Temporal Trends and MPA Effects in Mid-depth Reefs Across California's MPA Network Using a Remotely Operated Vehicle

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Introduction

In this analysis we investigated the MPA effect for a subset of focal fish species and for a grouping of key benthic species by analyzing the 17-year time series of ROV data collected by MARE and CDFW. We examine MPA effectiveness within each management bioregion (South, Central and North), statewide for a subset of species that occur across all management bioregions, and within individual MPAs. We examined the impact of MPA protection on the density of focal species, which are expected to increase in abundance following protection. Our focus is to assess the evidence to date for the MPA network meeting goals of helping sustain, conserve, and protect marine life populations and rebuild those that are depleted.

Methods

ROV surveys were conducted in paired MPA and reference sites across the MPA network between 2005 and 2021. 500 m long transects were broken into 10 m subunits for analysis to better capture the patchiness of habitats. Only MPAs that had three or more surveys were included so that trends could be better estimated (Table 1). A statistical modeling approach was taken to show how MPAs influenced the density of the focal species while accounting for important environmental drivers such as latitude, depth, and habitat. A term was also included in the model to allow the trend through time for each species outside of the MPAs to be determined. The MPA effect was modeled as a cumulative effect of years since implementation (YSI) and given a functional form by taking a log (YSI + 1) transformation (Figure 1).

Region	MPA Group	Transects by year (500 m)																	Total Transects	Total Series Replicates
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021		
North	Point St. George Reef Offshore SMCA										23	14					19	12	68	4
	Reading Rock SMR										19	19					20	14	72	4
	South Cape Mendocino SMR										14								14	1
	Mattole Canyon SMR										21	16							37	2
	Sea Lion Gulch SMR										15	6					18	20	59	4
	Big Flat SMCA										3								3	1
	Ten Mile SMR										19	20					20	18	77	4
	MacKerricher SMCA										12								12	1
	Point Arena SMR/SMCA							12				17					14	12	55	4
	Saunders Reef SMCA											8							8	1
	Stewarts Point SMR											3							3	1
	Bodega Bay SMR/SMCA							31				45				38	44		158	4
	Point Reyes SMR/SMCA					21													21	1
	North Farallon Islands SMR																10		10	1
	Southeast Farallon Islands SMR/SMCA							21				27				23	23		94	4
Central	Montara SMR											16					19	12.5	47.5	3
	Pillar Point SMCA											8					12	9	29	3
	Ano Nuevo SMR											9				10		10	29	3
	Soquel Canyon SMCA												3						3	1
	Portuguese Ledge SMCA												15			12		10	37	3
	Pacific Grove SMCA			12									8						20	2
	Asilomar SMR			13	26								15						54	3
	Carmel Bay SMCA			13							10		8						31	3
	Point Lobos SMR			12	31	23							24			23		34	147	5
	Point Sur SMCA				22				25				23			22		20.5	112.5	4
	Big Creek SMR/SMCA												28				13		41	2
	Piedras Blancas SMR/SMCA												8				15		23	2
	Point Buchon SMR				24	18			40				15			14		16	127	6
South	Point Conception										17					17		13	47	
	Naples SMCA										4								4	1
	Campus Point SMCA										19					18		16	53	3
	Harris Point SMR	30	24	21	21	19					23	23				24	33		218	9
	Carrington Point SMR	25	31	25	25	25					25	26				24	40		246	9
	South Point SMR	37	31	26	26	26					24	25				26	31		252	9
	Gull Island SMR	44	41	39	39	38					39	40				32	41		353	9
	Scorpion Point SMR										3	6							9	2
	Anacapa Island SMR/SMCA	39	29	30	28	25					59	29				28	37		304	9
	Point Dume SMR										18								18	1
	Santa Barbara Island SMR										19								19	1
	Farnsworth Offshore SMCA										25						27	18	70	3
	Swami's SMCA										25						13	14	52	3
	South La Jolla SMR/SMCA										24						27	20	71	3
	Total :	175	156	191	242	195		64	65		467	357	147			311	476	268.5	3,162	139

Table 1. Summary of ROV time series of 500-meter ROV transects across each management bioregion and MPA group. The total number of transects and the number of time-series year replicates are included in the total columns. Highlighted MPAs were included in the analyses presented. Selected MPAs had at least three surveys to allow better estimation of temporal trends. All MPAs had an associated reference area/s.

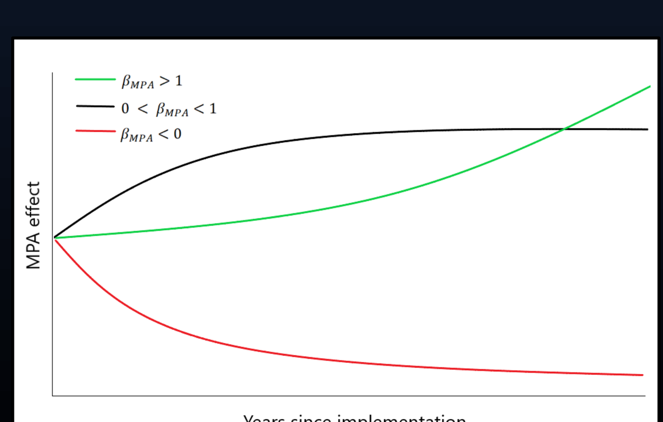


Figure 1. "Years since implementation" (YSI), the number of years that an MPA had been in place at the time of survey was used to quantify the MPA effect. This was modeled using a log (YSI + 1) transformation, which meant there was always a zero MPA effect for reference areas, and an accumulative effect through time for MPAs. The black line shows the expected response, though the model allows for the other responses (green = exponentially increasing, red = negative/decreasing).

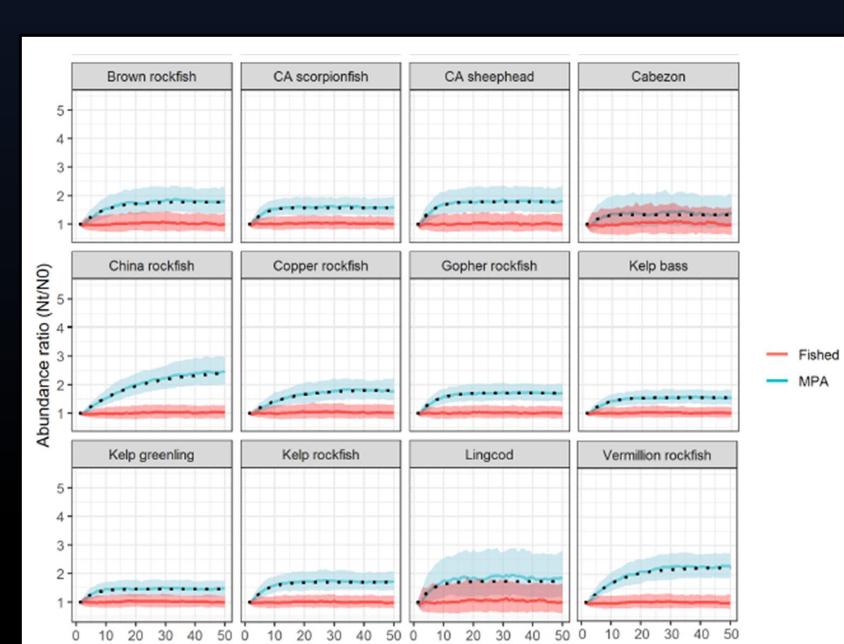


Figure 2. Theoretical trajectories of increased abundance inside MPAs through time for focal species taken from Kaplan et al. (2019).

Kaplan, K.A., et al., Setting expected timelines of fished population recovery for the adaptive management of a marine protected area network. Ecological Applications, 2019. 29: p. e01949.

Results

Increases in density outside of MPAs were found for all statewide and bioregional models, except for Lingcod in the North (Table 2). These positive trajectories over the survey period indicate that a combination of fisheries management measures over recent decades, combined with good recruitment, have been effective in rebuilding stocks of these focal species. Positive MPA effects were found in all statewide models and for 14 of 24 species regions (Figure 3). All model estimates for mean MPA effects at statewide and regional scales were between zero and 1, which conformed to expected trajectories (Figure 2). Confidence in MPA effects was greatest for the statewide models, which showed the strongest effects for Copper and Gopher rockfish (Figure 4). Greater uncertainty was seen in individual MPA effects, although some MPAs such as Bodega Bay SMR showed positive responses for a large number of species (Figure 5).

Video processing station with custom video annotation software and touchscreen GUI interface.

Species	Statewide	North	Central	South
Grouped species	0.096 (0.09, 0.102)	0.124 (0.107, 0.141)	0.132 (0.117, 0.147)	0.095 (0.088, 0.103)
Copper rockfish	0.111 (0.100, 0.123)	0.088 (0.042, 0.134)	0.161 (0.111, 0.213)	0.111 (0.098, 0.123)
Vermilion rockfish	0.067 (0.058, 0.076)	0.172 (0.134, 0.212)	0.106 (0.082, 0.130)	0.062 (0.052, 0.073)
Gopher rockfish	0.157 (0.146, 0.170)	0.232 (0.178, 0.289)	0.183 (0.163, 0.204)	0.174 (0.159, 0.189)
Lingcod	0.044 (0.033, 0.054)	-0.063 (-0.085, -0.042)	0.042 (0.021, 0.063)	0.071 (0.057, 0.086)
California sheephead				0.122 (0.110, 0.133)
Canary rockfish		0.078 (0.048, 0.078)	0.041 (0.003, 0.080)	
Quillback rockfish		0.129 (0.096, 0.162)		
Yelloweye rockfish		0.116 (0.086, 0.147)	0.116 (0.051, 0.184)	
Kelp greenling		-0.011 (-0.029, 0.007)	-0.024 (-0.053, 0.004)	
Brown rockfish *		0.117 (0.128, 0.228)		

Table 2 . Model-based year effect trend estimates for the density of focal species in each region. Results are for coefficients on the linear predictor (log) scale. When credible intervals (in brackets) incorporate zero the effect is considered non-significant. Effects colored green are positive estimated effects, red are negative estimated effects and non-shaded are non-significant effects.

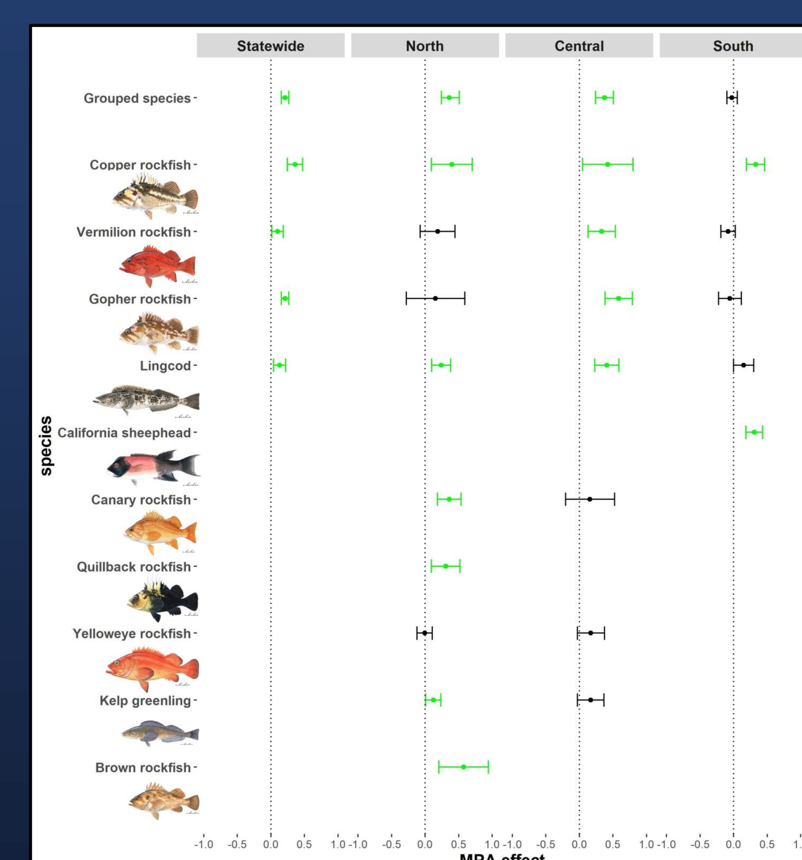


Figure 3. Statewide and regional MPA effects for modeled focal species. The dashed line represents a zero effect and when credible intervals incorporate zero the effect is considered non-significant. Dots and error bars colored green are positive estimated effects, red are negative estimated effects and black are non-significant effects.

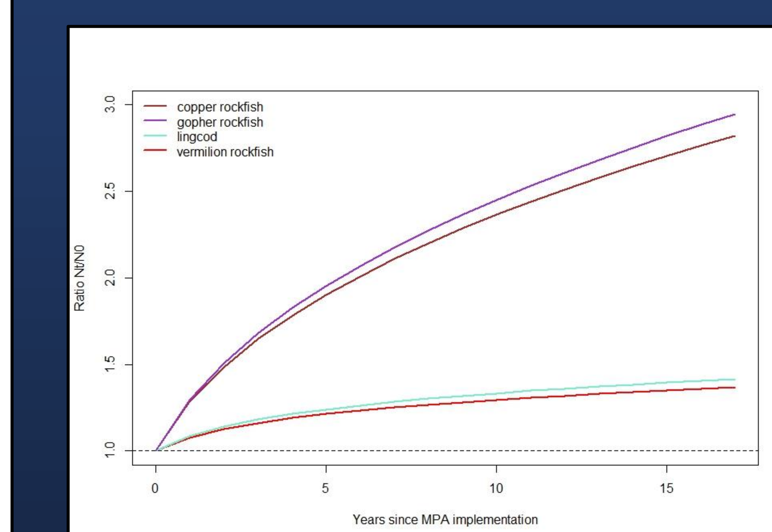
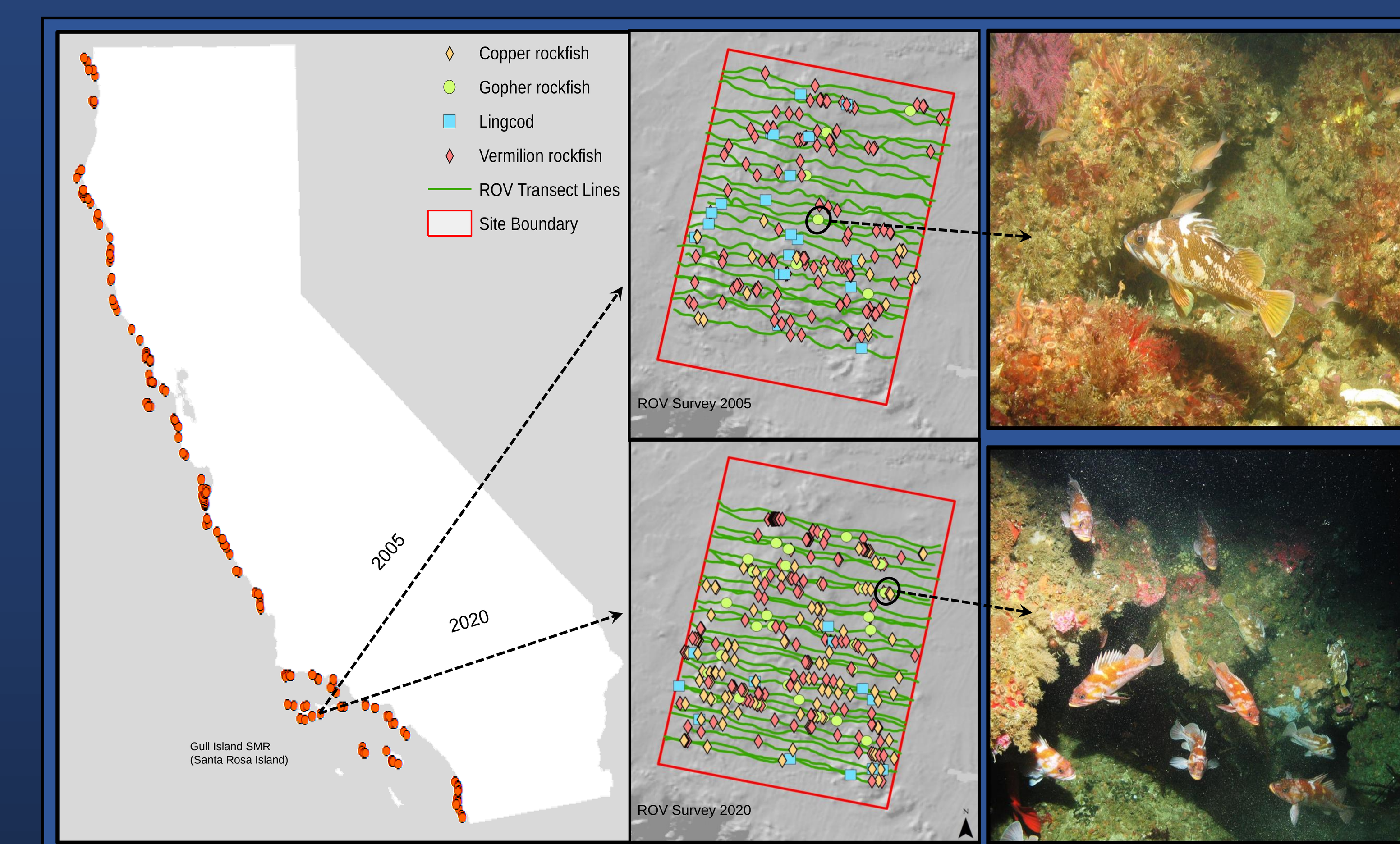


Figure 4. The mean MPA effect based on the statewide models for copper rockfish, gopher rockfish, lingcod and vermilion rockfish shown as the mean ratio through time compared to the abundance at the start of the survey (Nt/N0). The dashed line illustrates no change (multiplication factor of 1) for comparative purposes.

Figure 5. Individual MPA effects for MPAs nested within management bioregions. The dashed line represents a zero effect and when credible intervals incorporate zero the effect is considered non-significant. Dots and error bars colored green are positive estimated effects, red are negative estimated effects and black are non-significant effects. Note that credible intervals are much wider (from -5 to 5) than results shown for statewide and regional model outputs.

Conclusions

Following more than a decade of protection, these results demonstrate the ability of a well-designed ROV-based monitoring program to detect regional trends and MPA effects on the density of previously fished species across the California MPA Network. Results show encouraging signs of recovery in the abundance of these species statewide since 2003, and that MPAs are a contributing factor to this trajectory. Modeling showed that effects were more detectable at larger spatial scales (regional and statewide) where data from a larger number of MPAs was included. At the statewide level the rates of change associated with MPA establishment exceeded theoretical expectations for some species (Copper and Gopher rockfish), while for other species such as Vermilion rockfish and Lingcod the length of MPA establishment may not yet be long enough to fully realize recovery potentials. The increased detectability of MPA effects at larger scales and with longer time-series highlight the importance of collecting spatially extensive and temporally replicated data for large-scale monitoring programs such as the long-term monitoring of California's MPA Network.



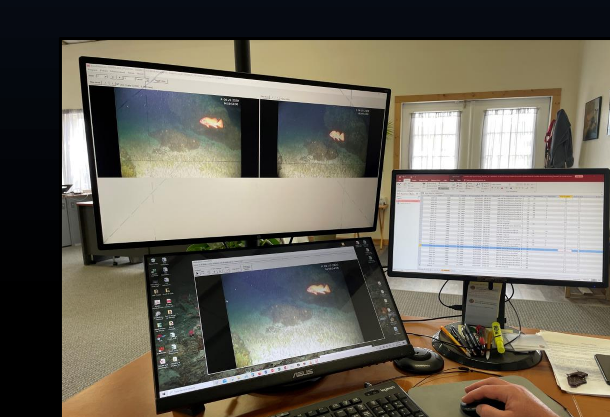
Locations of observed Lingcod, Copper, Gopher, and Vermilion rockfish at Gull Island SMR (Santa Rosa Island) from ROV surveys conducted in 2005 and 2020.

Key Findings

- Positive signs of MPA effectiveness were found for the majority of species with increased confidence at larger scales where more data over longer timeframes were included.
- MPA effect sizes for statewide and bioregional models fell within ranges expected from theoretical models, with current estimates exceeding expectations for some species.
- Positive trajectories in density outside MPAs were found for nearly all species over the survey period indicating a rebuilding of stocks.
- The modeling approach used allowed separation of MPA effects from overall trends while accounting for differences between important environmental factors such as depth, habitat and latitude.
- Results indicate that where data has been collected over a large number of MPAs through time, network wide and regional MPA effects can be reliably detected. Consideration should be given to ongoing monitoring that maintains the spatial extent and replication of monitoring surveys.

Next Steps

- Incorporate stereo size estimates calculated from 2014 through 2021 to look for changes in size frequency and biomass for ongoing MPA performance evaluation.
- In collaboration with CDFW, use data collected to inform stock assessments of Copper, Black and Canary Rockfish in 2023 and Quillback Rockfish in 2024.
- Analyze data collected on macro-invertebrates for MPA performance.



Stereo video processing station using SeaGIS EventMeasure© software.

Marine Applied Research and Exploration

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