Diving deep into the Network: remotely operated vehicle surveys reveal protection effects and regional trajectories of recovery across California's Marine Protected Area Network

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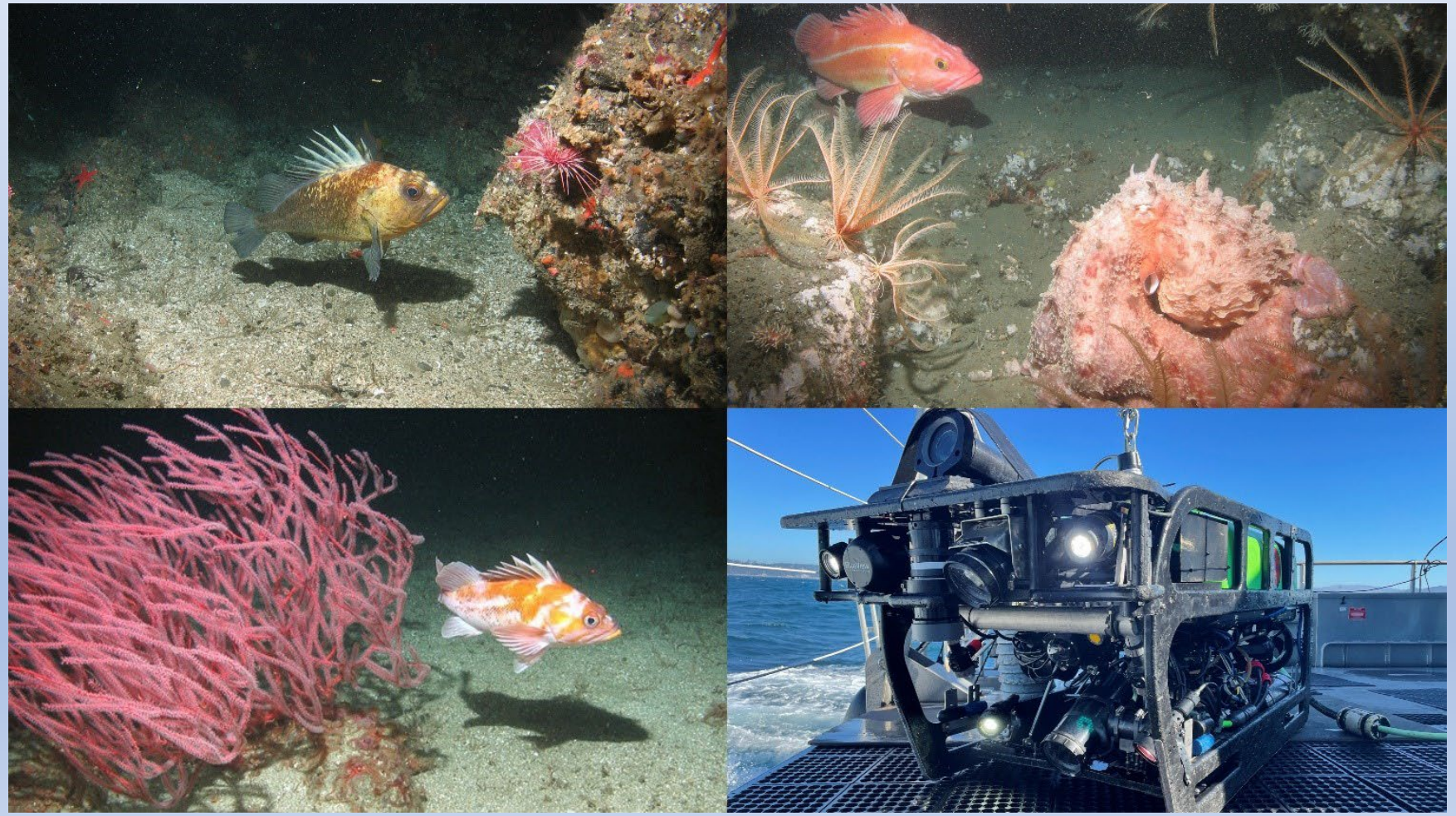
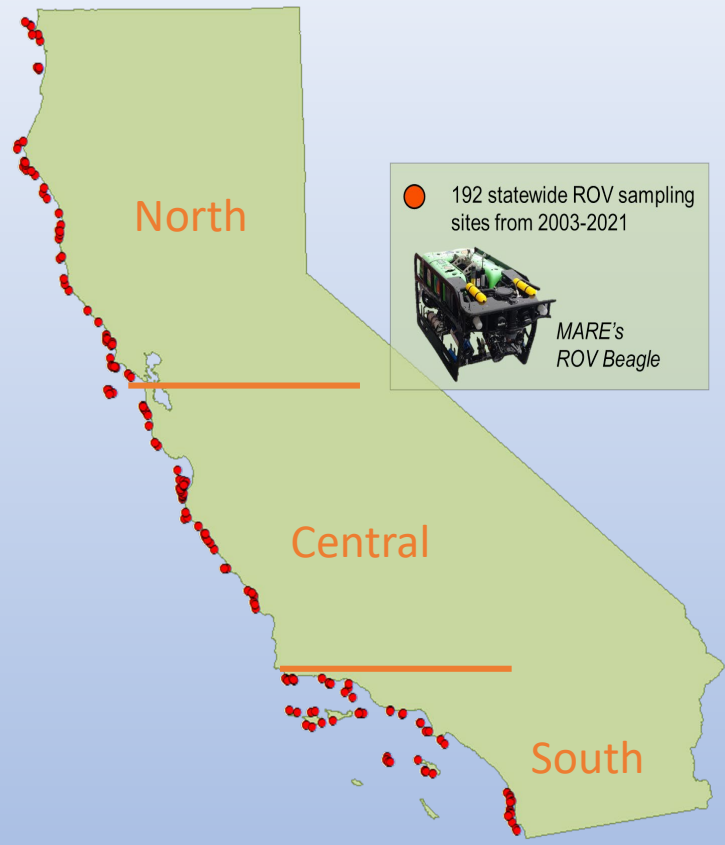


MARE/CDFW statewide MPA monitoring program

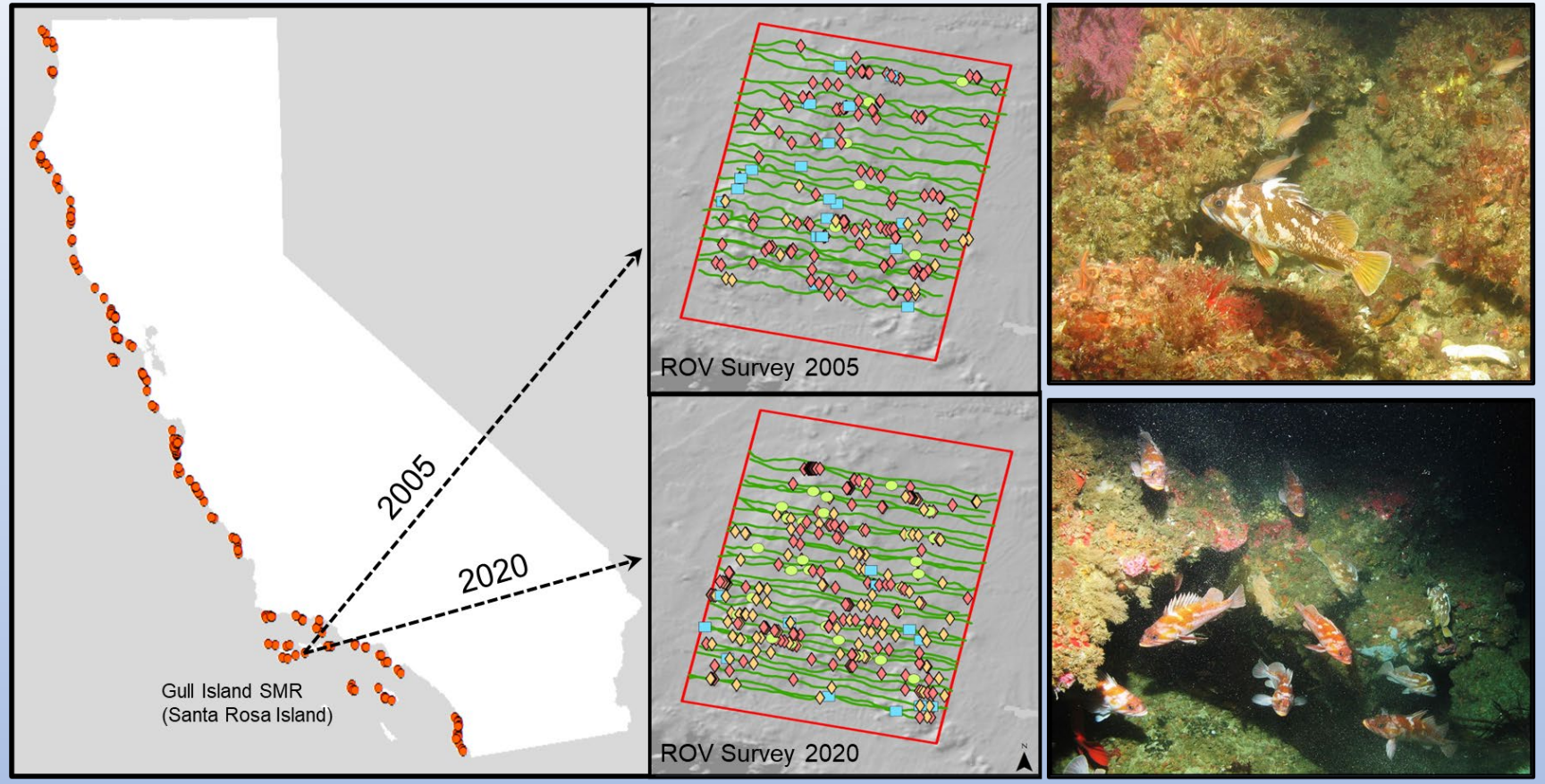
Region	MPA Group	Transects by year (500 m)																	Total Transects	Total Series Replicates
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021		
North	Point St. George Reef Offshore SMCA										23	14					19	12	68	4
	Reading Rock SMR										19	19					20	14	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	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
	Point Conception SMR										17					16		13	46	3
	South La Jolla SMR/SMCA										24						27	20	71	3
	Total :	175	156	191	242	195		64	65		484	357	147			327	476	281.5	**3,161**	**142**



- 2005 – 2021
- 24 MPAs with ≥ 3 surveys
- Statewide, bioregional, and individual MPAs modeled

ROV surveys and data collation

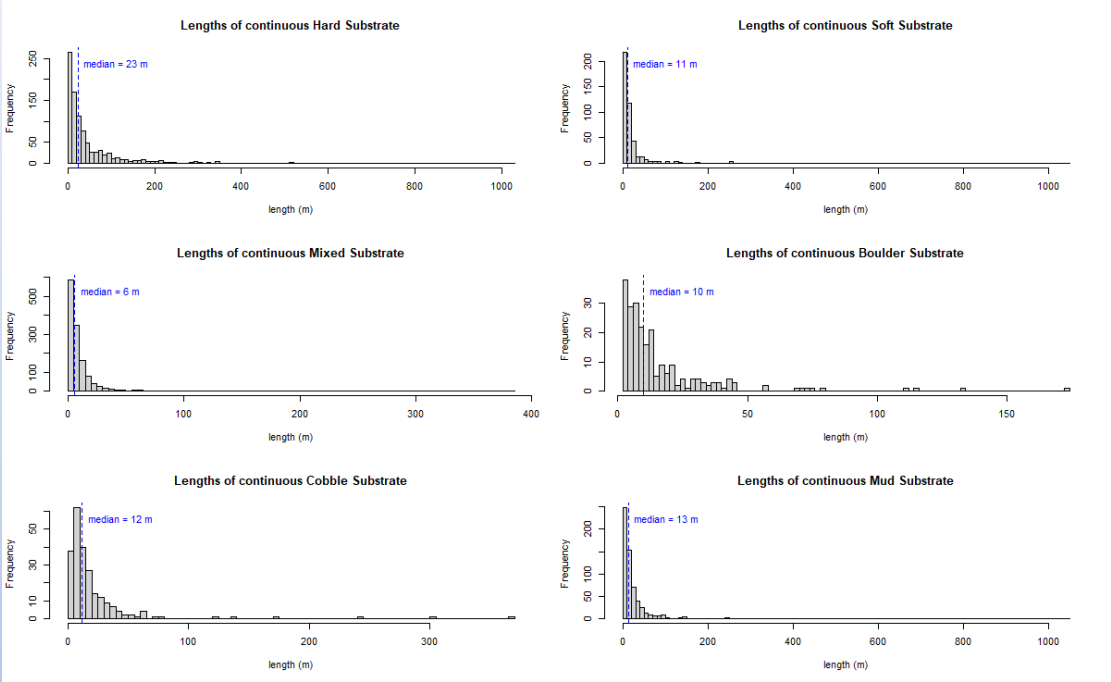
- Within MPA and reference site pairs, 500 m wide sites defined
- 500 m long transects
- All fish identified to species level and sized (stereo post 2014)
- Habitat start and stop times recorded
- Depth from sensors
- Positional information to allow matching to bathymetric mapping



Methods: subunits for analysis

- 500 m long transects cover a lot of variation in habitat!
- Previous researchers have used various ROV sub-sampling units e.g.,:
  - 50 m^2 (Karpov et. al., 2010)
  - 50 m length (Duffy et. al., 2014)
  - 20 m length (Budrick et. al., 2019)
- Smaller subunits provide higher power to detect change (Karpov et al., 2010)
- "Patchiness of habitat" analysis showed habitat patches typically on 10's of meters scale
- BUT….spatial autocorrelation needs to be accounted for…

Lengths of continuous substrate classes visual data

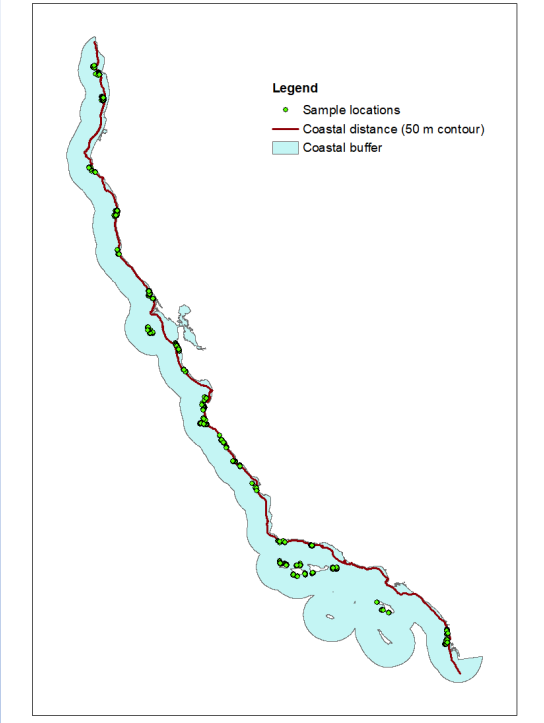


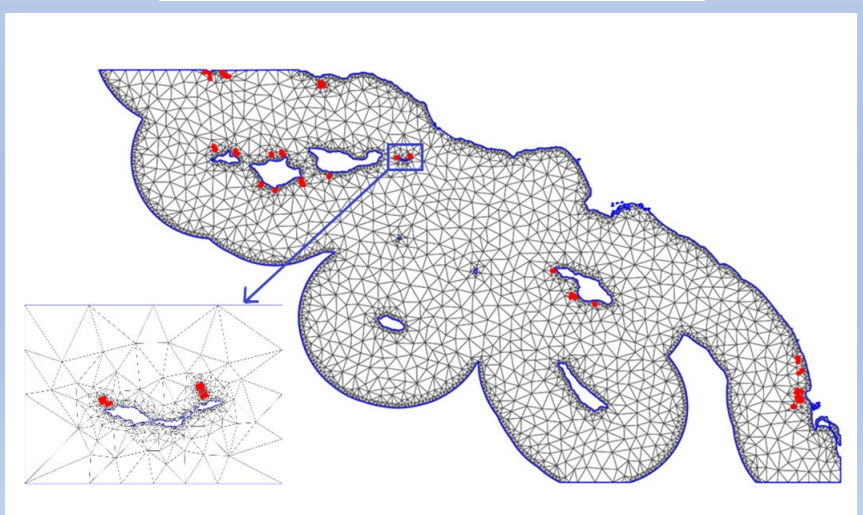
Areas of substrate classes mapped data

substrate		BB1	BB2	BB4	BB5
hard	min	4(2.2)	4(2.2)	4(2.2)	4(2.2)
	median	20(5.0)	24(5.6)	20(5.0)	24(5.6)
	max	397136(711.0)	451964(758.6)	275608(592.4)	104208(364.2)
mixed	min	4(2.2)	4(2.2)	4(2.2)	4(2.2)
	median	20(5.0)	16(4.6)	16(4.6)	16(4.6)
	max	219140(528.2)	107136(369.4)	209032(515.8)	534764(825.2)
soft	min	4(2.2)	4(2.2)	4(2.2)	4(2.2)
	median	16(4.6)	16(4.6)	16(4.6)	16(4.6)
	max	98880(354.8)	7832(99.8)	66364(290.6)	2748(59.2)

Methods: Spatial modelling with INLA

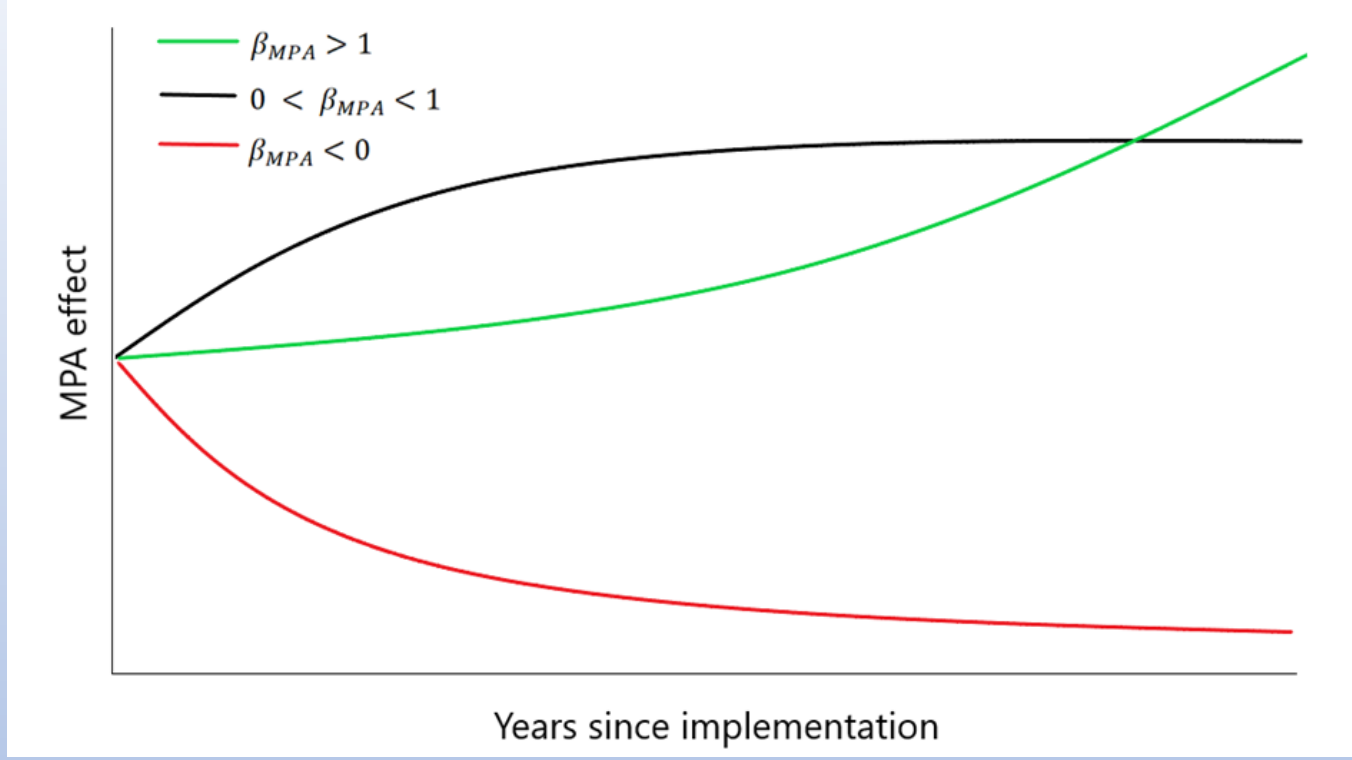
- Generalized linear model (GLM) approach
- Negative binomial distribution with swept area treated as an ‘offset’ (=density)
- Incorporated important covariates:
  - Proportion of hard and mixed habitat (visual)
  - Depth and depth^2
  - Coastal distance and coastal distance^2
  - Survey year (to capture general trends)
  - Years since MPA implementation (MPA effect)
- Spatial dependence between sampling units quantified across a mesh, accounting for residual spatial autocorrelation

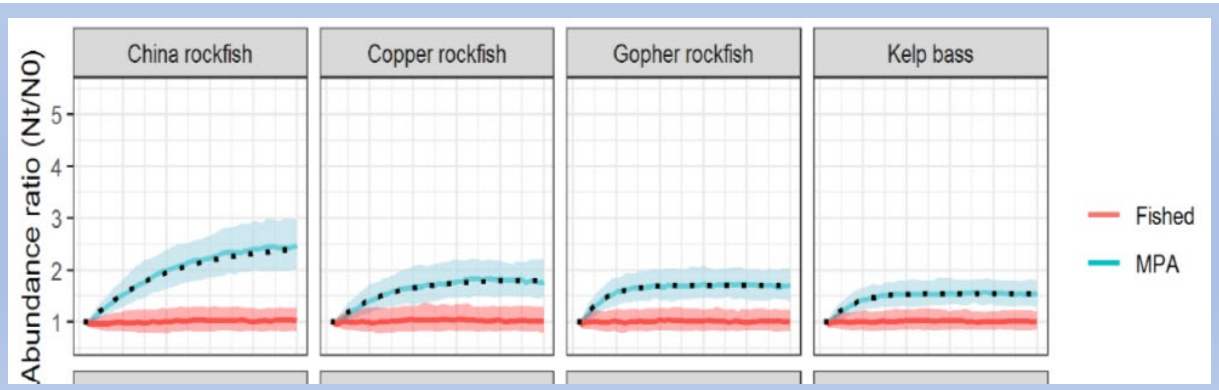




Methods: modeling the MPA effect

- MPAs expected to have a cumulative effect over time
- ”Years since implementation” (YSI) used as a measure
- $\log(YSI + 1)$ transformation:
  - Reference area = log (0 + 1) = 0 MPA effect throughout time
  - MPA in first year = log (0 + 1) = 0 MPA effect
  - MPA in subsequent years = cumulative effect
- Model coefficient determines the shape of the response
- $0 < \beta_{MPA} < 1$ expected

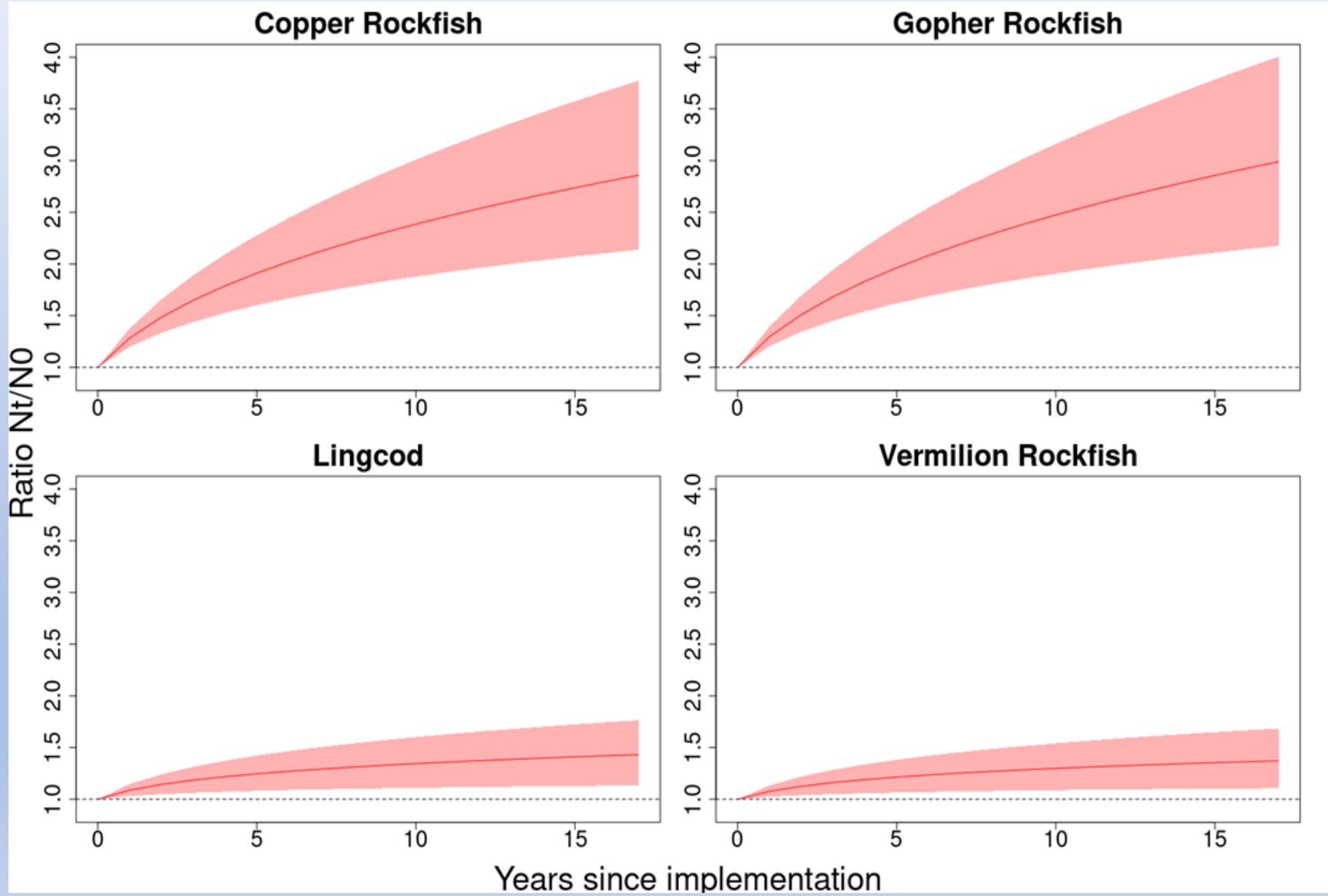




Kaplan et. al. (2019) “Setting expected timelines of fished population recovery for the adaptive management of a marine protected area network” Ecol. Apps (29)

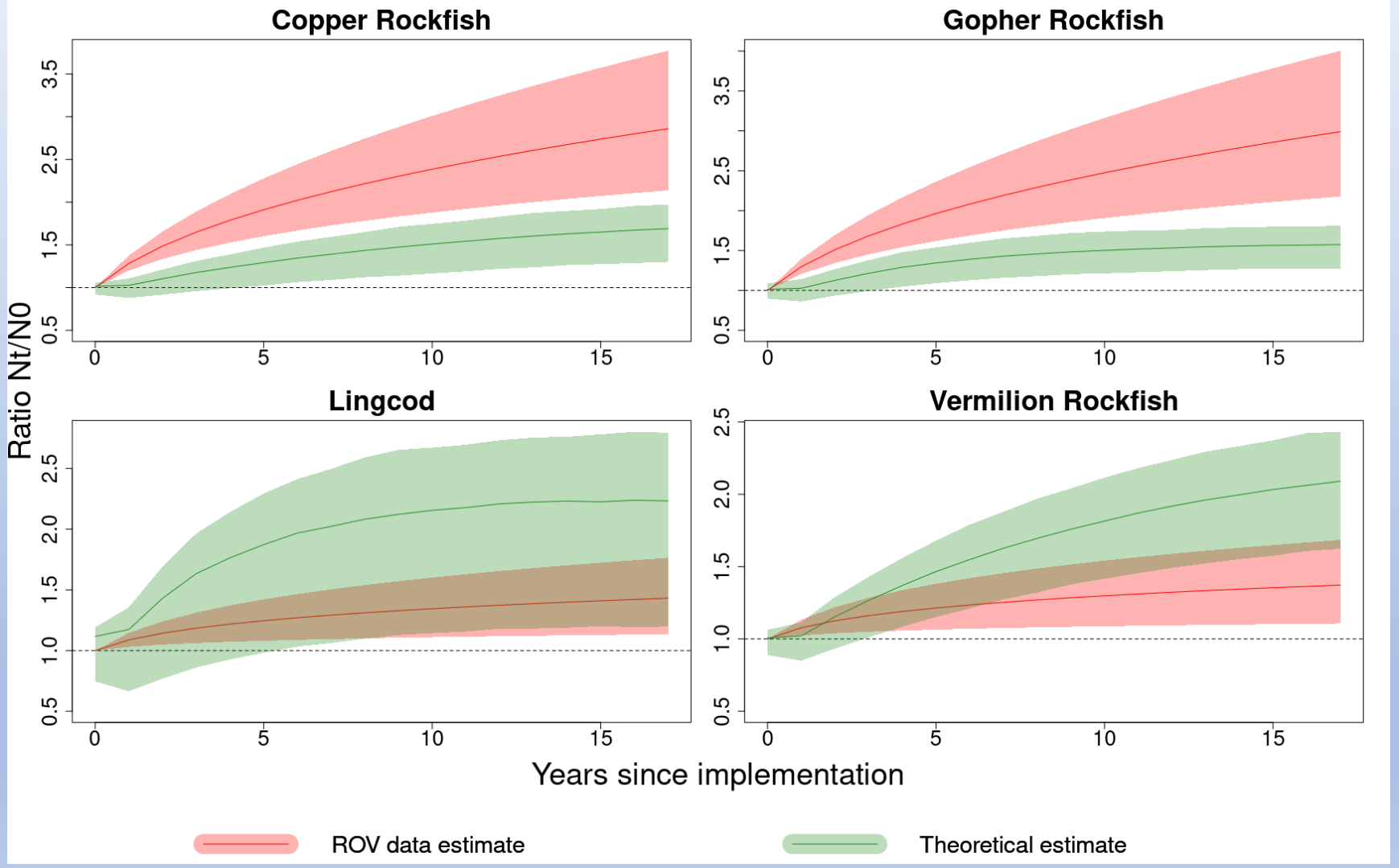
Results: statewide MPA effects

- Four species with wide distributions modelled across the network
- Positive MPA responses for all four species
- Largest responses for copper (2.5X) and gopher rockfish (3X)



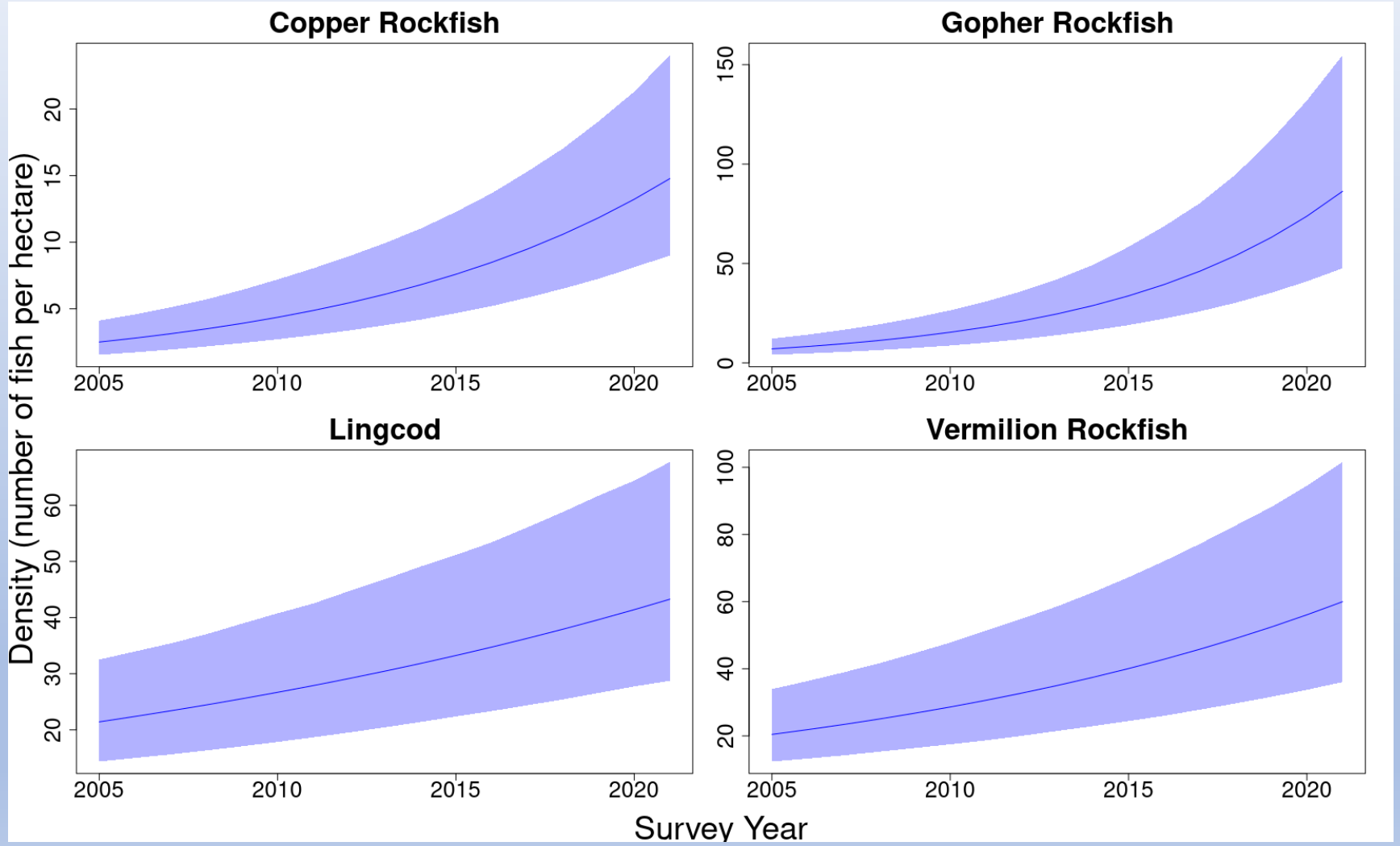
Results: comparison with theoretical expected responses

- Exceeding expectations for copper and gopher rockfish
- On the lower end of expectations for lingcod and vermilion rockfish



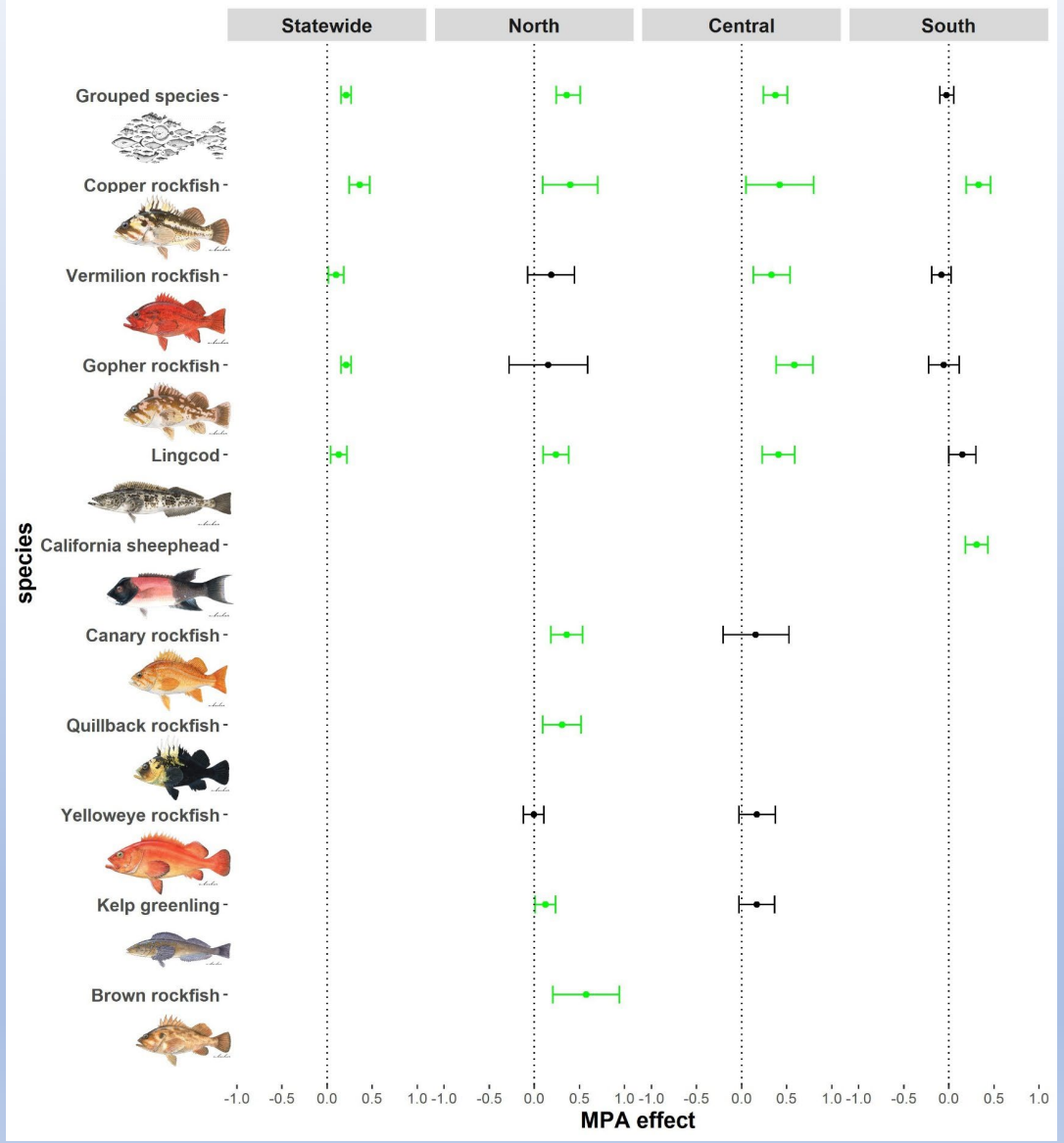
Results: statewide density trajectories

- Estimates represent an averaged response ignoring other covariates and spatial differences
- Strong trajectories of increased density for all four species 2005-2021
- Very strong signal for gopher rockfish (note y-axis scales)



Results: MPA effects and trends at regional scales

- Positive MPA effect for 14/24 species-bioregions
- Increased scale of analysis = Increased confidence in results



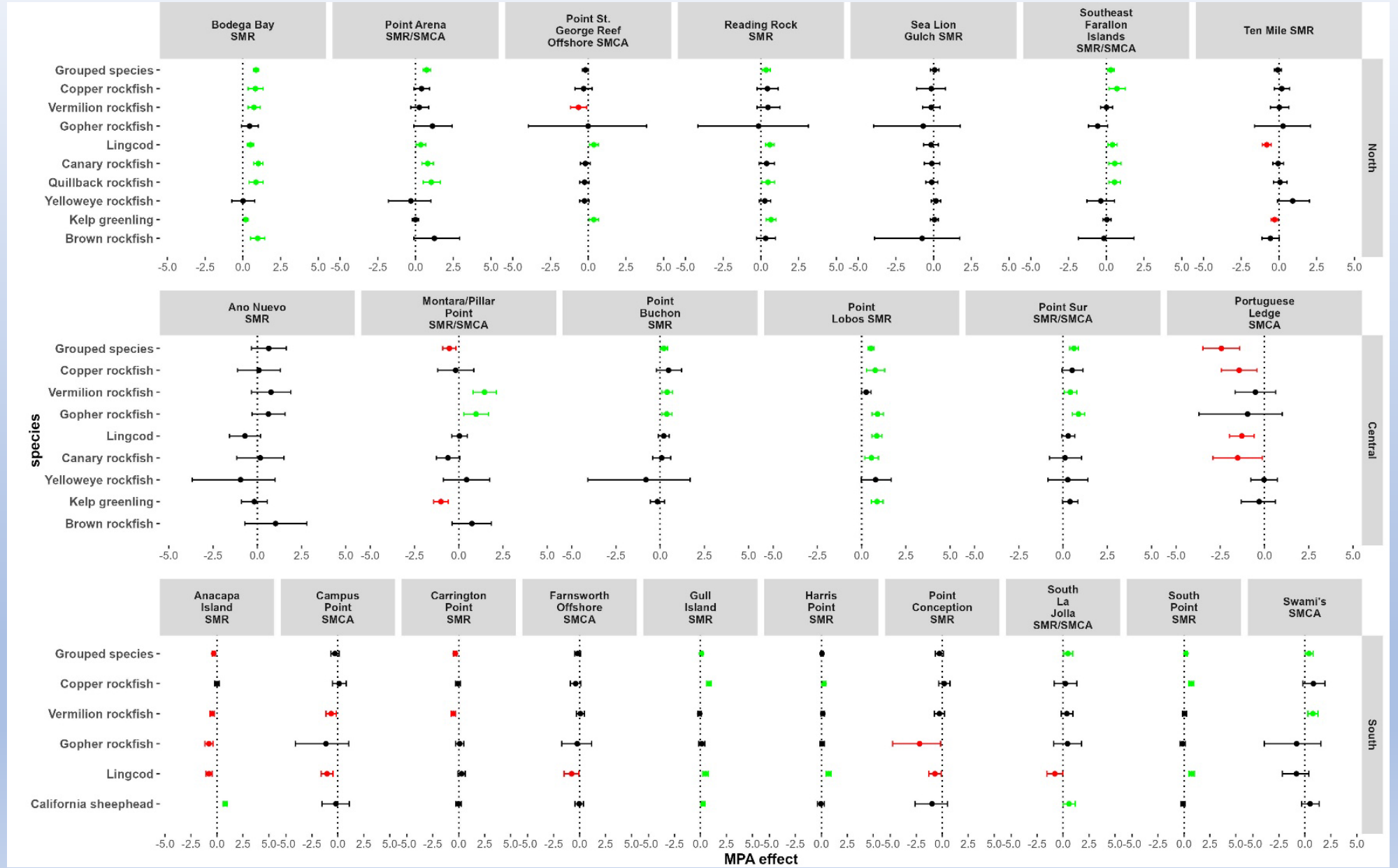
Species	Statewide	North	Central	South
Grouped species	0.096 (0.09, 0.102)	0.124 (0.107, 0.141)	0.132 (0.117, 0.147)	0.095 (0.088, 0.103)
Copper rockfish	0.111 (0.100, 0.123)	0.088 (0.042, 0.134)	0.161 (0.111, 0.213)	0.111 (0.098, 0.123)
Vermilion rockfish	0.067 (0.058, 0.076)	0.172 (0.134, 0.212)	0.106 (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)		

Positive trajectories for density outside MPAs for most species

Grouped species = combination of 16 groundfish species

Results: MPA effects at individual MPAs

- Considerable uncertainty at the individual MPA level
- Some MPAs performing well for multiple species



Conclusions

- MPAs having a detectable effect using spatially extensive ROV surveys following 10-17 years of protection

- MPA effects more detectable (and with higher confidence) at larger scales, incorporating more MPAs and longer time-series

- Positive trajectories of increased densities outside MPAs over survey period for nearly all species/regions modelled
  - Strong recruitment years
  - Other fisheries management measures (RCAs, quotas etc.)

- Future directions:
  - Testing of other covariates, especially bathymetric variables and fishing effort
  - Examining correlation with recruitment


Questions?