

# **MONITORING PLAN FOR THE SONGS REEF MITIGATION PROJECT**

Prepared for the staff of the California Coastal Commission by:

Daniel Reed

Kathryn Beheshti

David Huang

Mark Page

Stephen Schroeter

Rachel Smith

and

Mark Steele

In consultation with

Richard Ambrose, Peter Raimondi, and Russell Schmitt

Updated October 2022

## MONITORING PLAN FOR THE SONGS'S REEF MITIGATION PROJECT

EXECUTIVE SUMMARY.....	2
1.0 Introduction .....	3
2.0 Evaluation of condition compliance .....	5
2.1 Performance standards .....	6
2.2 Assigning mitigation credit .....	7
2.3 Reference reefs .....	9
2.4 Determination of similarity .....	9
2.5 Monitoring period.....	12
3.0 Sampling methods and data collection.....	13
3.1 General sampling design .....	13
3.2 Methods for assessing the performance standards .....	14
4.0 Data Management .....	24
4.1 Daily field and data transfer procedures .....	24
4.2 Data entry and quality assurance .....	24
4.3 Data storage and preservation .....	26
5.0 Dissemination of results .....	26
5.0 References.....	28
Tables.....	30
Figures.....	31
Appendix 1. Methods for estimating fish reproductive rates .....	37
Appendix 2. Methods for estimating fish production .....	39
Appendix 3. Methods for determining similarity in fish food-chain support.....	41
Appendix 4. Chronology of changes to the monitoring plan for SONGS' Reef mitigation.....	43

---

## **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 4 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<sup>1</sup>. 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

---

<sup>1</sup> 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 performance standards for Wheeler North Reef as stated in the SONGS permit, (2) an explanation of how mitigation credit is assigned for the different types of performance standards, (3) a summary of the process used to select the reference reefs used as a measure of comparison in assessing the relative performance standards, (4) a description of methods used to determine whether Wheeler North Reef and the reference reefs are similar, and (5) a schedule for the monitoring period.

## **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. Performance standards for (1) Substrate, (2) Kelp bed, and (3a) Fish standing stock are absolute standards; the remaining performance standards pertaining to Fish (3b-e) and Benthos (4a-c) are relative standards.

### 1. Substrate

- a. The mitigation reef shall be constructed of rock, concrete, or a combination of these materials.
- b. The total area of the mitigation reef (including the experimental reef modules) shall be no less than 150 acres.
- c. At least 42% but no more than 86% of the mitigation reef area shall be covered by exposed hard substrate
- d. At least 90 percent of the exposed hard substrate must remain available for attachment by reef biota.

### 2. Kelp bed

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 m<sup>2</sup> of sea floor.

### 3. Fish

- a. The standing stock of fish at the mitigation reef shall be at least 28 tons.
- b. The resident fish assemblage shall have a total density and number of species similar to natural reefs within the region.

- c. Fish reproductive rates shall be similar to natural reefs within the region.
- d. The total density and number of species of young-of-year fish (fish < 1-year old) shall be similar to natural reefs within the region.
- e. Fish production shall be similar to natural reefs within the region.

#### 4. Benthos

- a. The benthic community (both algae and macroinvertebrates) shall have coverage or density and number of species similar to natural reefs within the region.
- b. The benthic community shall provide food-chain support for fish similar to natural reefs within the region.
- c. The important functions of the mitigation reef shall not be impaired by undesirable or invasive benthic species (e.g., sea urchins or *Cryptoarachnidium*).

### **2.2 Assigning mitigation credit**

Mitigation credit is assigned on an annual basis and the manner in which credit is assigned varies with the different types of performance standards.

The requirement that at least 90 percent of the exposed hard substrate of the artificial reef remain available for the attachment by reef biota is by definition an absolute performance standard because it 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.

Fish standing stock and area of giant kelp are also absolute performance standards (i.e., measured only at Wheeler North Reef). The performance criteria for meeting these two standards are based on estimated annual losses in the San Onofre kelp forest caused by SONGS operations. In contrast to hard substrate, the performance criteria for fish standing stock (i.e., 28 US tons) and giant kelp

area (150 acres) do not need to be met every year for Wheeler North Reef to receive mitigation credit. Instead, mitigation 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 for annualized losses. For example, the accrued loss of fish standing stock due to SONGS operations is 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 remaining 12 performance standards are relative standards that are evaluated by comparing the value of the performance variable 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 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.

### ***2.3 Reference Reefs***

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.

### ***2.4 Determination of similarity***

A requirement of the SONGS permit is that as many of the response variables used to assess the relative performance standards of 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 mean (or the median in the case of fish reproductive rates) for a given relative performance variable at Wheeler North Reef not be significantly lower than the mean (or median) at 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 by means of a t-test except in the case of the performance standards pertaining to fish reproductive rates and food chain support for fish. For these two standards a resampling procedure is used to calculate the p-value for determining statistical significance.

The level of certainty in determining whether Wheeler North Reef meets the 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 is calculated as the proportional difference between the mean values for Wheeler North Reef and that of the lowest performing reference reef) with 80% power (i.e., the statistical power is calculated as 1- Type II error), using a Type I error ( $\alpha$ ) = 0.2. Once data are collected and an effect size for a given relative performance standard is determined, a critical  $\alpha$  needs to be assigned to evaluate whether the performance standard has been met 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 (Type I error =  $\alpha$ ) with the risk associated with falsely concluding that the standard was met (Type II error =  $\beta$ ).

The approach used to assign a value to  $\alpha$  involves linking it to the effect size because the importance of correctly determining whether Wheeler North Reef failed to meet a relative performance standard increases with the magnitude of the difference between Wheeler North Reef and the lowest performing reference reef (i.e., the effect size). If the effect size is small, then it is necessary to apply a correspondingly small value of  $\alpha$  to be certain that the difference between Wheeler North Reef and the reference reefs is real. Assigning a critical value of  $\alpha$  that is too large in this case runs the risk of falsely concluding that Wheeler North Reef met the performance standard when it did not (Type I error). By contrast, if the effect size for a relative performance standard is large, then assigning a critical value of  $\alpha$  that is too small runs the risk of falsely concluding that Wheeler North Reef did not meet the performance standard when it did (Type II error). Thus, linking the critical value of  $\alpha$  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 when assessing whether Wheeler North Reef meets a given relative performance standard (refer to Figure 2):

- 1) If  $\alpha \leq$  effect size for any  $\alpha$  ranging from 0.000 to 0.500, then Wheeler North Reef will be considered not to have met that performance standard (i.e., it is different from the reference sites) for the period of assessment ( $\alpha$  and effect size rounded to three significant figures).
- 2) If  $\alpha >$  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 ( $\alpha$  and effect size rounded to three significant figures).
- 3) If the effect size is  $> 0.500$  and  $\alpha$  is  $> 0.500$ , then assessment for the period will be considered inconclusive ( $\alpha$  and effect size rounded to three significant figures) 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 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 revision of the sampling design.
  - b. If needed, the revised sampling design will be implemented the following year.
  - c. If in the following year the standard is met, then the standard will be considered to have been met the previous year as well. If in the following year the 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 the standard is no longer inconclusive, unless the Commission changes the standard set forth in SONGS permit Condition C.
- 4) Monitoring data will be evaluated annually to determine if changes need to be made to the sampling program to bring it closer to the design objective of detecting a 20% deviation from the performance standards (i.e., the effect size) with an 80% probability (i.e., the statistical power) using a Type I error ( $\alpha$ ) = 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 mean value at Wheeler North Reef was 75% of the mean value at the lower of the two reference reefs), then a t-test yielding a p-value  $\leq 0.25$  would indicate Wheeler North Reef did not meet the performance standard, whereas p-values  $> 0.25$  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 p-value ( $\alpha$ ) to the effect size recognizes sampling error when estimating mean values and balances the probability of a Type I error (falsely concluding that Wheeler North Reef is not similar to the reference reefs when it is) with the probability of a Type II error (falsely concluding that 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 11 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, which must be met in a given year for the Wheeler North Reef to receive mitigation credit for that year as per section 2.2).

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 performance standard. Importantly, this approach deals realistically with the inherent variability of nature.

### ***2.5 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 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 defined the full operating life of SONGS to be the 32-year period spanning 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 of the performance of Wheeler North Reef will continue until: (1) Wheeler North Reef earns 32 years of mitigation credit for meeting the absolute

performance standard for hard substrate and the relative performance standards, and (2) Wheeler North Reef accrues mitigation credit for 896 tons of reef fish and 4800 acres of giant kelp. The level of sampling effort 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.

## **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 the following features: (1) spatially distributed sampling to increase accuracy in the characterization of each reef, (2) a method for adaptively altering sampling effort based on the analysis of data collected during previous years, and (3) a strategy for dealing with the potential loss of sampling units at the reference reefs caused by unforeseen events.

#### *3.1.1 Spatial distribution of sampling effort*

151 sampling locations, each defined by a fixed 50 m x 20 m area (hereafter referred to as transects), were established at Wheeler North Reef; 12 transects are in Phase 1, 70 in the primary polygons of Phase 2, 10 in the contingency polygons of Phase 2, and 59 in Phase 3 (Figure 3a). An additional 82 transects were established at both San Mateo and Barn in areas known to support persistent 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 measuring tape. A 20 m wide swath centered along the 50 m measuring tape defines the sample area. Different sized sampling units (e.g., 0.5 m<sup>2</sup>, 1 m<sup>2</sup>, 20 m<sup>2</sup>, and 150 m<sup>2</sup>) within this sampling area are used to evaluate different performance variables (Figure 3). Each year the three reefs are sampled concurrently.

The transects on each reef are arranged in pairs with the two transects in each pair spaced 25 m apart (Figures 3a -c). The exceptions to this rule are the single transects located on the Phase 1 and Phase 3 Reefs. Pairing of transects is done to increase sampling efficiency. Maps of kelp persistence and hard substrate were used to strategically distribute the 41 transect pairs at San Mateo and Barn across areas of reef known to support giant kelp. Transects at Wheeler North Reef were allocated to the polygons and the existing experimental reef modules in proportion to their area.

### *3.1.2 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.

### **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.

*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<sup>2</sup> 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<sup>2</sup> 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  $\geq 0.9$  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  $\geq 42\%$  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 ( $A_0$ ) 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<sup>2</sup> of ocean bottom. Adult giant kelp are 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<sup>2</sup> at each transect. The proportion of transects with a density > 4 adult kelp per 100 m<sup>2</sup> 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:

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

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<sup>2</sup>, 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<sup>2</sup> 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<sup>2</sup>. 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<sup>2</sup> 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 1). 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 1). 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 (based on the current year and the previous three years) must not be significantly lower than that of the reference reef with the lower four-year running average Fecundity Index as per the methods described in Section 2.4.

*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 2.

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. 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<sup>2</sup> 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<sup>2</sup> area are counted in a 0.5 m<sup>2</sup> area created by dividing the 1 m<sup>2</sup> 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 components of the benthic community are evaluated separately to determine whether this performance standard is met: (1) the percent cover of algae, (2) the number of species of algae, (3) the percent cover of sessile invertebrates, (4) the density of mobile invertebrates, and (5) the combined number of species of sessile and mobile invertebrates. The four-year running averages of each of these five components of the benthic community at 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 this performance standard for any given year.

*13. 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.

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

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).

$$\text{Proportional effect size} = (FCS_{RR} - FCS_{WN}) / FCS_{RR}$$

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 3 for details)

*14. 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 green seaweeds *Caulerpa taxifolia* and *C. prolifera*, which escaped from the aquarium trade to invade many marine habitats worldwide including some in southern California, or 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 two-step approach. First, 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 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 is found to be dissimilar (i.e., <) to the reference reefs, then this finding triggers a second 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 Daily Field and Data Transfer 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.

## 6.0 REFERENCES

- Bence, J.R., S.C. Schroeter, and R.O. Smith, 1989. Technical Report to the California Coastal Commission. F. Kelp Forest Invertebrates. Marine Review Committee.  
[https://marinemitigation.msi.ucsb.edu/documents/MRC\\_reports/final\\_tech\\_report/mrc2ccc.F\\_kelp-forest-invertebrates.pdf](https://marinemitigation.msi.ucsb.edu/documents/MRC_reports/final_tech_report/mrc2ccc.F_kelp-forest-invertebrates.pdf).
- Coastal Environments. 2008. Final construction report for Wheeler North Reef at San Clemente, California. Prepared for Southern California Edison and submitted to the California Coastal Commission. 4 November 2008.  
[https://marinemitigation.msi.ucsb.edu/documents/artificial\\_reef/sce\\_reports/vol2-data\\_wnr\\_%20final\\_constr\\_final\\_rpt\\_110408.pdf](https://marinemitigation.msi.ucsb.edu/documents/artificial_reef/sce_reports/vol2-data_wnr_%20final_constr_final_rpt_110408.pdf).
- Coastal Environments. 2020. Final construction report for Wheeler North Reef at San Clemente, California (SONGS artificial reef mitigation project Phase 3 expansion). Prepared for Southern California Edison and submitted to the California Coastal Commission. 30 November 2020.
- DeMartini, E. E; A. M. Barnett, T. D. Johnson, R. F. Ambrose. 1994. Growth and production estimates for biomass-dominant fishes on a Southern California artificial reef. *Bull. Mar. Sci.* 55:484-500.
- Elwany, H. S. T. Norall, Fugro Pelagos, Inc. 2009. Multibeam survey of Wheeler North Reef, San Clemente California (September 2009). CE Reference No. 09-23.  
[http://marinemitigation.msi.ucsb.edu/documents/artificial\\_reef/sce\\_reports/multibeam\\_survey\\_wheeler\\_north\\_reef-sep2009.pdf](http://marinemitigation.msi.ucsb.edu/documents/artificial_reef/sce_reports/multibeam_survey_wheeler_north_reef-sep2009.pdf).
- Gnose, C. E. 1967. Ecology of the striped sea perch, *Embiotica lateralis*, in Yaquina Bay, Oregon. M.S. Thesis, Oregon State University. 53 pp.
- Graham, M. H., J. A. Vasquez, and A. H. Buschmann. 2007. Global ecology of the giant kelp *Macrocystis*: from ecotypes to ecosystems. *Oceanography and Marine Biology, An Annual Review*, 45:39-88.
- Kuhn, G.G. and F. P. Shepard, 1984. *Sea Cliffs, Beaches, and Coastal Valleys of San Diego County. Some Amazing Histories and Some Horrifying Implications.* University of California Press, Berkeley. 193 pp.
- Love, M. S. 2011. *Certainly more than you want to know about the fishes of the Pacific Coast.* Really Big Press. Santa Barbara. 649 pp.
- Mahan, W. T. 1985. Initial growth rate and life expectancy of the bay pipefish *Syngnathus leptorhynchus* from Humbolt Bay, California. Humbolt State University, Report No. TML-11.
- Quast, J. C. 1968a. Estimates of the population and the standing crop of fishes. California Department of Fish and Game, Fish Bull. 139:57-79.
- Quast, J. C. 1968b. Fish fauna of the rocky inshore zone. California Department of Fish and Game, Fish Bull. 139:35-55.
- Page, H. M., J. E. Dugan, D. M. Schroeder, M. M. Nishimoto, M. S. Love, and J. C. Hoesterery. 2008. Trophic links and condition of a temperate reef fish: comparisons among offshore oil platform and natural reef habitats. *Marine Ecology Progress Series* 344:245-256.

- Rassweiler, A., Reed, D.C., Harrer, S.L. and Nelson, J.C., 2018. Improved estimates of net primary production, growth and standing crop of *Macrocystis pyrifera* in Southern California. *Ecology* 99: 2132-2132.
- Reed, D. C., S.C. Schroeter, and D. Huang. 2005. Final report on the findings and recommendations of the experimental phase of the SONGS artificial reef mitigation project. Report to the California Coastal Commission. 136 pp. <http://www.coastal.ca.gov/energy/songs/songs-report-8-1-2005.pdf>..
- Reed, D. S. Schroeter and M. Page. 2015. Report on the causes of low fish standing stock at Wheeler North Reef and possible solutions for remediation. Marine Science Institute, University of California Santa Barbara [https://marinemitigation.msi.ucsb.edu/documents/artificial\\_reef/ucsb\\_%20mm\\_reports/remediation\\_phase/requirements\\_report4remediation\\_wheeler\\_north%20reef\\_022515.pdf](https://marinemitigation.msi.ucsb.edu/documents/artificial_reef/ucsb_%20mm_reports/remediation_phase/requirements_report4remediation_wheeler_north%20reef_022515.pdf).
- Stepien, C. A. 1986. Regulation of color morphic patterns in the giant kelpfish, *Heterostichus rostratus* Girard: genetic versus environmental factors. *J. Exp. Mar. Biol. and Ecol.* 100:181-208.
- Wildermuth, D. A. 1983. Length-weight regression analysis for thirty-eight species of sport caught marine fishes. Progress report (Washington State Department of Fisheries) 198. 7 pp.

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	<i>Paralabrax clathratus</i>	egg layer (broadcast)	Midwater and benthic fish and invertebrates
señorita	<i>Oxyjulis californica</i>	egg layer (broadcast)	Zooplankton & small benthic invertebrates
sheephead	<i>Semicossyphus pulcher</i>	egg layer (broadcast)	Hard-shelled benthic invertebrates
blacksmith	<i>Chromis punctipinnis</i>	egg layer (demersal)	Zooplankton
black surfperch*	<i>Embiotica jacksoni</i>	live bearer	Small benthic invertebrates

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  $\alpha$ , and how it is used to determine whether Wheeler North Reef meets a given relative performance standard.

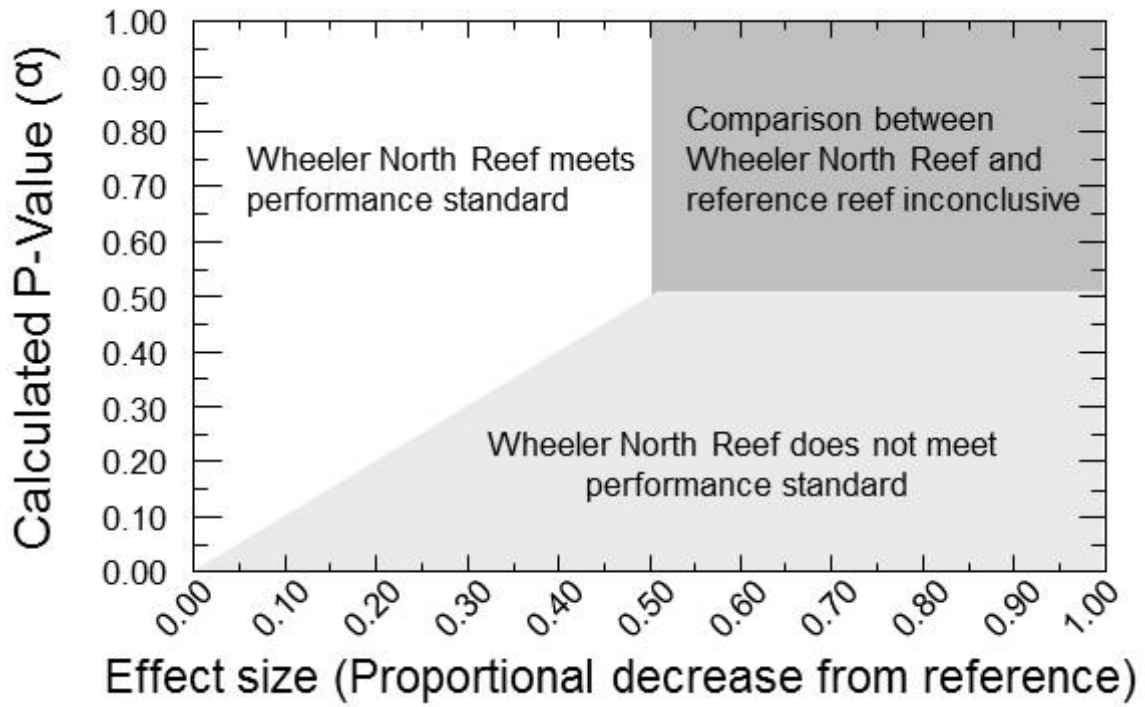


Figure 3a. Map of Wheeler North Reef showing the location of the 151 fixed transects where monitoring of the performance standards is done. Transects are shown as black lines (n = 12 Phase 1, n = 80 Phase 2, and n = 59 Phase 3).



Figure 3b. Map of the reef at San Mateo showing the location of the 82 fixed transects where monitoring of 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 of 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.

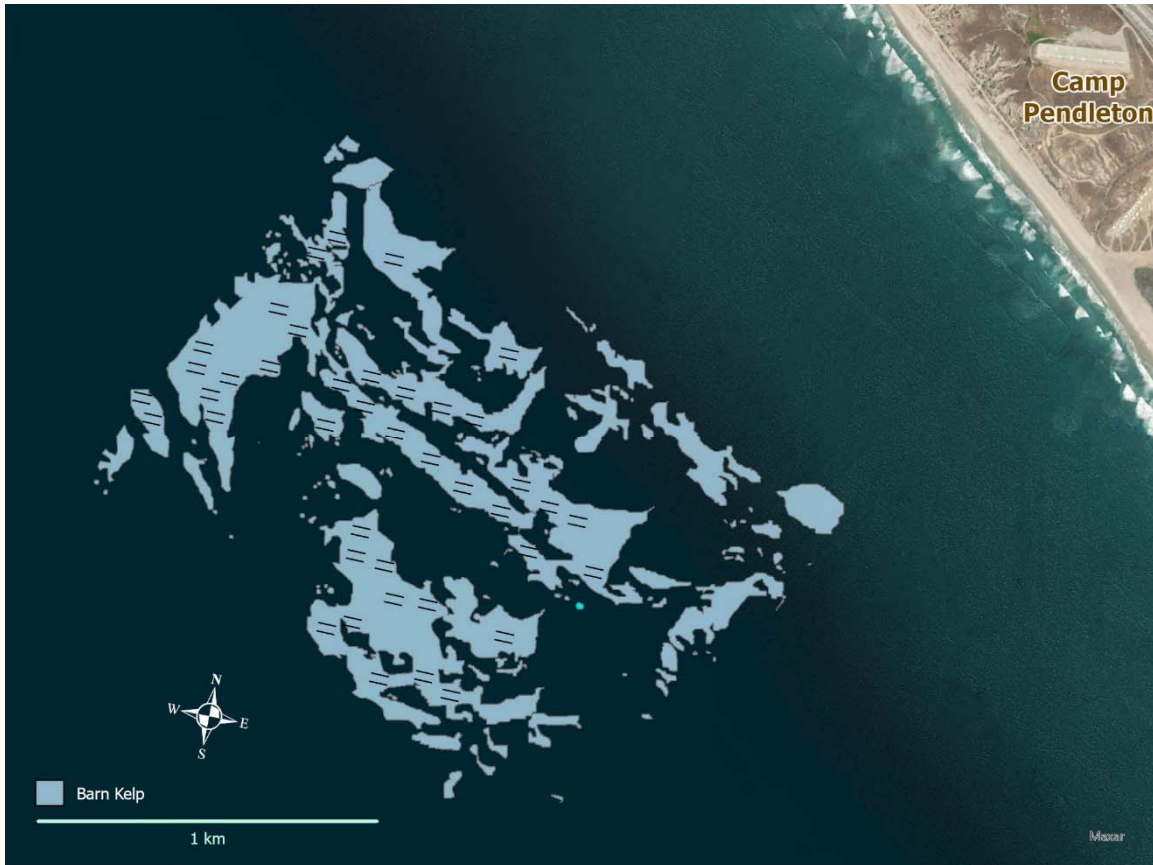
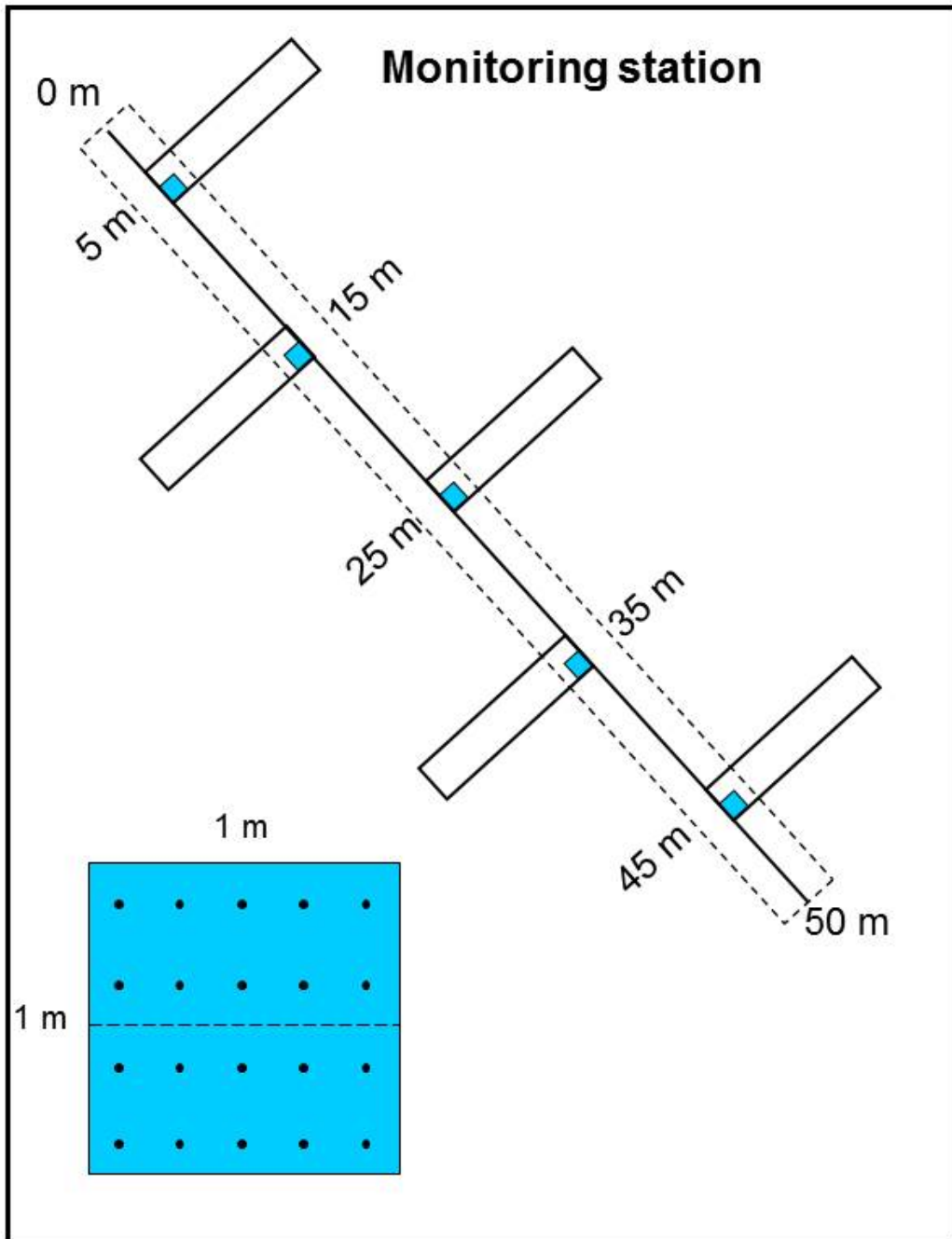


Figure 4. Schematic showing the different sized sampling areas that are used at each of the fixed monitoring stations; including a large 50 m x 3 m swath (delineated by dashed lines); five 10 m x 2 m quadrats perpendicular to the main transect and evenly spaced along it; five evenly spaced 1 m x 1 m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





## APPENDIX 1

### METHODS FOR ESTIMATING FISH REPRODUCTIVE RATES

#### ***General Methods***

Individuals of four targeted species (blacksmith, *Chromis punctipinnis*; sheephead, *Semicossyphus pulcher*; seniorita, *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.

#### **Fecundity Index for Egg-laying fish**

## Appendix 1: Methods for estimating fish reproductive rates

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:

$$P_k = \binom{N}{k} p^k q^{1-k}$$

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.

## Appendix 1: Methods for estimating fish reproductive rates

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 2

### METHODS FOR ESTIMATING FISH PRODUCTION

This document describes the approach used to estimate annual production of fish tissue using data on length, density, somatic growth rates, and production of reproductive tissues for a select group of target species. 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  $P_{Rt}$  is production of gonadal tissue over some time period  $t$ .

$P_{St}$  is estimated as:

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

where  $\bar{N}_{it}$  = 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:

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

where  $\bar{N}_{F,it}$  = 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:

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

where  $\bar{N}_{M,it}$  = 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,

## Appendix 2: Methods for estimating fish production

which is not readily measured, is estimated based on the ratio of testes to ovary size.

### 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 3

### METHODS FOR DETERMINING SIMILARITY IN FISH FOOD-CHAIN SUPPORT

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 1, 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,  $\mu$  = the mean FCS Index for sheephead averaged over all years and reefs, and  $\sigma$  = the standard deviation of the FCS Index for sheephead averaged over all years and reefs.

### Appendix 3: Methods for determining similarity in fish food chain support

2. For each year, reef, and species create 1000 means based on iterations of ZSCF 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:

$$P = (1000 - \text{nearest corresponding case number}) / 1000$$

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 4

### 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

## Appendix 4: Chronology of changes to monitoring plan

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

## Appendix 4: Chronology of changes to monitoring plan

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 (see Table 1).

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.

Table 1. Previous and revised relative standards for evaluating the performance of Wheeler North Reef

	PREVIOUS		REVISED
	<b><i>Benthic Community Standards</i></b>		<b><i>Benthic Community Standards</i></b>
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
	<b><i>Fish Standards</i></b>		<b><i>Fish Standards</i></b>
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

#### Appendix 4: Chronology of changes to monitoring plan

6.	Fish reproductive rates		
	<b><i>Fish + Benthic Community Standard</i></b>		<b><i>Fish + Benthic Community Standard</i></b>
1.	Food chain support	1.	Food chain support

#### ***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.***

## Appendix 4: Chronology of changes to monitoring plan

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.