Temporal and spatial patterns of species abundance on Wheeler North Reef

April 4, 2022

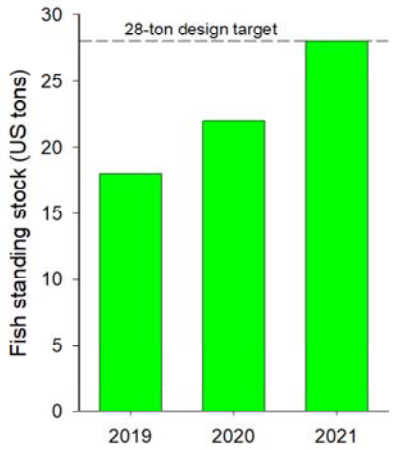
SONGS Mitigation Monitoring Project
Marine Science Institute, University of California Santa Barbara

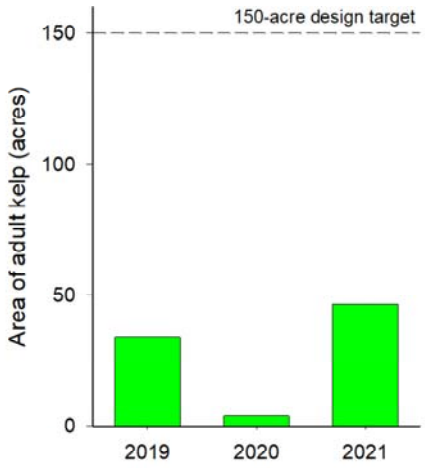
- In the previous presentation we reported on the ability of the Wheeler North Reef to meet specific performance standards required by the SONGS coastal development permit
- In this talk we present more detailed information on spatial and temporal patterns in species abundance at Wheeler North Reef, and how they vary among the different phases of the artificial reef which vary in age
- By examining the trajectories of species abundance on the Phase 1 and 2 reefs we hope to gain insight into the future trajectories of the newly constructed Phase 3 reef
- We focus our analyses on reef fishes and giant kelp because they are key components upon which the performance of the Wheeler North Reef is judged
- We also present information on temporal and spatial patterns of abundance in:
    1. The California spiny lobster, which is an important predator in kelp forests and the target of highly valued commercial and recreational fisheries, and
    2. Sea fans, which as mentioned in the previous presentation can form dense aggregations that impair important ecological functions of the reef by excluding giant kelp and other benthic species.

Chronology, design and purpose of the different phases of Wheeler North Reef

- Information on the chronology, design and objectives of the different phases of Wheeler North Reef provides important context for this talk
- The Wheeler North Reef was constructed in three phases, which collectively cover 373 acres of the sea floor along a 4.5-mile stretch of coast
- The first phase was a 25-acre experimental reef built in the summer of 1999 that consisted of 56 40m x 40m modules shown as dark pink squares in this image
    - The purpose of this experiment was to test the efficacy of different configurations of reef material and bottom coverage in meeting the objectives of the SONGS artificial reef mitigation requirement
- The design of Phase 2 was informed by the results of the Phase 1 experimental reef
- Phase 2 consisted of 150 acres of a monolayer of quarry rock deposited in 18 polygons of varying size and shape shown in green.
    - This phase was constructed in the summer of 2008 and its purpose was to fulfill SCE's mitigation requirement to compensate for the kelp forest habitat and associated biota that were damaged or lost due to the operations of SONGS
- Phase 3 expanded the existing reef by adding 125 acres in 11 polygons in 2019 and another 73 acres in 9 polygons in 2020
    - The design of Phase 3 mimicked that of Phase 2 and its primary purpose was to increase the standing stock of reef fish and area of adult giant kelp on the artificial reef

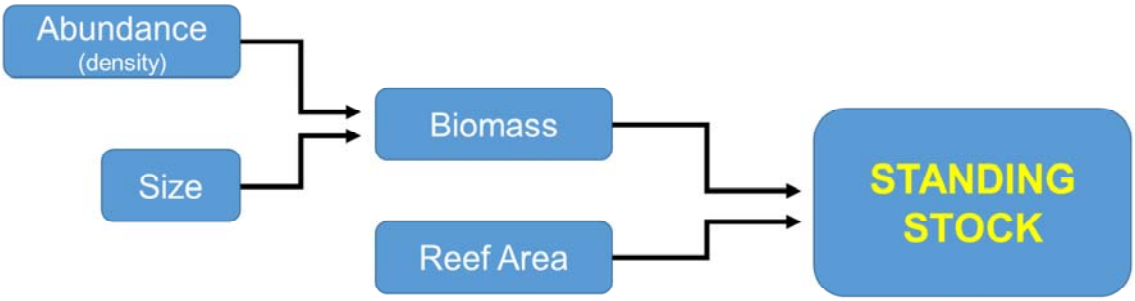
Reef fish standing stock and giant kelp area



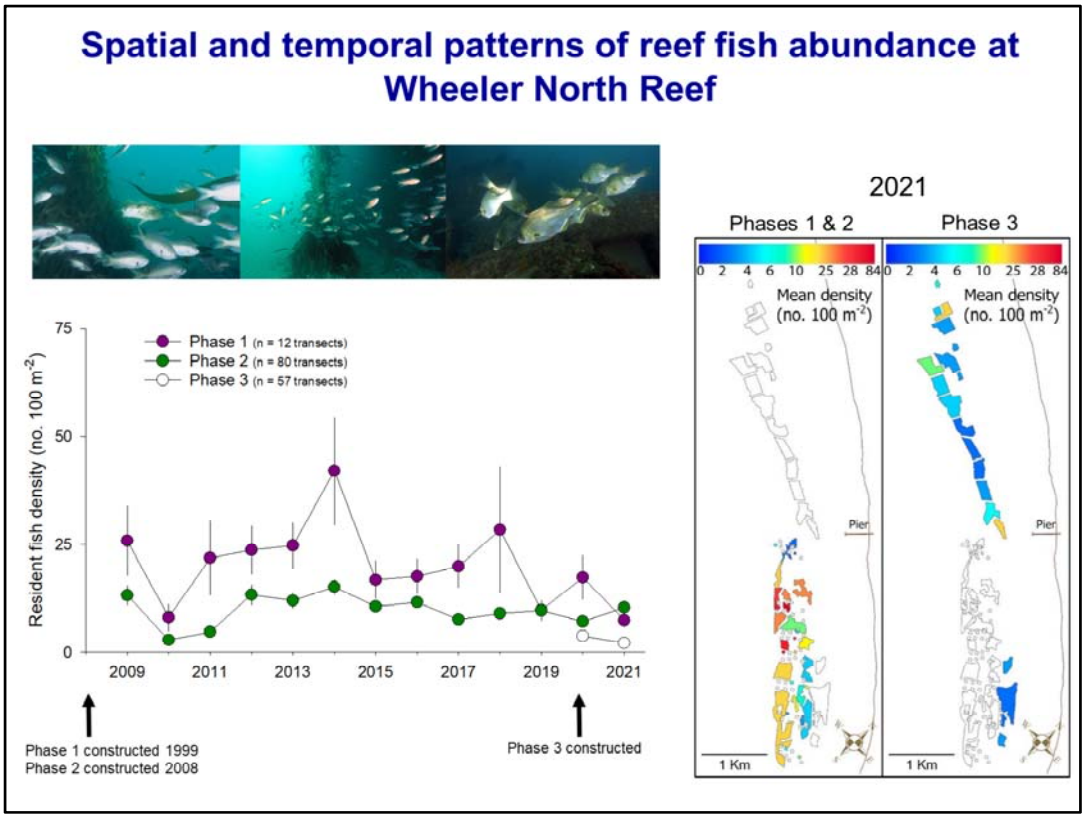


- In the previous talk we reported on the performance of the Wheeler North Reef in meeting the designed minimum targets of a 28-ton standing stock of reef fish and 150 acres of adult giant kelp.
- Here we examine the spatial and temporal patterns of the individual components that determine the standing stock of reef fish and the area of adult giant kelp on Wheeler North Reef

Components of Fish Standing Stock

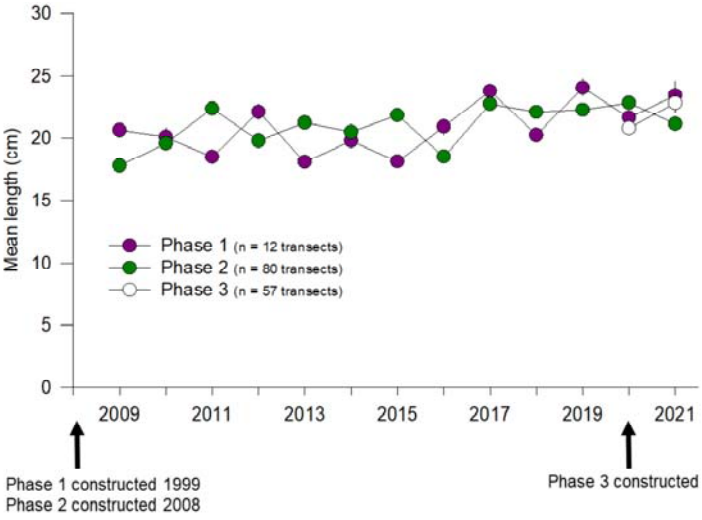


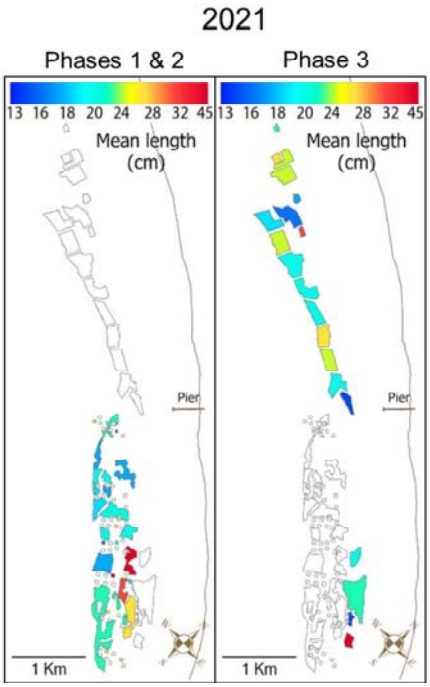
- Shown here are the major components that factor into estimates of reef fish standing stock.
- The abundance or density of fish coupled with their size determines the biomass of fish per unit area of reef
- The biomass of fish per unit area multiplied by the footprint area of a reef in turn determines the standing stock of fish on the reef.
- What follows are temporal and spatial patterns of these different components and how they scale up to estimates of fish standing stock.



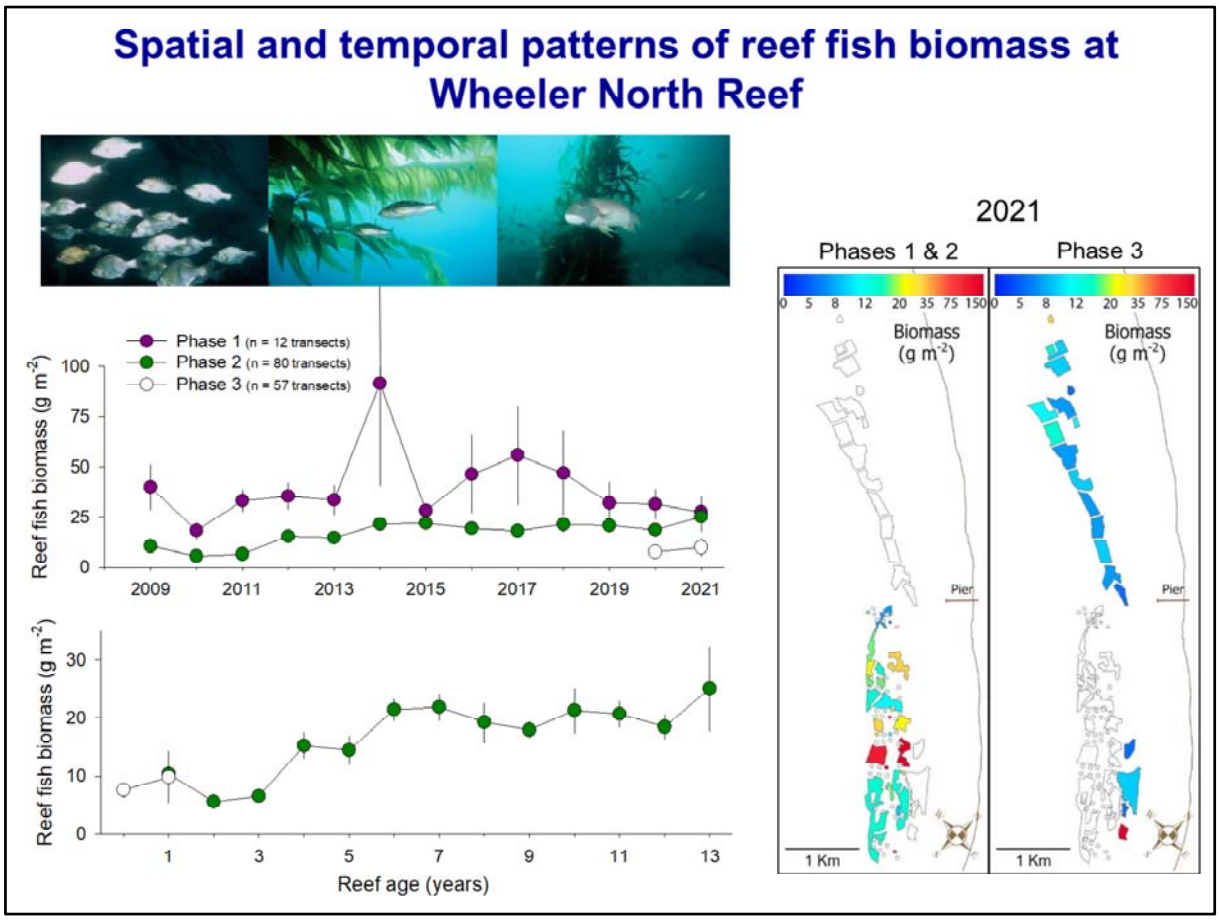
- Plotted in this graph is a time series of the average abundance (i.e., density) of reef fish on the three phases of Wheeler North Reef beginning in 2009, 1 year after the construction of Phase 2 and 10 years after the construction of Phase 1.
- Abundance is expressed as the mean number of fish per 100 m^2, which is the area of each transect sampled (the number of transects sampled for each reef phase are shown in parentheses of the legend in the figure)
- The vertical lines through the values are standard errors of the mean
- Densities of fish have generally been highest on Phase 1, except in 2021 when it declined to a level below Phase 2.
    - Recall Phase 1 consists of the smallest and oldest modules and its high within year variability reflects the small sample size (n = 12) and the wide range of reef designs used in the Phase 1 experiment
- Fish densities on Phase 2 have typically been lower than Phase 1 and relatively stable since 2012
- The lowest densities of reef fish have been recorded on Phase 3, which was first sampled in 2020 shortly after it was constructed
- This map shows the spatial distribution of reef fish on the Phase 1 and 2 reefs in 2021. Warmer colors denote higher densities than cooler colors
- We found that reef fishes were not distributed uniformly over the reef, but rather densities tended to be higher in the offshore portion of the Phase 2 reef, which is slightly deeper than the inshore portion
- By contrast, fish densities tended to be low in most of the Phase 3 polygons with a few exceptions

Spatial and temporal patterns of reef fish size at Wheeler North Reef



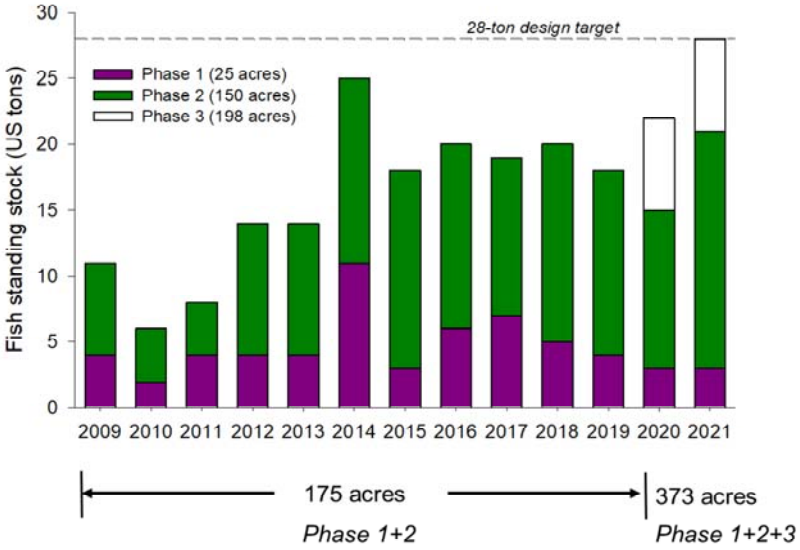


- The average size of fish was quite similar on all three Phases of Wheeler North Reef, and has remained relatively constant over time ranging between 18-24 cm in mean total length
- Unlike density, the average size of fishes in 2021 varied inconsistently among the polygons with no obvious spatial pattern



- Patterns in the biomass of reef fish per unit area generally followed that observed for fish density, suggesting that abundance rather than size has been the primary determinant of fish biomass at Wheeler North Reef
- Highest biomass values have typically been recorded on the smaller and older Phase 1 modules
- Fish biomass has slowly but gradually increased on the Phase 2 reef since 2010 and in 2021 was virtually identical to that of Phase 1
- As with fish density, the biomass of fish per unit area of reef was lowest in the newly constructed Phase 3 polygons
- When fish biomass is plotted vs. reef age we see that the average biomass of fish on Phase 3 is nearly identical to that observed on Phase 2 at a similar stage in its development
- If the biomass of reef fish on Phase 3 follows a trajectory similar to Phase 2, which it is similar to in design, then we can expect the biomass of reef fish on Phase 3 to double within the next couple of years
- When we examine the spatial distribution of fish biomass we see that unlike fish density, fish biomass was not concentrated in the offshore polygons of Phase 2 in 2021, but instead was more patchily distributed across the reef
- Fish biomass was generally low in all the Phase 3 polygons except for a small polygon at the southern inshore edge of the reef when a giant sea bass was recorded in one of the two transects surveyed

Reef fish standing stock

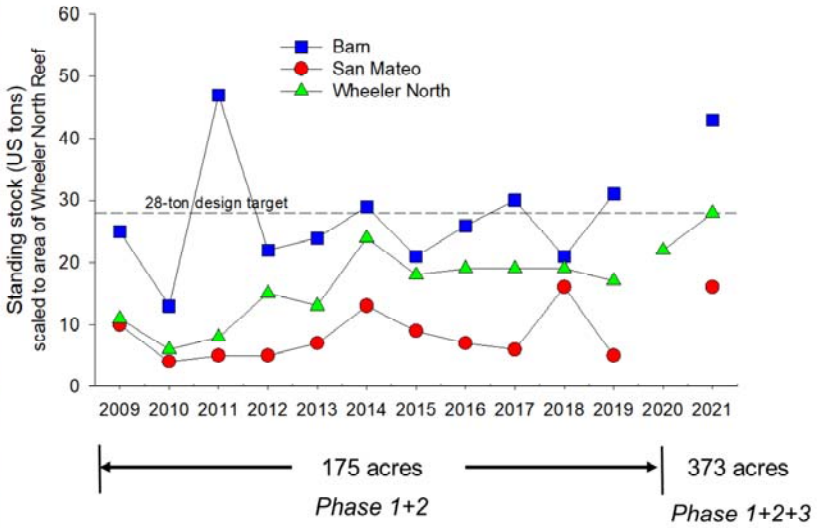


- *The biomass of reef fish on Phase 3 appears to be additive*
- *No evidence that the standing stock of fish on the Phase 3 expansion reef is having an adverse effect on fish standing stocks of the Phase 1 and 2 reefs*

- Shown here is a time series of the standing stock of reef fish on Wheeler North Reef with contributions from Phase 1 shown in dark pink, Phase 2 in green and Phase 3 in white
- Recall standing stock represents the biomass of fish per unit area scaled to the total area of the reef and the area of Wheeler North Reef in this time series changed from 175 acres in 2009 through 2019 when it consisted of Phase 1 and 2 only to 373 acres in 2020 and 2021 after it was expanded to include Phase 3
- 2021 is the first year that Wheeler North Reef met the 28-ton design target
- It is important to note that the standing stock of fish on the Phase 1 and 2 reefs did not decline with the addition of the Phase 3 expansion in 2020.
- This indicates that the biomass of fish in the newly constructed Phase 3 expansion reef is additive and that there is no evidence that it is having an adverse effect on fish standing stocks of the Phase 1 and 2 reefs

Fish standing stock

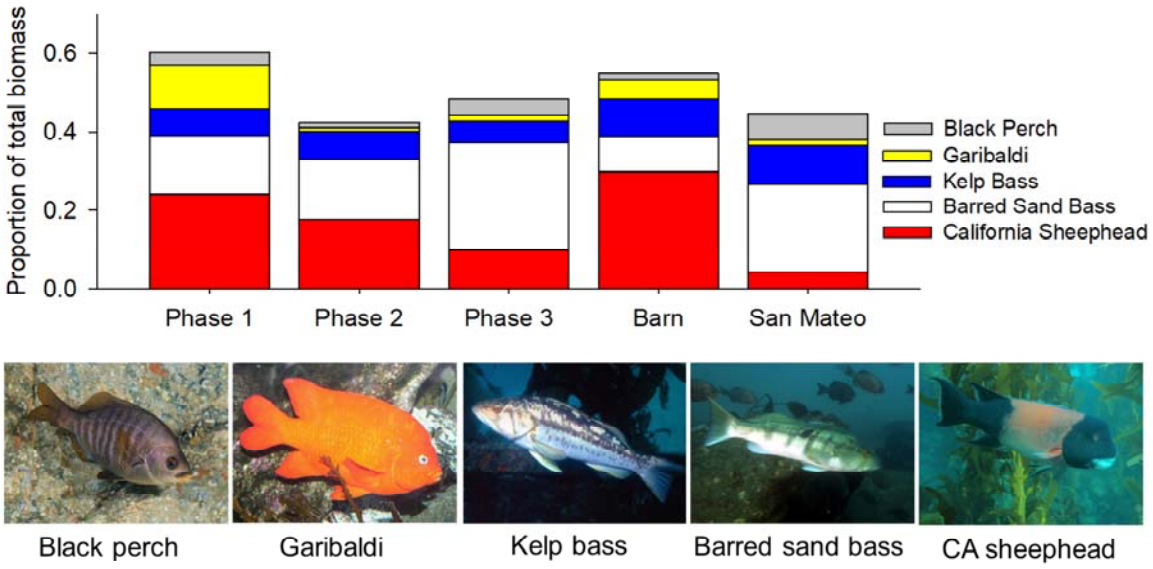
The standing stock of fish at Wheeler North Reef has been consistently *within the projected range* of nearby natural reefs scaled to the area of Wheeler North Reef



- One way to compare the standing stock of fish on the Wheeler North Reef to natural reefs is to scale the biomass of fish on the natural reefs to the area of the Wheeler North Reef
- When we do this we see that the standing stock of reef fish at Wheeler North Reef has been consistently lower than Barn, but higher than San Mateo

2021 Fish Standing Stock Composition

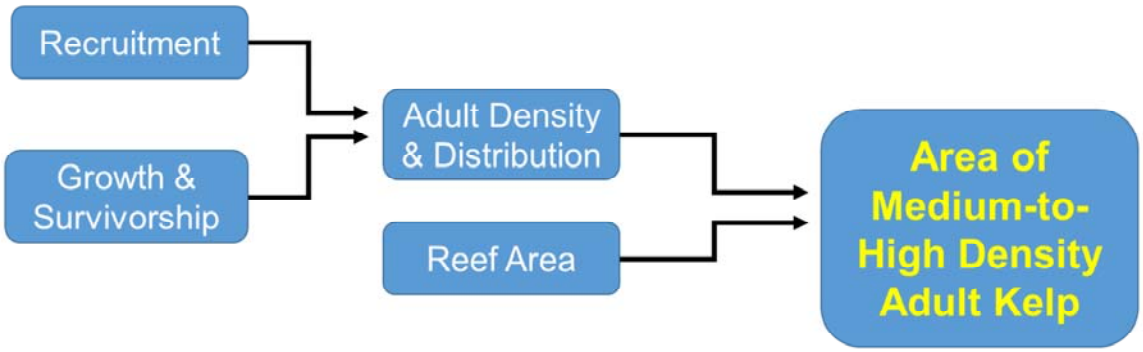
The same 5 species accounted for 42-60% of the fish standing stock on all reefs



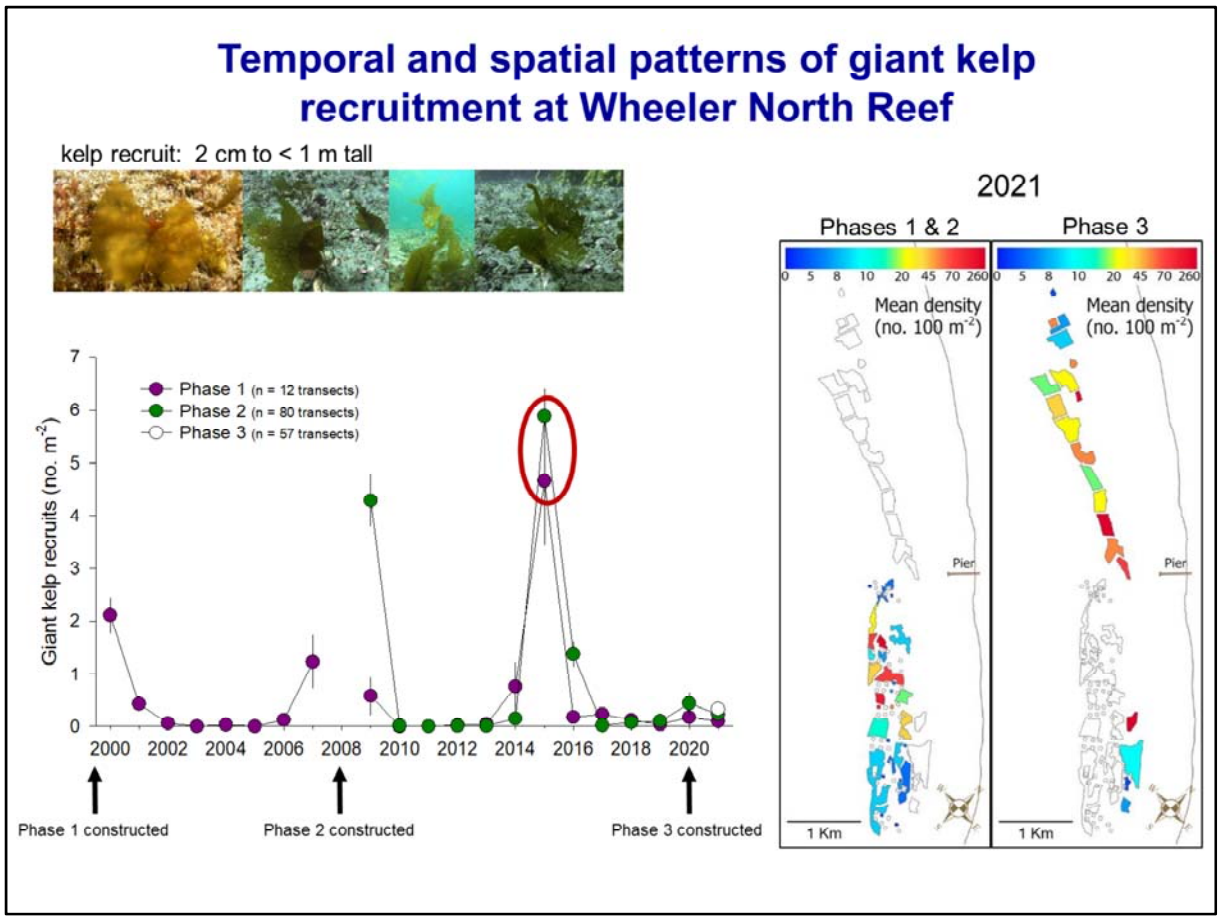
Black perch | Garibaldi | Kelp bass | Barred sand bass | CA sheephead

- The sizes and densities of species that determine the standing stock of fish can vary greatly with species composition, and the intent of the Wheeler North Reef was for it to resemble the communities of natural reefs
- This generally appears to be the case as the same 5 species accounted for 42-60% of the fish standing stock on the three phases of Wheeler North Reef as well as the reference reefs at Barn and San Mateo
- These five species are:
    - Black perch and garibaldi, which are medium-sized fish that feed on small invertebrates that live on the bottom, and
    - larger species such as kelp bass and sand bass which feed on fishes and the CA sheephead which feeds on large bottom-dwelling invertebrates

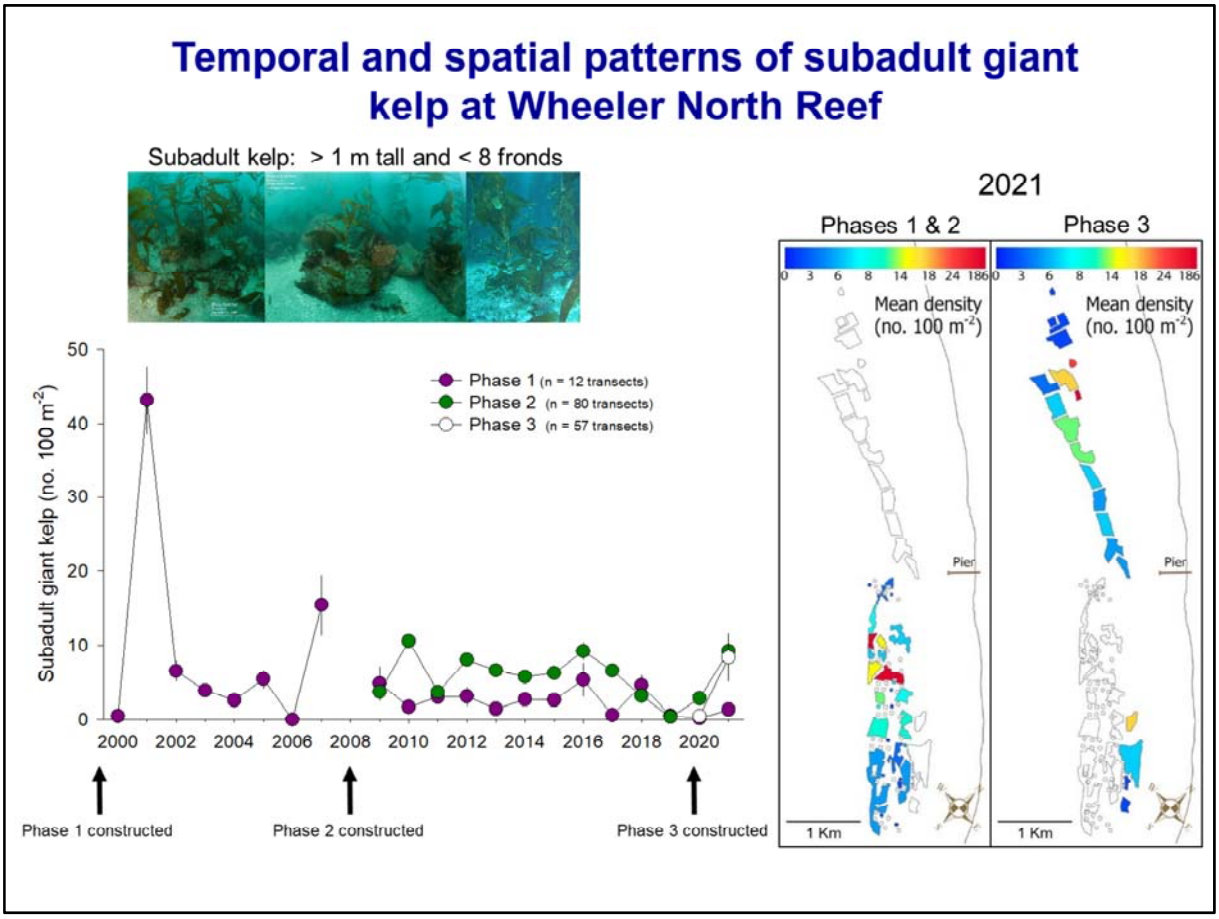
Components of the Area of Medium-to-High Density Kelp



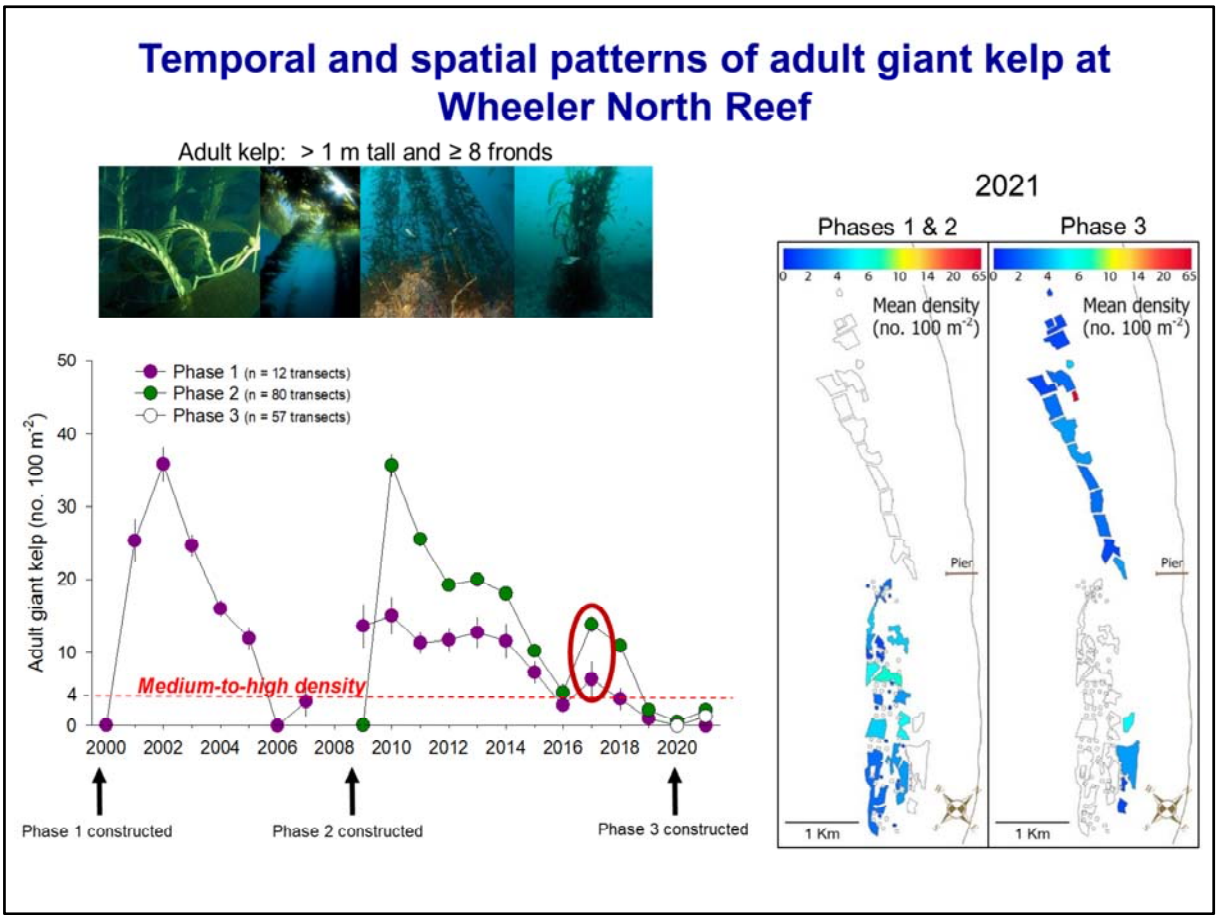
- In the case of giant kelp, the area of medium-to-high density adult kelp is determined by:
  - The recruitment of small plants and their subsequent growth and survival, which in turn determines the density and distribution of adult plants
  - When coupled with the area of a reef the density and spatial distribution of adult plants in turn determines the area of medium-to-high density adult kelp
- The next few slides examine the temporal and spatial patterns of these different components, and how they scale up to estimate the area of medium-to-high density adult kelp



- Plotted in this graph is a time series of small kelp recruits on the different phases of Wheeler North Reef
- We define recruits as plants that range in size from 2 cm to < 1 m tall
- The time series in this case begins in 2000, which is 1 year after the construction of Phase 1, through 2021 which is 1 year after the construction of Phase 3
- We saw very large pulses in recruitment in the year following construction for Phase 1 in 2000 and Phase 2 in 2009, and a smaller but nonetheless visible pulse for Phase 3 in 2021
- We also observed a very large pulse in recruitment on both Phase 1 and 2 in 2015
- There tends to be relatively little recruitment between pulses
- The map shows that recruitment of new kelp in 2021 varied substantially among the polygons of the Phase 2 and 3 reefs ranging from an average of < 5 per m^2 in some polygons to as high as 70 - 260 per m^2 in other polygons



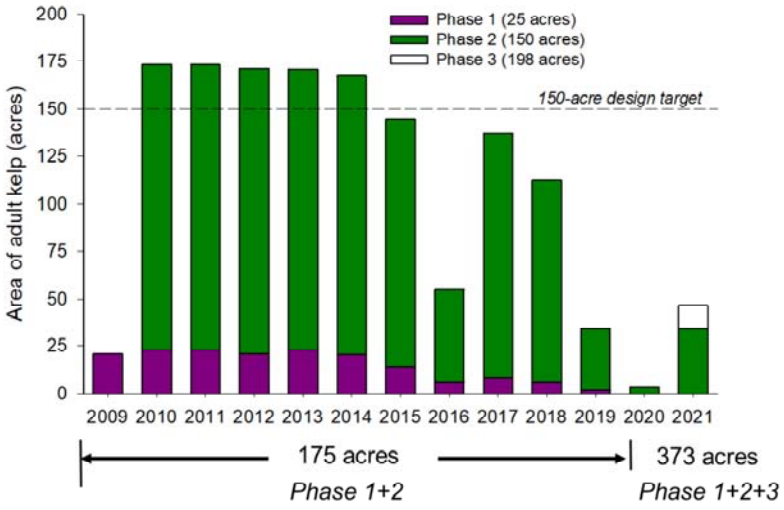
- The growth and survival of small kelp recruits is reflected in the density of subadult plants, which we define as individuals > 1 m tall with < 8 fronds
- Densities of subadults tend to spike during and immediately after years of high recruitment as shown in 2001 and 2007 for Phase 1
- Spikes in subadult densities were not as prominent in Phase 2, though the highest values were observed in 2010, 2016 and 2021, which followed years of relatively high recruitment
- It's also worth noting that in 2021 the highest densities of subadult kelp were observed in the Phase 2 and 3 polygons, which is significant because Phase 2 and 3 comprise 93% of the area of Wheeler North Reef
- Much like small recruits the densities of subadults were not uniformly distributed.
- The average density of subadult kelp in the polygons in 2021 ranged from as few as 1 per 100 m^2 in to as many as 186 per 100 m^2



- Shown here is a time series of adult giant kelp which we define as plants > 1 m tall with 8 or more fronds
- Adult densities on the Phase 1 and 2 reefs peaked within 1-2 years following reef construction
- We also observed a smaller peak in 2017 which reflects the large recruitment pulse in 2015 and the subsequent increase in subadult densities in 2016, which were shown in the previous two slides
- Peaks in adult densities were generally followed by rapid declines as the population of adult plants thins over time
- Adult kelp has been relatively sparse on Wheeler North Reef and surrounding areas the past few years reaching its lowest levels in 2020
- It is worth noting that medium-to-high density kelp is defined in the SONGS permit as > 4 plants per 100 m^2, which is sufficient to form a dense surface canopy.
- The overall mean density of adult giant kelp at Wheeler North Reef has usually exceeded this value except for the past few years.
- When we examine the map of adult kelp in 2021 we find that adult densities averaged < 4 plants per 100 m^2 in many of the Phase 2 and 3 polygons and in all the Phase 1 modules, but reached as high as 65 plants per 100 m^2 in one of the smaller polygons in the northern portion of Phase 3

Area of medium-to-high density adult giant kelp

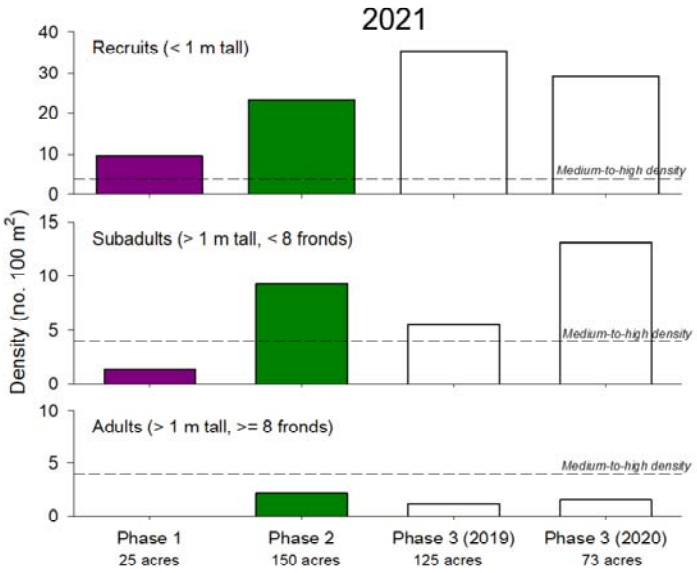
- *Nearly every acre of Wheeler North Reef supported medium-to-high density adult giant kelp between 2010 - 2015*
- *Kelp area has fluctuated erratically since 2016 reaching its lowest level in 2020*
- *In 2021 Phase 3 contributed 27% of the acreage of adult kelp and Phase 2 contributed the remaining 73%*



- This graph shows the area of medium-to-high density adult giant kelp on Wheeler North Reef since 2009
- We see a dramatic increase in the area of giant kelp in 2010 when high densities of adult kelp were observed across all of the Phase 1 and Phase 2 reefs
- The area of medium-to-high density kelp remained high through 2015 despite declining adult densities during this period as shown in the previous slide
- Kelp area has fluctuated erratically since 2016 reaching its lowest level in 2020 the year that Phase 3 construction was completed.
- In 2021 Phase 3 contributed 13 of the 47 acres (27%) of medium-to-high density adult kelp on Wheeler North Reef.
- The Phase 2 reef contributed the remaining 34 acres (73%)

Size structure of giant kelp at Wheeler North Reef in 2021

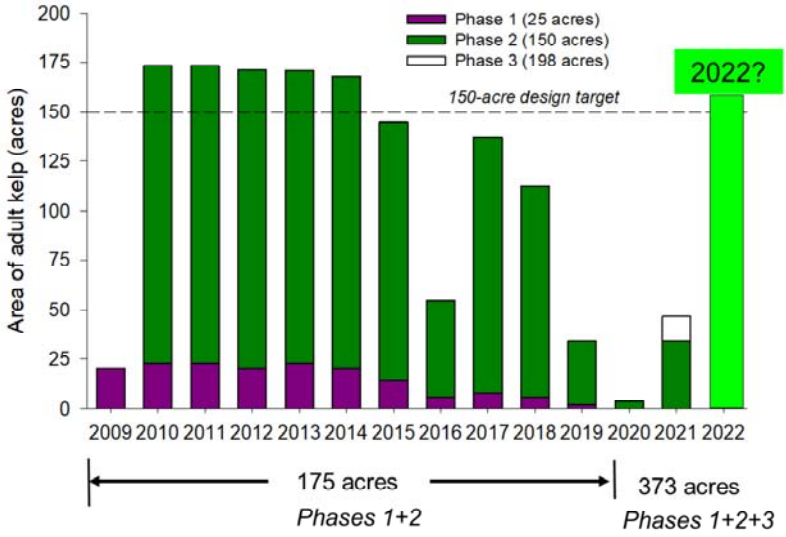
- *There were substantial numbers of recruit and subadult giant kelp in 2021, especially in the larger Phase 2 and 3 polygons*
- *If conditions for kelp growth and survivorship are favorable, then there should be a substantial increase in the density of adult kelp in 2022*



- Plotted here are the average densities of recruit, subadult and adult giant kelp on the different phases of Wheeler North Reef in 2021
- This graph shows that there were substantial numbers of recruit and subadult kelp this past year, especially in the Phase 2 and 3 polygons which comprise 93 % of the area of Wheeler North Reef
- If conditions for kelp growth and survival are favorable for all three size classes, then there should be a substantial increase in the density of adult kelp in 2022

Projections for the area of medium-to-high density adult giant kelp at Wheeler North Reef

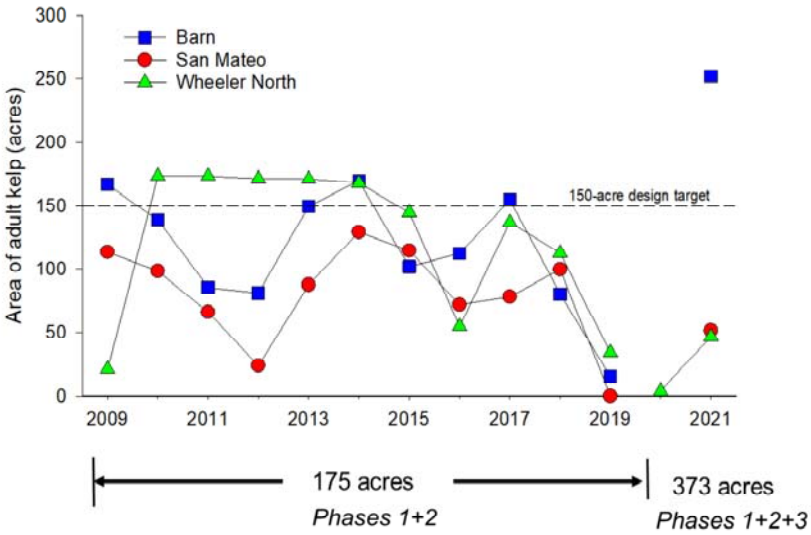
- *A substantial increase in the density of adult kelp in the Phase 2 and 3 polygons in 2022 should lead to a substantial increase in the area of medium-to-high density adult giant kelp at Wheeler North Reef*



- A substantial increase in the density of adult kelp in the Phase 2 and 3 polygons in 2022 should lead to a substantial increase in the area of medium-to-high density adult giant kelp at the Wheeler North Reef
- We will be watching this closely next year to see if this turns out to be the case

Area of Medium-to-High Density Adult Giant Kelp

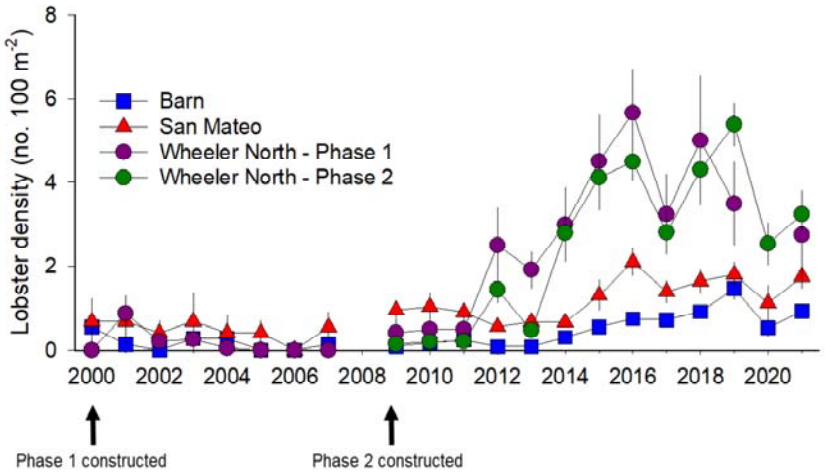
The area of adult giant kelp at Wheeler North Reef typically has been *within or above* that of nearby natural reefs scaled to the area of Wheeler North Reef

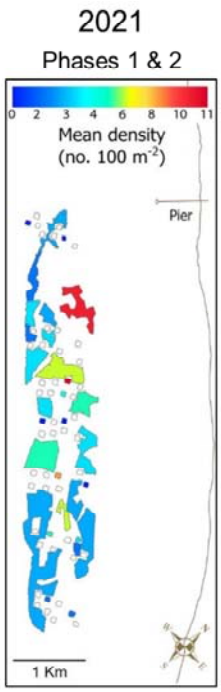


- Comparison of temporal changes in kelp area at nearby natural reefs provides insight into the relative ability of Wheeler North Reef to meet its targeted design of sustaining at least 150 acres of medium-to-high density adult kelp
- Comparisons to natural reefs also provide insight into whether the recent decline observed in kelp area is specific to Wheeler North Reef or more characteristic of the region
- To do this comparison we scaled the size of the natural reefs at Barn and San Mateo to the size of the Wheeler North Reef, which as mentioned earlier changed in size from 175 acres in 2009-2019 to 373 acres in 2020 and 2021
- The data plotted in this graph show that the area of medium-to-high density kelp supported by the Wheeler North Reef has typically been as high or higher than that supported by a similar sized area of natural reef
- Moreover, the erratic fluctuations and general decline in giant kelp observed at Wheeler North Reef since 2016 were also observed at the natural reference reefs
- In our more recent survey, the area of adult kelp at Barn, the more distant reference reef, increased dramatically in 2021 while the increase observed at San Mateo, which is located much closer to Wheeler North Reef, was more moderate and similar in magnitude to that observed at Wheeler North Reef

Temporal and spatial patterns of spiny lobster abundance at Wheeler North Reef

- *Regional increase in lobster density beginning in 2012*
- *Increase has been disproportionately higher at Wheeler North Reef*
- *Lobster density varies unpredictably in space across Wheeler North Reef*

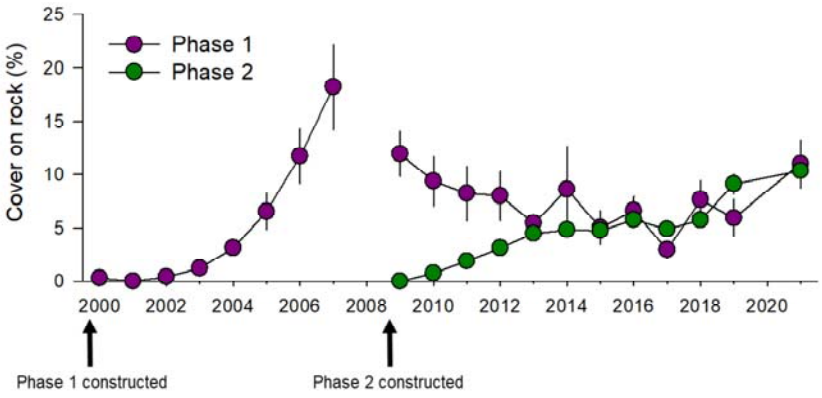


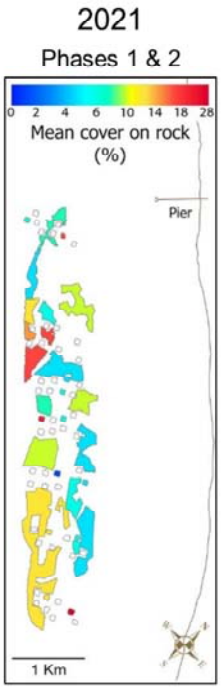


- While the SONGS permit does not include performance standards that pertain specifically to spiny lobster they are a species of special interest given their ecological and economic importance
- Data on lobster abundance have been collected as part of the performance monitoring of Phase 1 and 2 and we can use those data to examine the Wheeler North Reef's ability to sustain lobster populations
- Plotted here is a time series of lobster density (no. per 100 m^2) at the Phase 1 and 2 Wheeler North Reef and the two reference reefs at Barn and San Mateo since 2000
- The data show that lobster densities were generally below 1 per 100 m^2 on all reefs prior to 2012
- Since 2012 lobster densities have increased on all the reefs, but this increase has been 2-3 times higher on the Phase 1 and 2 reefs compared to Barn and San Mateo
- The map shows that in 2021 lobster densities averaged 2 or more per 100 m^2 in nearly all the polygons and as high as 11 per 100 m^2 in polygon 16 located just south of San Clemente Pier

Temporal and spatial patterns of sea fan coverage at Wheeler North Reef

- *Sea fan coverage on Phase 1 declined following a peak in 2006 and has not increased appreciably since*
- *Coverage on Phase 2 has gradually increased over time to a level similar to Phase 1*
- *Coverage tends to be higher on the offshore portion of Wheeler North Reef*

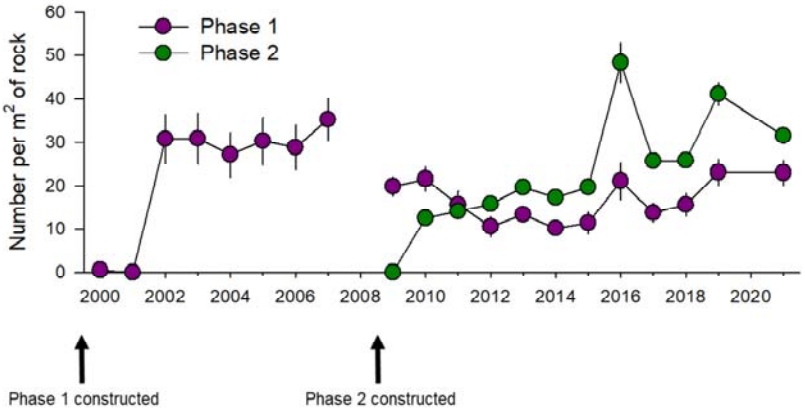


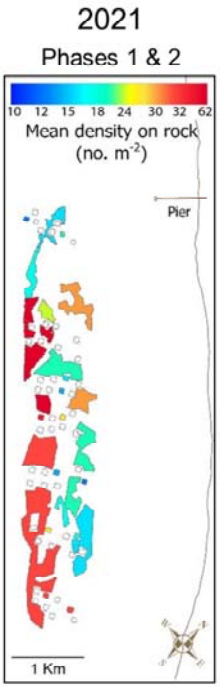


- The SONGS permit does include a performance standard aimed at ensuring that populations of native species don't reach undesirable levels that impair the important functions of the reef
- Sea fans have been identified as a species of potential concern and we have been following changes in their percent cover and density on the Phase 1 and 2 reefs since monitoring began in 2000.
- Shown here is a time series of the percent of rock on the Phase 1 and 2 reefs covered by sea fans
- Phase 1 was rapidly colonized by sea fans and it covered nearly 20% of the rock by 2007, which was 8 years after construction
- Mortality events cause the cover of sea fans to decline on Phase 1 reaching a low of ~4 % in 2017
    - Phase 1 has not shown a net increase in sea fan cover since 2009
- The cover of sea fans on Phase 2 has steadily increased over time to a level in 2021 that is similar to that of Phase 1, which is ~ 12 %
- If Phase 2 follows a trajectory similar to that of Phase 1, then the cover of sea fans on Phase 2 will likely level off rather than continue to increase
- The map on the right shows that sea fan cover in 2021 tended to be highest on the deeper offshore polygons

Temporal and spatial patterns of sea fan density at Wheeler North Reef

- *Sea fan density on Phase 1 has changed little since 2009 and increased gradually on Phase 2*
- *Densities highest on the offshore portion of Wheeler North Reef*





- Patterns of sea fan densities resemble those of percent cover
- Densities on Phase 1 declined by nearly 50% between 2007 and 2009 indicating a large mortality event
- Since 2009 there has been little change in sea fan density on Phase 1 and an overall increase in density on Phase 2
- As with percent cover, densities of sea fans were higher on the offshore polygons of Wheeler North Reef

Summary

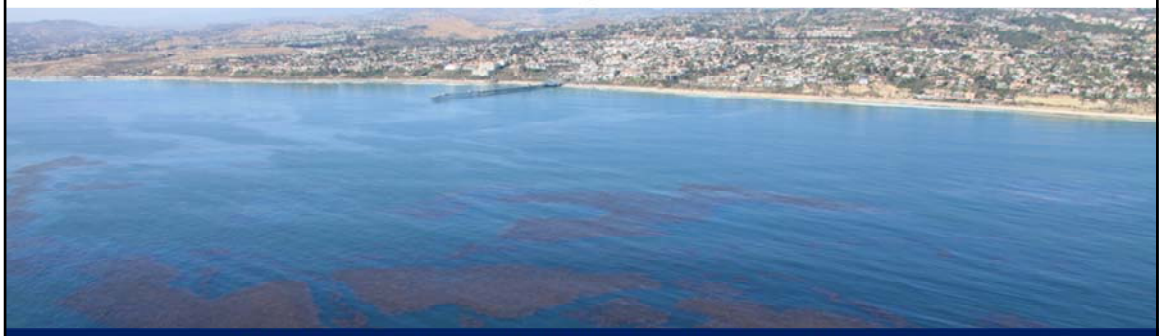
- The contribution of the Phase 3 expansion to the standing stock of reef fishes and the area of medium-to-high density giant kelp appears to be additive
- If the trajectory of community development of Phase 3 follows that of the similarly constructed Phase 2, then the standing stock of reef fish and the area of medium-to-high density giant kelp should increase over the next few years
- The design and location of Wheeler North Reef appears highly favorable for supporting populations of spiny lobster
- The coverage and density of sea fans on Phase 1 has not continued to increase during its 22 years of existence, suggesting that sea fans are not anticipated to reach “undesirable” levels on Phases 2 and 3 of the Wheeler North Reef any time soon

Annual Public Workshop

San Onofre Nuclear Generating Station Artificial Reef Mitigation Project
Monday, April 4, 2022

Agenda

1:30 – 1:40	**Introduction to SONGS reef mitigation –*Dan Reed, UCSB***
1:40 – 2:20	**Results from the 2021 performance monitoring of the Wheeler North Reef – *Steve Schroeter, UCSB***
2:20 - 2:40	**Questions and comments on performance monitoring results**
2:40 – 3:10	**Temporal and spatial patterns of species abundance on Wheeler North Reef – *Kat Beheshti, UCSB***
3:10 - ??	**Questions and comments and general discussion**



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