Performance of the Wheeler North Reef
2011 Monitoring Results

SONGS Mitigation Monitoring Project
Marine Science Institute, University of California Santa Barbara

This presentation focuses on:

1. The results of the first three years of compliance monitoring of the Wheeler North Reef, and

2. Our evaluation of whether the Wheeler North Reef met the performance standards required for successful mitigation.

Performance Standards

Physical performance standards

Pertain to the amount and area of hard substrate that must remain available to reef biota.

Biological performance standards

Pertain to the abundance, diversity and ecological function of giant kelp, understory algae, invertebrates, and fish.

- Physical and biological performance standards were established by the CCC which are used to evaluate the success of the Wheeler North Reef in compensating for the kelp bed resources lost due to SONGS operations.

Types of Performance Standards

1. Fixed standards: Measured against an absolute value

(e.g., 150 acres of giant kelp, 28 tons of fish biomass)

2. Relative standards: Must be similar to natural reefs

(e.g., the abundance and number of species of algae and macroinvertebrates must be similar to that of natural reefs)

Two types of physical and biological standards are used to judge the performance of the Wheeler North Reef.

1) Fixed standards are measured against an absolute value,

2) Relative standards are measured against natural reefs used as a reference.

Relative standards require comparison to natural reference reefs

RATIONALE: **To be successful the Wheeler North Reef must sustain a kelp forest community that is *similar* to those of natural reefs in the region.**

Criteria for reference reef selection:
1) **history of sustaining giant kelp.**
2) **occur at a depth similar to that of the artificial reef.**
3) **primarily low relief, preferably consisting of cobbles and boulders.**
4) **located within the local region.**

The kelp forests at San Mateo and Barn best met these criteria

•Choosing the natural reefs that are used as reference is a critical element because they are used in evaluating the success of the Wheeler North Reef.

Definition of *similar*:
Related in appearance or nature; alike though not identical

What counts as similar in the context of assessing the performance of the Wheeler North Reef?

Definition: **The mean value for a performance variable at Wheeler North Reef must be *equal to or greater than* the lower 80% confidence limit of the reference reef having the lowest value for that performance variable.**

Rationale: **The Wheeler North Reef should perform at least as well as the lowest performing natural reef used as a reference.**

• "Similar" as defined in the dictionary means related in appearance, or alike though not identical.

• The SONGS Coastal Development Permit envisioned a more quantitative definition of "similar" for evaluating the performance of the reef and wetland mitigation projects relative to reference sites, and it specified that the measure of similarity be defined in the monitoring plans for these projects.

• After considerable discussion the definition for the measure of similarity that was chosen is that the mean value for a performance variable at Wheeler North Reef must be > the lower 80% confidence limit of the reference reef having the lowest value for that performance variable.

• This definition recognizes that no two natural reefs are identical, but that any reef chosen as a reference site should serve as an acceptable standard. Because there is a certain amount of error associated with any type of sampling (especially when diving in less than favorable conditions) we determined that we needed to be at least 80% confident that the Wheeler North Reef performed as well as the lowest performing reference site.

Performance Standards for Wheeler North Reef

1. Hard substrate
2. Giant kelp
3. Benthic community (% cover)
4. Benthic community (density)
5. Benthic community (species number)
6. Resident fish (density)
7. Resident fish (species number)
8. Young-of-Year fish (density)
9. Young-of-Year fish (species number)
10. Fish standing stock
11. Fish reproductive rates
12. Fish production
13. Food chain support
14. Invasive species

Ron McPeak

Fixed standards = green; Relative standards = blue

• Shown here are the 14 performance standards by which the success of the Wheeler North Reef is being judged.

• Fixed standards are shown in green and relative standards are shown in blue.

• What follows is a summary of the monitoring results as they pertain to each of these standards.

Performance Standard: Hard Substrate

At least 90 percent of the exposed hard substrate must remain available for attachment by reef biota

Phase 1 Reef, March 2000

•The performance standard for hard substrate is a fixed standard that requires at least 90% of the exposed rock initially present at Wheeler North Reef to remain available for the attachment by reef biota.

Evaluating the Performance of Hard Substrate

1. Measure footprint area (A) of Wheeler North Reef
2. Measure percent cover of exposed rock (P)
3. Calculate area of exposed rock as A x P
4. Compare area of exposed rock to that measured immediately after reef construction to determine whether 90% or more is still available for reef biota


Phase 1 Reef, August 2003

9 Substrate categories:

Bedrock
Large boulder ($\geq$ 100 cm)
Medium boulder ($\geq$ 50cm & <100cm)
Small boulder ($\geq$ 26cm and <50cm)
Cobble ($\geq$ 7cm and $\leq$ 25cm)
Pebble ($\geq$ 2mm and < 7cm)
Sand (< 2mm)
Shell hash
Mudstone

The performance standard for hard substrate is evaluated in the following way:

•Measuring the footprint area (A) of Wheeler North Reef using multi-beam sonar.

•Estimating the percent cover of exposed rock (P) in the same 1 m^2 quadrats used to verify the construction of Wheeler North Reef.

•The product A x P is the estimate of the area of exposed hard substrate.

•We compare this estimate to that obtained immediately following construction of Wheeler North Reef.

•The SONGS coastal development permit requires that this amount not fall below 90% of what was available immediately after the reef was constructed.

•Divers collect percent cover data for nine different types of bottom substrate.

•The categories of bottom substrates outlined in the green box are those that counted as hard substrate in our analyses.

Exposed Hard substrate

Reef footprint area

Percent of the bottom covered by rock
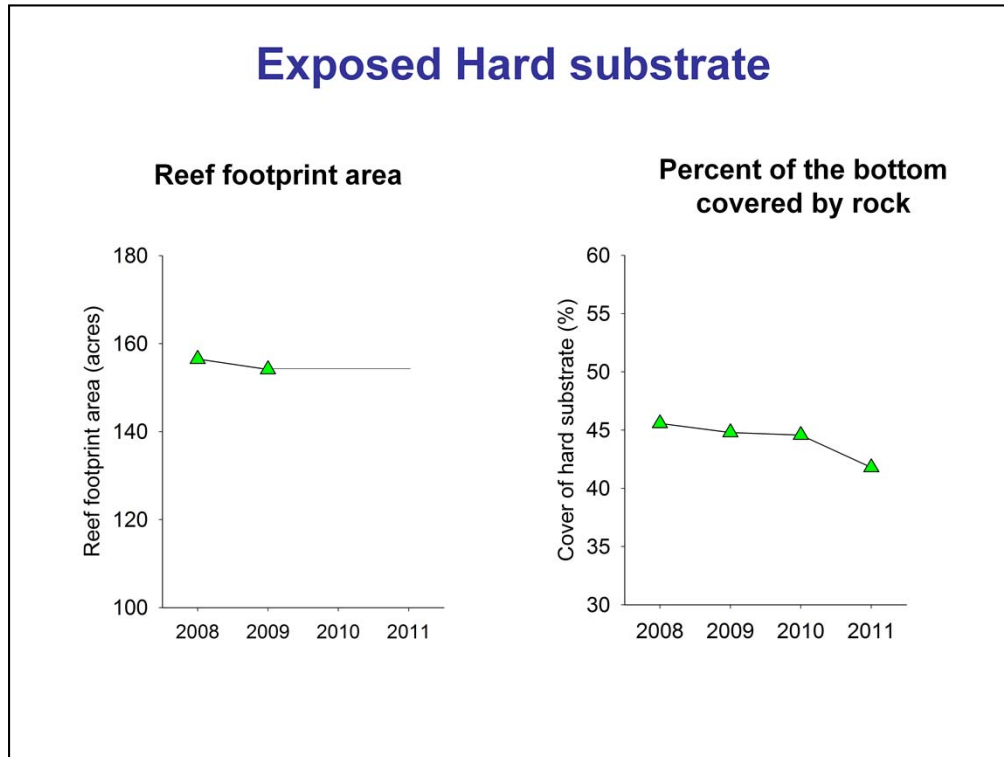
•This slide shows the two variables required to estimate the amount of exposed hard substrate on the Wheeler North Reef.

•Both of these variables apply only to the 154 acre subset of the Wheeler North Reef, which was the portion of the reef used to meet the 150 acre standard of > 42% cover of rock.

•There was a slight decrease in the footprint area in the year following construction (2009), which is not unexpected as rocks settle into the soft sandy bottom.

•Because the footprint area of the reef is not expected to change much from year-to-year multi-beam sonar surveys are only done once every five years.

•The last sonar survey was done in 2009. Thus the value for reef footprint area is assumed to be the same in 2010 and 2011 as it was in 2009,

•Unlike footprint area, the percent of the bottom covered by rock is measured every year by divers.

•There was a slight decrease in the percent cover of rock from 2008 to 2010, and a slightly larger decrease in 2011.

Performance Standard: Hard Substrate

At least 90 percent of the exposed hard substrate must remain available for attachment by reef biota
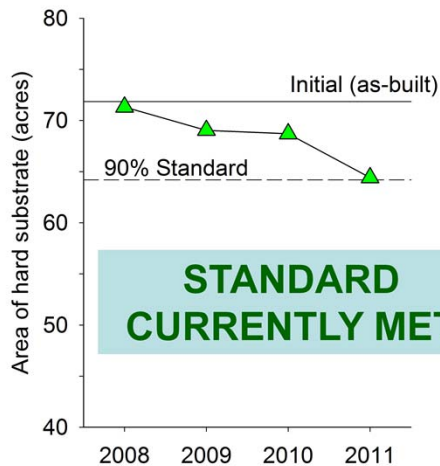
- The small declines in footprint area and % cover of hard substrate that have occurred since the Wheeler North Reef was built have resulted in nearly a 10% decrease in the total area of hard substrate on Wheeler North Reef.

- This change is almost at the 90% value of the performance standard and will need to be monitored closely in future years.

- Thus the Wheeler North Reef has met the standard for hard substrate in 2009, 2010 and 2011.

Performance Standard: Giant Kelp

The artificial reef(s) shall sustain 150 acres of medium-to-high density giant kelp

• Medium-to-high density giant kelp is defined as at least 4 adult plants 100 m^{-2}
• Adult plants are defined as individuals having at least 8 fronds

•The performance standard for giant kelp is a fixed standard that requires the Wheeler North Reef to sustain 150 acres of medium-to-high density giant kelp.

•Medium-to-high density giant kelp is defined as at least 4 adult plants per 100 m^2.

•Adult plants are defined as individual plants with at least 8 fronds.

•These definitions for kelp are the same ones that were used to quantify the impacts to giant kelp caused by SONGS

Evaluating the Performance of Giant Kelp

Measure the density of adult giant kelp in fixed 100 m² transects on Wheeler North Reef

Determine whether:

P x 176 acres ≥ 150 acres

where:
**P = the proportion of transects with at least 4 adult plants**
and
176 = Footprint area of Wheeler North Reef in acres

• The performance standard for giant kelp is evaluated by measuring the density of giant kelp in the fixed transects across the entire Wheeler North Reef.

• Using these data we calculate the proportion of transects on the Wheeler North Reef that have adult kelp densities greater than or equal to 4 plants per 100 m².

• This proportion is multiplied by 176 acres (= the total footprint area of Wheeler North Reef measured in the most recent sonar survey) to obtain the total acreage of adult kelp on the Wheeler North Reef.
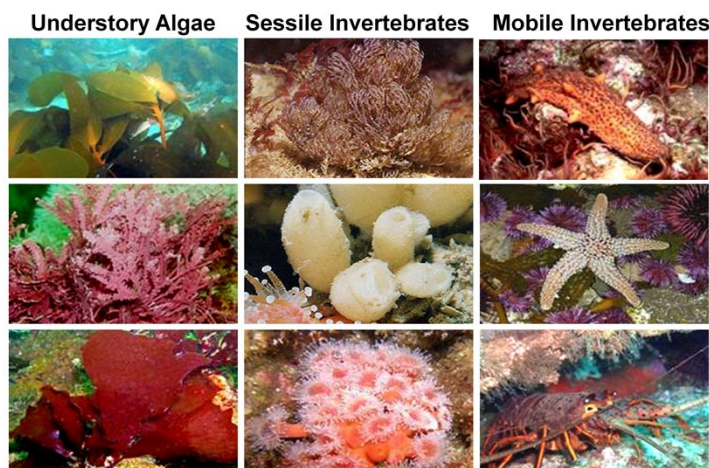
Performance Standard: Giant Kelp

The artificial reef(s) shall sustain 150 acres of medium-to-high density giant kelp

STANDARD CURRENTLY MET
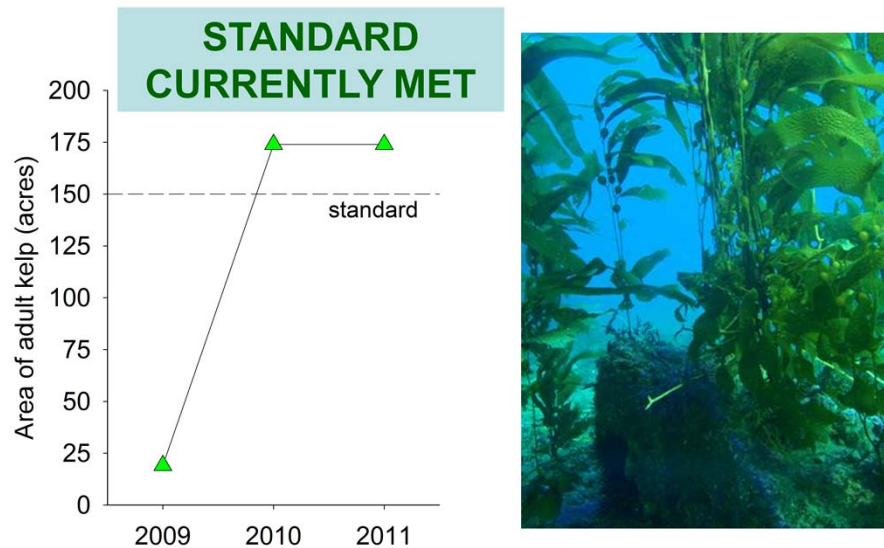
- The area of medium-to-high density adult kelp on Wheeler North Reef increased dramatically from 19 acres in 2009 to 174 acres in 2010.

- This represented the growth of the young kelp that colonized in 2009.

- 91 of the 92 transects sampled had at least 4 adult plants 100 per m^2 in 2010 and 2011.

- Thus the Wheeler North Reef met the performance standard for giant kelp in both 2010 and 2011.

Performance Standard: Benthic Community

The benthic community (algae & macroinvertebrates) shall have coverage or density and number of species similar to natural reefs within the region

Understory Algae   Sessile Invertebrates   Mobile Invertebrates

•The performance standard for the benthic community is a relative standard that requires the abundance and number of species of algae and invertebrates on the Wheeler North Reef to be similar to that on reference reefs in the region.
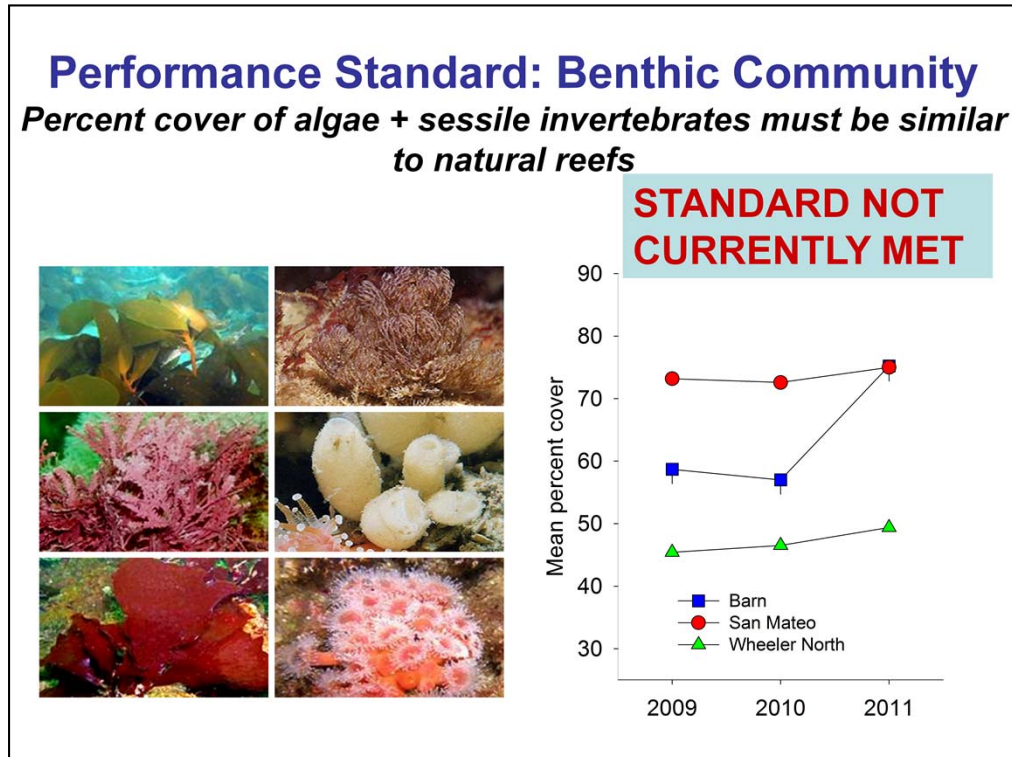
Evaluating the Benthic Community

Three components of the Benthic Community standard are evaluated separately

1. Percent cover of understory algae + sessile invertebrates
2. Density of mobile invertebrates
3. Number of species of all algae and invertebrates combined

Phase 1 Reef, August 2000

Because it is not possible to evaluate the benthic community standard using a single metric we consider 3 separate components of the benthic community when evaluating this standard.

1. The combined percent cover of understory algae and sessile invertebrates is used to estimate the abundance of sessile organisms.

2. Density is used to estimate the abundance of mobile invertebrates.

3. The number of all species of algae and invertebrates combined is used to evaluate species richness of the benthic community.

Performance Standard: Benthic Community
Percent cover of algae + sessile invertebrates must be similar to natural reefs

STANDARD NOT CURRENTLY MET

•This graph shows the combined percent cover of understory algae and benthic invertebrates at Wheeler North Reef, Barn and San Mateo.

•The colored symbols in this graph represent the mean value of each reef, and the vertical lines through the symbol of reference reef with the lowest mean value, which in this case is Barn, represents the lower 80% confidence interval.

•This same format will be used for all the graphs in this presentation that pertain to the relative performance standards.

•As described in the previous presentation, the increase in the percent cover of sessile invertebrates at Wheeler North Reef was countered by a corresponding decrease in the percent cover of understory algae.

•This has resulted in only a very modest increase in the combined cover of algae + invertebrates on Wheeler North Reef since 2009, with the resultant cover continuing to be noticeably lower than that at both reference reefs.

•Consequently, the Wheeler North Reef has yet to meet this performance standard.

Performance Standard: Benthic Community
Density of mobile invertebrates must be similar to natural reefs

STANDARD CURRENTLY MET

Mobile Invertebrates

- Barn
- San Mateo
- Wheeler North
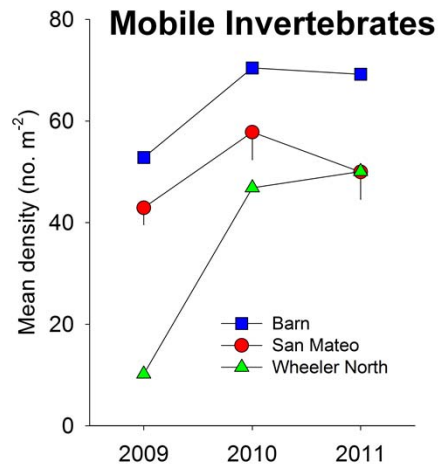
•Plotted in this graph is the mean density of mobile invertebrates at Wheeler North Reef, San Mateo and Barn.

•Mobile invertebrate density increased at all three reefs between 2009 and 2010, but more dramatically so at the Wheeler North Reef.

•The mean density of mobile invertebrates increased slightly in 2011 at Wheeler North Reef, while decreasing at San Mateo, such that densities at these two reefs were nearly identical in 2011.

•Consequently, the Wheeler North Reef met the performance standard for the density of mobile invertebrates in 2011 but not in 2009 or 2010.

Performance Standard: Benthic Community
Number of species of algae + invertebrates must be similar to natural reefs

Determining the number of species
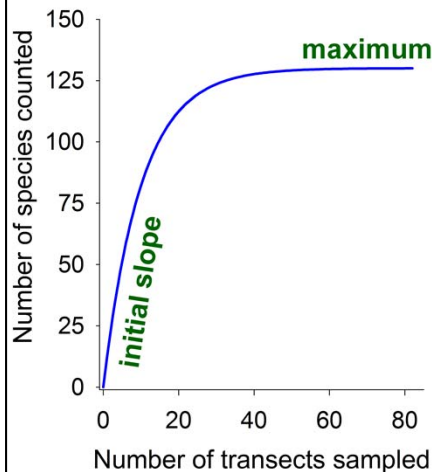
• The number of species counted on a reef is related to the amount of area that is sampled.

• The relationship between the number of species counted and the area sampled is typically curve-shaped as the number of new species counted initially increases very rapidly, then slows to the point where no new species are counted even as the number of transects sampled increases
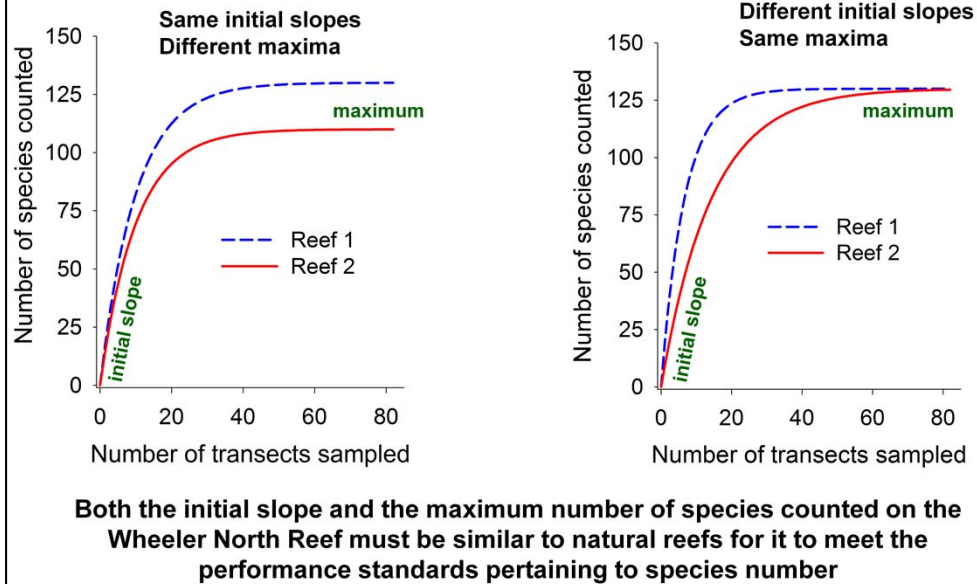
• This relationship can be described by the initial rate of increase in the number of new species counted (**initial slope**) and the total number of species counted (**maximum**)

•In order to evaluate performance standards that require the number of species on Wheeler North Reef to be similar to natural reefs it is important to understand how the number of species that are counted on a reef is related to the amount of area that is sampled on a reef.
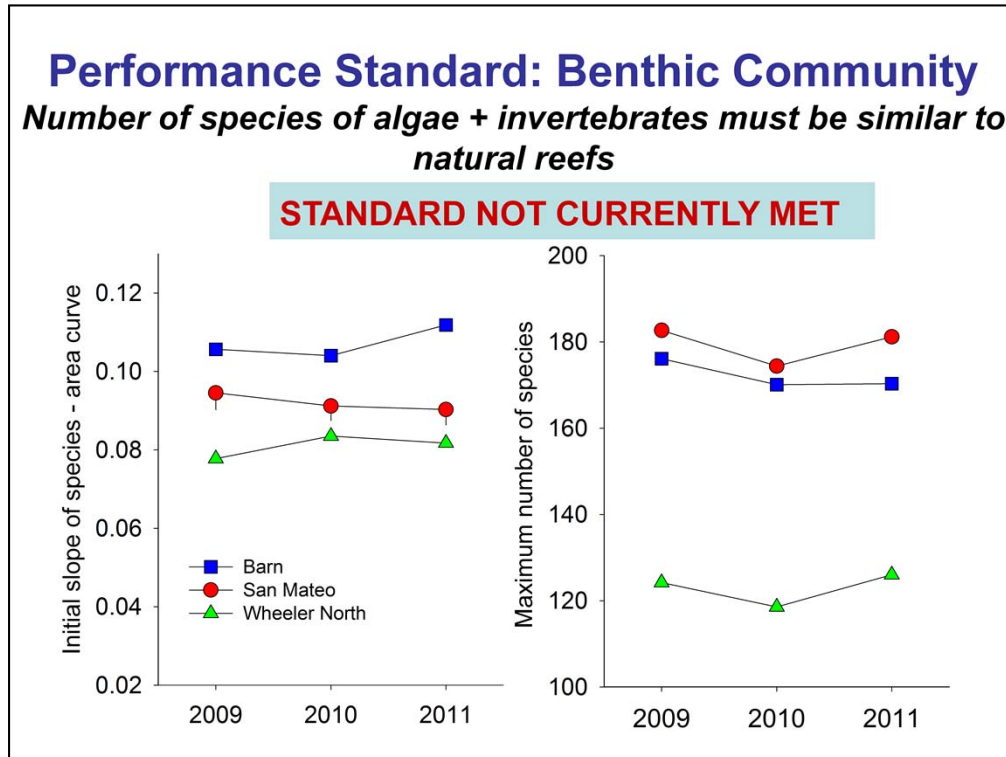
•The relationship between the number of species counted and the area sampled is typically curve-shaped where the number of species counted initially increases very rapidly then slows to the point where no new species are counted even as the number of transects sampled increases.

•This relationship can be described by the initial rate of increase in the number of new species counted which we will refer to as the initial slope of the curve, and the total number of species counted, which we will refer to as the maximum.

The number of species on any two reefs would differ if either the initial slopes or maxima of their species area curves were different

Same initial slopes
Different maxima

Different initial slopes
Same maxima

Both the initial slope and the maximum number of species counted on the Wheeler North Reef must be similar to natural reefs for it to meet the performance standards pertaining to species number

•The example on the left shows a situation where Reef's 1 and 2 have the same initial slopes in their species area curves, but different maximum number of species.

•This means that the rate at which the number of species counted increases with increasing sampling area is the same on reefs 1 and 2, but the maximum number of species counted on reef 2 will never reach that counted on reef 1 no matter how many transects are sampled.

•In this scenario the average number of species encountered in any one transect is likely to be very similar on both reefs, but in contrast to Reef 1, many of the same species are encountered over and over again in the transects on Reef 2 resulting in a lower maximum number of species counted.

•The example on the right shows a situation where the species area curve on Reef 1 has a steeper initial slope compared to Reef 2, but ultimately reaches the same maximum number of species.

•In this scenario the average number of species on any one transect on Reef 2 is less than that on Reef 1 (~25 for Reef 1 vs. 12 for Reef 2 in the example shown)

•However, if enough transects are sampled the two reefs ultimately end up with the same maximum number of species.

Performance Standard: Benthic Community
Number of species of algae + invertebrates must be similar to natural reefs

STANDARD NOT CURRENTLY MET

•The graph on the left shows the initial slope for the species area curve for algae and invertebrates for the Wheeler North Reef and the two natural reefs.

•The initial slope at Wheeler North Reef increased slightly from 2009 to 2010 with little change in 2011.

•Because the initial slope at Wheeler North has been below that of the two reference reefs in all three years, this component of the performance standard pertaining to the number of species of algae and invertebrates was has yet to be met, though it has been very close to the lower 80% confidence limit for San Mateo in both 2010 and 2011.

•The graph on the right shows that the maximum number of species of algae and invertebrates on all three reefs for 2009 through 2011.

•The maximum number of species declined slightly on all three reefs in 2010 and increased slightly in 2011.

•The maximum number of species of algae and invertebrates on Wheeler North Reef has been well below that of Barn and San Mateo in all three years.

•Consequently, this component of the standard for species number of algae and invertebrates has also yet to be met by Wheeler North Reef.

•Because the Wheeler North Reef failed to meet both components of species number it has failed to meet this performance standard for all three years.

Performance Standard: Resident Fish

The resident fish assemblage shall have a total density and number of species similar to natural reefs within the region

Resident Fish are defined as reef associated species 1 year of age or older

• The next several performance standards pertain to the abundance and number of species of reef fish.

• The first of these standard is that "The resident fish assemblage shall have a total density and number of species similar to natural reefs within the region".

• Resident Fish are defined as reef associated species 1 year of age or older.

• Because there is no single metric for measuring the density and number of species of fish, we evaluate density and species number separately in order to assess the performance of the Wheeler North Reef with respect to this standard.

**Measuring the density, size and number of species of reef associated fishes**

- Count the number of reef fish within 1.5 m of the bottom in a 3 m wide swath along each 50 m transect.
- Record the size (to the nearest cm) and species identity of each fish observed on each transect

Phase 1 Reef, November 2005

- Reef fish are visually counted and sized by divers within 1.5 m of the bottom in a 3 m wide swath centered along each 50 m transect.
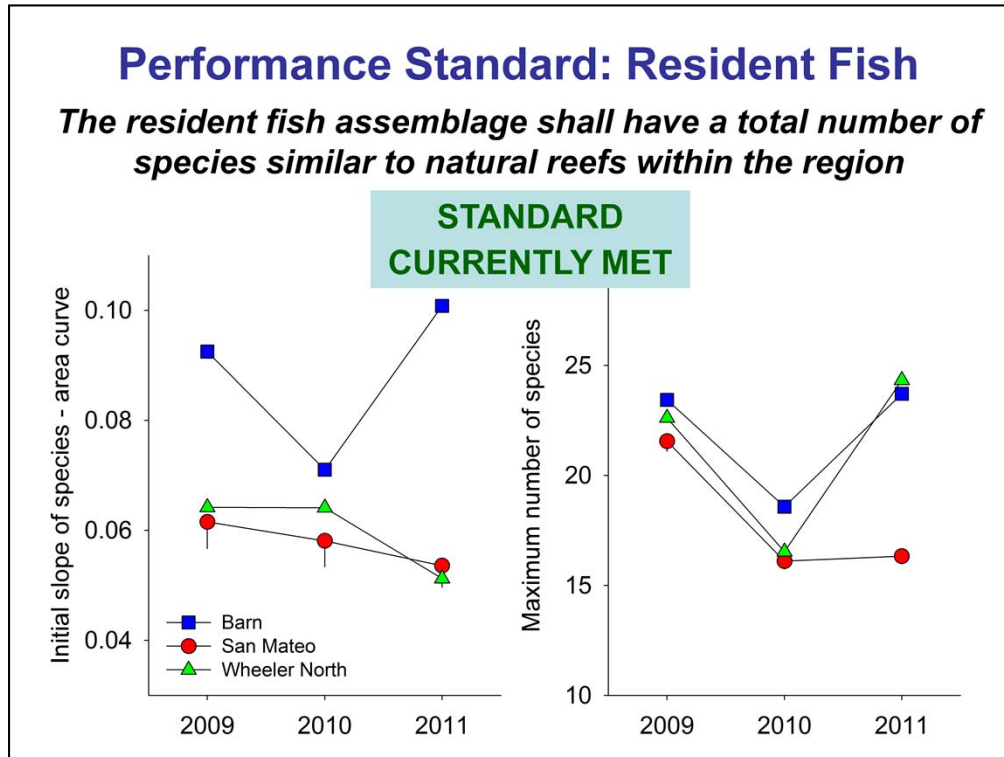- Size data are used when evaluating several of the other performance standards pertaining to kelp bed fish.

Performance Standard: Resident Fish

The resident fish assemblage shall have a total density similar to natural reefs within the region

STANDARD CURRENTLY MET

Phase 1 Reef, November 2002

- Barn
- San Mateo
- Wheeler North

Mean density (no. 100 m^{-2})
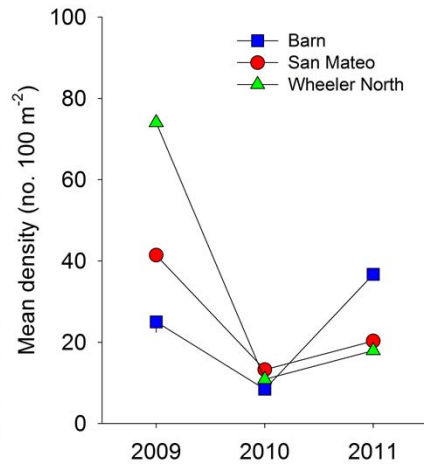
•This graph shows the mean density of resident fish on each of the three reefs for 2009 , 2010 and 2011.

•In 2009, 1 year after it was built, the density of fish on the Wheeler North Reef was 2 to 3 times greater than that of the reference reefs.

•The density of fish declined dramatically at all three reefs in 2010, such that densities were similar on all three reefs.

•The density of fish increased in 2011 by ~ 20% at Wheeler North Reef and San Mateo and by nearly 400% at Barn.

•While the mean density of fish at Wheeler North Reef fell below that of both reference sites in 2011, it was within the lower 80% confidence limit for San Mateo.

•Thus these results show that the Wheeler North Reef has met this performance standard in all three years.

Performance Standard: Resident Fish

The resident fish assemblage shall have a total number of species similar to natural reefs within the region

•Temporal patterns in the initial slopes in the species-area curves for resident fish as shown in the graph on the left varied among the three reefs.

•The relatively high initial slopes observed at Barn varied greatly among years where the relatively low values of initial slope at San Mateo has shown a steady decline

•The initial slope at Wheeler North Reef has more closely followed that at San Mateo than that at Barn.

•Because the mean value of the initial slope of the species area curve at Wheeler North Reef has been consistently above the lower 80% confidence limit of San Mateo it has met this portion of the species number standard for resident fish in all three years.

•While the temporal pattern in the initial slope of the species area curve at Wheeler North Reef followed that at San Mateo, the temporal pattern in the maximum number of resident fish species has closely followed that at Barn, showing an ~20% decrease in 2010 and a 20% increase in 2011.

•The Wheeler North Reef has been consistently within or above the range of the two reference sites with respect to the maximum number of resident fish species.

•Thus the Wheeler North Reef has met the performance standard pertaining to the number of species of resident reef fish in all three years.

Performance Standard: Young-of-Year Fish

The total density and number of species of young-of-year fish shall be similar to natural reefs within the region
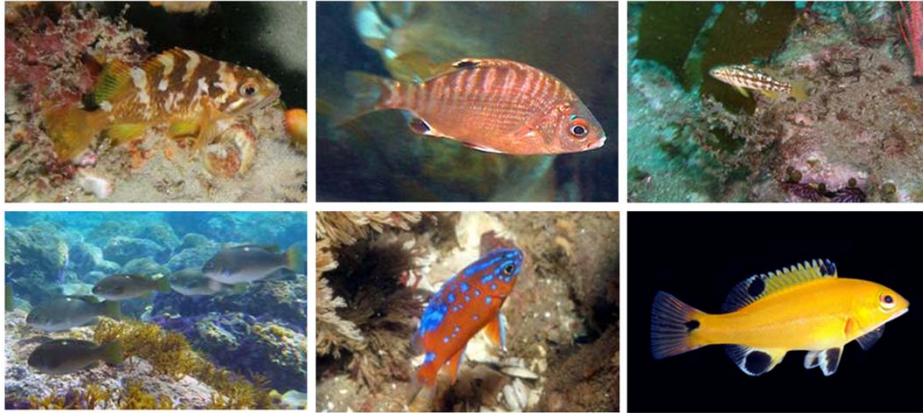
Young-of-Year Fish are defined as reef associated fish that were born in the year that they were sampled

• There are similar performance standards for the density and number of species of young-of-year fish as there are for older resident fish.

• Young-of-Year Fish are defined as reef associated fish that were born in the year that they were sampled.

• The rationale for this standard is that kelp forests serve as important nursery habitat for reef associated fish and that it is important for the Wheeler North Reef to provide this important ecological function.

Performance Standard: Young-of-Year Fish

The total density of young-of-year fish shall be similar to natural reefs within the region

STANDARD CURRENTLY MET
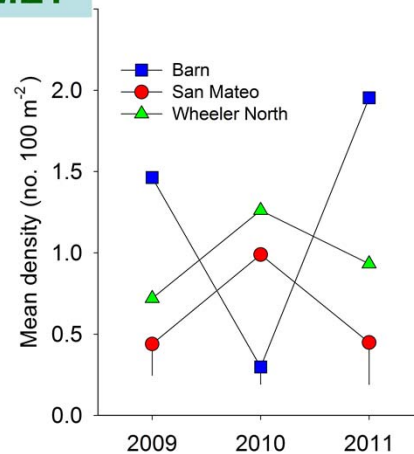
- Plotted in this graph is the average density of young-of-year fish for Wheeler North Reef, San Mateo and Barn for 2009 , 2010, 2011.

- Densities of young-of-year fish at Wheeler North and San Mateo increased from 2009 to 2010 and decreased from 2010 to 2011, with the Wheeler North Reef having higher densities in all three years.

- Barn showed the exact opposite pattern; a decrease in 2010 and an increase in 2011.

- While these trends appear to be distinct the actual densities of young-of-year fish were quite low on all three reefs, averaging about 1 individual per transect.

- Nonetheless, these data show that the Wheeler North Reef easily met this performance standard in all three years.

Performance Standard: Young-of-Year Fish

The number of species of young-of-year fish shall be similar to natural reefs within the region

STANDARD CURRENTLY MET
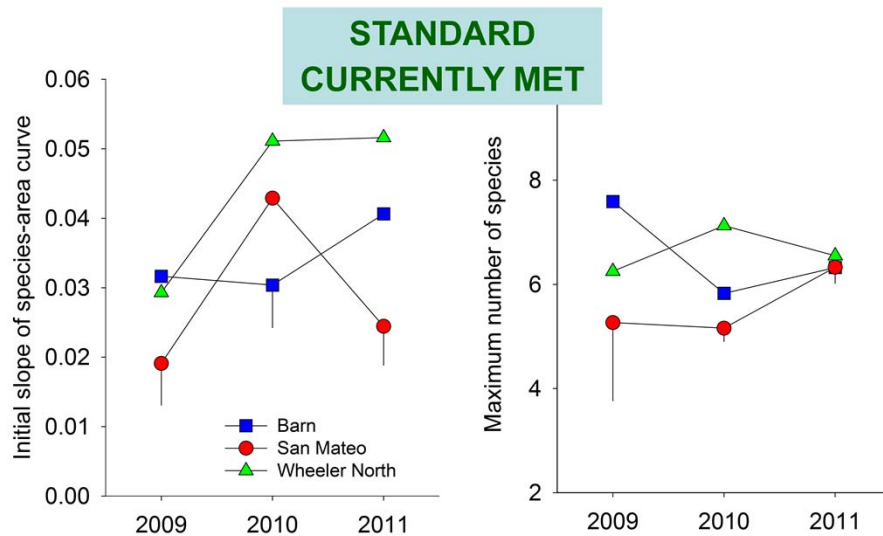
•In 2009 the initial slope of the species-area curve for young-of-year fish and the maximum number of young-of-year fish species counted on the Wheeler North Reef were intermediate between Barn and San Mateo.

•In 2010 and 2011, however, both of these components of species number had the highest values on the Wheeler North Reef; the maximum number of species of young-of-year fish encountered in 82 transects at Wheeler North Reef averaged about 7 species.

•Thus the Wheeler North Reef has met this standard in all three years.

Performance Standard: Fish Standing Stock

The standing stock of fish at the mitigation reef shall be at least 28 tons

Phase 1 Reef, November 2002

• The performance standard for fish biomass is a fixed standard that requires the Wheeler North Reef to support at least 28 US tons of fish, which is the estimated reduction in the biomass of kelp bed fish caused by SONGS operations

**Methods used to evaluate the standing stock of reef fish**

1. Apply species-specific length-weight relationships to data on fish density and size to calculate the average biomass density (biomass m^{-2} reef) of all fish near the bottom from all transects.

2. Scale up estimates of biomass m^{-2} to biomass for 176 acres to obtain an estimate of the standing stock of fish near the bottom on Wheeler North Reef.

Phase 1 Reef, November 2002

- Data on fish density and length collected from the 50 m transects are used to calculate the total standing stock of fish near the bottom on Wheeler North Reef to determine whether it supports 28 tons of reef fish.

- The weight of each fish counted is estimated from known relationships between length and weights for each species.

- The weights of all fish counted on the transect are summed to obtain an estimate of fish biomass density for each transect in units of grams per m^2 of reef.

- The mean biomass density averaged over all transects is multiplied by 176 acres to obtain an estimate of the standing stock of fish near the bottom on Wheeler North Reef.

Performance Standard: Fish Standing Stock

The standing stock of fish at the mitigation reef shall be at least 28 tons

STANDARD NOT CURRENTLY MET
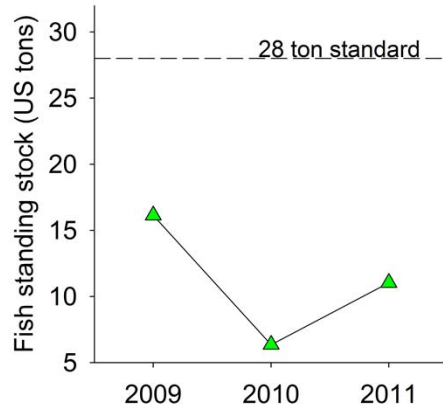
•Plotted in this graph is the estimated standing stock of fish on the 176 acre Wheeler North Reef for each of the three years.

•Temporal trends in fish standing stock resemble those observed for fish density with highest values reported in 2009, lowest in 2010 and intermediate values in 2011.

•The Wheeler North Reef has been far below the fixed performance standard of 28 tons in all three years with the highest value reported for 2009 when standing stock was estimated at 16 tons.

•Thus the Wheeler North Reef has yet to meet the performance standards for fish standing stock.

Performance Standard: Fish Reproductive Rates

Fish reproductive rates shall be similar to natural reefs within the region

Goal :
Estimate annual egg production for three common "indicator"species
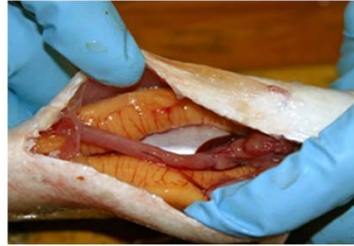
Method of Evaluation:
•Measure egg production and body length of individuals of each species collected from Wheeler North Reef and the two reference reefs
•Standardize egg production and body length for each species across all reefs for each year
•Use the standardized data to calculate a "Fecundity Index" for each reef in each year that represents an average fecundity index for the three species

Kelp bass

Senorita

Sheephead

• The rationale for the performance standard pertaining to fish reproductive rates is that for artificial reefs to be considered successful, fish must be able to successfully reproduce.

• Our goal in evaluating this performance standard is to estimate the annual egg production (which we refer to as annual fecundity) for three common indicator species of reef

• The species are the California sheephead and senorita, which are wrasses that feed on invertebrates and the kelp bass which primarily feed on other species of fish.

• To estimate annual fecundity we measure egg production and body length of individuals of each species collected from Wheeler North Reef and the two reference reefs

• We then standardize the values of egg production and body length across all species and reefs for a given year

• These standardized data are then used to calculate a "Fecundity Index" for each reef in each year that represents an average fecundity index of the three species
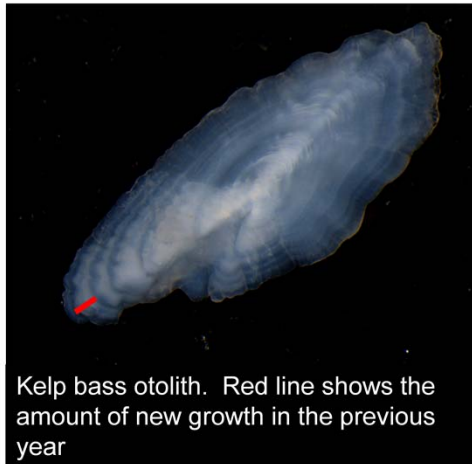
Performance Standard: Fish Reproductive Rates

Fish reproductive rates shall be similar to natural reefs within the region
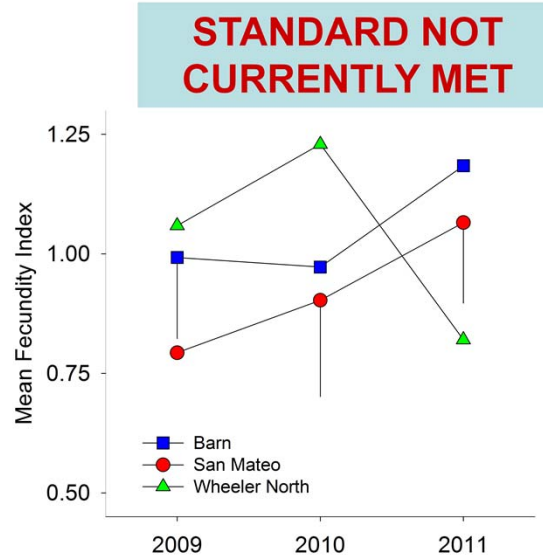
- Plotted here is the Mean Fecundity Index averaged across the three species for Wheeler North Reef, San Mateo and Barn from 2009 through 2011.

- The value of the Mean Fecundity Index was higher at Wheeler North Reef in 2009 and 2010 than at the two reference reefs, but declined by ~ 40% in 2011.

- In contrast the Fecundity Index increased at San Mateo and Barn in 2011.

- As a result, unlike in 2009 and 2010, the Wheeler North Reef did not met the standard for fish reproductive rates in 2011.

Performance Standard: Fish Production

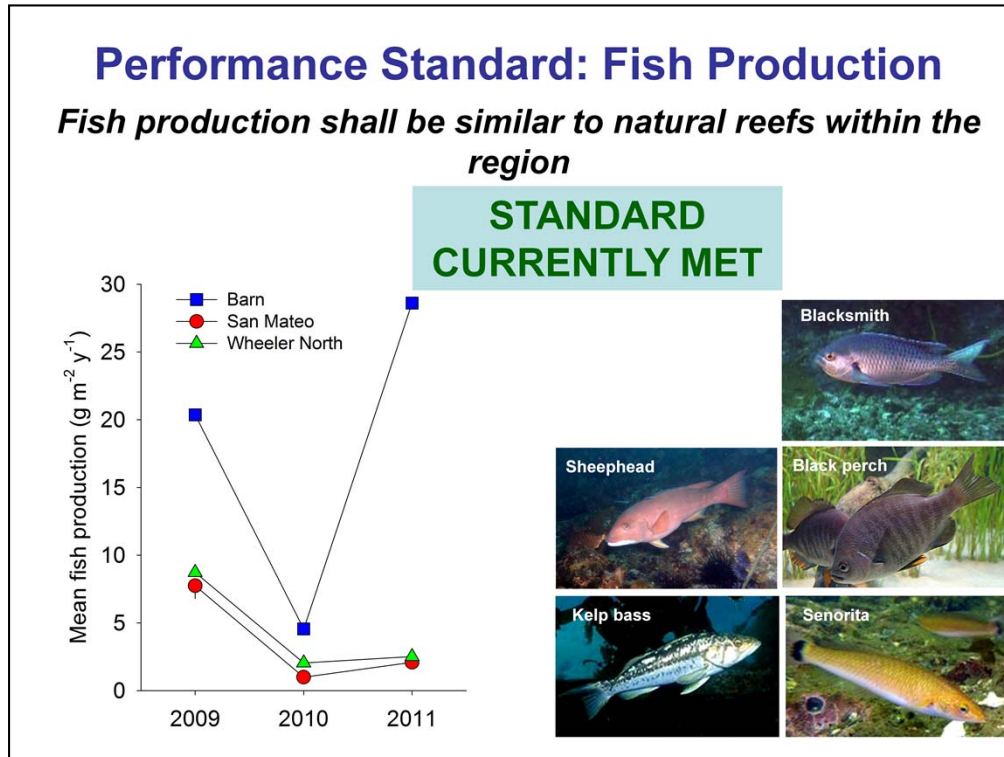## *Fish production shall be similar to natural reefs within the region*

Production: *the rate at which biomass is produced per unit area per unit time.*

Method of Evaluation

Use information collected on fish density, size structure, and reproductive rates combined with estimates of somatic growth obtained from ear bones (otoliths) to calculate fish production in terms of the biomass of fish produced per unit area of reef per year

Kelp bass otolith. Red line shows the amount of new growth in the previous year

•There is also a standard for fish production. The rationale for this standard is that it is important that the Wheeler North Reef actually produce new fish and new biomass on older fish rather than simply attract older slow growing fish from other natural reefs.

•Production differs from standing stock in that production relates to the rate at which biomass is produced per unit time, whereas standing stock is simply a measure of the biomass that is on the reef regardless of where and when it was produced.

•Like most organisms fish can allocate the production of new biomass to growing larger (referred to as somatic growth) or to reproduction (referred to as gonadal growth).

•Both of these components need to be measured to estimate the amount of fish biomass produced on a reef.

•We use information on fish density, size structure, and reproductive rates combined with estimates of somatic growth obtained from ear bones to calculate fish production in terms of the biomass of fish produced per area of reef per year.

Performance Standard: Fish Production

Fish production shall be similar to natural reefs within the region

STANDARD CURRENTLY MET

- We use five indicator species to estimate fish production on Wheeler North, San Mateo and Barn.

- These species were chosen because they are among the most common species of fish in the kelp forest and they represent different feeding guilds that use the reef in different ways.

- Blacksmith eat plankton during the day and seek shelter on the reef at night, black perch and senorita feed on small invertebrates that live on or near the bottom, sheephead feed on larger invertebrates, and kelp bass feed on other species of fish.

- Plotted in this graph is the average production of these five species combined for Wheeler North, San Mateo and Barn.

- Much like fish density and fish biomass, fish production declined on all three reefs in 2010.

- Fish production remained low at Wheeler North and San Mateo in 2011 but increased dramatically at Barn.

- The mean value of fish production at Wheeler North has been slightly greater that that at San Mateo in all three years indicating that it has consistently met this performance standard.

Performance Standard: Food Chain Support

The benthic community shall provide food-chain support for fish similar to natural reefs within the region

Method of Evaluation:

- Weigh gut contents in two common species of reef fish that feed directly on the bottom
- Scale mass of gut contents to total mass of fish to calculate an index of Food Chain Support (FCS)

Phase 1 Reef, November 2005

- There is also a performance standard that requires the benthic community of the Wheeler North reef to provide food for the fishes that feed on the reef in an amount that is similar to that provided by natural reefs.

- The way that we evaluate this standard is by weighing the content of the guts of two common species of fish that feed on the bottom.

- We then compare the mass of the gut contents relative to the mass of the fish, and use this ratio (mass of gut contents/ mass of entire body) to calculate a index of food chain support that is scaled to the weight of a fish.

Performance Standard: Food Chain Support

The benthic community shall provide food-chain support for fish similar to natural reefs within the region

STANDARD NOT CURRENTLY MET
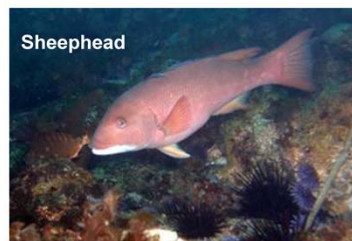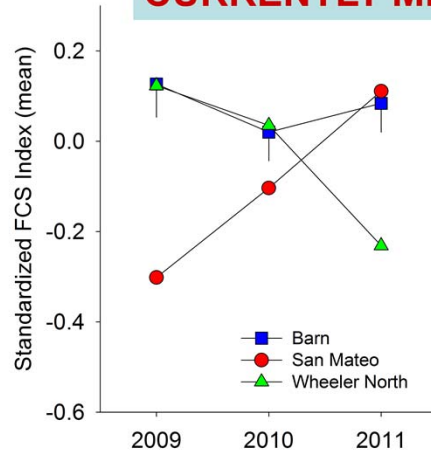
•To evaluate the Food Chain support performance standard we transform the values for the FCS index for each of the two species into a standardized FCS index and assess the performance standard using data from both species.

•When we do this we see that the standardized FCS index has fluctuated substantially at the three reefs since 2009, with all sites showing an increase in 2010 and an decrease in 2011.

•The FCS index at Wheeler North Reef was within or above the range of the two references sites in 2009 and 2010, but dropped substantially below them in 2011.

•This indicates that the benthic community of Wheeler North Reef provided less food for the two indicator species than did the two natural reference reefs this past year.

•Thus the Wheeler North Reef did not meet the performance standard for food chain support in 2011.

Performance Standard : Invasive Species
The important functions of the reef shall not be impaired by undesirable or invasive benthic species

•The final performance standard that is used to judge the success of the reef mitigation project was enacted to ensure that the important ecological functions of the Wheeler North Reef do not become impaired by invasive or undesirable species.

Performance Standard : Invasive Species

The important functions of the reef shall not be impaired by undesirable or invasive benthic species

Important reef functions may include: food-chain support and nursery habitat for fishes, and primary production by giant kelp

Sea fan aggregation

Caulerpa taxifolia

Sea urchin barrens

Sargassum horneri
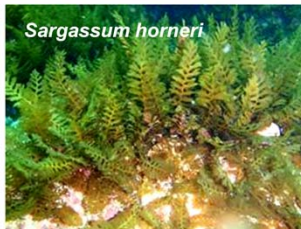
Undesirable or invasive species that are of potential concern include:
• Sea urchins
• Sea fans
• Non-native algae (e.g., *Caulerpa*, and *Sargassum*)

•Important functions of the reef can include, but are not limited to: food chain support for fishes, nursery habitat for fishes as estimated by the density of young-of-year fish and primary production by giant kelp, which can be estimated from the density of kelp fronds.

•Undesirable or invasive species that are of potential concern can include native species when they attain very high abundances, which can be the case for dense aggregations of sea fans that can monopolize space and exclude other species, or high densities of sea urchins that can over graze the bottom and create large deforested areas commonly called sea urchin barrens.

•Undesirable or invasive species can also include introduced or non-native species such as the green seaweed *Caulerpa* which has escaped from the aquarium trade and invaded many marine habitats worldwide including some in southern California, and the brown seaweed *Sargassum* which was accidentally introduced from Asia and has become increasingly abundant on some reefs off southern California.

Invasive/Undesirable Species: Sea Fans

High densities of sea fans may exclude giant kelp

data from Ambrose et al. 1987
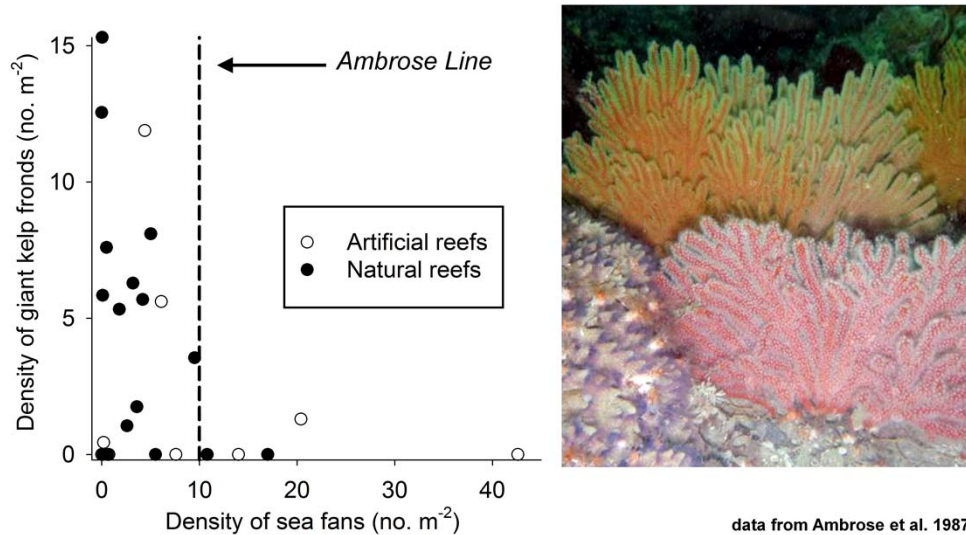
•Whether they are natives or non-natives, undesirable or invasive species are those species that attain abundances that are high enough to adversely effect the normal functions of a reef.

•Native sea fans are one such group of species and are know to attain high abundances on artificial reefs in California.

•Dr. Rich Ambrose and colleagues did a broad survey of artificial and natural reefs in southern California during the 1980's and found that giant kelp was rare or absent on reefs where sea fan abundance exceeded 10 per m^2.

•We refer to a density of sea fans of per 10 m^2 as the "Ambrose line" which indicates a potential problem for a reef with respect to its ability to support giant kelp.

Invasive/Undesirable Species: Sea Fans
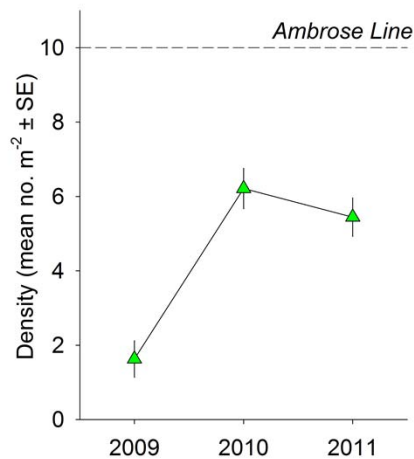
- Initial colonization of sea fans in 2010, but no increase in 2011
- Sea fan density still below *Ambrose line*
- Sea fans cover < 2% of the bottom at Wheeler North Reef

•Plotted here are the mean densities of sea fans at Wheeler North Reef for 2009 - 2011.

•The vertical lines through the symbols represent the standard error of the means.

•2010 was a good year for sea fan recruitment and the densities of sea fans at Wheeler North Reef increased dramatically to about 6 per m^2.

•No increase in sea fan density was observed in 2011 suggesting little if any new sea fan recruitment.

•Thus sea fan density on Wheeler North Reef remains below the Ambrose line of 10 per m^2.

•It is worth noting that sea fans observed in the earlier study by Ambrose were mostly very large individuals that occupied a large amount of space on the bottom.

•In contrast, sea fans on Wheeler North Reef are mostly very small young individuals that do not yet occupy much space on the bottom (in 2011 sea fans covered < 2% of the bottom).

Invasive/Undesirable Species: Sea Urchins

**High densities of sea urchins may over graze giant kelp**
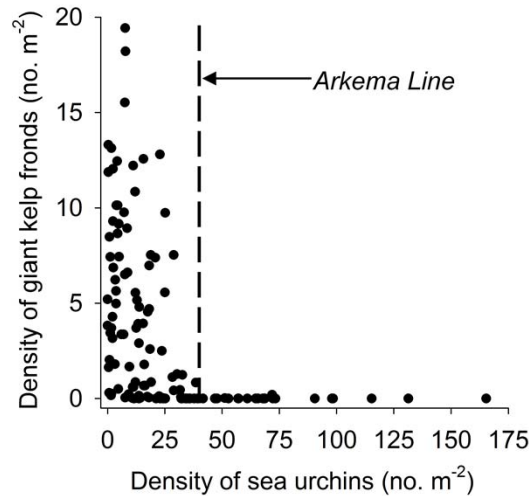
data from Arkema et al. 2009

•The destructive damage to kelp forests caused by the grazing activities of large aggregations of sea urchins has been observed in kelp forests throughout the world.

•Similar to the Ambrose study, Katie Arkema, a former graduate student of ours, found there was a critical density of sea urchins above which giant kelp was unable to persist.

•This density was about 35 urchins per m^2.

•For the sake of convention we refer to this density of sea urchins as the Arkema line.

Invasive/Undesirable Species: Sea Urchins

There continues to be few sea urchins at Wheeler North Reef
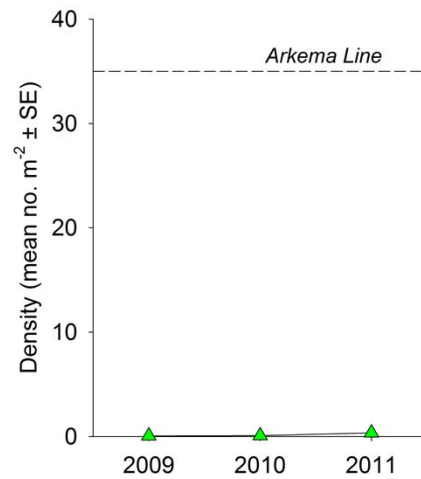
•Plotted here are the mean densities of sea urchins on the Wheeler North Reef for 2009 to 2011.

•We have observed very low densities of sea urchins on the Wheeler North Reef so far, and the densities are well below the Arkema line.

Performance Standard : Invasive Species

The important functions of the reef shall not be impaired by undesirable or invasive benthic species

Caulerpa taxifolia

Sargassum horneri

No non-native invasive species of algae have been observed at Wheeler North Reef

Performance Standard : Invasive Species

The important functions of the reef shall not be impaired by undesirable or invasive benthic species

Conclusion: No evidence that invasive or undesirable species have adversely affected the important functions of Wheeler North Reef

STANDARD CURRENTLY MET

•We conclude from these data that the important ecological functions of the Wheeler North Reef have not been impaired by invasive or undesirable species.

•Thus the Wheeler North Reef has consistently met this standard in all three years.

Permit Compliance

To be in compliance with the SONGS permit in any given year the Wheeler North Reef must meet all 14 performance standards for that year

Wheeler North Reef, July 2010

•All 14 performance standards must be met in a given year for the Wheeler North Reef to be in compliance with the SONGS permit for that year.

Performance Summary

	2009	2010	2011
1. Hard Substrate	YES	YES	YES
2. Giant kelp	NO	YES	YES
3. Algal and Invertebrate % cover	NO	NO	NO
4. Mobile Invertebrate density	NO	NO	YES
5. Algal and Invertebrate species number	NO	NO	NO
6. Resident fish density	YES	YES	YES
7. Resident fish species number	YES	YES	YES
8. YOY fish density	YES	YES	YES
9. YOY fish species number	YES	YES	YES
10. Fish standing stock	NO	NO	NO
11. Fish reproductive rates	YES	YES	NO
12. Fish production	YES	YES	YES
13. Benthic food chain support for fishes	YES	YES	NO
14. Invasive species	YES	YES	YES
	9/14	10/14	9/14

•Shown here is a summary of the performance of the Wheeler North Reef for each of the standards in 2009, 2010 and 2011.

•Yes means that the standard was met for that year, No means that it was not met for that year.

•The Wheeler North Reef met 10 of the 14 performance standards in 2010 compared to 9 of the standards in 2009 and 2011.

•The Wheeler North Reef has yet to meet three of the 14 performance standards; algal and invertebrate percent cover, algal and invertebrate and species number and fish standing stock

•None of these three standards appear to be getting close to meeting their expectation

•In contrast, the standard for mobile invertebrate density had not been met in 2009 or 2010, but was met in 2011.

•This reflects the steady increase in the density of mobile invertebrates on Wheeler North Reef over time

•There were two cases in which a standard was met in 2009 and 2010, but not met in 2011 ; fish reproductive rates and benthic food chain support for fishes.

Plans for Wheeler North Reef in 2012

- Monitor the Wheeler North Reef and reference reefs as planned.
- Conduct additional analyses to better understand why the performance standards for the benthic community and fish standing stock, reproduction and feeding have not been met.

The plan for monitoring in 2012 is to:

•Continue monitoring the Wheeler North Reef, San Mateo and Barn using the same methods as in previous years, and

•Conduct additional analyses in order to better understand why the performance standards for the benthic community, and for fish standing stock, reproduction and feeding have not been met.

•These analyses will involve:

1. Closer examination of the longer time series data collected at the Phase 1 modules to get a better sense of the likely trajectories of different performance variables

2. Determining which species of algae and invertebrates are missing at Wheeler North Reef and whether they have similar taxonomic, demographic or ecological affinities

3. Determining whether particular species of fish are responsible for the decreased performance of Wheeler North Reef with respect to reproductive rates and food chain support