Diving deep into the network: Quantifying protection effects across California's marine protected area network using a remotely operated vehicle

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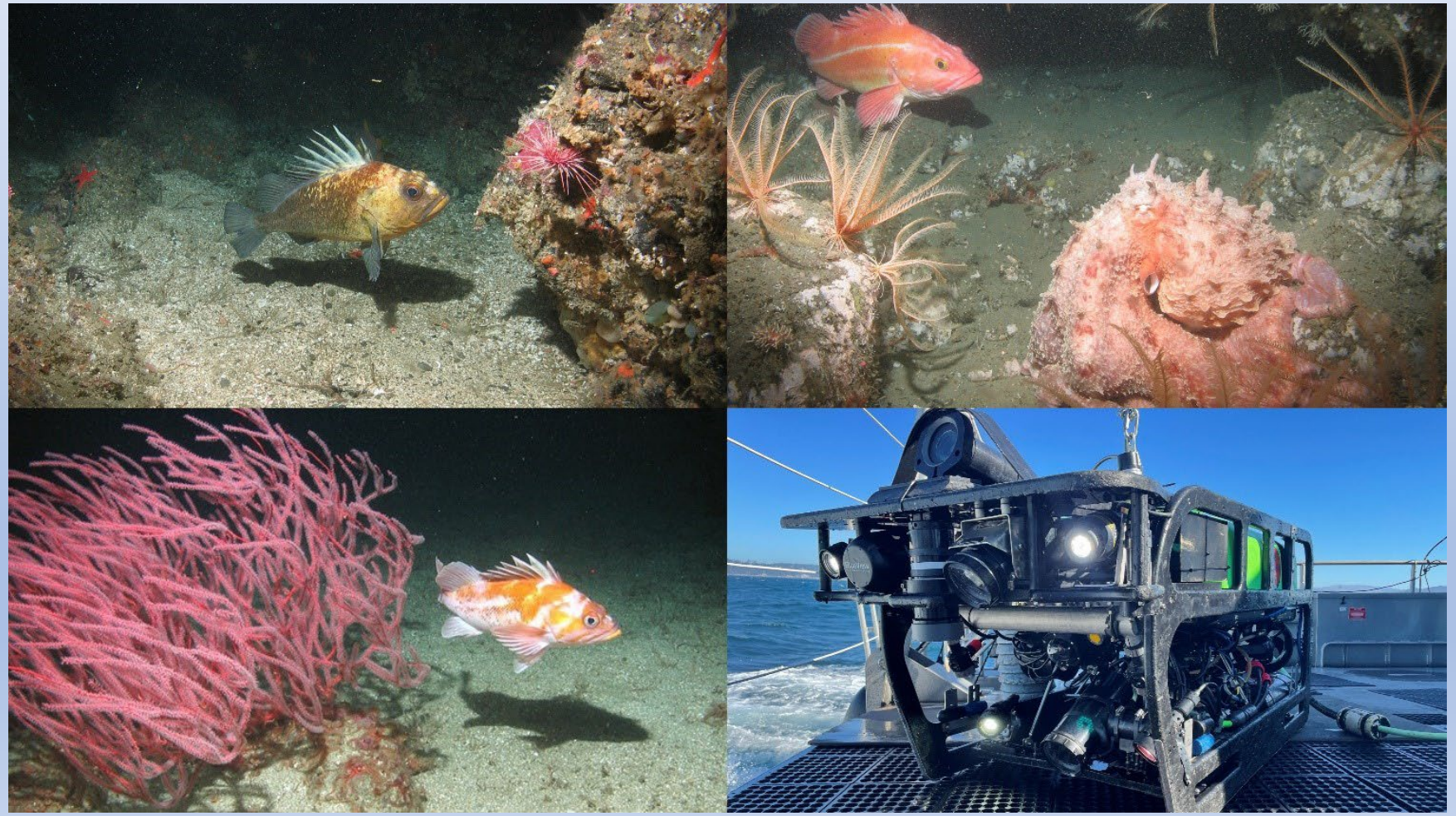

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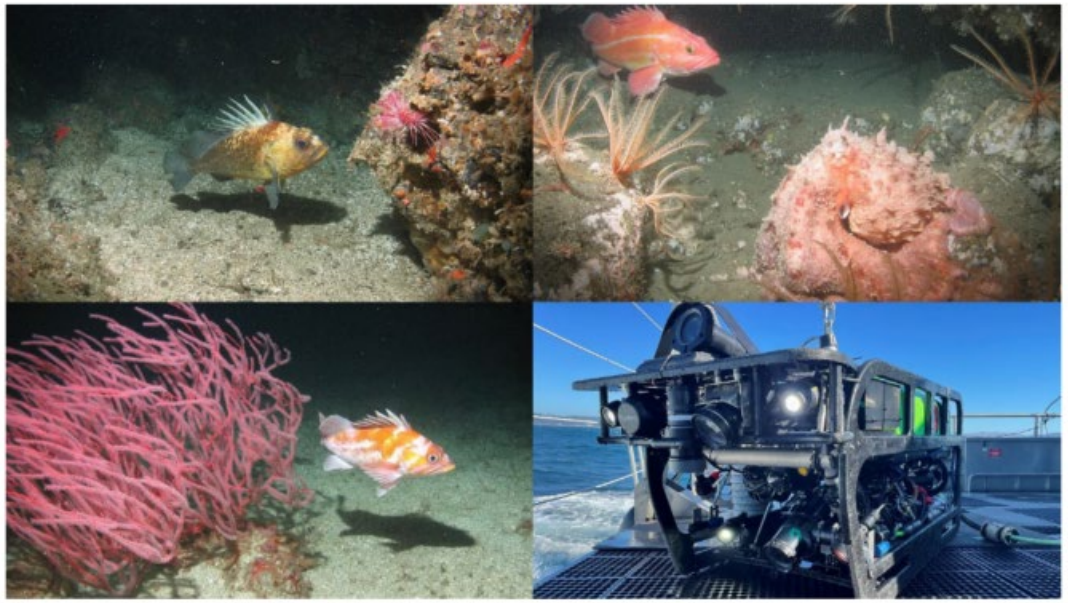
Analysis of a time-series of remotely operated vehicle surveys: temporal trends and marine protected area (MPA) effects in mid-depth reefs across California's MPA Network



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Background: MARE/CDFW statewide ROV MPA monitoring program

MPA group	Transects by year (500 m)																	Total transects	Total repeats
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021		
Point St. George Reef Offshore SMCA										23	14					19	12	68	4
Reading Rock SMR										19	19					20	14	72	4
Sea Lion Gulch SMR										15	6					18	20	59	4
Ten Mile SMR										19	20					20	18	77	4
Point Arena SMR/SMCA							12				17					14	12	55	4
Bodega Bay SMR/SMCA							31				45				38	44		158	4
Southeast Farallon Islands SMR/SMCA							21				27				23	23		94	4
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
Portuguese Ledge SMCA												15			12		10	37	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
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
Anacapa Island SMR/SMCA	39	29	30	28	25					59	29				28	37		304	9
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	282	2841	119

Abbreviations: ROV, remotely operated vehicle; SMCA, State Marine Conservation Area; SMR, State Marine Reserve.

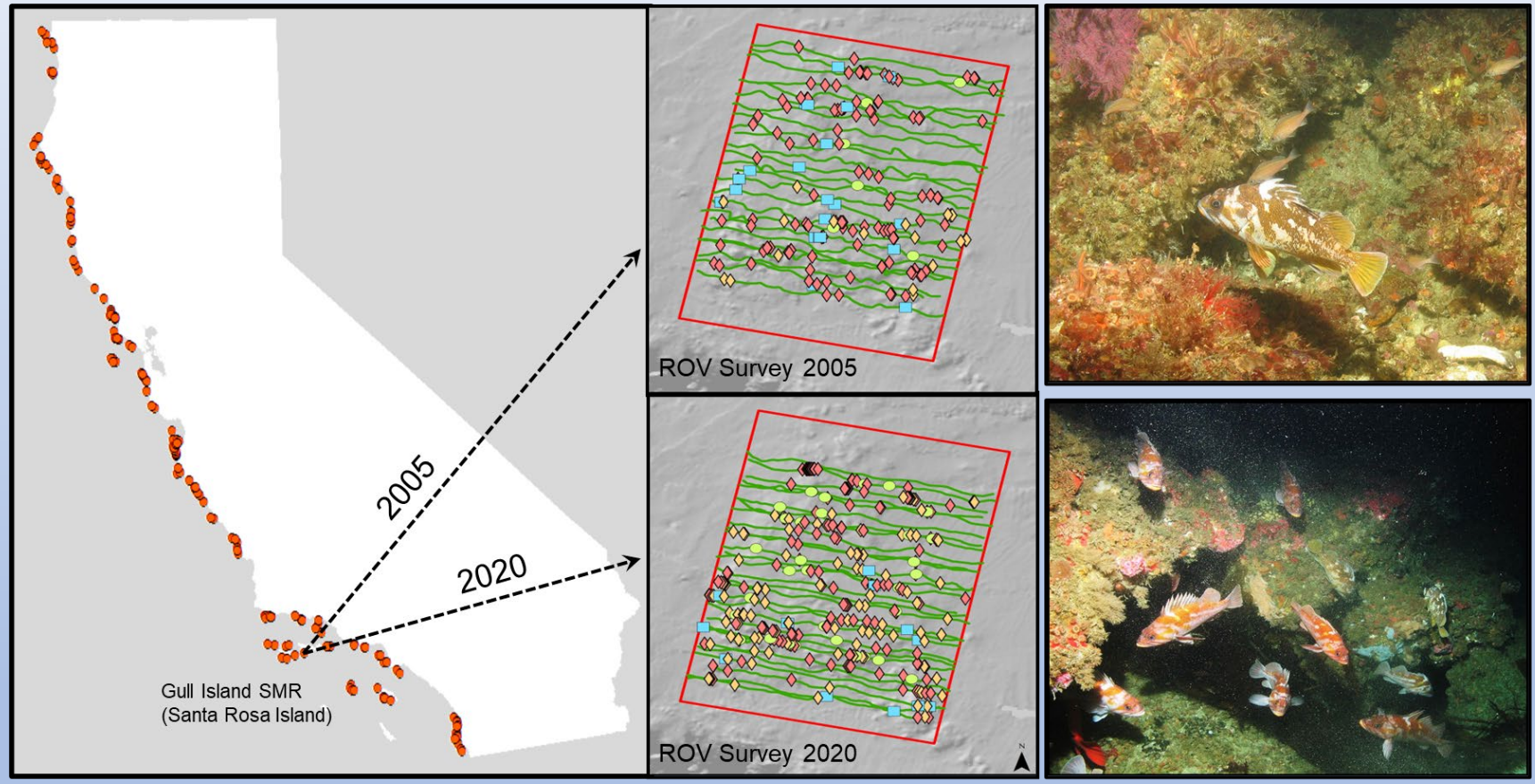
- 2005 – 2021
- 26 MPAs with at least one repeat survey
- Up to 9 repeat surveys

Study Aims

- **Quantify temporal trends and MPA effects across mid-depths at statewide and bioregional (North, Central, and South) scales**
  - Utilizing the full temporal and spatial scale of the ROV data set
  - Account for important environmental covariates and spatial autocorrelation
  - Separate out statewide/regional trends that may be due to a variety of factors (e.g., other management measures) from trends specific to MPAs since network implementation

Methods: 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: species modeled

- 10 focal species modelled
- Focussed on demersal species that are captured well with the ROV survey methodology
- 4 species had wide enough distributions to be modelled across the state:
  - Copper, gopher and vermilion rockfish and lingcod
- Regional trends modelled for all species where there were at least 50 observations in the region through time

Methods: 10 m 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.,:
  - 5m^2 (Grinyo et. al. 2018, Enrichetti et. al. 2023)
  - 50 m^2 (Karpov et. al., 2010, Karpov et. al., 2012)
  - 50 m length (Duffy et. al., 2014)
  - 20 m length (Budrick et. al., 2019)

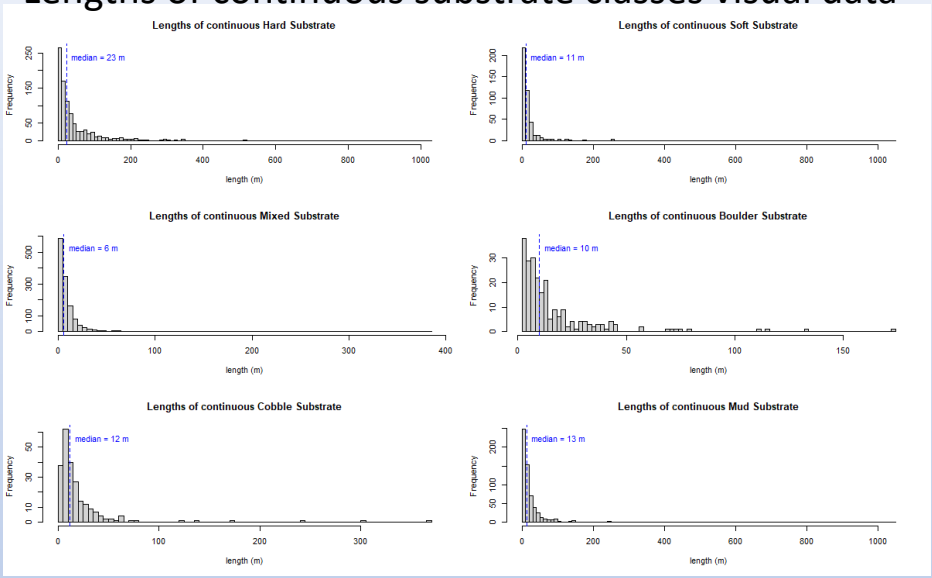
- "Patchiness of habitat" analysis showed habitat patches typically on 10's of meters scale

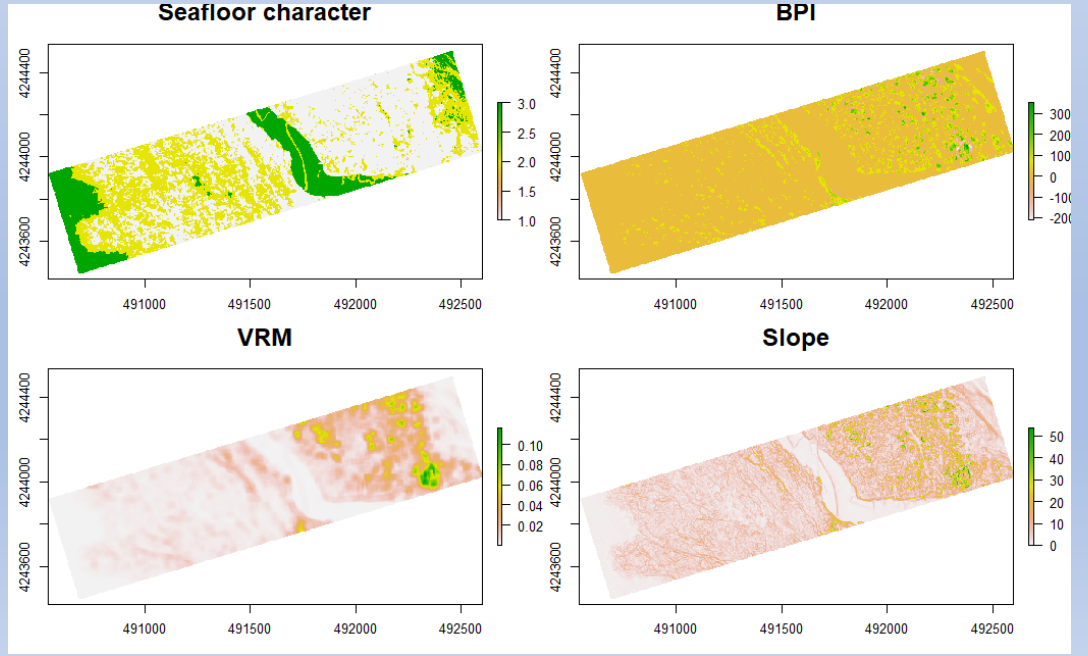
- Necessary to have smaller sampling units if we want to match to seafloor mapping

- Smaller subunits provide higher power to detect change (Karpov et al., 2010)

- BUT….subunits unlikely to be independent and spatial autocorrelation needs to be accounted for…

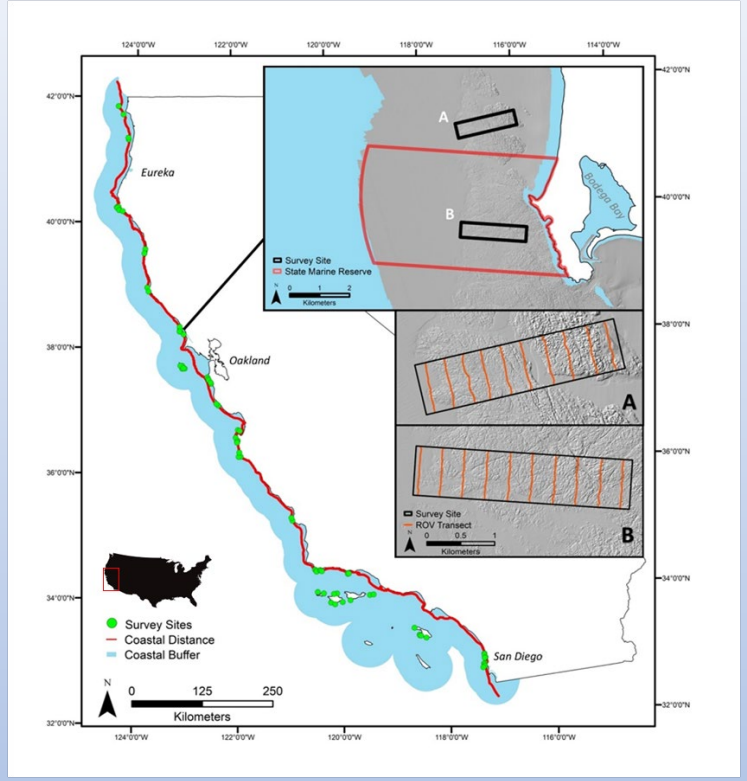
Lengths of continuous substrate classes visual data

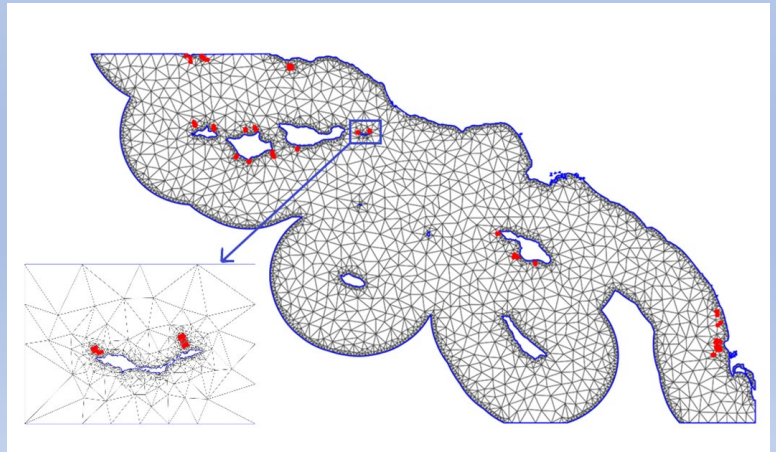




Methods: Spatial modeling with INLA

- 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 temporal trends)
  - Years since MPA implementation (MPA effect)
- Spatial dependence between sampling units quantified across a mesh, accounting for residual spatial autocorrelation





Methods: separating MPA effects from general trends

- Survey year term used to capture statewide/regional trends
- ”Years since implementation” (YSI) used as a measure to model non-linear response
- $\log(YSI + 1)$ 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

Other covariates

Spatial random effects

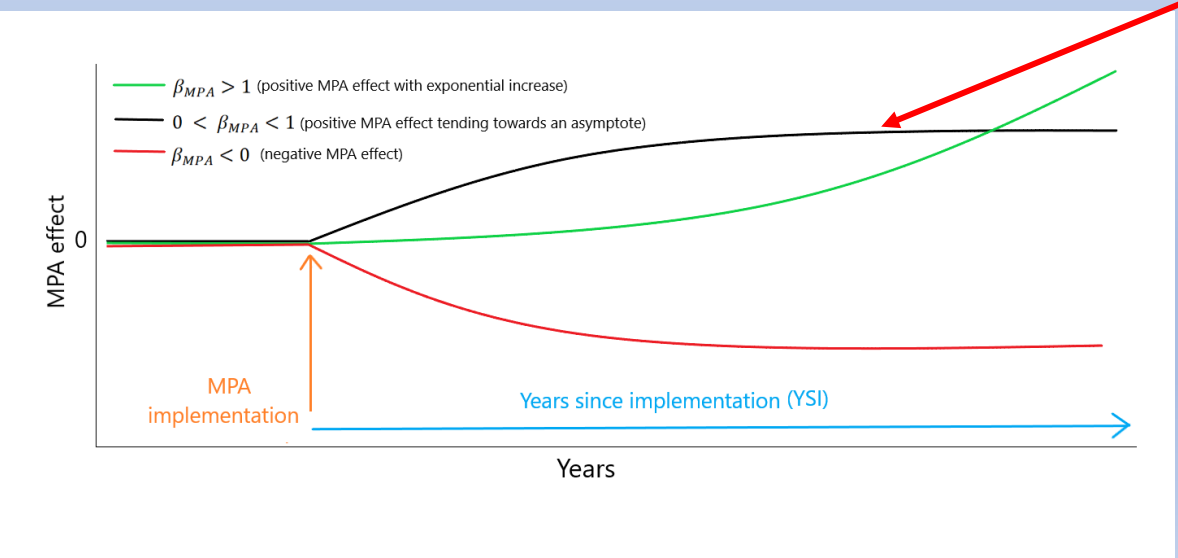
$$log(E(y)) = \beta_0 + \beta_{MPA} * log(YSI + 1) + \beta_1 * \text{Survey Year} + \cdots \beta_z x_z + \omega(s_i)$$

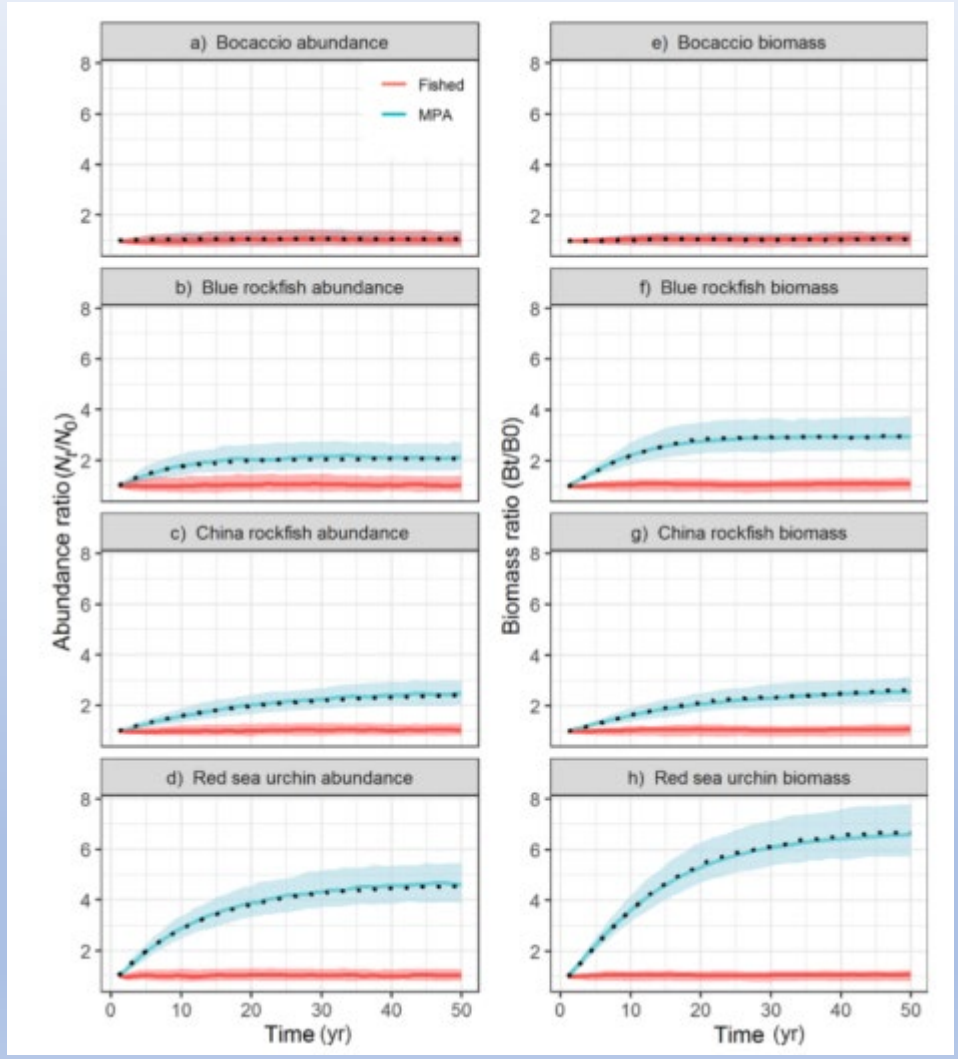
Unique to MPAs

Capturing statewide/regional density trends

MPA effects: comparison with theoretical responses

- Temporal trends and MPA effects were transformed to ratios of abundance from initial surveys/MPA implementation through time
  - Since MPA implementation for MPA effects
  - Since first surveys for temporal trends
- Allowed comparison with theoretical expectations from population dynamics models (Kaplan et al. 2019)

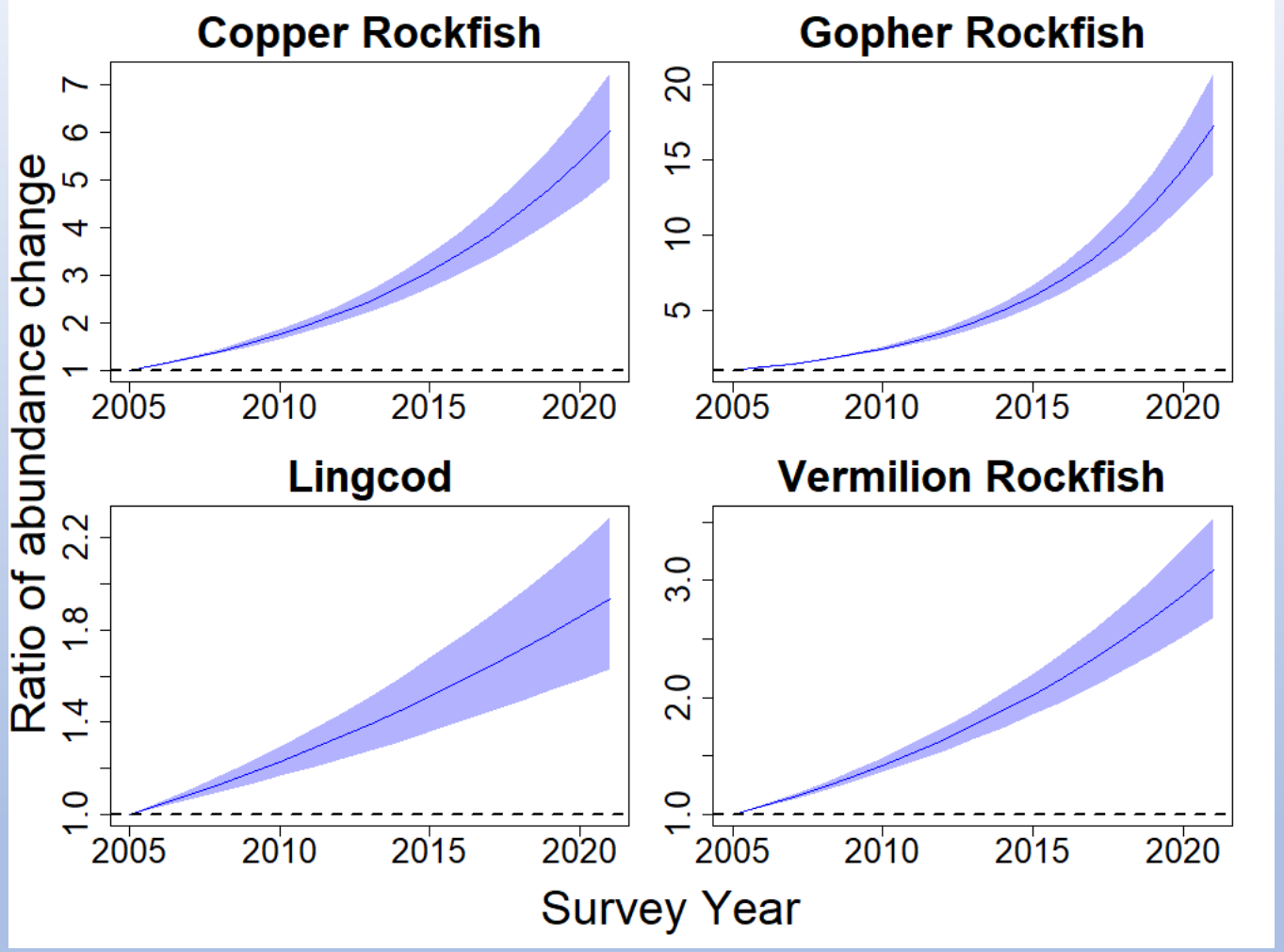




Kaplan et. al. (2019) "Setting expected timelines of fished population recovery for the adaptive management of a marine protected area network" Ecol. Apps (29)

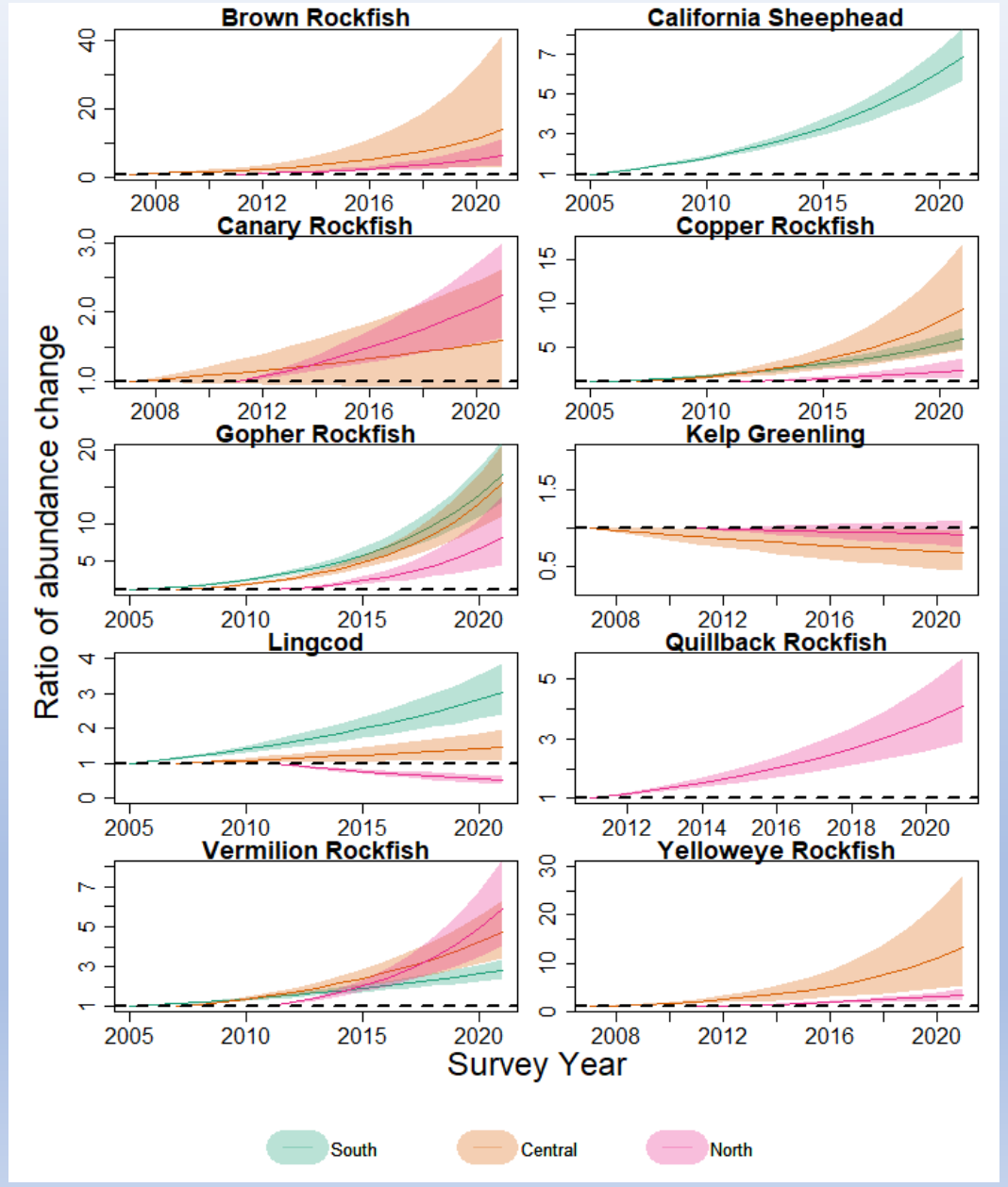
Results: statewide temporal trends

- Increasing trends since 2005
- Large increases for copper (6x) and gopher (16x)
- Moderate increases for vermilion (3x) and lingcod (2x)



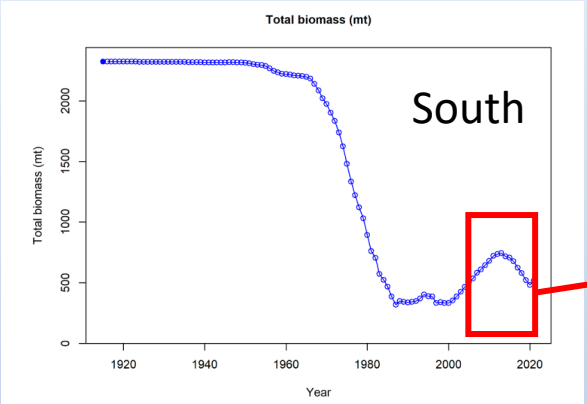
Results: regional temporal trends

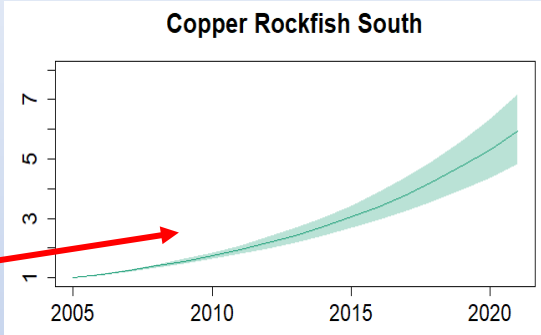
- 18 out of 22 species-regions showed increasing trends
- Only 2 showed negative trends: kelp greenling in Central region and lingcod in the North region
- Quillback showed a 4x increase in abundance in the North between 2011 and 2021

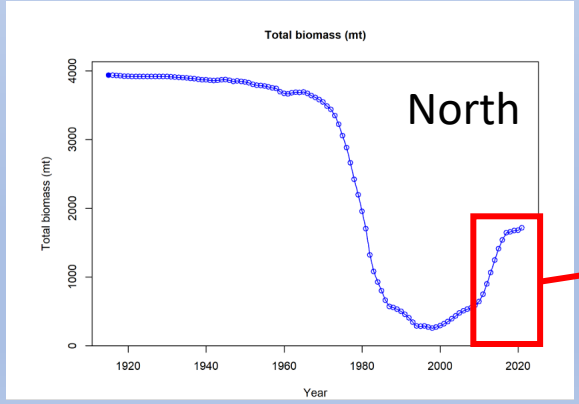


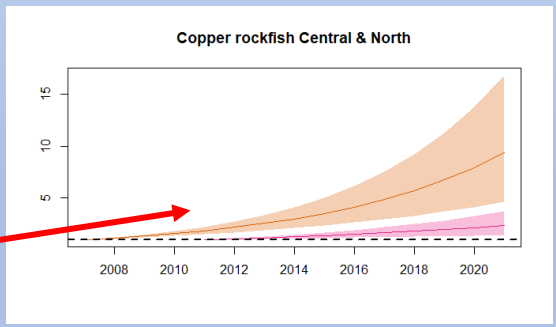
Comparison with stock assessments: copper & vermilion

Copper rockfish

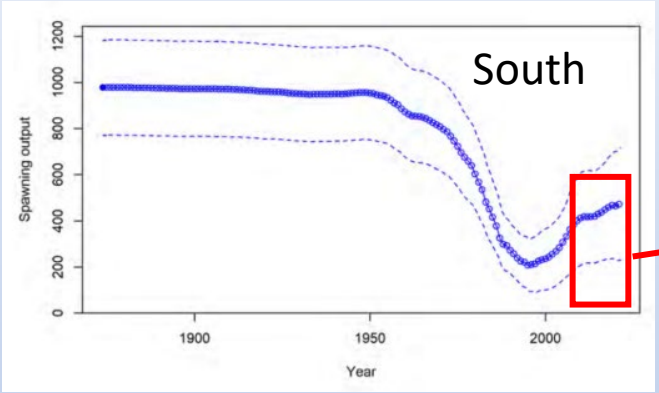


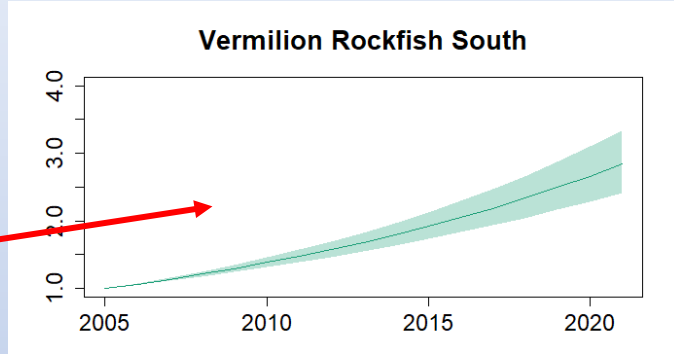


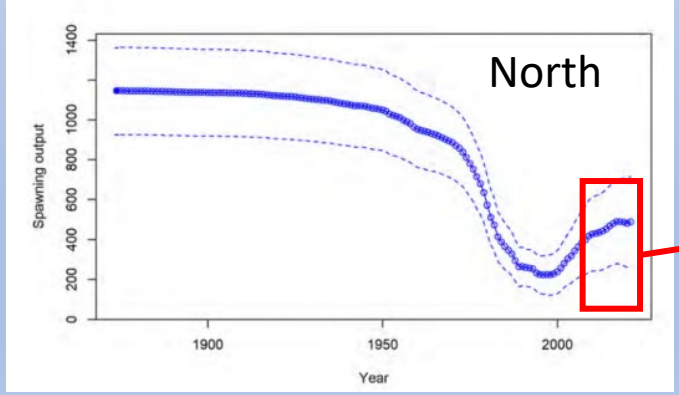


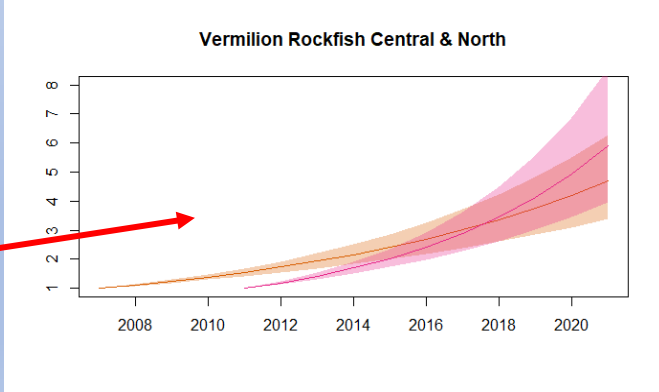


Vermilion rockfish



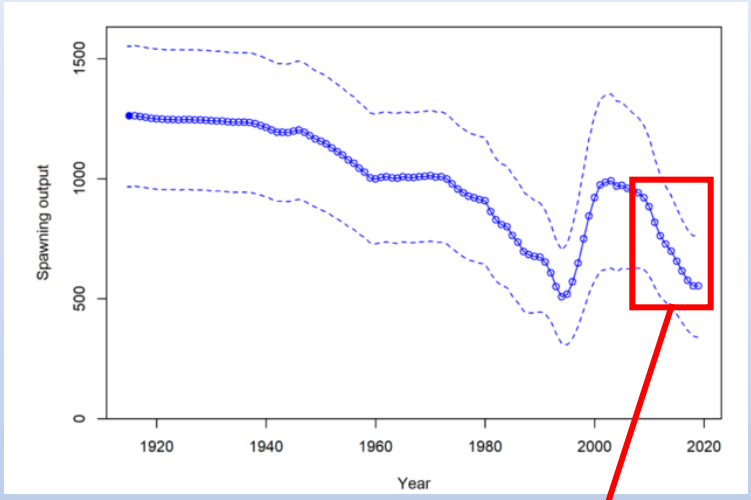


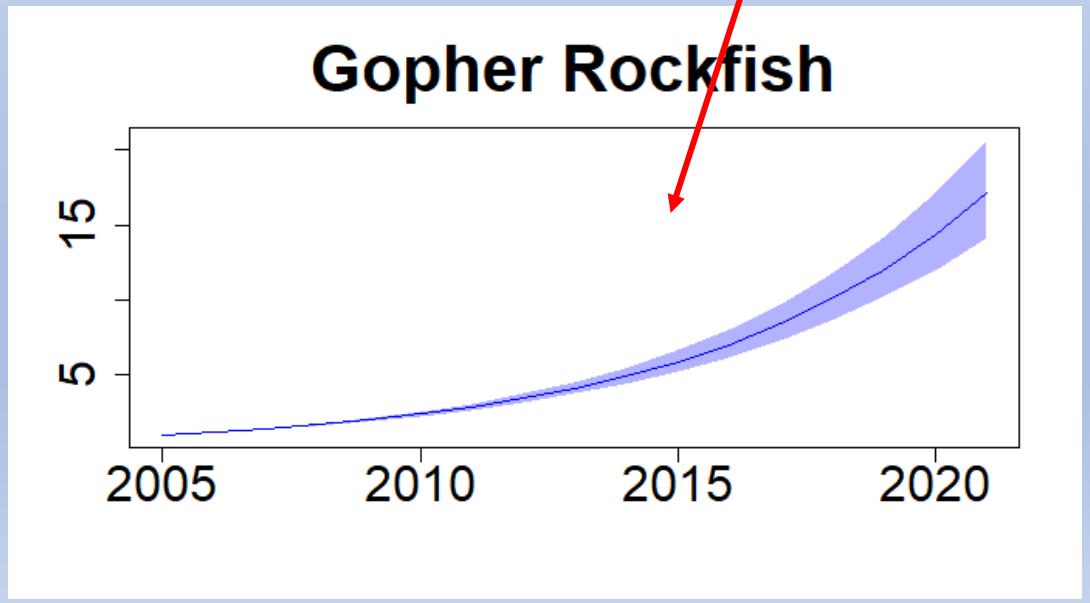




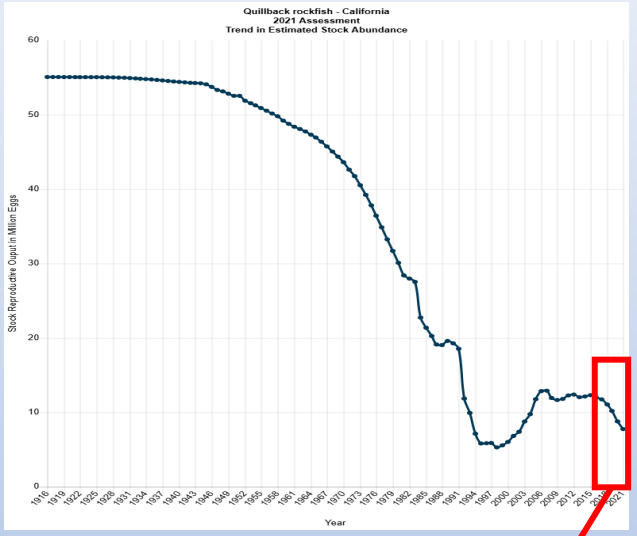
Comparison with stock assessments: gopher & quillback

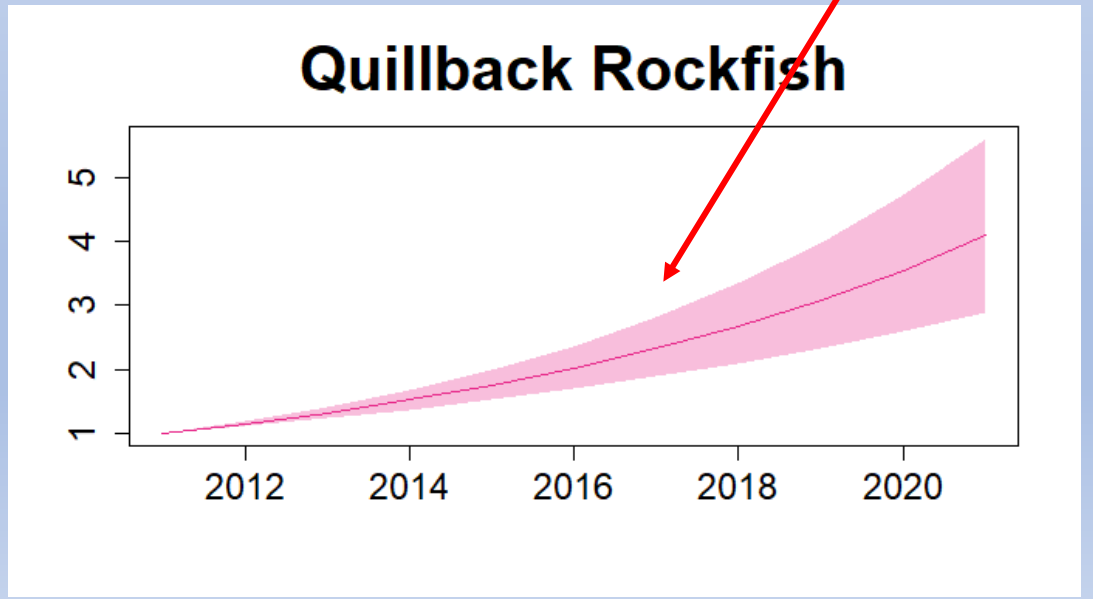
Gopher & Black & Yellow rockfish





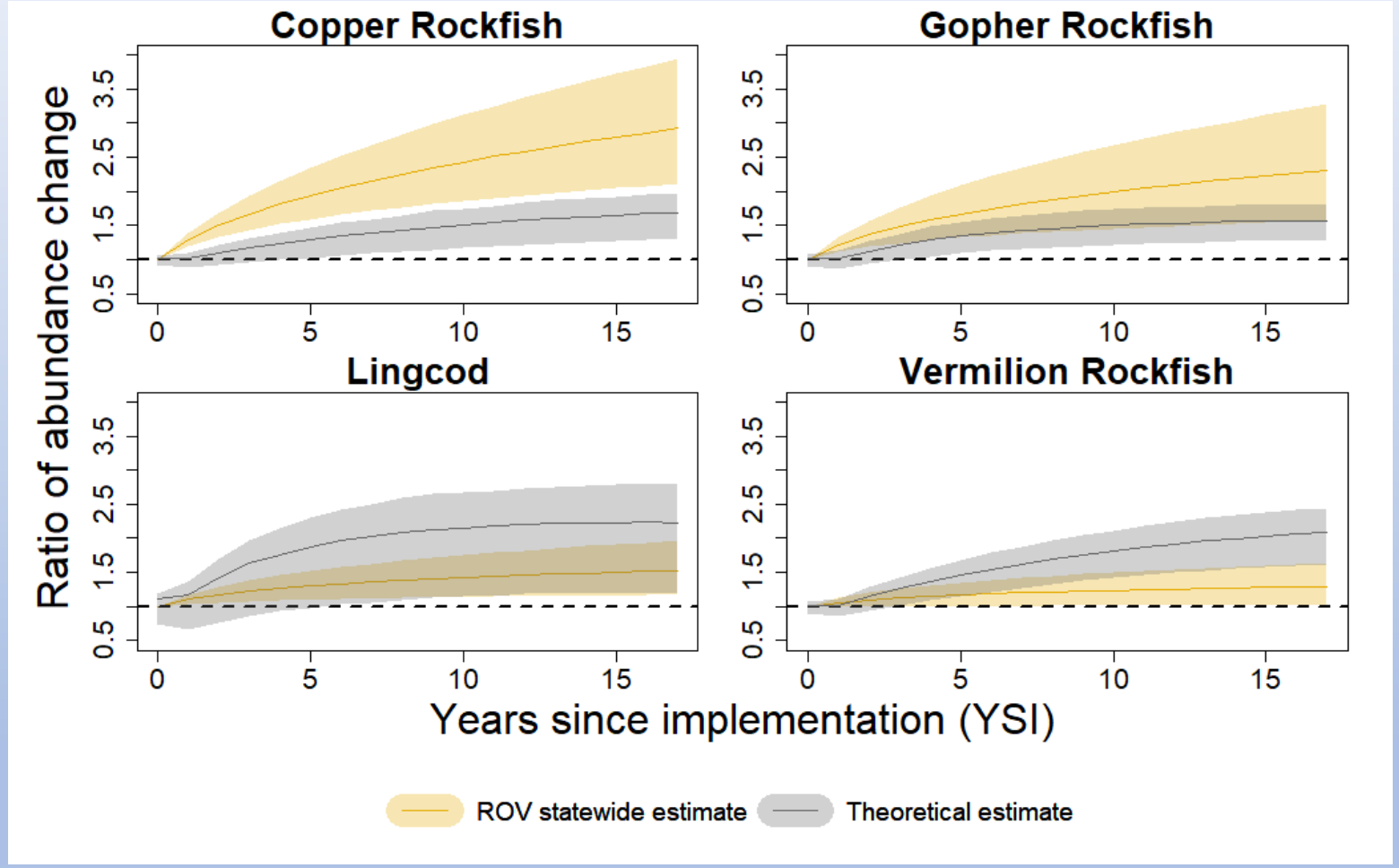
Quillback rockfish





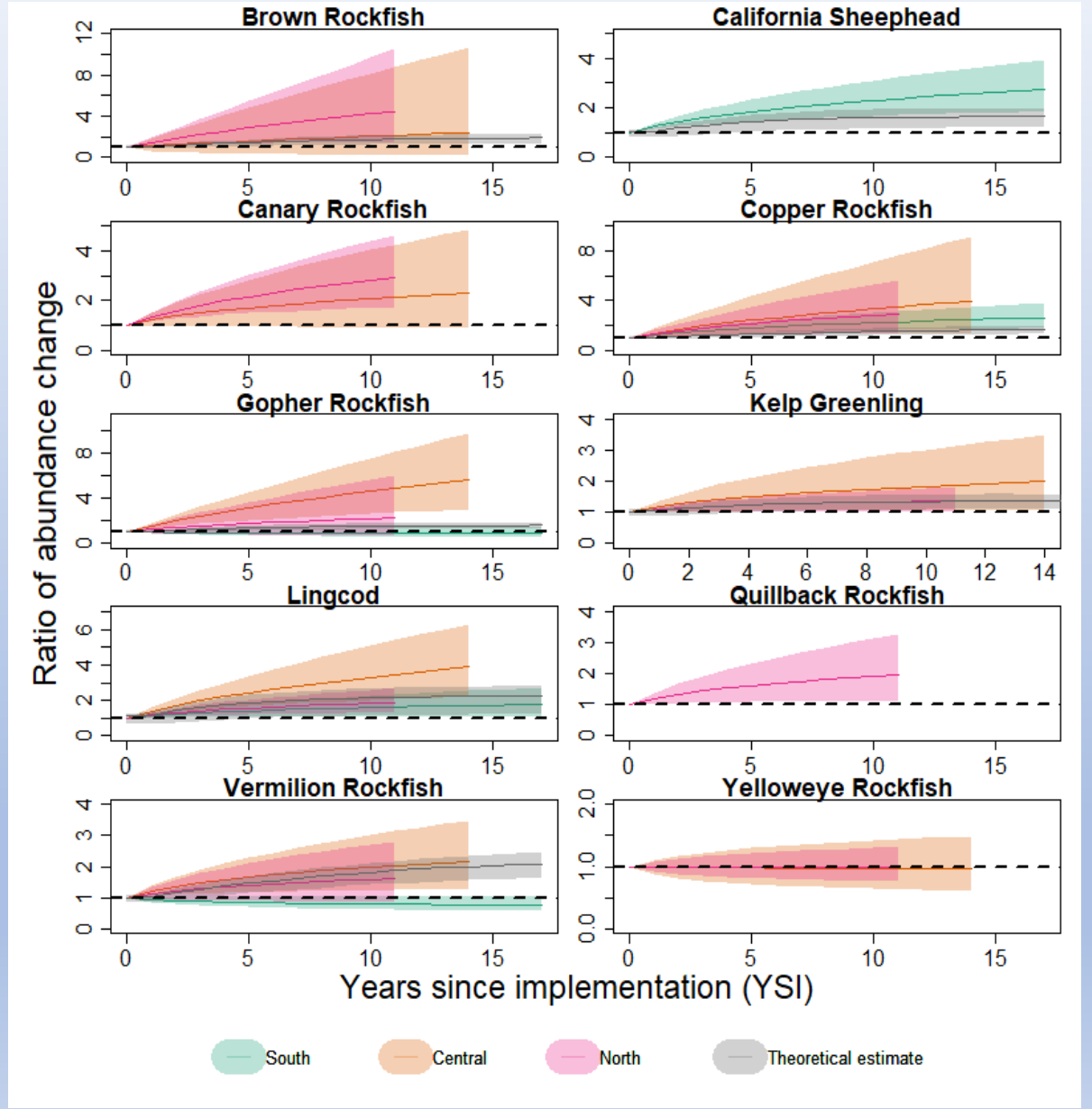
Results: statewide MPA effects

- All four species modelled across the state showed positive MPA effects
- Copper and Gopher rockfish exceeded theoretical expectations
- Lingcod and vermilion showed lower than expected responses

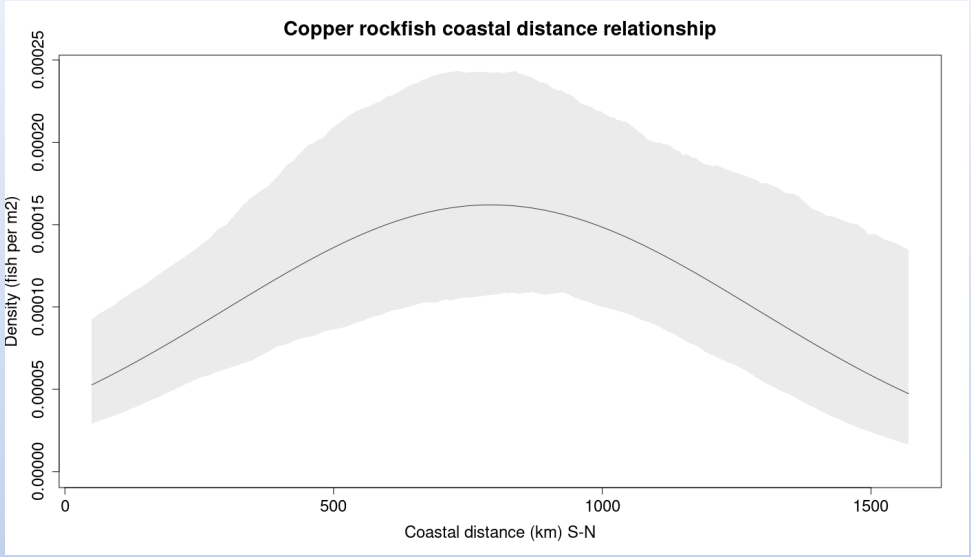


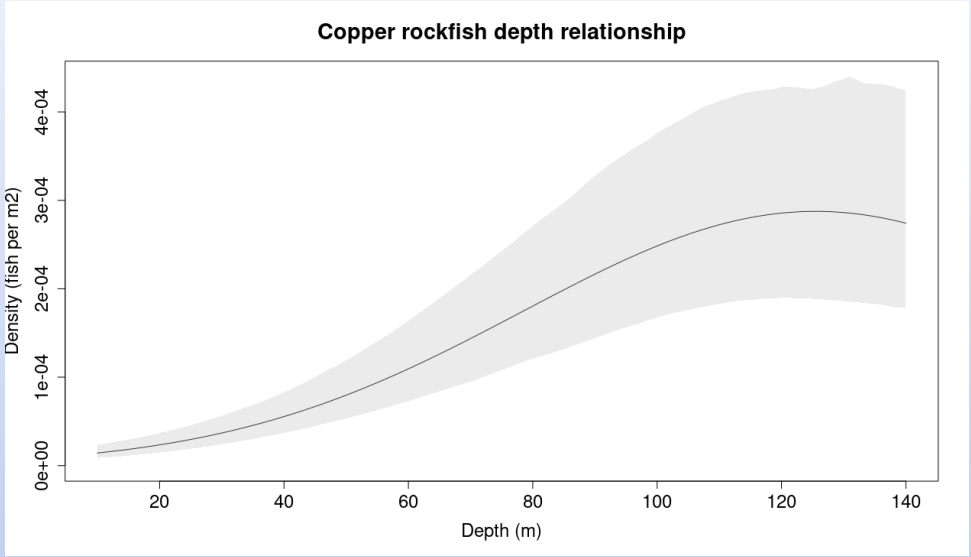
Results: regional MPA effects

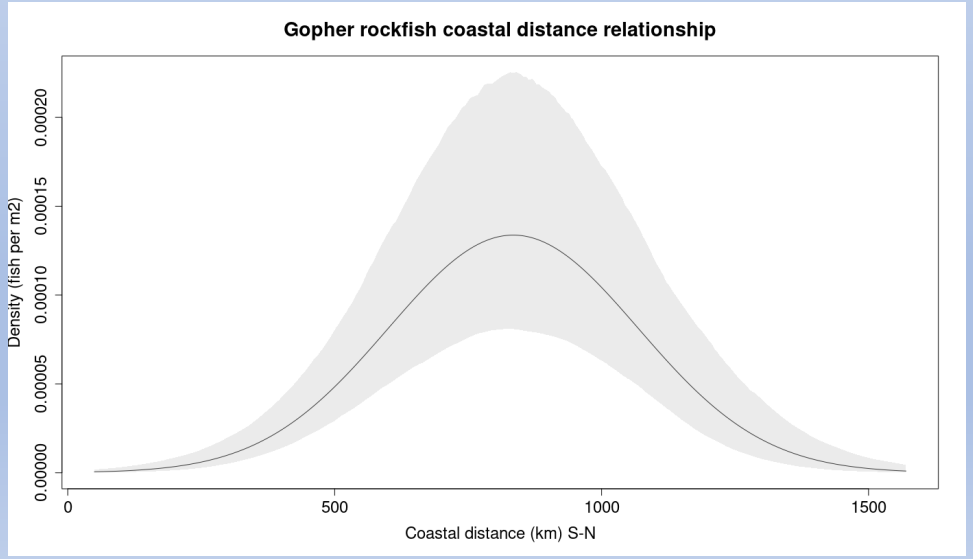
- 11 out of 17 species-region displayed higher mean MPA effects than expected
- No negative MPA effects
- 3 non-significant MPA regional effects
  - Yelloweye rockfish
  - Vermilion rockfish in the South

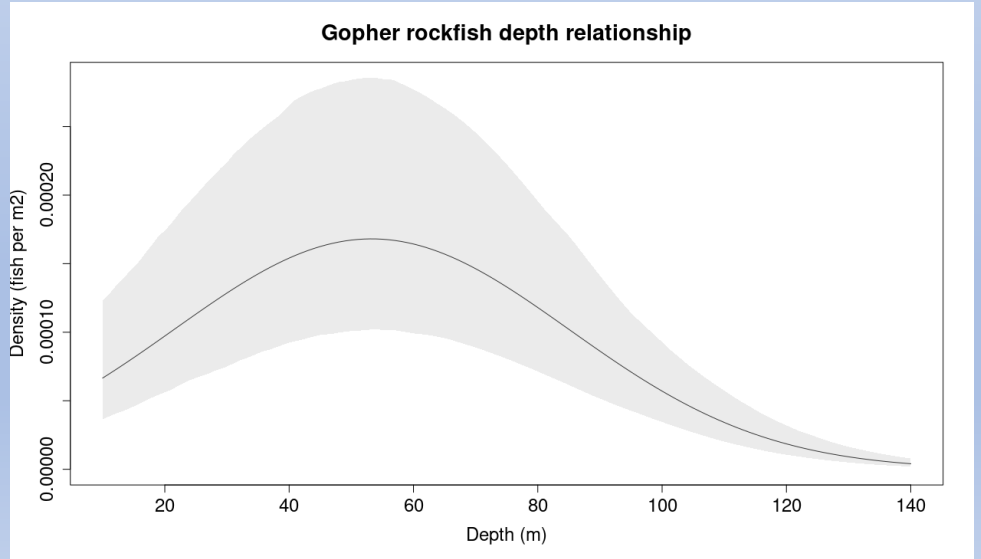


Environmental covariates





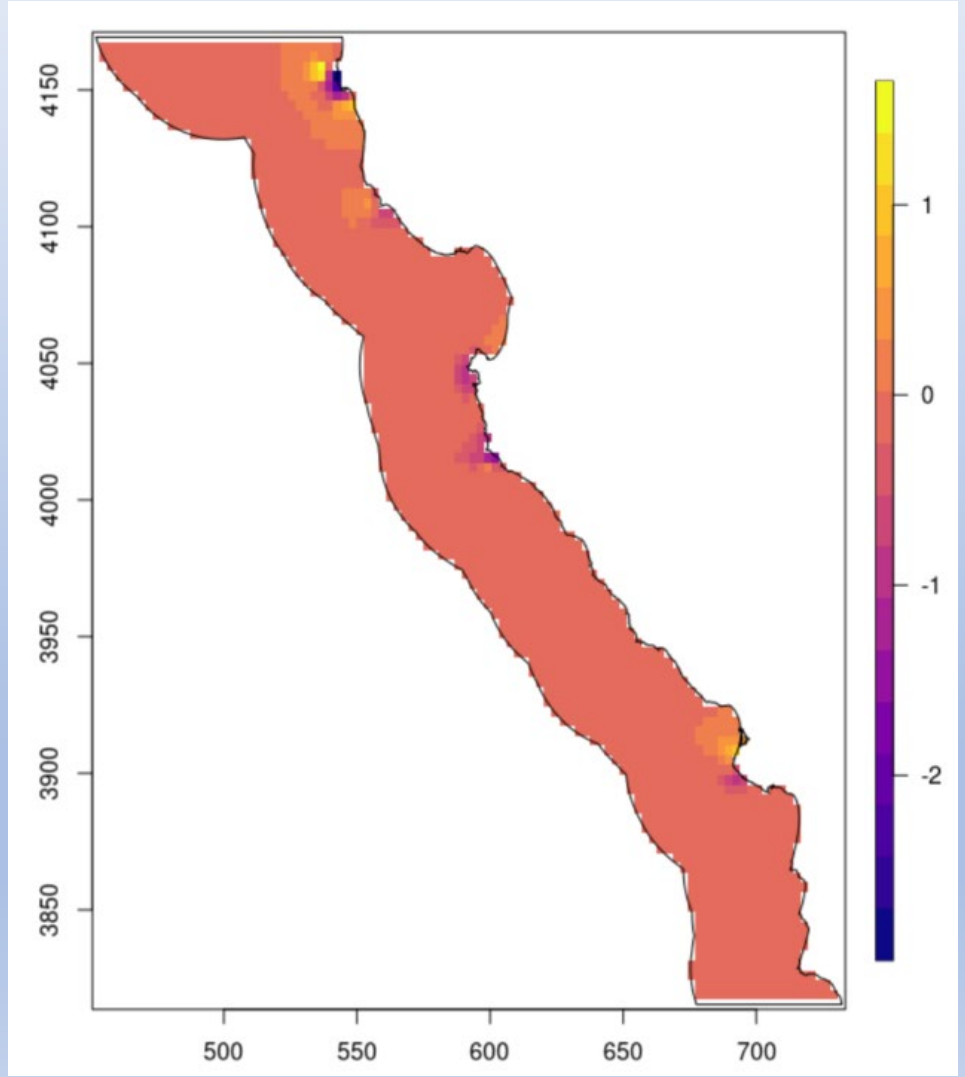




Spatial autocorrelation

- Residual spatial autocorrelation tended to occur on relatively small scales (2-6 km)
- Indicates small scale variation is important with nearby areas showing higher/lower than expected densities than are accounted for by fixed covariates
- Spatial standard deviation ranged from moderate (1.1) to high (9.4) indicating this variation was important to account for

Residual spatial autocorrelation: vermilion rockfish central coast



Additional covariates: seafloor mapping

- Additional modeling conducted for vermilion rockfish in the central region where 2m resolution mapping was available

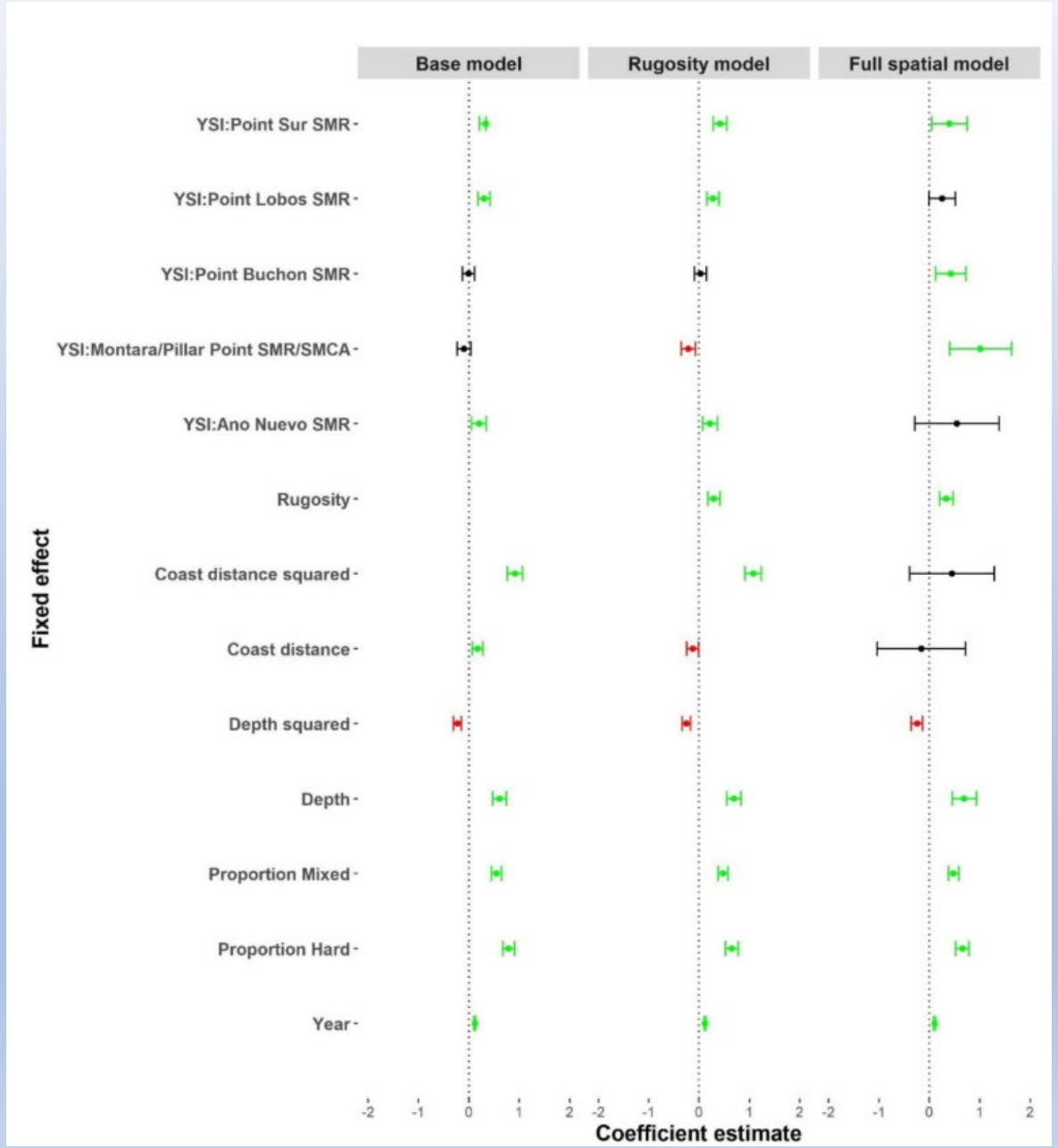
- Rugosity in 20 m radius included (see Tolimieri et. al. 2009* – home ranges typically 1200-2500 m^2 = 20-30 m radius)

- 3 models compared

Model	Marginal log-likelihood (MLL)	Change in MLL
Base model	-4341.57	-
Rugosity model	-4333.39	8.18
Full Spatial model	-4319.22	22.35

- 10 m subunits allow for inclusion of scales relevant to small-scale habitat assocations

* Tolimieri et. al. (2009) "Home range size and patterns of space use by lingcod, copper rockfish and quillback rockfish in relation to diel and tidal cycles"



Conclusions

- 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.)

- MPAs having a detectable additional effects at statewide and regional scales following 10-16 years of protection

- Future directions:
  - Testing of other covariates, especially bathymetric variables, fishing effort, oceanographic variables, and climate change
  - Examining correlation with recruitment
  - Size structure/biomass


Questions?