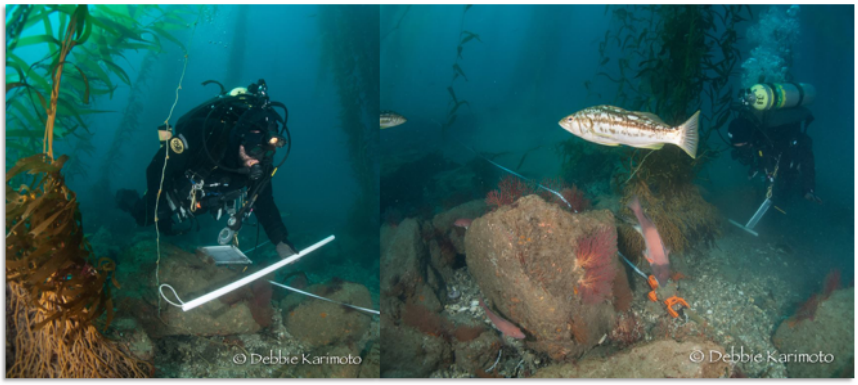
Lessons learned from 24 years of monitoring Wheeler North Reef



April 8, 2024

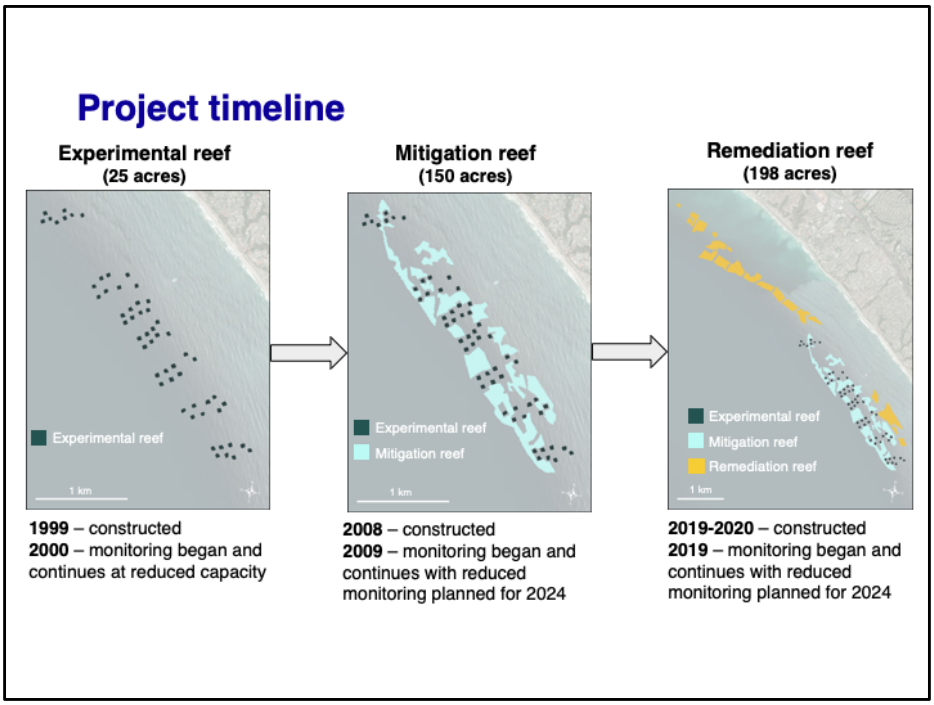
This talk reviews a series of lessons learned from 24 years of monitoring Wheeler North Reef.

Unprecedented in size and scope of project – Wheeler North Reef

- World's largest artificial reef (373 acres)
- 24 years of monitoring
  - 15 performance standards evaluated annually
  - Two reference reefs monitored concurrently
- ~ 650 dive hours per year

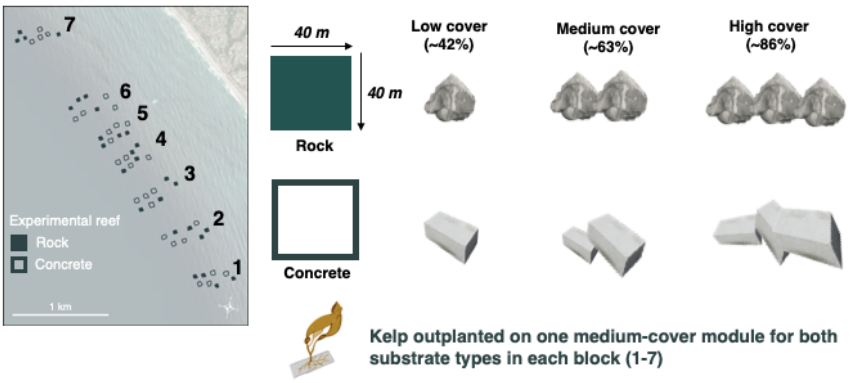
What have we learned?

• First, we'd like to acknowledge the unprecedented size and scope of the project. Wheeler North Reef is the world's largest artificial rocky reef of its kind at 373 acres.
• The artificial reef and two natural reference reefs have been monitored annually for 24 years, with dive hours averaging 650 per year.
• As the previous talk highlighted, Wheeler North Reef is functioning similarly to reference reefs and as a result, we are moving to reduced monitoring this year, which seemed like an opportune time to reflect on what have we learned from this long-term mitigation monitoring program.



• We have organized this talk chronologically, starting first with the lessons learned from the 25-acre experimental reef that was constructed in 1999 and monitored from 2000 to present. Full monitoring of the experimental reef extended from 2000-2004.
• We will then move on to a subset of the lessons learned from the mitigation reef which was constructed in 2008 and monitored from 2009 to present.
• Finally, we will demonstrate how monitoring data can be used to identify reasons for project underperformance and inform remedial action using the 198-acre remediation reef as our example. The remediation reef was constructed over a two year period from 2019 to 2020 and monitoring began in 2019 and continues today.

Lessons learned from the experimental reef



The experimental reef (25-acres) tested reef design
(substrate type, % cover of hard substrate, kelp out-planting)

• Before we jump into the lessons learned from experimental reef, I'd like to provide a brief overview of the motivation for the experimental reef. It was unknown how the % cover of hard substrate or substrate type would influence colonization of fish and kelp.

• In addition, concerns were raised during the planning stages of the experimental reef that:

1. concrete, which at the time was the cheaper of the two material types, wouldn't perform as well as rock, and
2. kelp was not capable of dispersing the 3.5 km necessary for natural colonization across the entire artificial reef.

• The first phase of the artificial reef was designed as an experiment to explicitly address these concerns and unknowns.

• It was organized into seven blocks and each block had eight modules constructed with either rock or concrete, indicated by the squares on the map.

• Each module was built to have one of three nominal coverages of reef material, low (42%), medium (63%), and high (86%) and on a subset of the medium cover modules, kelp was outplanted.

Lessons learned from the experimental reef (2000-2004)

Experimental reef addressed several unknowns:

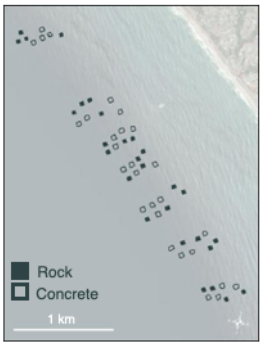
Artificial reef design

Do kelp and fish density vary by substrate type and cover?

Kelp colonization

How does kelp recruitment vary as function of distance from source population?

Can outplanting be used to augment natural kelp recruitment?



Now that we are familiar with the experimental reef design, let's jump into several unknowns addressed by the experimental reef:

• The first, do kelp and fish density vary by substrate type and cover? addressed uncertainty regarding how to design an artificial reef that supported a giant kelp forest and met the objectives of the project.

• The last two questions pertained to unknowns about the ecology of kelp colonization, which has implications that could inform ongoing efforts of kelp restoration in California and elsewhere in the world:

1. how does kelp recruitment vary as function of distance from source population? Or put in other words, how far can kelp disperse, and
2. can outplanting be used to augment natural kelp recruitment in the event that dispersal is limited.

Lessons learned from the experimental reef (2000-2004)

Experimental reef addressed several unknowns:

Artificial reef design

Do kelp and fish density vary by substrate type and cover?

Kelp colonization

How does kelp recruitment vary as function of distance from source population?

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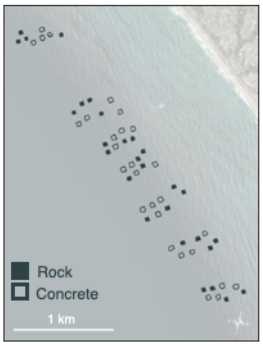
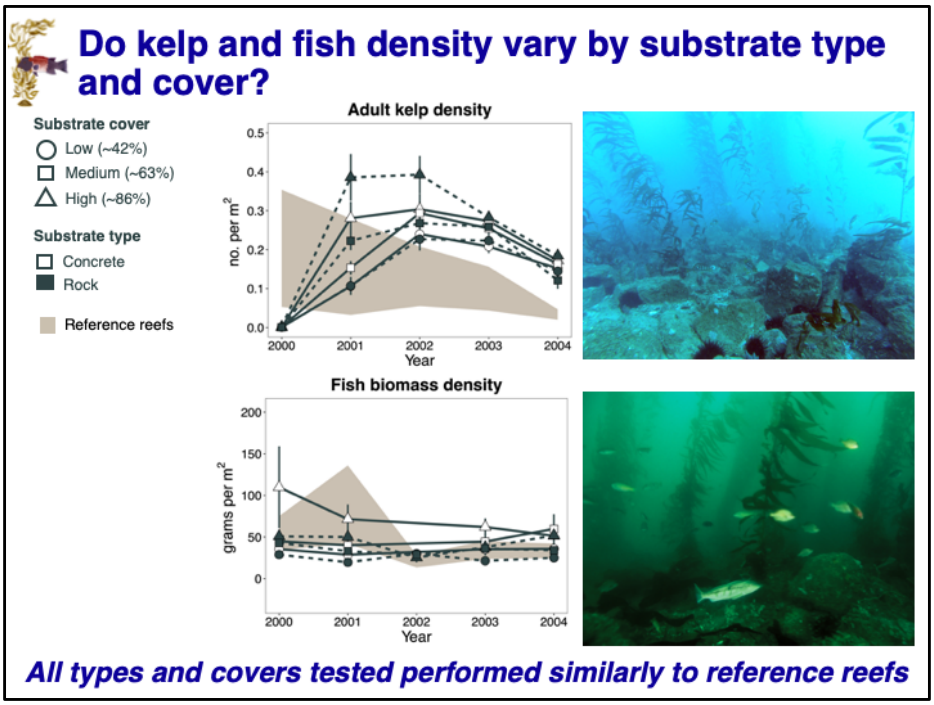


Starting with the first unknown, do kelp and fish density vary by substrate type and cover?



- Plotted is adult kelp density for low, medium, and high cover of hard substrate. White points represent data from concrete modules and filled points represent data from rock modules.
- Generally, we see little difference in adult kelp density within cover categories of both concrete and rock in a given year and a general pattern that higher substrate cover yields higher kelp density.
- Importantly, when we overlay data from the reference reefs shown as gray shading that represents the range defined by mean - 1 standard error for the lowest performing reference reef and the mean + 1 standard error for the highest performing reference reef in any given year, we see that, with the exception of the first year following construction, the experimental reef supported kelp densities similar to or greater than that observed at the reference reefs.
- In the bottom graph we show fish biomass, color coded the same as the above figure for kelp. Fish biomass was similar between substrate cover and types and generally falls within mean values observed at the reference reefs.
- These results indicate that kelp density and fish biomass were comparable to reference reefs for all substrate types and substrate coverages tested. It's important to note that analyses of the benthic community of invertebrates and understory algae showed similar results.

Artificial reef design

Experimental reef results set parameters (substrate type and cover) for the mitigation reef

- Higher particle emissions and cost of concrete factored into Southern California Edison's (SCE) proposal to construct a mitigation reef of relatively low cover quarry rock

Mitigation reef construction (2008)

- To summarize, the results from the experimental reef set the design parameters with respect to substrate type and cover (i.e., substrate cover of the mitigation reef could not be below the lowest cover tested, which averaged 42%).
- Ultimately, given the higher environmental impact (emissions, air quality) associated with using concrete over rock and the increasing cost of concrete, SCE's proposal, that was approved by the Commission, was to construct a low relief reef with a minimum of 42% bottom coverage of quarry rock.

Lessons learned from the experimental reef (2000-2004)

Experimental reef addressed several unknowns:

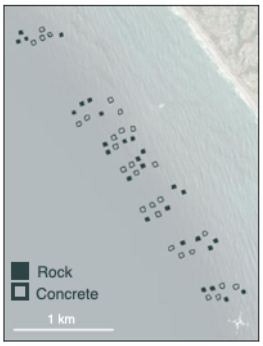
Artificial reef design

Do kelp and fish density vary by substrate type and cover?

Kelp colonization

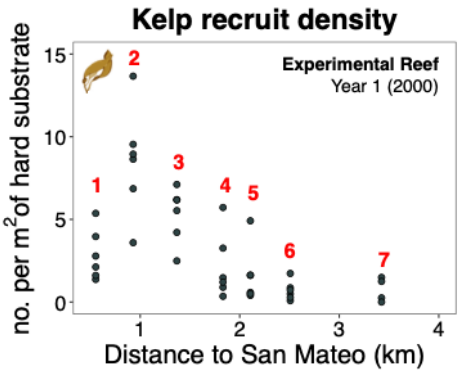
How does kelp recruitment vary as function of distance from source population?

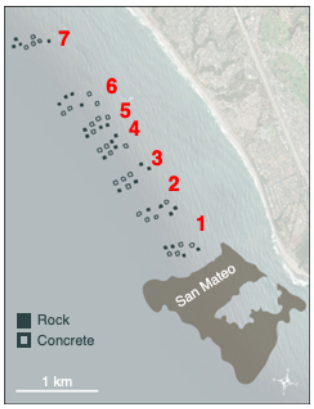
Can outplanting be used to augment natural kelp recruitment?



- Next we will address the unknowns relevant to recent statewide investment and interest in kelp restoration.
- First, how does kelp recruitment vary as function of distance from the nearest source population of giant kelp?

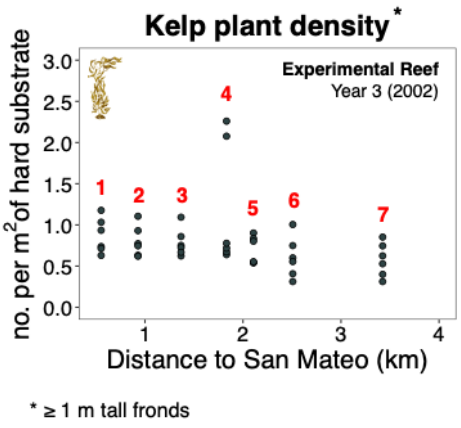
Kelp recruited across the experimental reef in the first year

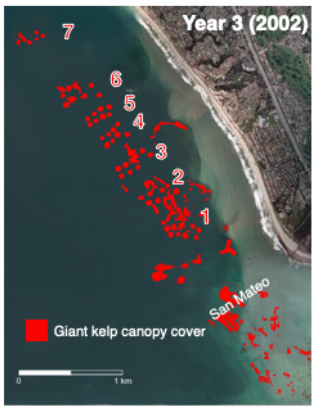




- Here we show kelp recruit density on the experimental reef one year after reef construction as a function of distance from San Mateo, the nearest source population of giant kelp.
- You can see that kelp recruited across the entire 3.5 km long footprint of the experimental reef.
- The density of kelp recruits was highly variable among the modules within the seven experimental blocks, as well as among the blocks as it generally decreased with increasing distance from San Mateo,

Dense kelp stands formed across experimental reef within three years





- The pattern of decreasing kelp density with increasing distance from San Mateo shown in the previous slide disappeared by year 3 due to density-dependent thinning of plants on modules with high recruitment.
- Importantly, recruitment densities were sufficient on all of the modules (even those farthest from San Mateo with the lowest densities of recruits) to produce dense kelp stands with floating surface canopies by year 3
- This is shown in the infrared satellite image on the right taken in 2002 which depicts the kelp canopy in red covering all 56 modules of the experimental reef

Lessons learned from the experimental reef (2000-2004)

Experimental reef addressed several unknowns:

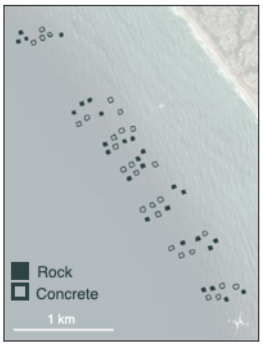
Artificial reef design

Do kelp and fish density vary by substrate type and cover?

Kelp colonization

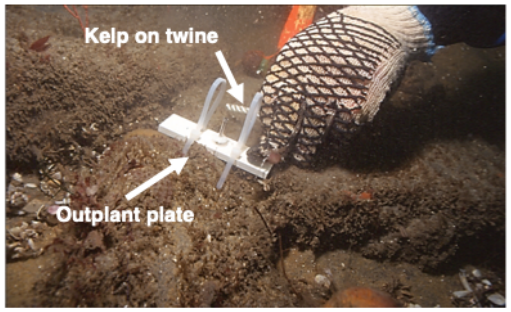
How does kelp recruitment vary as function of distance from source population?

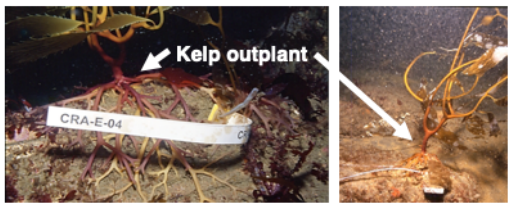
Can outplanting be used to augment natural kelp recruitment?

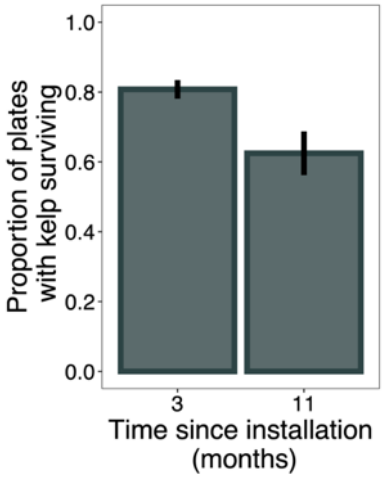


Next we examined whether outplanting laboratory-reared kelp embryos to the artificial reef can be used to augment natural kelp recruitment

Outplanting kelp can be successful







- The photos on the left show a recently installed plate with embryonic kelp on twine and what those kelp outplants looked like at subsequent monitoring dates.
- Plotted on the right is the proportion of plates with kelp that survived 3 and 11 months post-installation. These results show that the kelp outplanting effort on the experimental reef was successful with majority of kelp surviving almost one year following installation.
- This is just one of many different methods that can be used to outplant kelp
- That said, mimicking what nature does by outplanting kelp takes a tremendous amount of effort, and in this case was not needed as kelp rapidly colonized the entire reef without assistance.
- Our finding of widespread and rapid colonization by giant kelp is very important from a kelp forest restoration standpoint because it suggests that costly and laborious interventions aimed at seeding degraded populations in many cases is likely unnecessary.
- Instead, kelp restoration efforts may be better served if they focus on ameliorating the stressors that cause kelp degradation and allow for natural colonization and succession to occur whenever possible.

Kelp colonization

Widespread kelp dispersal across 3.5 km experimental reef

- Kelp dispersal was widespread; recruit density decreased with distance from source
- Even at low recruitment densities, dense kelp canopy formed within 3 years
- Outplanting, while successful, was not needed—natural kelp colonization was sufficient

Kelp canopy on experimental reef

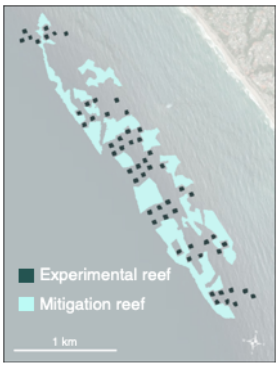
Kelp outplant on experimental reef

- To summarize, kelp dispersal and subsequent colonization was widespread and despite recruit density decreasing with distance from the nearest source population, dense stands of kelp formed within three years on all 56 modules, as shown by the aerial image of a subset of the modules of the experimental reef.
- Finally, outplanting kelp to Wheeler North Reef (shown in the photo on the far right) while successful, was unnecessary. Natural kelp colonization was sufficient and resulted in high densities of adult kelp.

Lessons learned from mitigation monitoring (2009-2023)

Monitoring addressed several unknowns:

- Do sea fans exclude kelp on Wheeler North Reef?
- Does Wheeler North Reef produce reef fish or simply attract them from natural reefs?
- How long does it take Wheeler North Reef to resemble natural reefs?



- Moving now to the lessons learned from mitigation monitoring which as I mentioned before began in 2009 and continues today.
- There were several unknowns related to the ecological dynamics of artificial reefs; including their propensity to support high densities of sea fans, which were shown by earlier studies to exclude kelp, a concern most relevant to reefs in Southern California.
- The other two listed unknowns were more applicable to artificial reefs in general, specifically with regards to:

1) the extent to which they produce new fish as opposed to simply attracting them from other reefs, and

2) their ability to resemble natural reefs and the time frame for doing so

Lessons learned from mitigation monitoring (2009-2023)

Monitoring addressed several unknowns:

- **Do sea fans exclude kelp on Wheeler North Reef?**
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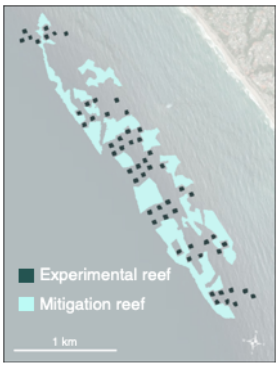
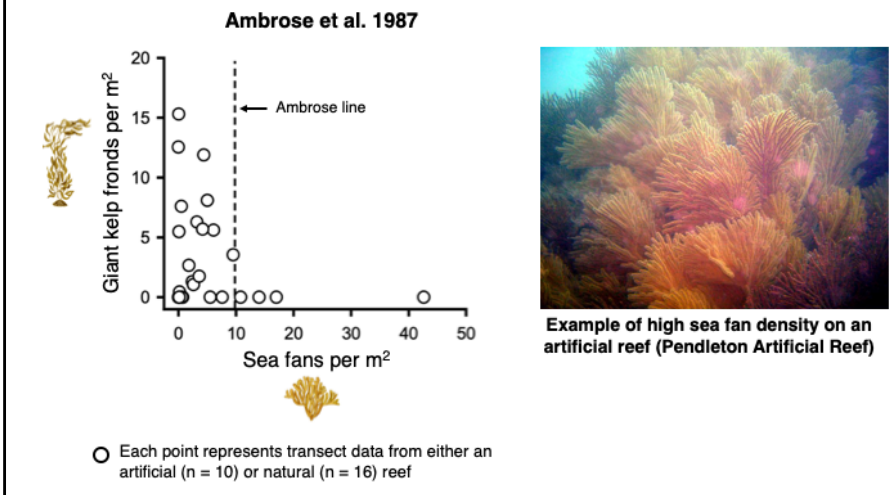


Beginning with our first question, do sea fans exclude kelp on the artificial reef…

Sea fans shown to exclude kelp on reefs



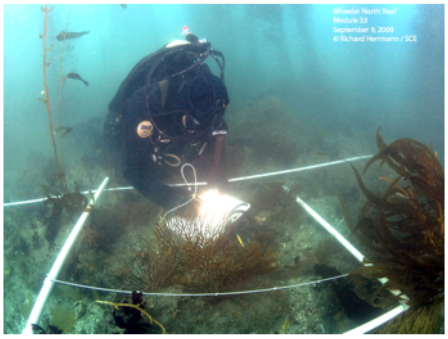
Example of high sea fan density on an artificial reef (Pendleton Artificial Reef)

- During the impact assessment phase of the SONGS mitigation project Rich Ambrose and colleagues examined the propensity of sea fans to exclude giant kelp
- They did this by comparing the mean densities of sea fans and giant kelp at 10 artificial and 16 natural reefs which is shown in the figure on the left
- Ambrose et al. identified a threshold density of 10 adult sea fans per m2, beyond which, giant kelp frond density dropped to zero
- We refer to that this threshold as the “Ambrose line”. The photo on the right provides an example of the high densities of sea fans that can occur on artificial reefs

Sea fans appeared more prevalent on high-relief, high-cover reefs

- **Low-relief reefs purported to have sufficient scour to reduce sea fan abundance**
  - **Design was to construct low-relief, low-cover artificial reef**

Pendleton Artificial Reef
HIGH-RELIEF

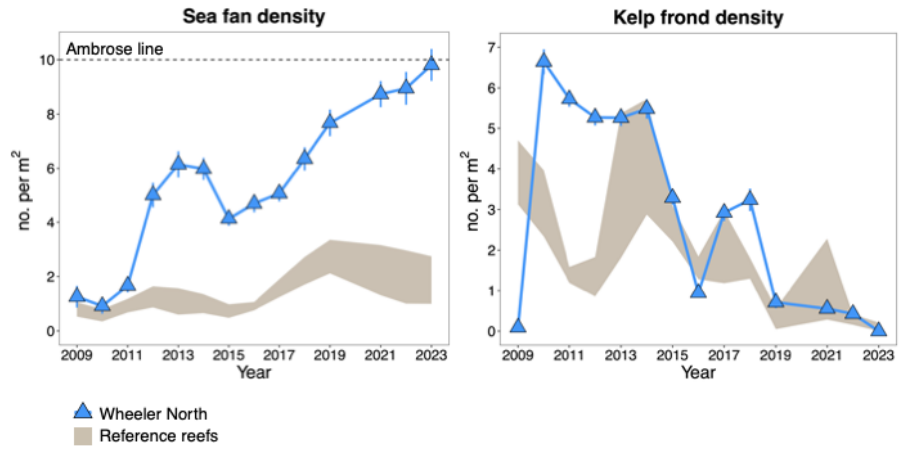


Wheeler North Reef
LOW-RELIEF

Do sea fans exclude kelp on Wheeler North Reef?

- Work by Ambrose and others suggested that sea fans are more likely to dominate high-relief reefs with high rock cover,
- Low-relief reefs were purported to have sufficient scour to reduce sea fan establishment.
- This line of thinking coupled with the desire to replace the resources lost at the San Onofre Kelp Forest, which was also a low-relief reef , formed the basis for the decision to design Wheeler North Reef as a relatively low-relief, low-cover reef.
- A classic example of a high relief artificial reef in the region is Pendleton Artifical Reef shown on the left. Versus the low-relief Wheeler North Reef, shown on the right.
- Given this concern, we wanted to explore whether or not sea fans exclude kelp on Wheeler North Reef.

Wheeler North Reef supports high sea fan densities but they do not exclude kelp

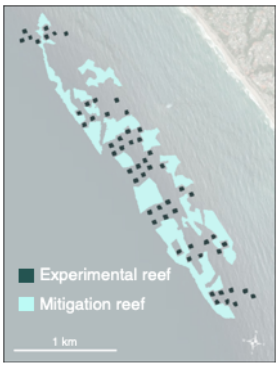


- The plot on the left shows adult sea fan density on Wheeler North Reef, represented by the blue triangles versus the reference reefs, represented by the shaded ribbon. The “Ambrose line” at 10 sea fans per m2 is shown for reference.
- We see that sea fan densities have been climbing on Wheeler North Reef and nearly approached the Ambrose line in 2023, whereas densities on the reference reefs have remained low and relatively stable.
- While Wheeler North Reef supports high densities of sea fans, the sea fans do not appear to be excluding kelp. The figure on the right shows kelp frond density, which serves as a good estimate of kelp biomass.
- While we see a regional decline in kelp frond density since 2011, frond density on Wheeler North Reef has remained as high as, if not greater than, the reference reefs in all years except for 2009 and 2016
- This indicates that despite high sea fan densities on Wheeler North Reef, there is no evidence that they are excluding kelp.

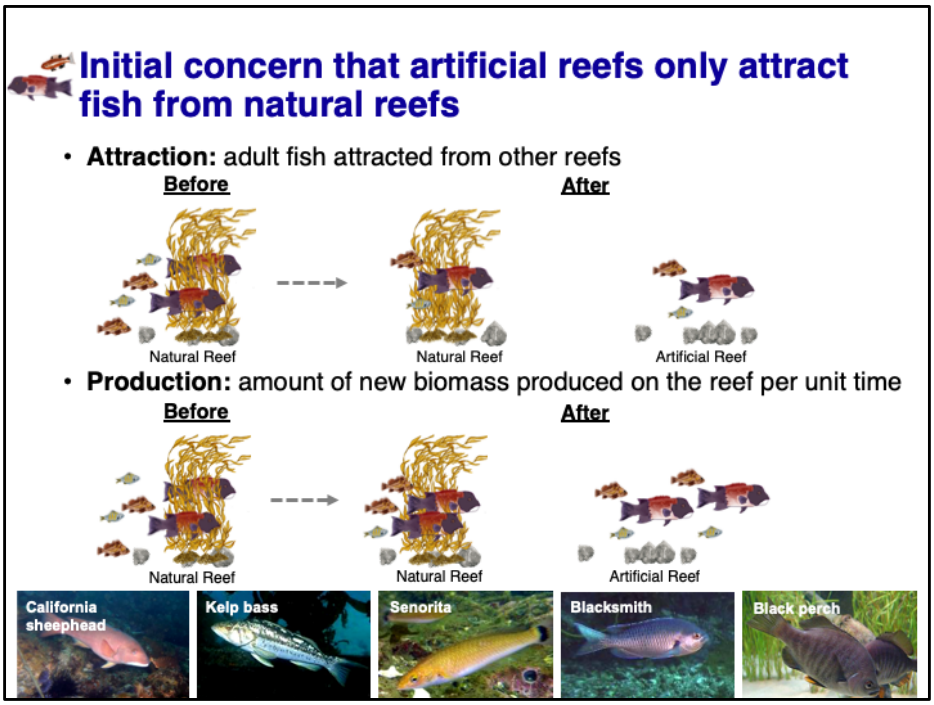
Lessons learned from mitigation monitoring (2009-2023)

Monitoring addressed several unknowns:

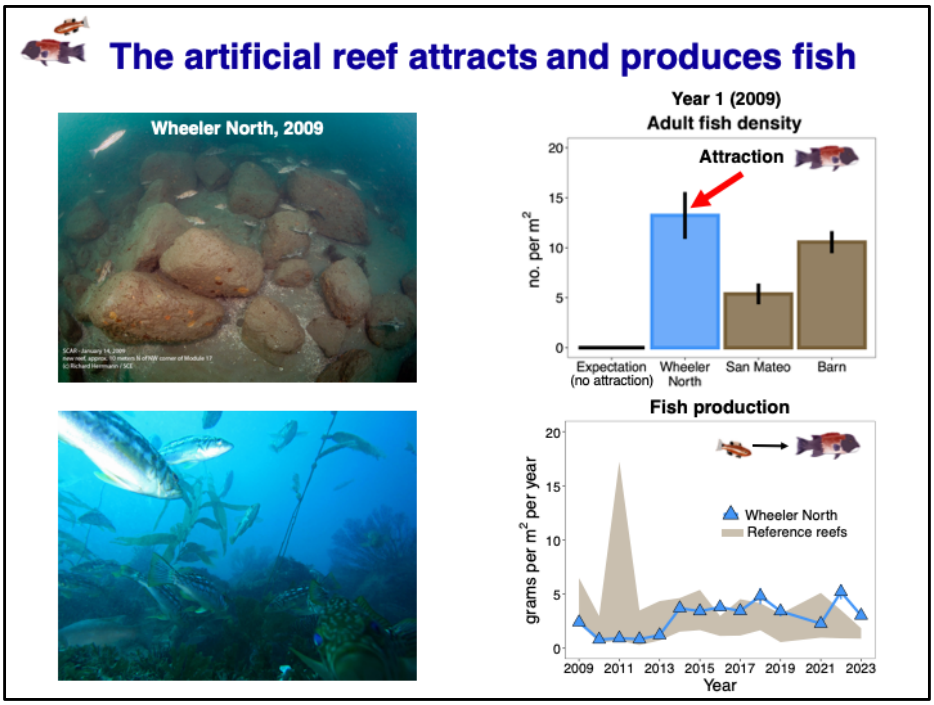
- Do sea fans exclude kelp on Wheeler North Reef?
- **Does Wheeler North Reef produce reef fish or simply attract them from natural reefs?**
- How long does it take Wheeler North Reef to resemble natural reefs?



Next we will address the unknown of whether Wheeler North Reef produced new fish or only attracts existing fish from other reefs



- Here, attraction refers to the relocation of fish from natural reefs to the artificial reef,
    - It is most easily evaluated by looking at the density of adult fish on a reef immediately following construction.
    - The schematic here illustrates a natural reef before the artificial reef was constructed versus the natural and artificial reef after the artificial reef was constructed.
    - With attraction, the same individuals on the nearby natural reef are spread across the natural reef and newly constructed artificial reef, leading to a redistribution of fish in the region rather than an overall increase.
- Production, on the other hand, is the amount of new biomass produced on the reef per unit time. In this case, the construction of new habitat produces new fish and adds fish biomass to the region.
    - Given this concern that the artificial reef would only attract fish, fish production was included as one of the performance standards in the SONGS permit.
    - As Rachel mentioned in the previous talk, we evaluate the fish production standard using data on biomass density, and somatic and gonadal growth collected from the five species shown below.

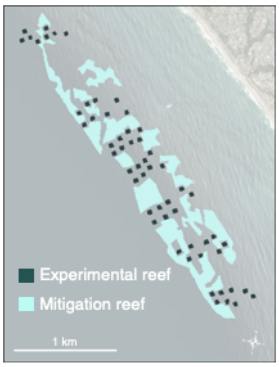


- The arrival of adult fish on the artificial reef soon after construction would indicate attraction. If there was no attraction, then the expectation would be that no adult fish would be observed.
- During the first year of monitoring we found strong evidence that Wheeler North Reef attracted fish from natural reefs.
- We observed relatively high densities of adult fish on Wheeler North Reef that were considerably greater than the densities observed at both reference reefs, indicating that existing adult fish on natural reefs relocated to the artificial reef within the first year following its construction.
- When looking at fish production at Wheeler North Reef relative to the reference reefs, we see that it took ~ 5 years for fish production at Wheeler North Reef to reach levels within or above the those observed at the reference reefs.
- In summary, these data taken together suggest that the artificial reef both attracts and produces new reef fish.

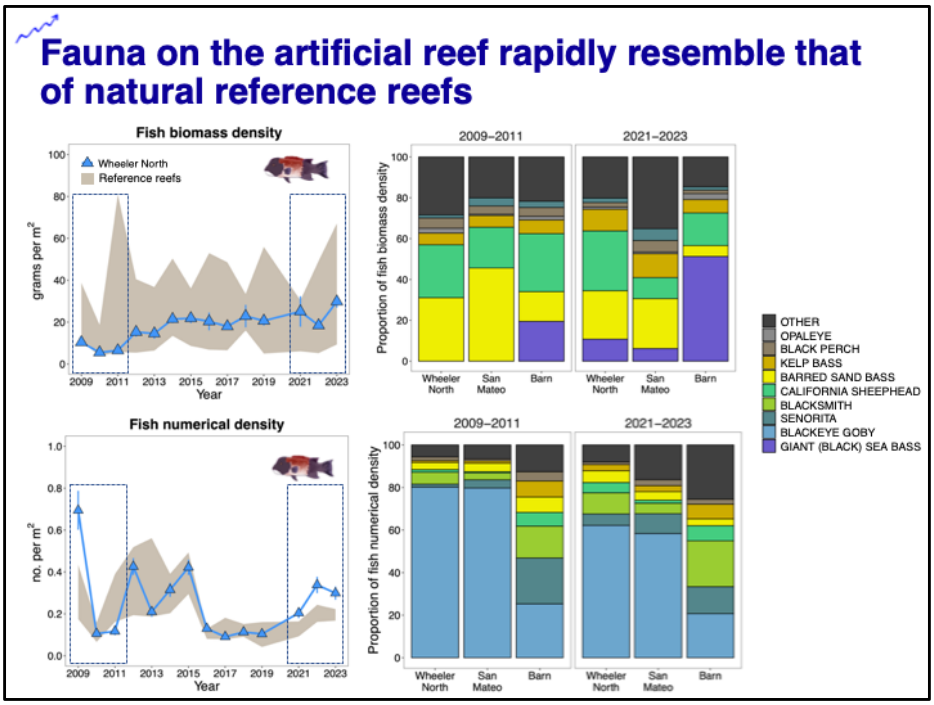
Lessons learned from mitigation monitoring (2009-2023)

Monitoring addressed several unknowns:

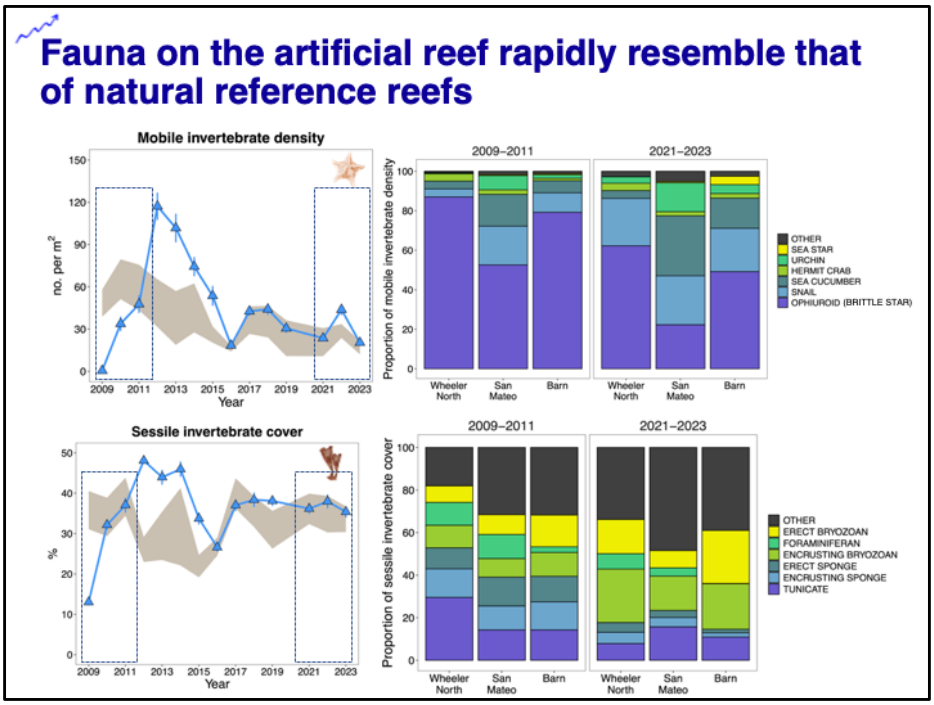
- Do sea fans exclude kelp on Wheeler North Reef?
- Does Wheeler North Reef produce reef fish or simply attract them from natural reefs?
- **How long does it take Wheeler North Reef to resemble natural reefs?**



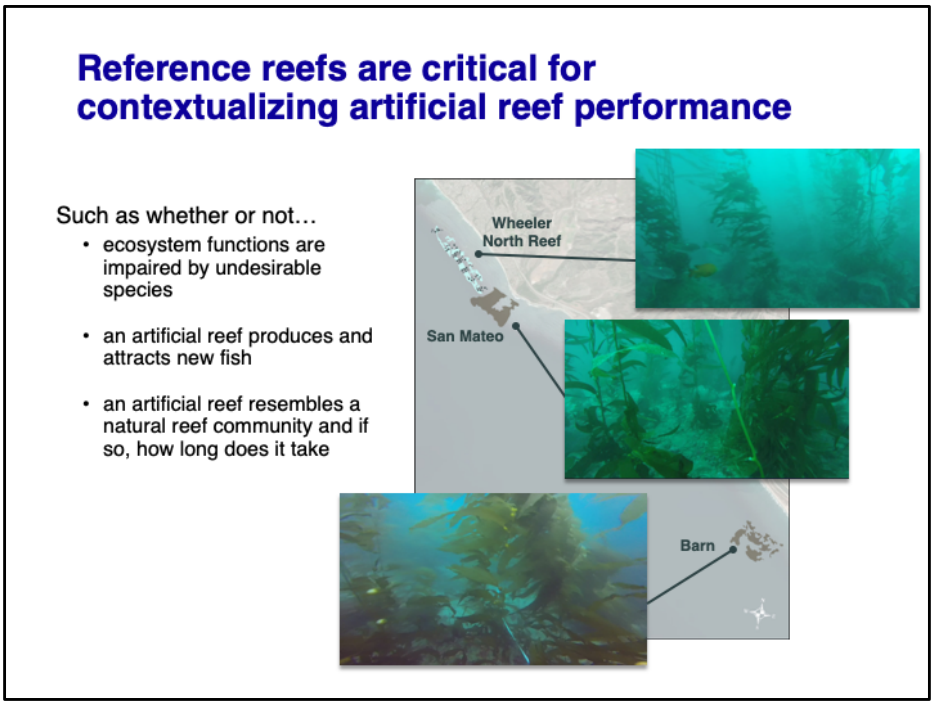
Next we will show data that answers the question, how long does it take Wheeler North Reef to resemble natural reference reefs?



- Plotted on the left is fish biomass density at Wheeler North Reef and the reference reefs over time. We found that fish biomass density has been within the range of the reference reefs throughout the time series, but this does not address whether or not the fish community at Wheeler North resembled that of the natural reefs. The stacked bar graph on the right shows the proportion of fish biomass comprised by the top 9 species on the three reefs averaged over the first three years of monitoring (2009-2011). These species make up ~70-80% of the total biomass on the three reefs. Species are color coded as shown in the legend on the right. In those early years, the species composition of fish biomass at Wheeler North Reef most resembled San Mateo, the closer of the two reference reefs. The species composition at Barn was similar to Wheeler North Reef as well with the exception of a few Giant sea bass individuals that made up a large proportion of the total biomass at Barn. When we look at the last three years of monitoring (2021-2023) we see similar patterns suggesting that the similarity in the species composition of fish biomass among the three reefs persisted over time, Wheeler North Reef most resembled San Mateo and the few giant sea bass on Barn make up a large proportion of the biomass on the reference reef.
- Next we plot fish numerical density and see that throughout the time series it has generally been as high or higher at Wheeler North Reef compared to the reference reefs. These 9 species make up >90% of the fish observed on all three reefs. The species composition of fish at Wheeler North Reef during the first three years after its construction in terms of its numerical abundance was most similar to San Mateo, with blackeye goby comprising the largest proportion of individuals. This pattern remained relatively consistent during the last few years of monitoring, except blackeye goby made up a smaller proportion of the total and other species such as California sheephead and senorita made up a larger proportion.



- Here we produce similar figures for mobile invertebrate density. We see that it took three years for mobile invertebrate densities to reach or exceed the densities observed at the reference reefs. Since 2011, Wheeler North Reef has been within or above the range of reference reefs. During the first three years the species composition of the mobile invertebrate community was dominated by brittle stars at all three reefs. Wheeler North Reef most resembled Barn and that pattern has largely continued the last few years of monitoring with the exception that the relative abundance of brittle stars has declined at all three reefs while that of snails has increased
- The percent cover of sessile invertebrates at Wheeler North Reef shown in the bottom graph has been within or above the range of reference reefs with the exception of 2009. The species composition of sessile invertebrates in the first few years of monitoring was similar across the three reefs, though percent cover of tunicates was higher on Wheeler North Reef relative to the reference reefs. In the last few years of monitoring, we saw a relative increase in the cover of erect and encrusting bryozoans at all three reefs as well as an increase in the proportion of sessile invertebrate cover represented by other species.



These lessons learned demonstrate importance of reference reefs for contextualizing artificial reef performance with respect to:

1) whether or not ecosystem functions are impaired by numerically abundant species capable of outcompeting valued species as was shown between sea fans and giant kelp.

2) whether or not the production of fish biomass is comparable to that of natural reefs, and

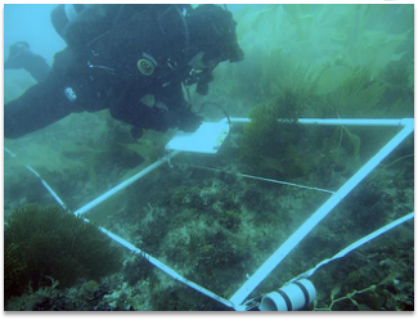
3) whether or not the species composition of an artificial reef resemble that of a natural reef community and if so, how long it takes.

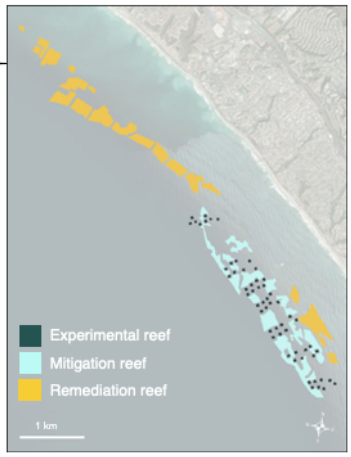
Lessons learned from long-term monitoring (2000-2023)

Monitoring data are used to:

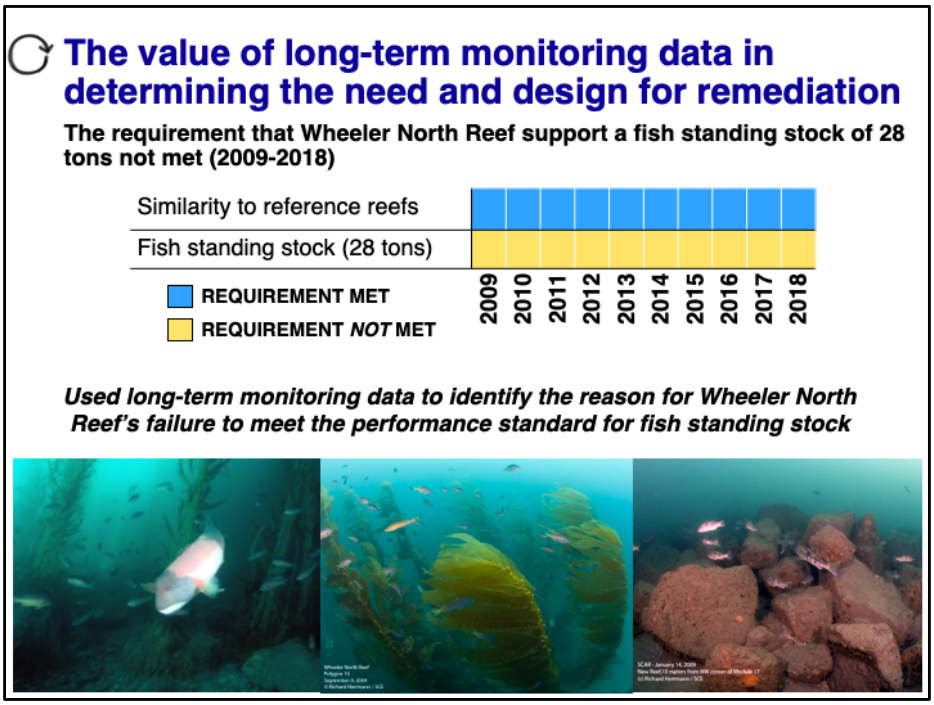
- Evaluate project performance
- Investigate the reason(s) for project failure or underperformance
- Develop recommendations for potential remedial action(s) or adaptive management that addresses failure(s)

How can monitoring data inform remedial action?

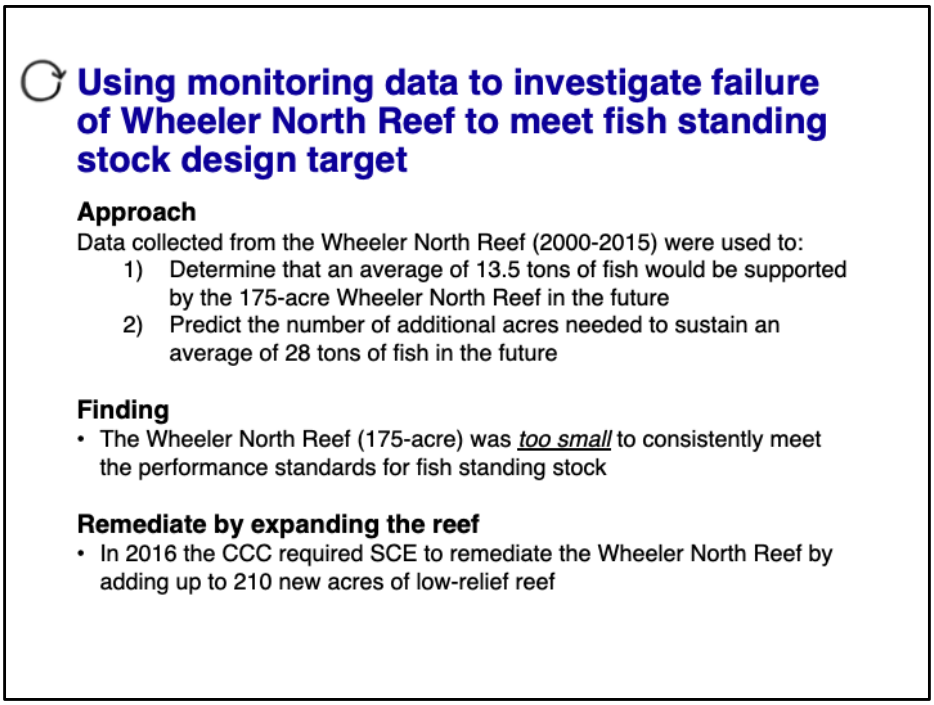




- The last section of this talk reviews lessons learned from long-term monitoring.
- First, we'd like to highlight the value of long term monitoring data in 1) evaluating project performance, 2) investigating the reason(s) for project failure or underperformance, and 3) developing recommendations for potential remedial action or adaptive management that addresses failure(s)..
- The talk by Rachel that preceded this presentation and the results that I have shown up to this point demonstrate the first point; how monitoring data can be used to evaluate project performance.
- The remainder of my talk focuses on the other two uses of long-term monitoring data to ask, how can monitoring data inform remedial action?
- I will highlight the use of different components of the long-term monitoring dataset to answer this question.



- Although the biomass density of fish at Wheeler North Reef was similar to that of the reference reefs it consistently failed to meet the requirement that it sustain a fish standing stock of 28 tons.
- In 2015, we conducted analyses using long-term monitoring data to identify the reason for this failure

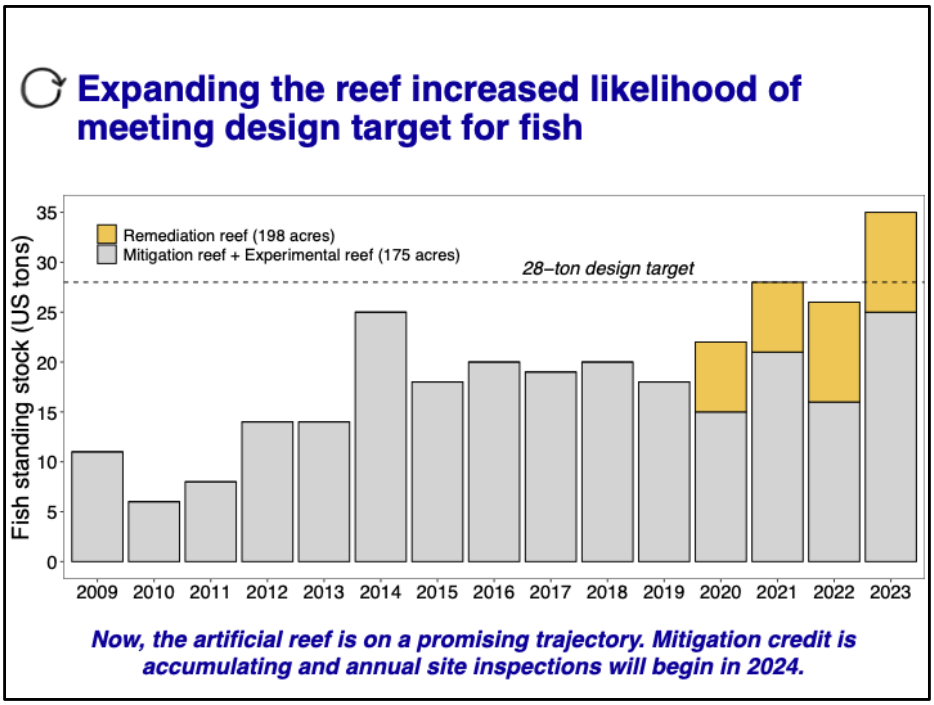


Data collected from the 175-acre Wheeler North Reef from 2000-2015 were used to:

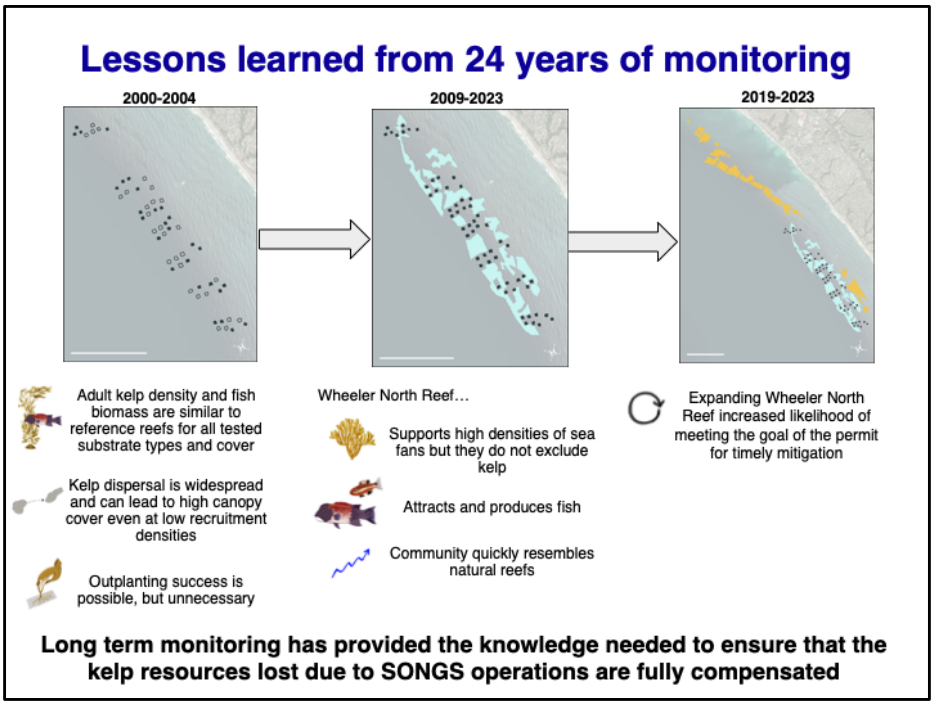
1. determine that an average of 13.5 tons of fish would be supported by the 175-acre Wheeler North Reef in the future, and
2. predict the number of additional acres needed to sustain an average of 28 tons of reef fish in the future.

- These analyses showed that the configuration of the reef was too small to consistently meet the 28-ton standard for fish standing stock
- The CCC used this information to require SCE to expand the reef by up to 210 acres in order for the reef to meet the fish standing stock requirement.

The large photo shows the construction of the 198-acre remediation reef which occurred from 2019-2020 and the smaller photos on the bottom show what that reef looked like underwater soon after the rock was dropped.



- Shown here is a time series of fish standing stock from 2009 to 2023.
- The contribution to fish standing stock from the 175-acre experimental and mitigation reefs is shown in grey, and the 198-acre remediation reef in gold.
- From 2009 to 2018, Wheeler North Reef had yet to meet the 28-ton design target.
- With the addition of the 198-acre remediation reef, it met the 28-ton design target in two of the last four years.
- Following the expansion, the artificial reef is now considered to be on a promising trajectory. Mitigation credit is accumulating and annual site inspections will begin in 2024



To summarize some of the lessons learned from the past 24 years of monitoring, from the experimental reef we learned that:

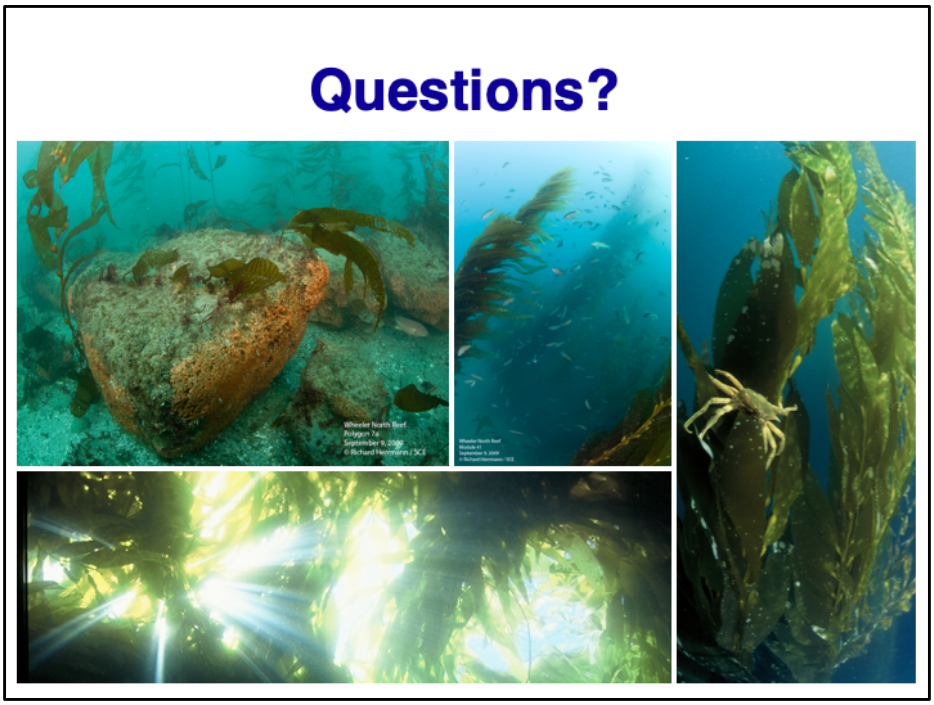
1. Adult kelp density and fish biomass were similar to reference reefs for all tested substrate types and coverages
2. Outplanting kelp to augment natural recruitment was successful, but unnecessary
3. Kelp dispersal was widespread and led to dense stands of adult kelp across the entire 3.5 km footprint of the reef within 3 years

From mitigation monitoring we learned that Wheeler North Reef:

1. Supports high densities of sea fans, despite being a low relief reef with low rock cover, but they do not exclude kelp
2. Attracts and produces fish
3. Supports a community of fish and invertebrates that quickly resembled natural reefs

Leveraging the long-term monitoring time series, we determined that expanding the reef was the remedial action necessary to consistently meet the requirement for fish standing stock and attain the goal of timely mitigation.

Overall, this talk highlights how long-term monitoring has provided the knowledge needed to ensure that the kelp resources lost due to SONGS operations are fully compensated.



I'd be happy to answer any questions. Thank you for listening.