performance standards as the lowest performing reef used as reference.

	Wheeler North		**San Mateo**		**Barn**	
Year	Full sampling	Reduced sampling	Full sampling	Reduced sampling	Full sampling	Reduced sampling
2012	8	8	6	5	10	9
2013	7	8	6	5	10	9
2014	8	8	5	5	10	9
2015	9	8	6	5	9	9
2016	9	8	6	5	9	9
2017	9	7	5	5	10	10
2018	8	7	8	6	9	9
2019	8	6	8	7	10	9
2020	9	7	7	6	10	9
2021	9	8	7	4	10	9
# years similar	**10**	**9**	**2**	**1**	**10**	**10**

Table 3. Comparison of the sampling effort between full monitoring and annual site inspections for the relative performance standards evaluated using data collected from transect surveys (#s 1-8, & 11) and data obtained from fish collections (#s 9-11). Also shown are the reductions in sampling effort for the relative performance standard for undesirable and invasive species (#12) and the absolute performance standards (i.e., area of hard substrate, area of giant kelp, and fish standing stock) that will occur during annual site inspections.

Type of standard	Performance variable	Full monitoring	Annual site inspections	% reduction
Relative	1. Algal % cover	82 transects, 3 reefs	15 transects, 3 reefs	82
	2. Algal species richness	82 transects, 3 reefs	15 transects, 3 reefs	82
	3. Sessile invertebrate % cover	82 transects, 3 reefs	15 transects, 3 reefs	82
	4. Mobile invertebrate density	82 transects, 3 reefs	15 transects, 3 reefs	82
	5. Invertebrate species richness	82 transects, 3 reefs	15 transects, 3 reefs	82
	6. Resident fish density	82 transects, 3 reefs	15 transects, 3 reefs	82
	7. Young-of-year fish density	82 transects, 3 reefs	15 transects, 3 reefs	82
	8. Fish species richness	82 transects, 3 reefs	15 transects, 3 reefs	82
	9. Fish reproductive rates	collections & lab work of 4 species (n=100 fish/species/reef)	collections & reduced lab work of 2 species (n=50 fish/species/reef)	> 75
	10. Fish production	collections & lab work of 5 species (n=100 fish/species/reef)	15 transects, 3 reefs using fish biomass as proxy	100
	11. Fish food chain support	collections & lab work of 2 species (n=100 fish/species/reef)	collections & lab work of 2 species n=50 fish/species/reef)	50
	12. Undesirable/invasive species	151 transects WNR, 82 transects San Mateo and Barn	111 transects WNR, 15 transects San Mateo and Barn reefs	55
Absolute annual	Area of hard substrate	82 transects, WNR only	42 transects, WNR only	48
Absolute cummulative	Giant kelp area & fish standing stock	151 transects, WNR only	111 transects, WNR only	26

Table 4. The probability that Wheeler North Reef does not meet *n* number of relative performance standards (P ≥ n) in successive years due to chance. Values in bold red indicate (P ≥ n) is < α =0.1. Values bounded by a black box indicate possible scenarios in which (P ≥ n) is > α =0.1, but Wheeler North Reef fails to receive mitigation credit (i.e., it meets fewer standards than either reference reef).

		Year 1	Year 1 + 2	Year 1 + 2 + 3
Year	Standards NOT met (n)	P ≥ n	P ≥ n	P ≥ n
Year 1	0	1.0000	1.0000	1.0000
	1	0.9884	0.9999	1.0000
	2	0.9248	0.9984	1.0000
	3	0.7658	0.9907	0.9998
	4	0.5273	0.9649	0.9987
	5	0.2889	0.9038	0.9948
	6	0.1220	0.7938	0.9833
	7	**0.0386**	0.6379	0.9565
	8	**0.0088**	0.4598	0.9049
	9	**0.0014**	0.2929	0.8211
	10	**0.0001**	0.1631	0.7047
	11	**0.0000**	**0.0787**	0.5650
Year 1 +2	12		**0.0327**	0.4189
	13		**0.0116**	0.2851
	14		**0.0035**	0.1770
	15		**0.0009**	**0.0998**
	16		**0.0002**	**0.0509**
	17		**0.0000**	**0.0235**
	18		**0.0000**	**0.0097**
	19		**0.0000**	**0.0036**
	20		**0.0000**	**0.0012**
	21		**0.0000**	**0.0004**
	22		**0.0000**	**0.0001**
Year 1 + 2 +3	23			**0.0000**
	24			**0.0000**
	25			**0.0000**
	26			**0.0000**
	27			**0.0000**
	28			**0.0000**
	29			**0.0000**
	30			**0.0000**
	31			**0.0000**
	32			**0.0000**
	33			**0.0000**

Figure 1. Map showing the locations and construction dates of the three phases of Wheeler North Artificial Reef.

Figure 2. The relationship between effect size and α, and how it is used to determine whether Wheeler North Reef meets a given relative performance standard.

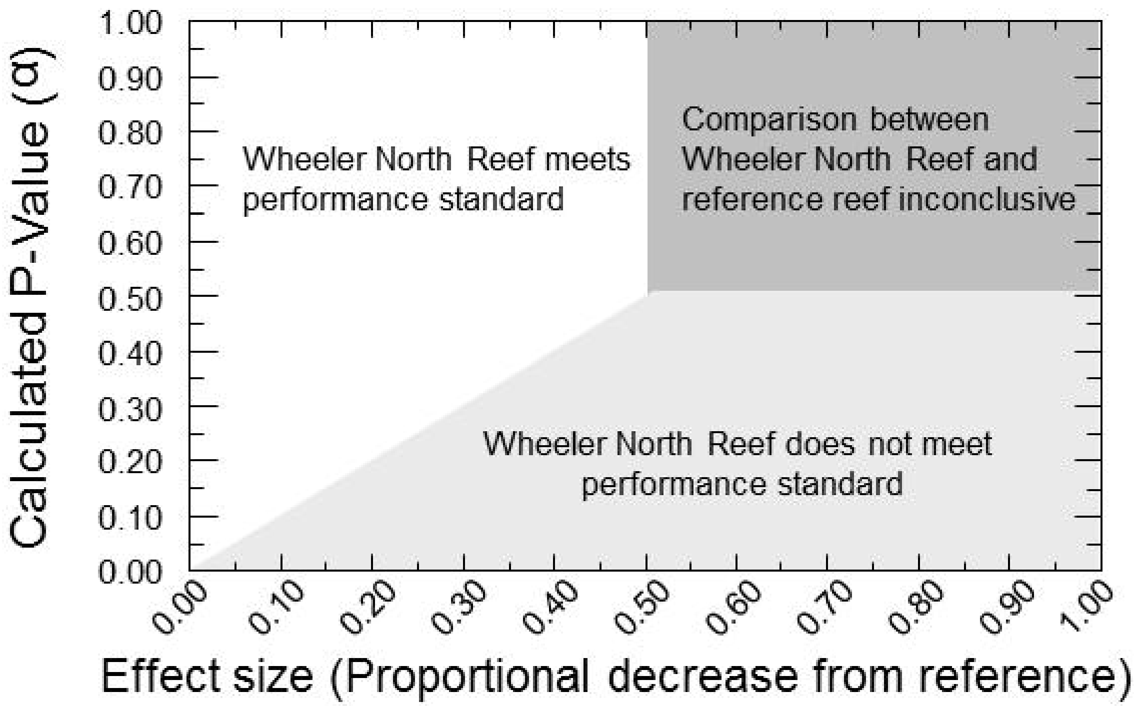


Figure 3a. Map of Wheeler North Reef showing the location of the 151 fixed transects where monitoring the performance standards is done. Transects are shown as black lines (n = 12 Phase 1, n = 80 Phase 2, and n = 59 Phase 3).

Figure 3b. Map of the reef at San Mateo showing the location of the 82 fixed transects where monitoring the performance standards is done. Transects are in pairs and are shown as black lines in the light blue shaded areas, which denote hard substrate.

Figure 3c. Map of the reef at Barn showing the location of the 82 fixed transects where monitoring the performance standards is done. Transects are in pairs and are shown as black lines in the light blue shaded areas, which denote hard substrate.

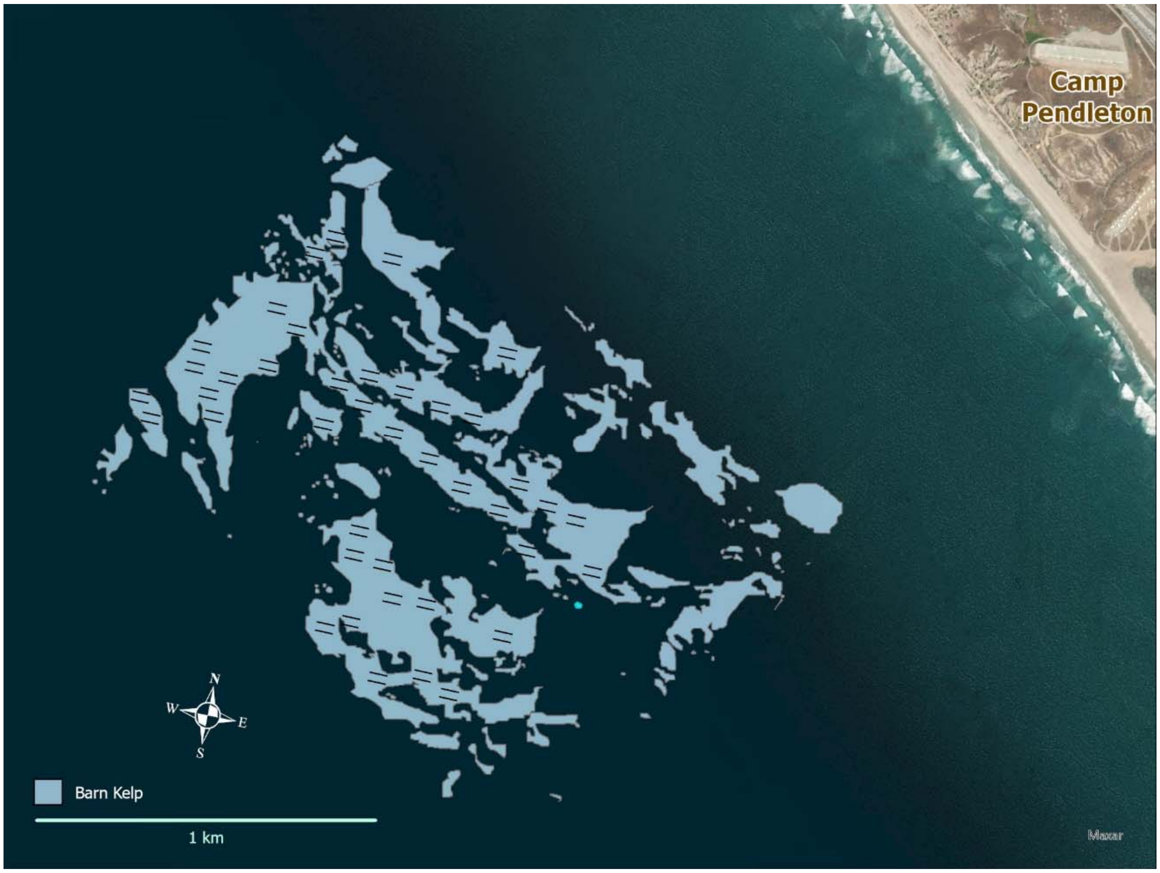


Figure 4. Schematic showing the different sized sampling areas that are used at each of the fixed monitoring stations; including a large 50 m x 3 m swath (delineated by dashed lines); five 10 m x 2 m quadrats perpendicular to the main transect and evenly spaced along it; five evenly spaced 1 m x 1 m quadrats (shaded squares and inset) containing 20 evenly spaced point contact locations and divided into two 0.5 m^2 quadrats. Note: One of the survey methods for measuring cryptic resident fish (50 m x 2 m) falls within the 50 m x 3 m swath used for non-cryptic fishes and is not shown in this schematic.

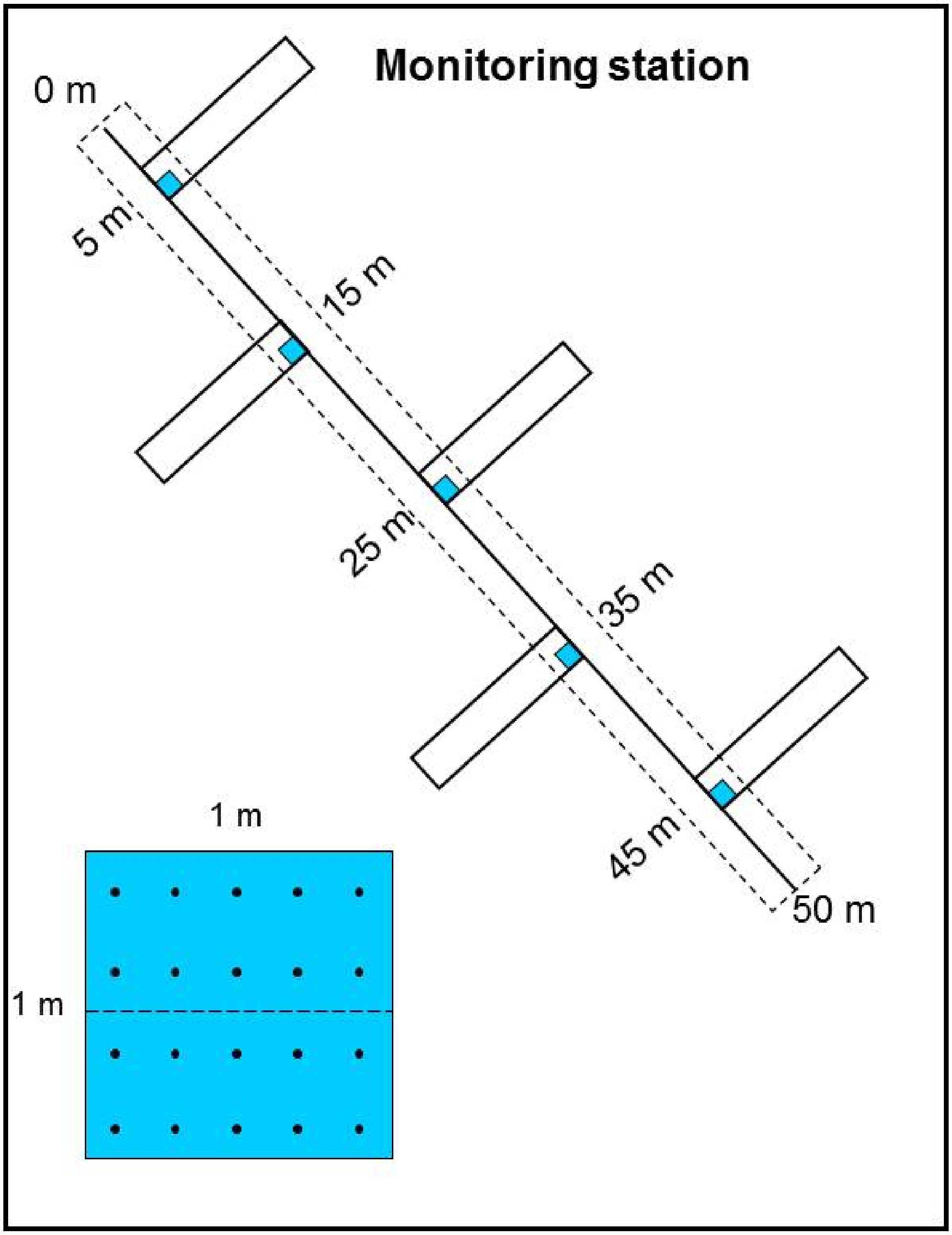
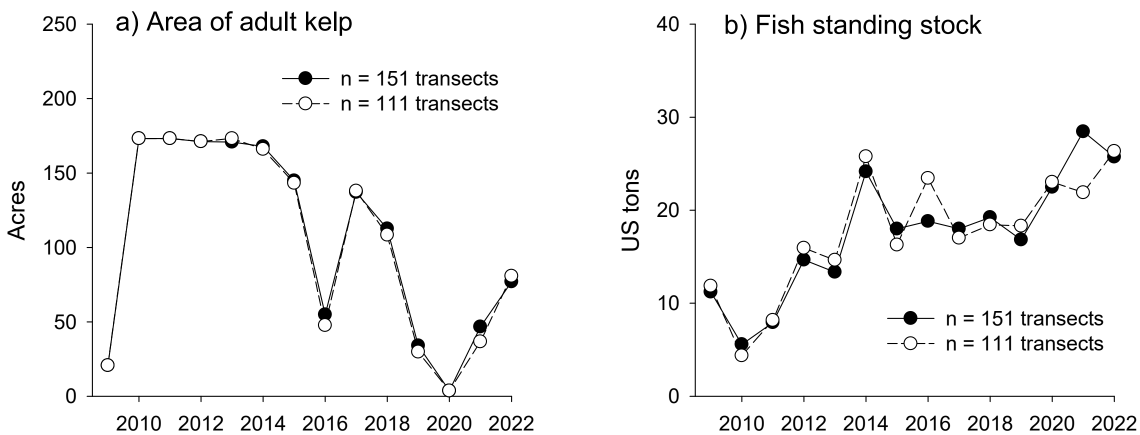


Figure 5. Wheeler North Reef time series of: (a) the area of medium-to-high density adult giant kelp, and (b) the standing stock of fish for full sampling based on 151 transects that includes 40 paired transects in Phase 2 (shown as solid black circles and solid lines), vs. reduced sampling based on 111 unpaired transects in which one of the transects in each of the 40 pairs was eliminated (open circles and dashed lines).



APPENDIX 1. Annual Site Inspections

Determination of Similarity:

The approach used to determine similarity among Wheeler North Reef, San Mateo and Barn for the 11 relative performance standards measured annually during annual site inspections differs from that used during full monitoring. The determination of similarity during full monitoring involves the use of inferential statistics. In contrast, similarity for annual site inspections is based on a means test that simply compares the value of the 4-y running averages of the performance standards of the three reefs without the use of inferential statistics (see Section 2.4.2).

The similarity outcomes for these two approaches (inferential statistics vs. means test) were compared using the full sampling data collected from 2009-2021 for the 11 relative performance standards measured annually (performance standards 7-17). The relative standard for undesirable and invasive species (#18) was not included in this analysis because it is evaluated using a different sampling design and must be met each year for Wheeler North Reef to receive mitigation credit for that year. The number of standards passed by each reef was calculated for each year using both methods. The outcomes using the two methods were very similar, although not identical, as Wheeler North Reef passed 8 out of 10 years using the means test vs. 10 years using inferential statistics and San Mateo passed 3 years using the means test vs. 2 years using inferential statistics. Barn passed all 10 years using both approaches (Table S1).

Table S1. Comparison of the number of relative performance standards met each year by Wheeler North Reef, San Mateo and Barn using inferential statistics vs. the means test to assess similarity. Shown are results from 2012 to 2021 for the 11 relative performance standards measured annually using full monitoring. Numbers in green indicate a reef met as many or more performance standards as the lowest performing reef used as reference. Numbers in red indicate a reef met fewer performance standards than the lowest performing reef used as reference. The bottom row (# years passed) shows the total number of years during 2012-2021 that a reef met as many or more performance standards as the lowest performing reef used as reference.

	Wheeler North		San Mateo		Barn	
Year	Inferential statistics	Means test	Inferential statistics	Means test	Inferential statistics	Means test
2012	8	8	6	5	10	9
2013	7	6	6	6	10	10
2014	8	7	5	5	10	10
2015	9	9	6	6	9	7
2016	9	8	6	5	9	9
2017	9	8	5	5	10	9
2018	8	6	8	7	9	9
2019	8	6	8	7	10	9
2020	9	8	7	5	10	9
2021	9	9	7	6	10	7
# years passed	**10**	**8**	**2**	**3**	**10**	**10**

General sampling design: The sampling design used to evaluate the relative performance standards during annual site inspections differs from the sampling design used during full monitoring in that it reflects a substantial reduction in sampling effort (see Table 3 Section 3.1.2).

Sampling effort for the relative performance standards evaluated using data collected in transects is reduced by decreasing the number of transects sampled at each reef from 82 transects during full monitoring to 15 transects during annual site inspections. The 15 transects were strategically located to optimize the spatial distribution of sampling and adequately characterize the mean percent cover of hard substrate of each reef (Figure S1). Mean percent cover of hard substrate averaged from 2009-2021 was nearly identical for the 15 transects selected for reduced sampling relative to the values calculated for the 82 transects measured during full sampling for all reefs (Figure S2). For this evaluation the four-year running averages for the relative performance standards were calculated using only the 15 fixed transects chosen for reduced sampling.

Similarity among the three reefs using the means test was compared for full sampling (n = 82 transects) vs. reduced sampling for annual site inspections (n = 15 transects) for the eight relative standards that are evaluated using only data collected from transect surveys (performance standards 7, 8, 9, 12, 13, 14, 15, 16) and for the relative standard for fish production (# 11), which is evaluated using data on biomass density collected from transect surveys along with data of somatic and gonadal growth obtained from fish collections. Fish biomass density is a very good predictor of fish production (Figure S3) and was used as a proxy for fish production in this comparison. The results of this comparison showed that the number of years passed by each reef was largely similar for full and reduced sampling designs; Wheeler North Reef passed 10 out of 10 years using reduced sampling vs. 9 years using full sampling, San Mateo passed 0 years using reduced sampling vs. 1 years using full sampling, and Barn passed all 10 years using both sampling designs (Table S2).

Several reduced sampling scenarios were developed and compared to full monitoring in the case of the two relative performance standards evaluated using only data obtained from fish collections (i.e., fish reproductive rate and fish food chain support). The reduced sampling scenarios included a shorter sampling window (July and August for reduced sampling vs. June through October for full sampling), a ~50% reduction in the number of individuals of each species collected (N = full sampling, N/2 = reduced sampling), and using a subset of the three species used to assess fish reproductive rate (Sheephead, Kelp bass, and Señorita). For each reduced scenario, data were sub-sampled from the full dataset of fish collection data from 2009-2021 and fish reproductive rate and food chain support for each reef were re-calculated for each year using the sub-sampled data. Four-year running averages were calculated for each reef from 2012-2021 and similarity among the reefs for each performance standard was determined using the means test. Each reduced scenario was compared to the full sampling scenario and a “best” reduced scenario was chosen that was most similar to full sampling in terms of number of years passed across all three reefs (Table S3,). Reduced scenarios for fish reproductive rate used the gonad mass of females with hydrated eggs as a proxy for the batch fecundity. The effort to measure gonad mass is significantly less than that needed to measure batch fecundity and they are significantly correlated at all sites for all three species (Figure S4). Moreover, the annual median fecundity index calculated using gonad mass is significantly correlated with the annual fecundity index calculated using batch fecundity (Figure S5).

For fish reproductive rate, the scenario chosen for annual site inspections will target 40-50 individuals of two species (Kelp bass and Sheephead) as opposed to 75-100 individuals of four species in full monitoring (Table S3). Although Sheephead will be collected throughout the full season, Kelp bass collection will be restricted to July and August. For food chain support, the scenario chosen for annual site inspections will continue to collect two species (Sheephead, Black perch) throughout the full season, but will reduce collections from 75-100 individuals of each species to 40-50 individuals of each species (Table S4).

Figure S1. Maps of sampled transects for Wheeler North Reef, San Mateo, and Barn for the full sampling design (left column, n = 82 transects) and the reduced sampling design used for annual site inspections (right column, n = 15 transects).

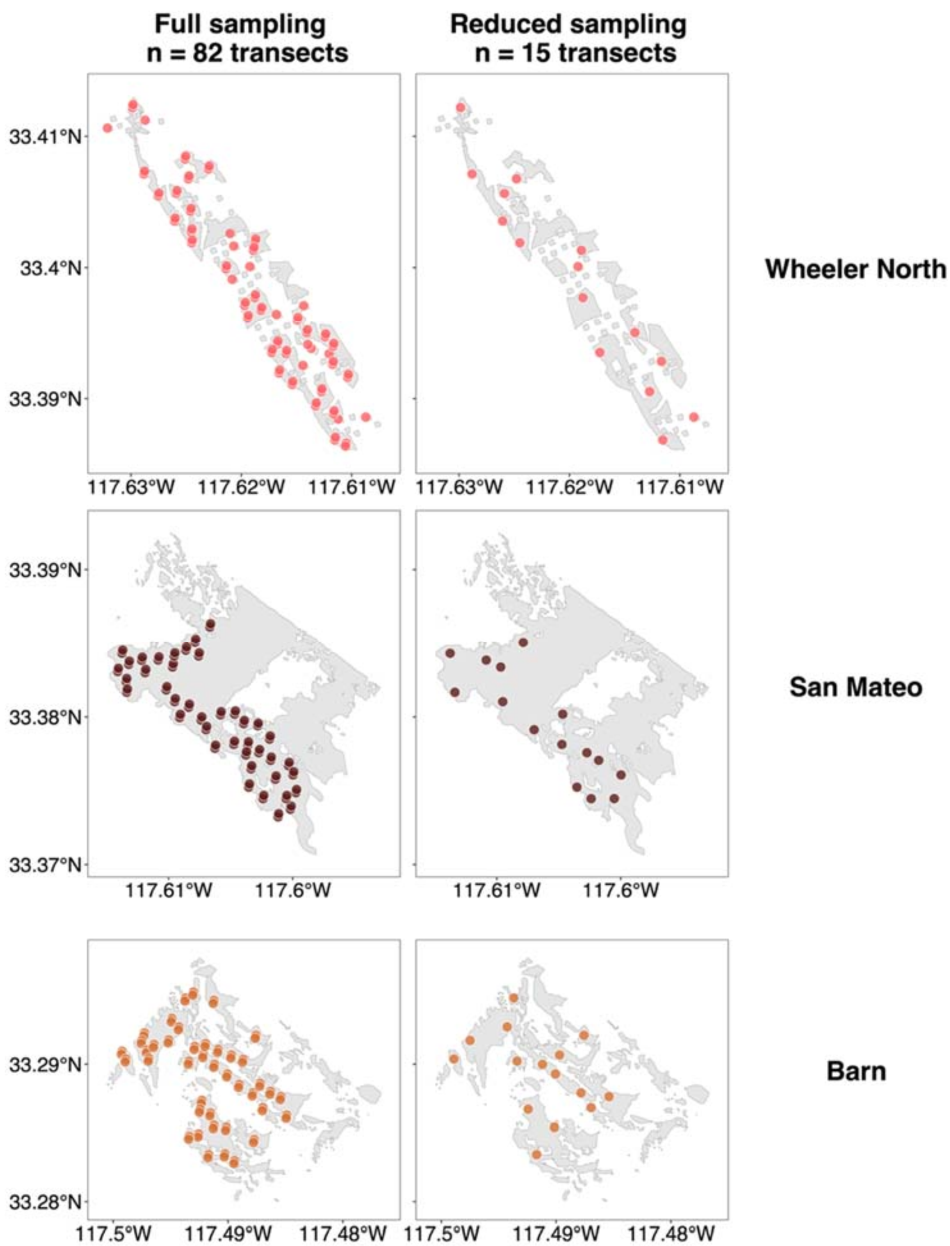


Figure S2: Histograms of the percent cover of hard substrate for Wheeler North Reef, San Mateo, and Barn for transects monitored in full sampling (top row) and reduced sampling (bottom row). Vertical line and numeric values given in each plot represent the mean value (from 2009-2021) for the selected transects. Transects chosen for reduced sampling during annual site inspections had comparable mean hard substrate cover relative to those used in full sampling.

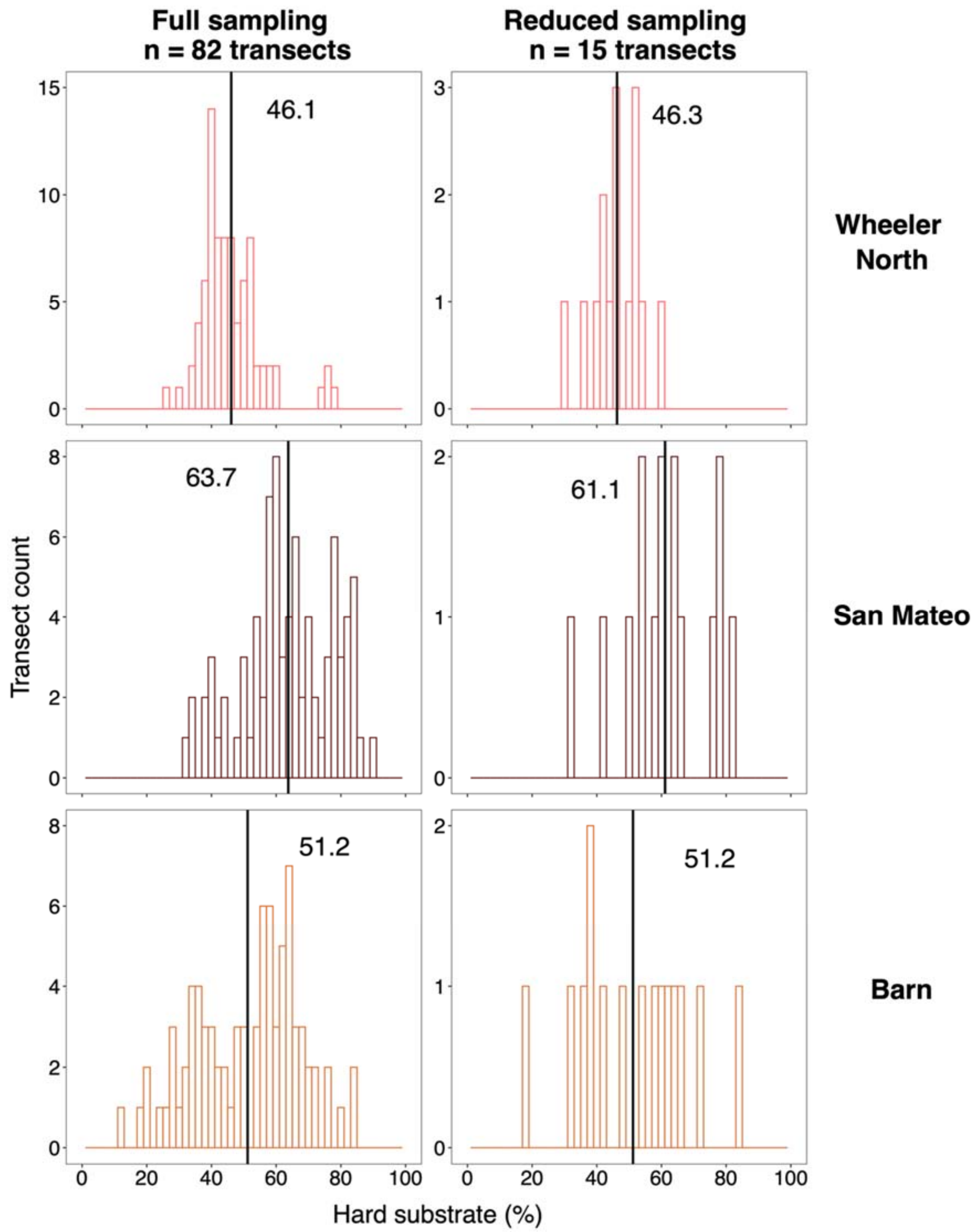


Table S2. Comparison of the number of relative performance standards met each year by Wheeler North Reef, San Mateo and Barn using the means test for full sampling (n = 82 transects) vs. reduced sampling of annual site inspections (n = 15 transects). Results are for the eight performance standards evaluated using data only from transect surveys (performance standards 7, 8, 9, 12, 13, 14, 15, 16,) and the performance standard for fish production (11), which uses transect data of biomass density and estimates of somatic and gonadal growth obtained from fish collections. The evaluation of the fish production standard for this comparison uses biomass density as a proxy for fish production. Numbers in green indicate a reef met as many or more performance standards as the lowest performing reef used as reference. Numbers in red indicate a reef met fewer performance standards than the lowest performing reef used as reference. The bottom row (# years passed) shows the total number of years during 2012-2021 that a reef met as many or more performance standards as the lowest performing reef used as reference.

	Wheeler North		**San Mateo**		**Barn**	
Year	Full sampling	Reduced sampling	Full sampling	Reduced sampling	Full sampling	Reduced sampling
2012	6	6	4	4	8	8
2013	6	6	4	4	8	8
2014	7	7	3	3	8	8
2015	7	7	4	3	7	8
2016	7	7	3	3	8	8
2017	7	7	3	3	8	8
2018	6	7	5	4	7	7
2019	5	6	6	5	7	7
2020	6	6	5	5	7	7
2021	7	7	5	4	6	7
# years passed	**9**	**10**	**1**	**0**	**10**	**10**

Figure S3. The relationship between biomass density and fish production for Wheeler North Reef, San Mateo, and Barn. Data are annual transect values for the period 2009 -2021.

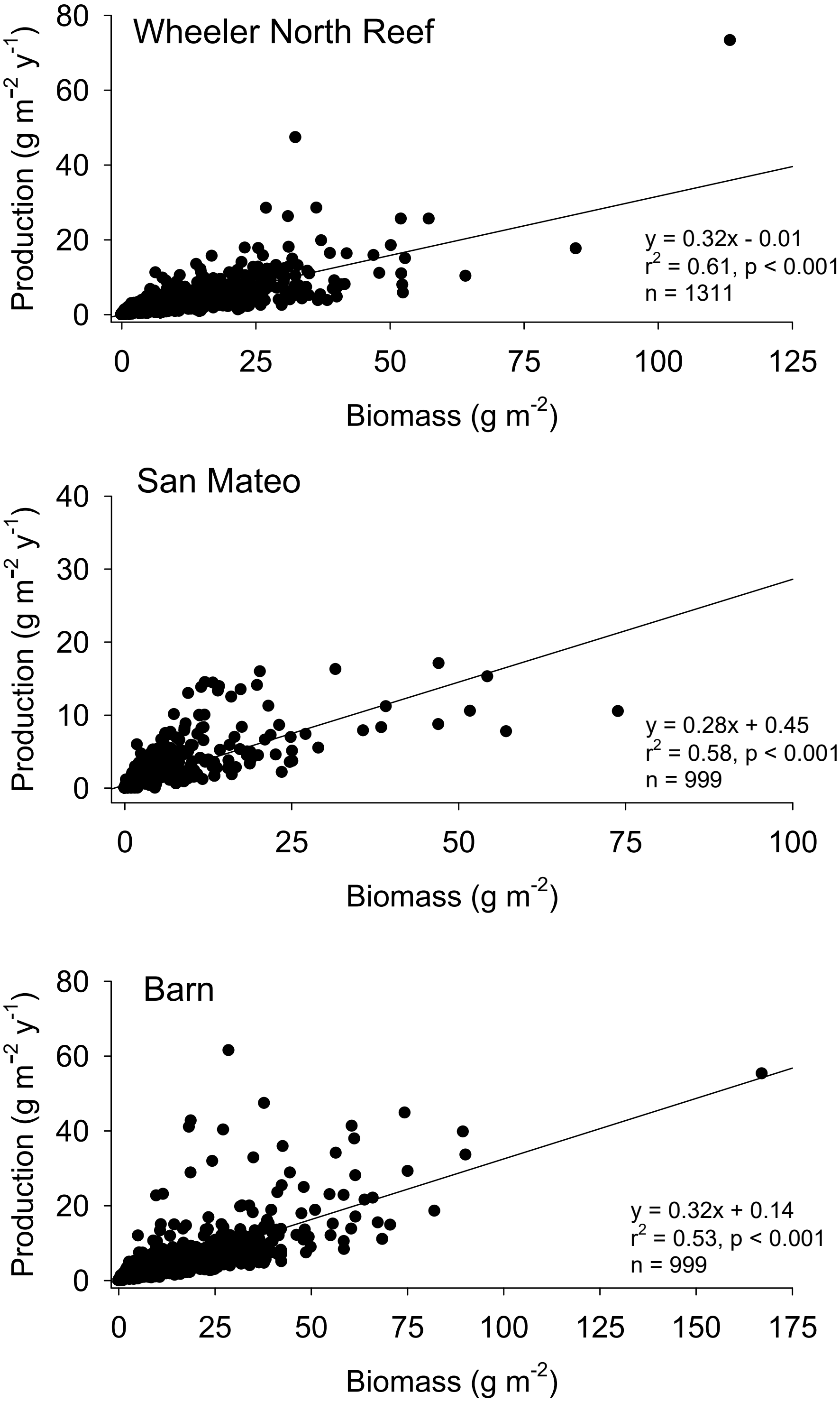


Figure S4. The relationship between gonad mass (wet g) of females with hydrated eggs and batch fecundity (i.e., the number of hydrated eggs in the ovaries) for Señorita, Kelp bass, and Sheephead collected at Wheeler North Reef, San Mateo and Barn from 2009 – 2021.

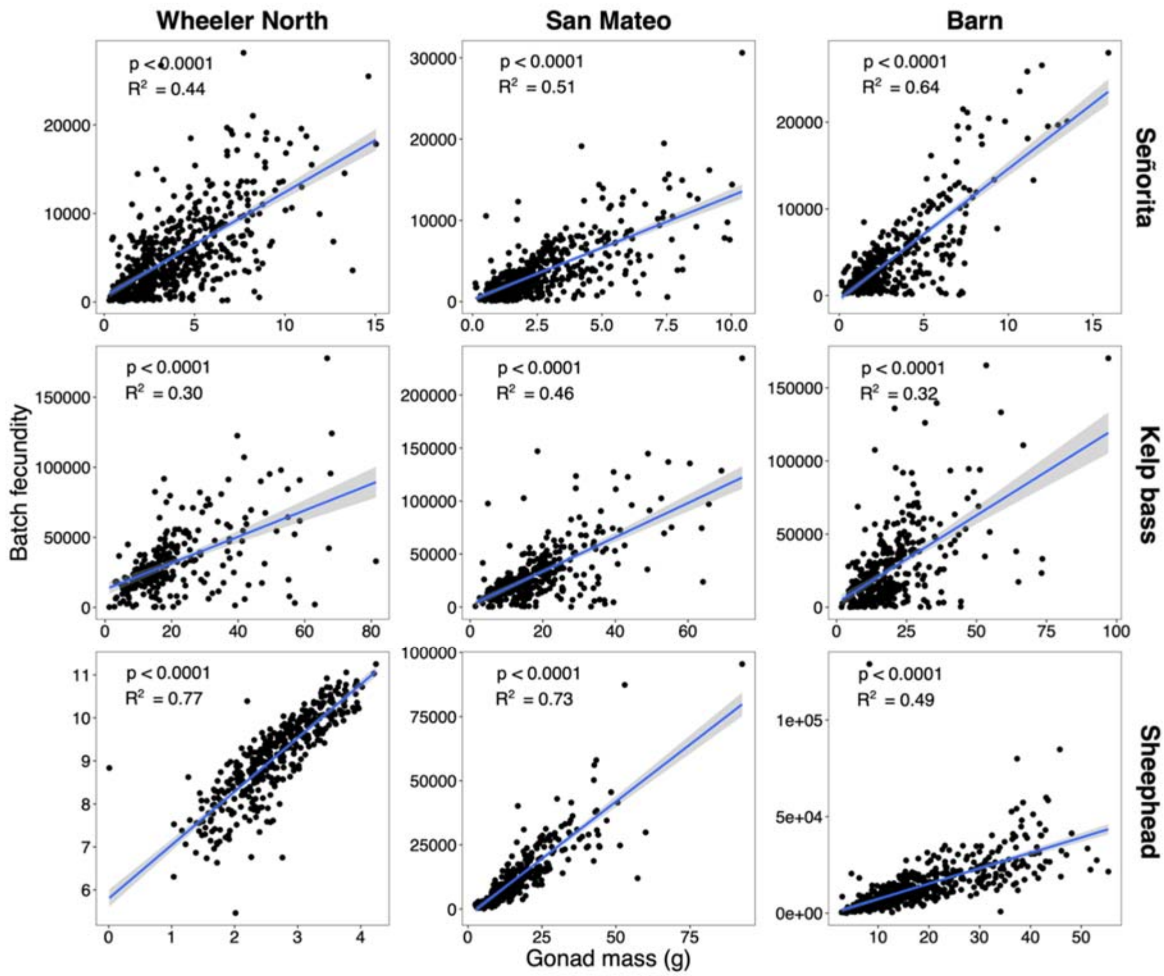


Figure S5. The relationship between the median fecundity index calculated with gonad mass of females with hydrated eggs vs. the median fecundity index calculated with batch fecundity for A) Wheeler North Reef, B) San Mateo, and C) Barn. Data are annual values from 2009-2021.

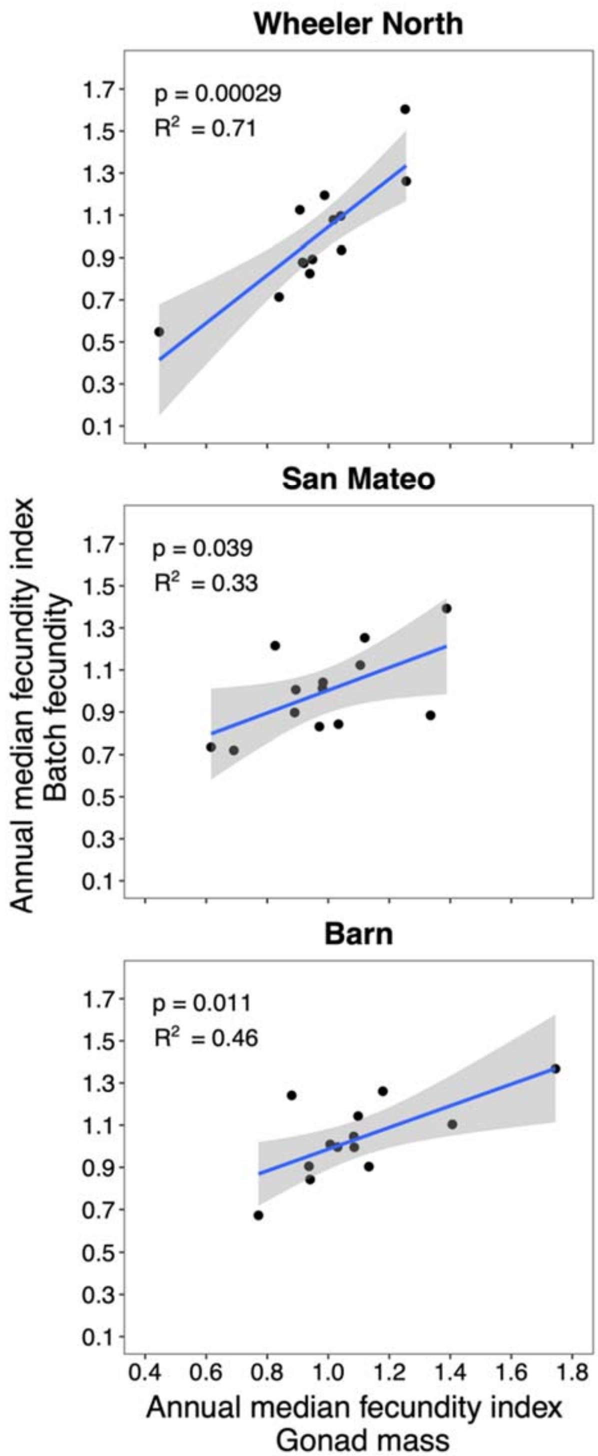


Table S3. Comparison of the number of years (out of 10) that each reef (Wheeler North Reef, San Mateo, Barn) passed the performance standard for fish reproduction for full monitoring and different scenarios of reduced sampling. All scenarios used the gonad mass of females with hydrated eggs as a proxy for batch fecundity and the means test to determine similarity. The scenarios differed in terms of the sampling window (full season vs. July/August), sample size (N = full season sample size, N/2 = reduced sample size that approximates the number of individuals collected in July/August), and species (Sheephead, Kelp bass, Señorita). All reduced sampling scenarios were compared to the full sampling scenario (highlighted in green). The reduced sampling scenario highlighted in gray best approximated full sampling, and is the scenario that will be used for fish collections during annual site inspections.

Scenario	Sampling window	Sample size	Species	Wheeler North	San Mateo	Barn
Full Sampling	Full season	N	Sheephead, Kelp bass, Señorita	5	8	7
Reduced Sampling	Full season	N/2	Sheephead, Kelp bass, Señorita	7	9	4
Reduced Sampling	Full season	N	Sheephead, Kelp bass	4	10	6
Reduced Sampling	Full season	N/2	Sheephead, Kelp bass	5	9	6
Reduced Sampling	Full season	N	Sheephead	7	4	9
Reduced Sampling	Full season	N/2	Sheephead	7	6	7
Reduced Sampling	July/August only	N/2	Sheephead, Kelp bass, Señorita	6	9	5
Reduced Sampling	July/August only	N/2	Sheephead, Kelp bass	3	9	8
Reduced Sampling	July/August only	N/2	Sheephead	2	8	10
Reduced Sampling	Full season July/August only	N/2 N/2	Sheephead Kelpbass	4	10	6

Table S4. Comparison of the number of years (out of 10) that each reef (Wheeler North Reef, San Mateo, Barn) passed the performance standard for benthic food chain support for full monitoring and different scenarios of reduced sampling. All scenarios used the means test to assess similarity. The scenarios differed in terms of the sampling window (full season vs. July/August), sample size (N = full season sample size, N/2 = reduced sample size that approximates the number of individuals collected in July/August), and species (Sheephead, Black perch). All reduced sampling scenarios were compared to the full sampling scenario (highlighted in green). The reduced scenario highlighted in gray best approximated full sampling, and is the scenario that will be used for fish collections during annual site inspections.

Scenario	Sampling window	Sample size	Species number	Wheeler North	San Mateo	Barn
Full sampling	Full season	N	Sheephead, Black perch	6	8	9
Reduced sampling	Full season	N/2	Sheephead, Black perch	5	6	9
Reduced sampling	Full season	N	Sheephead	1	9	10
Reduced sampling	Full season	N/2	Sheephead	0	10	10
Reduced sampling	July/August only	N/2	Sheephead, Black perch	7	8	5
Reduced sampling	July/August only	N/2	Sheephead	1	9	10

APPENDIX 2

METHODS FOR ESTIMATING FISH REPRODUCTIVE RATES

General Methods

Individuals of four targeted species (blacksmith, *Chromis punctipinnis;* sheephead, *Semicossyphus pulcher;* senorita, *Oxyjulis californicus;* and kelp bass, *Paralabrax clathratus*) are collected monthly throughout their reproductive period (May to September) at Wheeler North Reef, San Mateo, and Barn to estimate fish reproductive rates. Fish are collected between 8 am and 1 pm by divers with spears or anglers with hook and line. Collection sites are chosen throughout each reef where reasonable numbers of fish occur, and fish of reproductive size are selected for collection haphazardly. Like all common egg-laying species at the study sites, the four species targeted for assessing reproductive rates are batch spawners, that is, they spawn multiple batches of eggs throughout a single spawning season.

On the day that a batch of eggs is spawned, the eggs are first hydrated within the ovaries and then ovulated. Hydrated ova appear only within several hours of spawning and are recognized by their relatively large size and translucent appearance. At least 50 females with hydrated eggs in their ovaries are targeted for capture from each reef for each year. In the field, the body cavity of each specimen is opened and the sex and stage of development of the ovaries of females is noted. Ovaries are classified based on macroscopic examination as immature/inactive (no obvious oocytes); mature (obvious oocytes but none hydrated); and ripe (hydrated oocytes present). Specimens are kept on ice until they can be processed in the laboratory (no more than 24 h).

In the laboratory, each fish is weighed to the nearest 0.1 gram, and measured for total length and standard length. Sagittal otoliths are removed from each specimen for age and growth analysis needed for evaluating the performance standard pertaining to Fish Production. Ovaries from female fish are removed, blotted dry, and weighed to the nearest 0.1 g. Ovary-free body weight is determined by subtracting the ovary weight from the body weight. Ovaries are preserved in 10% formalin for fecundity analysis in the laboratory.

Batch fecundity is estimated using hydrated eggs. It is usually impractical to count all of the hydrated ova within the ovaries of a female, so batch fecundity is estimated from subsamples, and the number of hydrated eggs in these subsamples is extrapolated to the entire ovary pair. The number of hydrated ova in each subsample is counted using a dissecting microscope and the number of hydrated ova is extrapolated to the entire ovary.

Appendix 2: Methods for estimating fish reproductive rates

Fecundity Index for Egg-laying fish

The Fecundity Index for egg-laying fish is calculated for each reef as the product of batch fecundity and the proportion of individuals that produced eggs. A resampling approach is used to obtain an estimate of the variance of these two variables, which is needed to statistically determine whether Wheeler North Reef has met this performance standard in a given year.

Estimating Batch Fecundity
Larger fish tend to produce more eggs. Therefore, the production of eggs is scaled to body length to obtain a standardized measure of fecundity that accounts for differences in size within a species. Standardization for each species is achieved by dividing the length and fecundity of an individual by the mean length or mean fecundity averaged across all individuals of that species collected at all three reefs. These standardized measurements are used to develop species-specific regression models for each reef in a given year using standardized fecundity as the dependent variable and standardized length as the independent variable. Data used in each regression model are resampled 1000 times using a bootstrap approach (i.e., resampling with replacement) yielding 1000 regression equations. The integrated area under each regression function provides a species-specific estimate of batch fecundity (F_b) across all sizes for a given reef and year.

Estimating the proportion of individuals that produced eggs
The number of individuals of each species that are sampled in a given year (*N*) and the proportion of them that produced eggs (*p*) are used in a binomial model to generate 1000 estimates of the number of reproductive individuals in each iteration (*k*). The proportion of individuals that produced eggs in a given iteration (P_k) is calculated as:

$$=$$

where q = 1-p.

Calculation of Fecundity Index
The 1000 estimates of F_b generated for each species, reef, and year are merged with the 1000 estimates of P_k for each species, reef, and year. The product of these two variables yields 1000 estimates of population fecundity (F_p) for each species at each reef for a given year. Values of F_p are then standardized to ensure that each species is weighted equally. This procedure divides each species-specific value of F_p by the median of the resampled distribution of F_p for that species to produce 1000 cases of standardized fecundity (F_s) for each species at each reef for a given year. Values of F_s are averaged across all target species for which there are data to obtain 1000 estimates of reef fecundity (F_r) for each reef in a given year. The annual estimates of F_r for the current year and the preceding three years are averaged by case to produce 1000 estimates of the four-year running average of F_r for a given year. The four-year running average of

the Fecundity Index of each reef for a given year is calculated as the median of the resampled distribution of the four-year running average of F_r for that year.

An implicit assumption of using the Fecundity Index to evaluate whether fish reproductive rates at Wheeler North Reef is similar to that at reference reefs is that the frequency of spawning for a given species does not vary significantly among the three reefs.

APPENDIX 3

METHODS FOR ESTIMATING FISH PRODUCTION

The approach used to estimate annual production of fish tissue relies on using data of length, density, somatic growth rates, and production of reproductive tissues for a select group of five target species (Black perch, Blacksmith, Senorita, Sheephead, and Kelp bass). The result is an estimate of production per unit area of reef for each species. The approach is conceptually similar to that used by DeMartini et al. (1994), but differs in the details of the production model and some of the methods used to estimate key parameters. This approach to estimating tissue production includes production of both somatic and reproductive tissues. Hence, total production of tissue biomass for a given species is:

$$P_{TOTAL} = P_{St} + P_{Rt}$$

where P_{St} is production of soma and P_{Rr} is production of gonadal tissue over some time period t.

P_{St} is estimated as:

$$P_{St} = \sum_{i=1}^{n} (\overline{N}_{it} \bullet g_{it})$$

where $\overline{N}_{it}$ = mean population density of size class *i, during period t,* and g_{it} is the average growth increment (mass) of individuals in size class *i* over time period t.

P_{Rt} is estimated as:

$$P_{Rt} = P_{Ft} + P_{Mt}$$

where P_{Ft} is production of eggs by females in all size classes and P_{Mt} is production of milt (sperm and semen) by males in all size classes over time period t.

P_{Ft} is estimated as:

$$P_{Ft} = \sum_{i=1}^{n} (\overline{N}_{F,it} \bullet E_i \bullet w_e)$$

where $N_{F,it}$ = density of females in size class *i* during period *t; E_i* =mean number of eggs produced by a female in size class *i*; and w_e is the average weight of an egg.

P_M is estimated as:

$$P_{Mt} = \sum_{i=1}^{n} (\overline{N}_{M,it} \bullet E_i \bullet w_e \bullet r_i)$$

where $N_{M,it}$ = density of males in cohort *i* during time *t*; and r_i is the ratio of testes weight to ovary weight for males and females in cohort *i*. Thus, milt production, which is not readily measured, is estimated based on the ratio of testes to ovary size. Unlike the other four species, Black perch are viviparous and produce live young. Thus one caviat using the above approach is the production of reproductive tissue by Black perch is assumed to be zero, which results in an underestimate of their total production.

Parameter estimation

The equations above include several parameters that are estimated using data collected from the three field sites.

N_{it} — The density of individuals in a size class *i* during time *t* is determined from field surveys of fish density and size structure.

N_{Ft} and N_{Mt} — The density of females and males in each size class during period t is estimated from total densities in field surveys and sex ratios determined from the work on reproductive output.

g_{it} — Cohort specific growth increments over period t are estimated for the year preceding capture by back-calculation from otoliths of fishes collected for the work on reproduction and supplemented with collections of juveniles. In brief, somatic growth is estimated from otolith growth for species where clear increments are present and a tight relationship between otolith size and body size exists.

E_i — Per capita egg production is estimated as the product of the batch fecundity and the number of reproductive bouts per year.

w_e — Egg weight is estimated from the largest 20% of yolked (but not hydrated) eggs in a large, random selection of ovaries of each species. Egg weight is calculated as egg volume in cc (using measured radius and assuming spherical shape) times a specific gravity of 1.

r_i — Ratio of testes to ovary weights is calculated for each size class from samples collected for the reproduction standard. Only mature, reproductively active fish are used in estimating this ratio; and only females with mature but non-hydrated eggs are used.

APPENDIX 4

METHODS FOR DETERMINING SIMILARITY IN BENTHIC FOOD-CHAIN SUPPORT TO FISHES

The ratio of gut mass to somatic mass in two benthic feeding reef fishes (the black surfperch and California sheephead) is used as an index of food-chain support (i.e., FCS Index) to represent the contribution of reef associated macroalgae and invertebrates to the diets of benthic reef fishes. The methods for collecting fish are described in Appendix 2, and the calculation of the 4-year running average and proportional effect size of the FCS Index are described in Section 3.2.

Determining similarity in fish food-chain support in any given year involves testing for significant differences in the mean FCS index between the reefs with the two lowest values. This test calculates the proportional effect size between the four-year running averages of the two reefs and the probability (i.e., p-value) that they are significantly different. Because proportional effect sizes of the FCS Index are based on data collected from varying numbers of individuals of two species (rather than on data collected from 82 replicate transects) and because raw FCS values differ considerably between the two species (due to species effects rather than reproductive condition effects), the p-value is calculated using a resampling procedure of standardized FCS values (i.e., z transformed data by each species, reef and year). This method ensures each species and reef are weighted equally. Standardized FCS values for each species and reef in a given year are resampled with replacement and this process is iterated to produce a “null” distribution of the four-year averaged standardized FCS values from which the p-value is calculated.

The steps used to calculate the p-value for testing differences between the two reefs with the lowest 4-year running average FCS Index are as follows:

1. Standardize the FCS Index by calculating the z score (ZFCS) for each individual of each species across all reefs and years using the values of the FCS Index for each species and reef. This method will produce a ZFCS dataset with the same number of observations as the FCS dataset from which it was derived. For example, the ZFCS value for a sheephead collected from Wheeler North Reef in 2022 is:

   $$ZFCS = (x - \mu) / \sigma$$

   Where x = FCS for an individual sheephead collected in 2022 from Wheeler North Reef, μ = the mean FCS Index for sheephead averaged over all years and reefs, and σ = the standard deviation of the FCS Index for sheephead averaged over all years and reefs.

2. For each year, reef, and species create 1000 means based on iterations of ZFCS values having a sample size of 100 per species. This step will produce two sets of means (one for each species) per reef per year.
3. For each reef, calculate the average ZFCS for each iteration (e.g., the mean for iteration 1 across both species, the mean for iteration 2 for both species and so on). This step will produce a ZFCS dataset of 1000 mean values for each year and reef.
4. Calculate 1000 replicates for the 4-year running average of ZFCS for each reef and each four-year time period using the dataset produced in step 3.
5. For a given 4-year period, combine the 1000 replicates of the 4-year running average of ZFCS for the reef with the lowest FCS index (hereafter reef 3) with the 1000 replicates of the 4-year running average of ZFCS reef with the second lowest FCS index (hereafter reef 2) to create a “Combo” dataset of 2000 values of the 4-year running average of ZFCS.
6. Resample (with replacement) the Combo dataset created in step 5 to produce two “null” datasets (null 1 and null 2) of 1000 cases.
7. Subtract null 1 from null 2, yielding the null distribution of 1000 differences. This null distribution should be centered at zero and be normally distributed.
8. Order the null distribution from highest value to lowest value such that the highest value is referred to as case 1 and the lowest case 1000.
9. Calculate the actual effect size between reef 2 and reef 3 by subtracting the 4-year running average ZFCS Index of reef 2 from the 4-year running average ZFCS Index of reef 3 (this will always be a negative number)
10. Find the “nearest corresponding” case number in the null distribution in step 8 that aligns with the actual effect size calculated in step 9. Determine the p-value of the calculated effect size as:

    P= (1000 – nearest corresponding case number) / 1000

    For example, if the calculated difference is -1.1 and the corresponding case number is 923 then the p-value = (1000-923/1000) = 0.077.

APPENDIX 5

CHRONOLOGY OF CHANGES TO THE MONITORING PLAN FOR SONGS REEF MITIGATION

All changes to the monitoring plan for reef mitigation become effective the date they are implemented and do not affect the assessment of reef performance in previous years.

Changes made in February 2013 revision.

1. Changes with respect to how the absolute performance standards are evaluated.

Previous approach: For a given year, each absolute standard is evaluated using data collected at Wheeler North Reef (WNR) for that year.

New approach: For a given year, the evaluation of each absolute standard will be based on the greater value obtained from either: (1) data collected at WNR that year, or (2) a four-year running average calculated from data collected at WNR for that year and the previous three years.

Rationale for change: Short–term fluctuations in the physical and biological attributes of a kelp forest community are a common feature of natural reefs unaffected by SONGS operations. Assessing the absolute standards using either the current year's value or a four-year running average recognizes that such short-term fluctuations at WNR are expected even if it is performing as well as or better than natural reefs in the region. As in the past, all absolute standards must be met in a given year for that year to count towards compliance with Condition C.

2. Changes with respect to how the relative performance standards are evaluated

Previous approach: All relative standards at WNR must be met in a given year for that year to receive mitigation credit towards meeting the requirements of Condition C. For WNR to meet a relative performance standard, the value for that standard at WNR must be statistically equal to or greater than the value at the lower of the two reference reefs. In addition, WNR cannot have the lowest value (regardless of statistical significance) for more standards than expected by chance for that year to receive mitigation.

New approach:

1) Instead of requiring WNR to meet every relative standard in a given year, it must meet only as many of the relative standards as the lowest performing reference site.
2) A four-year running average calculated from data collected for that year and the previous three years (instead of the mean calculated from data collected only in that year) will be used to determine whether a performance standard is met in that year.

3) Assessment of the fish community and benthic community of algae and invertebrates is based on an equal (instead of unequal) number of standards pertaining to the fish and benthic communities.
4) The number of species of fish, invertebrates, and algae is based on the mean number of species per transect (species density) rather on estimating the total number of species on the reef (species richness) using a two-parameter model relating the number of species encountered to the number of transects sampled.

Rationale for change # 1: Analyses of the monitoring data collected to date show that reference reefs would not consistently meet all the relative performance standards required of WNR. Thus, requiring WNR to meet all the relative standards each year for that year to count towards meeting the mitigation requirements of Condition C in effect requires WNR to consistently outperform the reference reefs. Requiring WNR to meet only as many relative standards as the lowest performing reference reefs achieves the desired mitigation goal, which is for WNR to perform as well as the natural reefs in the region chosen as suitable measures of comparison.

Rationale for change # 2: The purpose of the relative standards is to ensure that WNR performs at least as well as the natural reference reefs over the operating life of SONGS. Using a running average rather than a mean value for a given year recognizes that short-term fluctuations in the biological attributes of WNR are expected even if it is performing as well as natural reefs in the region. An either/or criteria (i.e., using data from either a single year or a running average) is not appropriate in this case because the desired goal for the relative performance standards is not to achieve a specified value that is linked to estimated losses at San Onofre kelp forest. Instead, the purpose of the relative standards is to evaluate whether the abundances and numbers of species of kelp forest biota at Wheeler North Reef are similar to that of the reference reefs. This goal is best accomplished using a short-term running average that accounts for natural variation. A running average calculated over four years approaches the desired monitoring goal of being able to reliably detect a 20% difference between WNR and the reference reefs while providing the CCC and SCE with a reasonable time frame for evaluating the performance of WNR.

Rationale for change #3: The relative performance standards described in the SONGS permit do not specify the metrics to be used to evaluate whether the fish and benthic communities are similar to those of the reference reefs. The CCC contract scientists chose to evaluate the performance standards with metrics that best met the intent of the SONGS permit (i.e., similarity with the reference reefs) in the fairest manner possible. The number of standards pertaining to the fish community relative to those pertaining to the benthic community was not critical using the previous approach because all standards had to be met. The number of metrics used to evaluate each relative standard, however, was important because the probability of WNR meeting all the relative standards in a given year diminishes with an increasing number of metrics evaluated. Thus, to meet the requirements of Condition C in the fairest manner possible, a concerted effort was made to institute the fewest number of metrics in the previous approach. Limiting the number of metrics is not a constraint in the new approach because it requires WNR to meet only as many standards as the lowest performing reference reef. However, implementing the new approach requires a more equitable balance in the number of performance standards for the fish and benthic communities, because both are equally important in ensuring that WNR complies with Condition C. Consequently, the ratio of performance standards for fish and the benthos in the new approach is 5:5 compared to 6:3 in the previous approach.

	PREVIOUS		**REVISED**
	Benthic Community Standards		***Benthic Community Standards***
1.	Algae + sessile invertebrate cover	1.	Algal cover
2.	Mobile invertebrate density	2.	Algal species richness
3.	Benthic species richness	3.	Sessile invertebrate cover
		4.	Mobile invertebrate density
		5.	Invertebrate species richness
	Fish Standards		***Fish Standards***
1.	Resident fish density	1.	Resident fish density
2.	Resident fish species richness	2.	YOY fish density
3.	YOY fish density	3.	Fish species richness (all ages)
4.	YOY fish species richness	4.	Fish production
5.	Fish production	5.	Fish reproductive rates
6.	Fish reproductive rates		
	Fish + Benthic Community Standard		***Fish + Benthic Community Standard***
1.	Food chain support	1.	Food chain support

Rationale for change #4: The two-parameter model previously used to estimate species richness of an entire reef required WNR to meet both model parameters (i.e., the slope and asymptote), which in effect resulted in two separate performance standards for species number. Species density is a direct and easily measured estimate of the average number of species per unit area that provides a single measure of the number of species in each of the four groups of organisms targeted in the monitoring plan (i.e., algae, invertebrates, resident fish, and young-of-year fish). Thus, the use of species density for assessing reef performance resulted in the abundance of individuals having the same weight as the number of species, which is consistent with the intent of the SONGS permit.

Appendix 5: Chronology of changes to the monitoring plan for SONGS reef mitigation

Changes made in March 2014 revision.

Revisions reflect recent decisions on the methods used to determine the as-built footprint area of the Phase 1 and Phase 2 portions of Wheeler North Reef that were jointly agreed upon by SCE and CCC contract scientists at a meeting in La Jolla on Sept 24, 2013. Other changes include clarification of methods used to estimate fish biomass and fish reproductive rates (including updating Appendix 1).

Changes made in January 2015 revision.

Revisions reflect changes in the multibeam sonar data used to assess the footprint area of SONGS. Bathymetry data have proven to be more reliable than backscatter data in estimating the area of Wheeler North Reef. Consequently, bathymetry data are now used to determine changes in the footprint area of Wheeler North Reef. The exception is in 2008 when only backscatter data were collected.

Changes made in April 2017 revision.

Revisions consisted of changes to the methods used to evaluate the performance standards for Fish Reproductive Rates and Benthic Food Chain Support. Specifically, the methods used to calculate standardized Fecundity and the standardized Food Chain Support Index were slightly changed to ensure that all species and years were weighted equally when assessing performance.

Changes made in April 2021 revision.

Most notable revisions include changes to accommodate: (1) monitoring of the Phase 3 Expansion Reef constructed as remediation for the failure of the Phase 1 and 2 Reefs to consistently support a fish standing stock of 28 tons and 150 acres of medium-to-high density giant kelp, (2) assignment of mitigation credit for kelp area and fish standing stock on a cumulative basis, and (3) the CCC’s decision to define the operating life of SONGS Units 2 and 3 as 32 years for the purpose of mitigating their impacts.

Changes made in October 2022 revision.

The most prominent changes were in the methods used to evaluate the performance standards for: (1) undesirable and invasive species, and (2) benthic food chain support for fishes.

Revisions to the methods for undesirable and invasive species standard included providing a formal definition for the impairment of reef functions and detailed methods for determining whether the impairment of reef functions was caused by undesirable and invasive species. These two elements were lacking in previous versions of the reef monitoring plan. More specifically, these revisions included using secondary production by reef fish and primary production by giant kelp as the “important functions” for evaluating this performance standard, and a two-step approach using the reference reefs for comparison to determine whether these functions are impaired by undesirable and invasive species, which in effect makes this a relative performance standard that must be met in a given year for the Wheeler North Reef to receive mitigation credit for that year.

Revisions to the methods for evaluating the benthic food chain support standard consisted of using the actual data to calculate the proportional effect size of the 4-year running average of the mean standardized FCS Index (= ZFCS) used to evaluate similarity. Previously, the proportional effect size had been calculated using data obtained from resampling a null distribution of the four-year averaged standardized FCS values from which the p-value is calculated. In contrast to the mean FCS Index calculated from the resampled data, the mean FCS Index calculated from the actual data is always positive and fluctuates less erratically among reefs and years. As such, the use of the actual data is more appropriate for evaluating the statistical significance of effect sizes.

Changes made in 2023 revision.

The major change in this revision is the inclusion of the methods and their rationale for annual site inspections, which involves a substantial reduction in monitoring effort that is implemented after the Wheeler North Reef demonstrates three consecutive years of success in meeting the performance standards following ten years of full monitoring. Portions of the document were rearranged to include this information and a new appendix (Appendix 1) was added with details of the sampling design for annual site inspections, results of analyses that informed this design, and justification for the methods used to assess similarity among reefs using annual site inspections.