Multivariate Autoregressive State-Space Models (MARSS): PVA for data-poor species:

ESA-listed rockfishes in Puget Sound

Nick Tolimieri
Elizabeth Holmes
Greg Williams
Northwest Fisheries Science Center
National Marine Fisheries Service

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

Population viability analysis

- Tool for evaluating population status of spp thought to be at risk of extinction

- Two general types:
  - Demographic population modeling (Leslie matrices)
  - Time-series analysis (count-based) eg MARSS

- Goal of both:
  - Long-term population growth rate

Data-poor species

- Many potentially at risk species are ‘data-poor’
  - Poor quality or incomplete data
  - Disparate data sources
  - Gappy data (missing data in the time-series)

- Problem because no action taken
  - Species of concern
  - Data-deficient

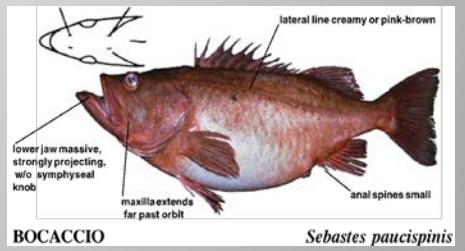
MARSS

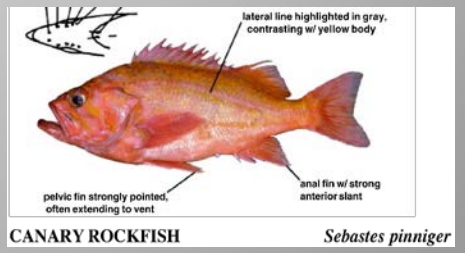
Multivariate Autoregressive State Space Models

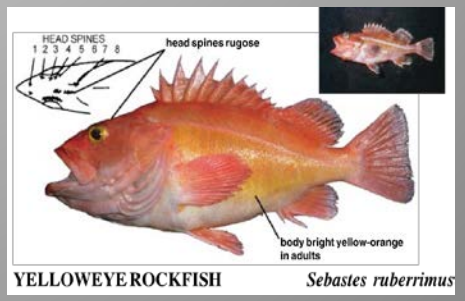
- Combine data from multiple sources
- Combine data cross changes in regulations
- Use gappy data
- Ask questions about space
- Estimate process and observation variance

Three ESA-listed rockfishes in Puget Sound

- Listed 2010
- 5 year review







Data sources – three surveys

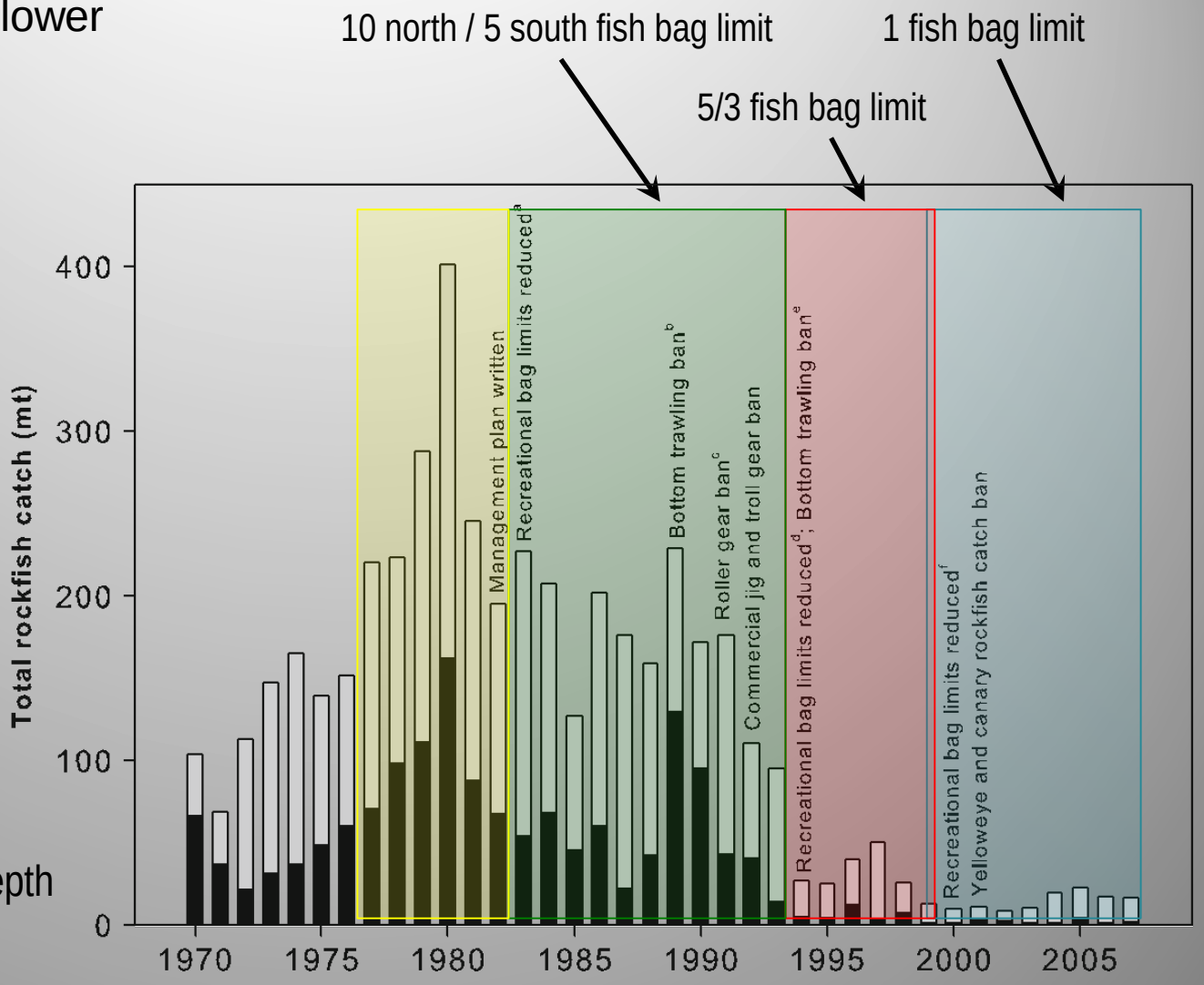
- WDFW Recreational fishery survey
  - 1977-2014 (& 1965-1973)
  - Primary data source
- REEF survey
  - Citizen science scuba survey
  - 1998-2014
- WDFW trawl survey
  - 1987-2014

All have data gaps
Need to combine

Regulatory changes – reduction in bag limits in Rec fishery

CPUE capped lower and lower

~ Catchability



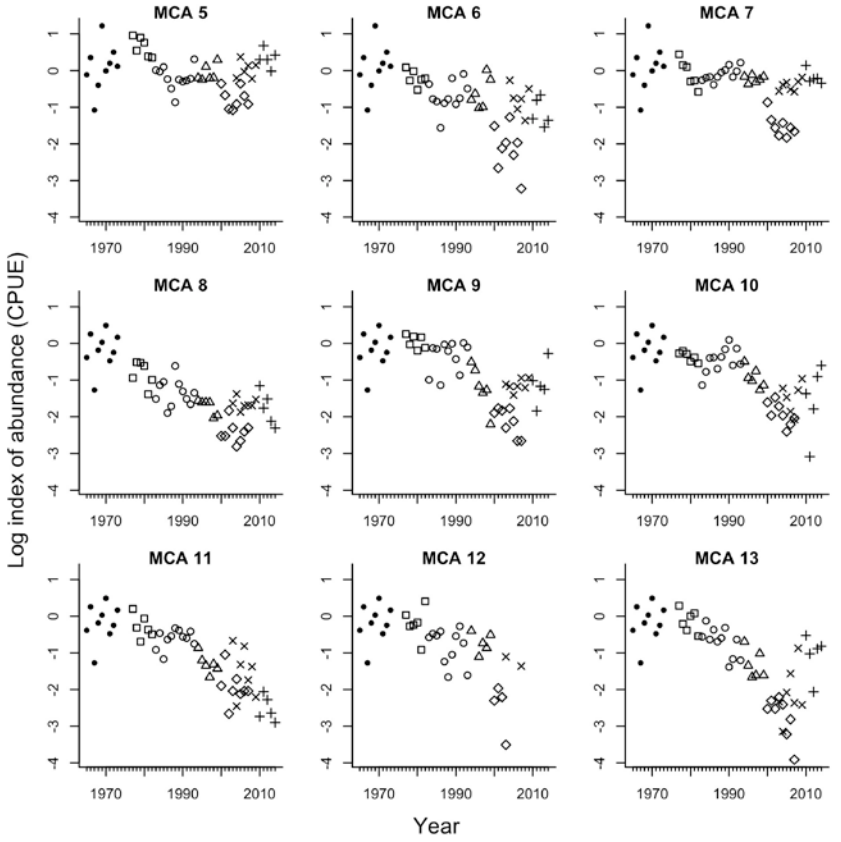
2010 Listing: 120 foot max depth limit for bottom fishing

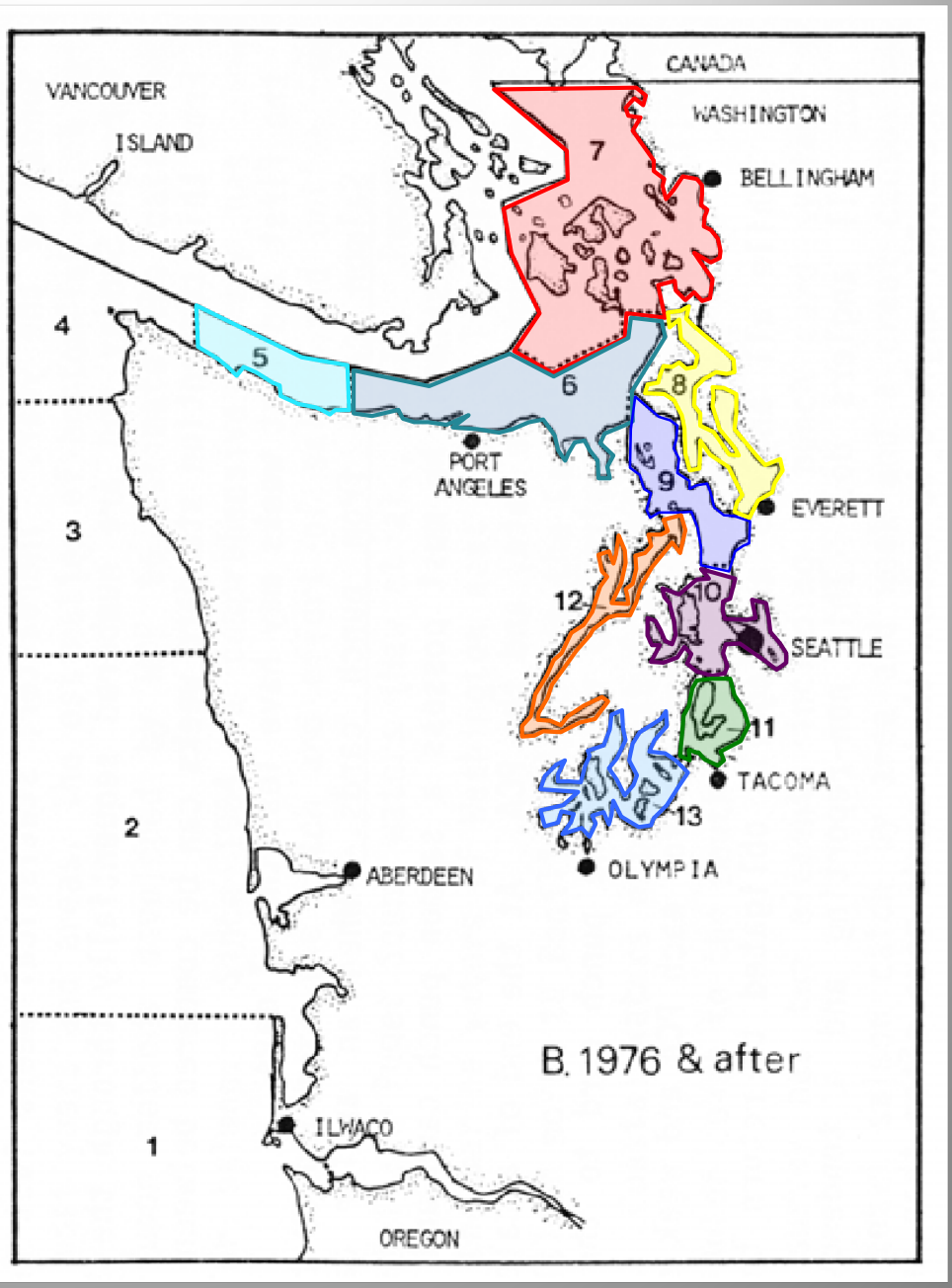
Catch after 2010 is either estimated release or illegal catch (retention)

Space – Management Conservation Areas (MCAs)

9 MCAs within “Greater Puget Sound”

Recreational survey data

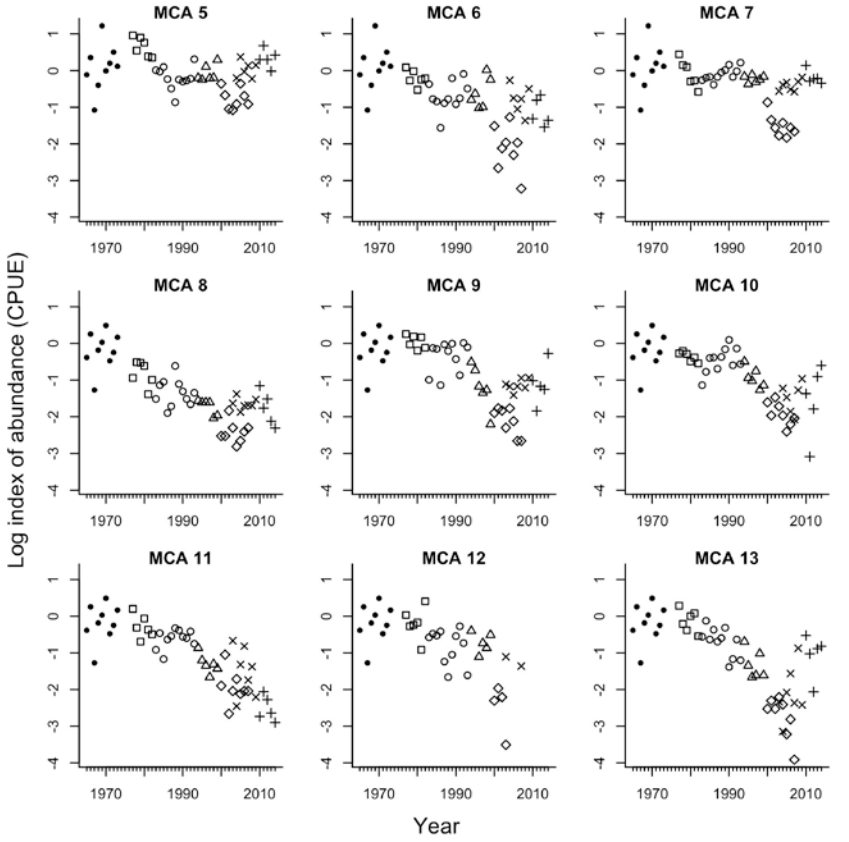


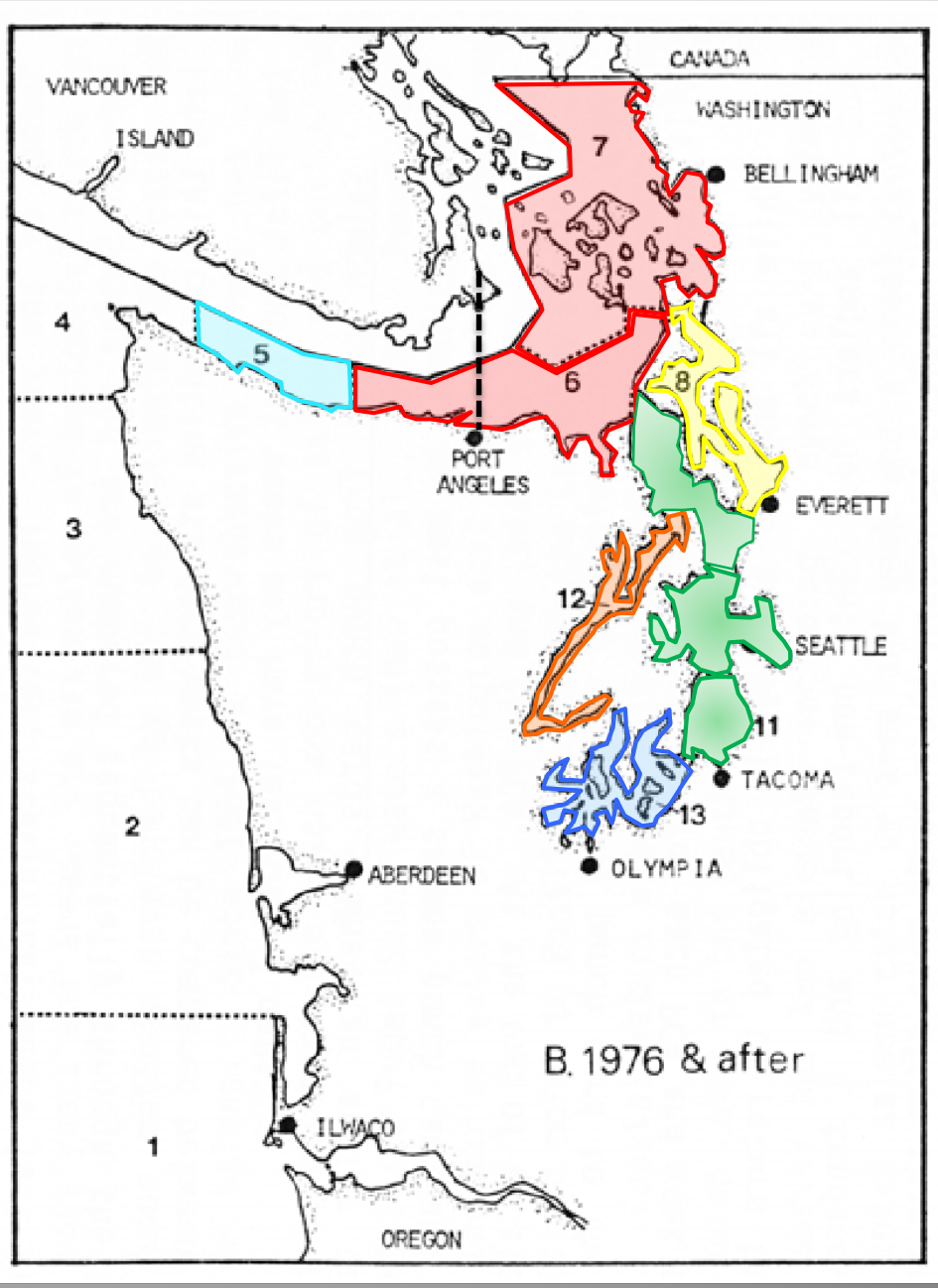


Space – five basins

9 MCAs within “Greater Puget Sound”…

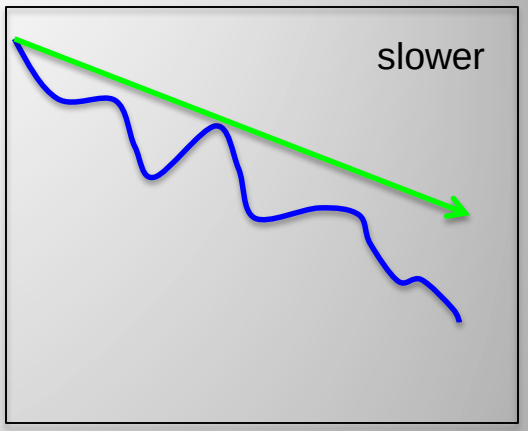
….align with the major basins in the Sound

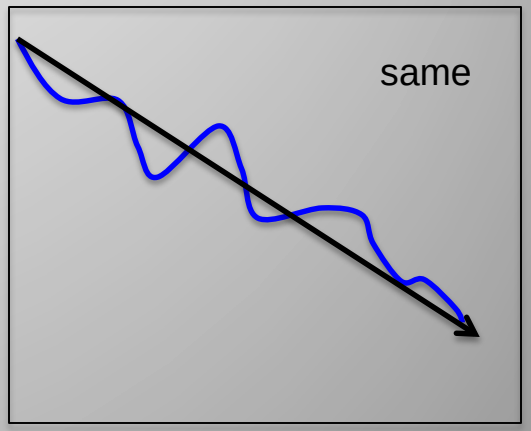


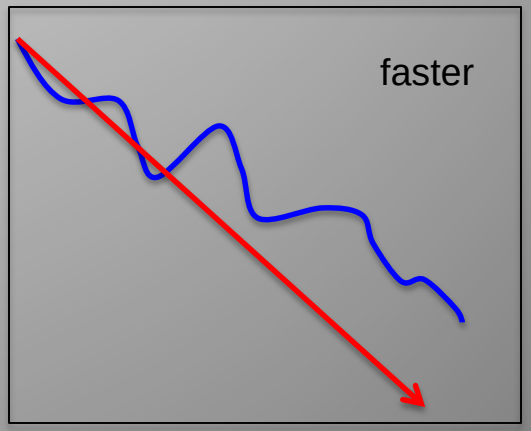


Basket approach

- Very few data on the listed species
- Some species composition data (CREEL)
- MARSS to estimate trend in TOTAL ROCKFISH
- Compare to species composition data
  - % listed increases = not decreasing as fast
  - % listed constant = decreasing at same rate
  - % listed decreases = decreasing faster



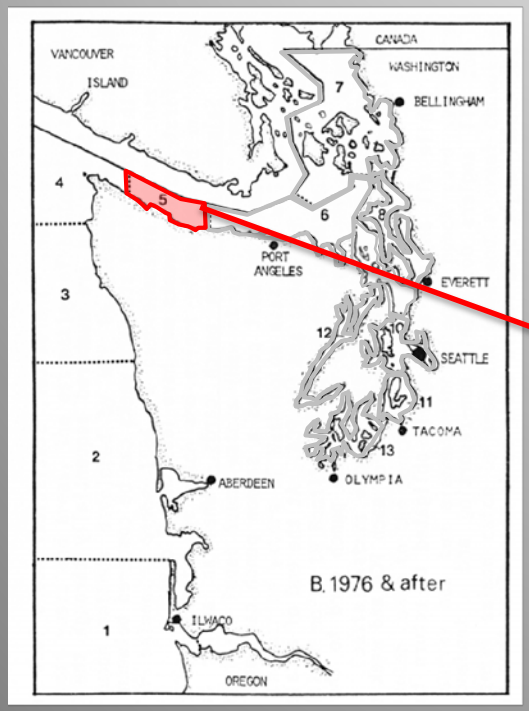


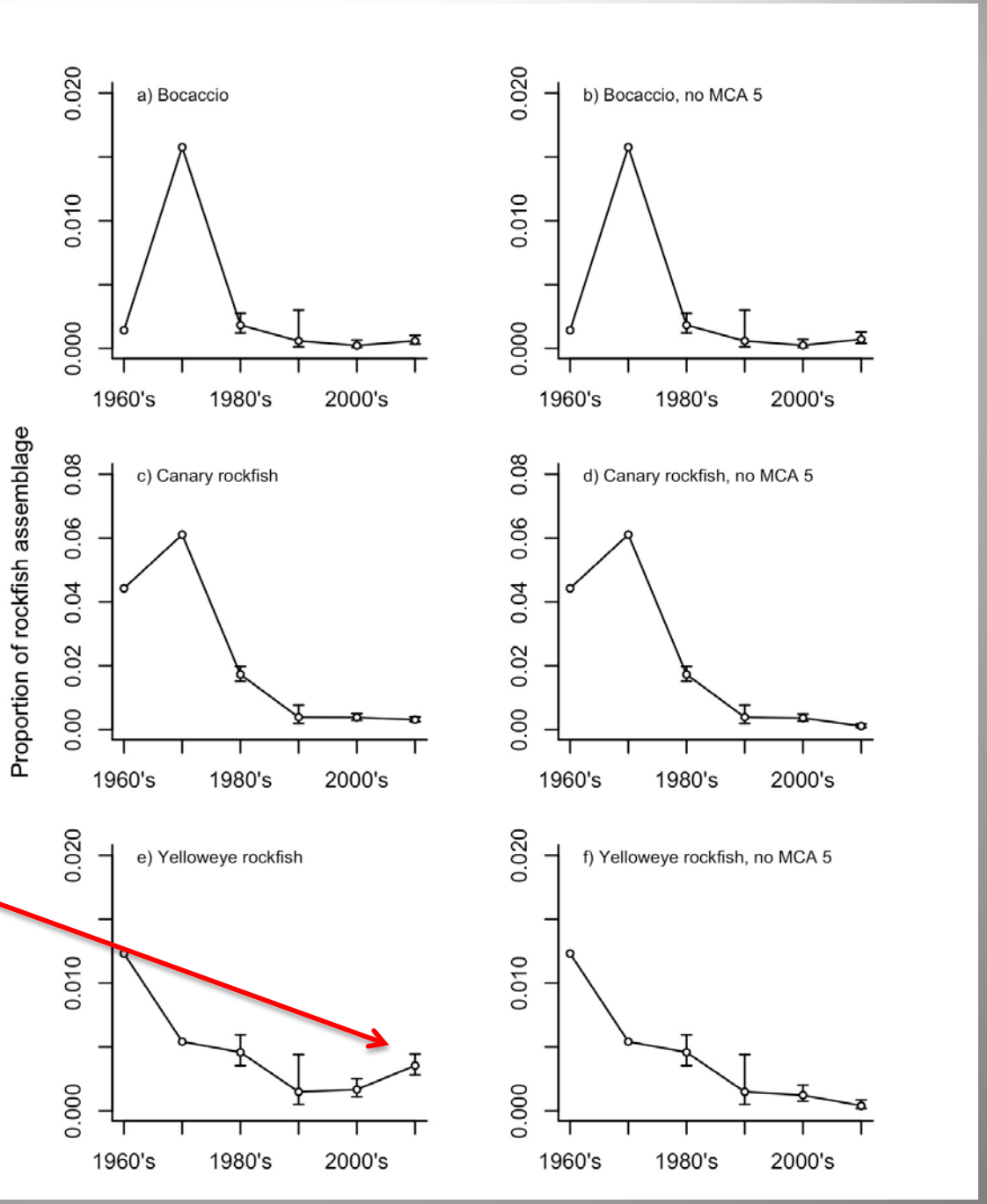


Species comp

All three listed species have declined in relative abundance in the recreational catch

Small bump up for yellow eye recently





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- Some species composition data (CREEL)
- Estimate trend in TOTAL ROCKFISH CPUE
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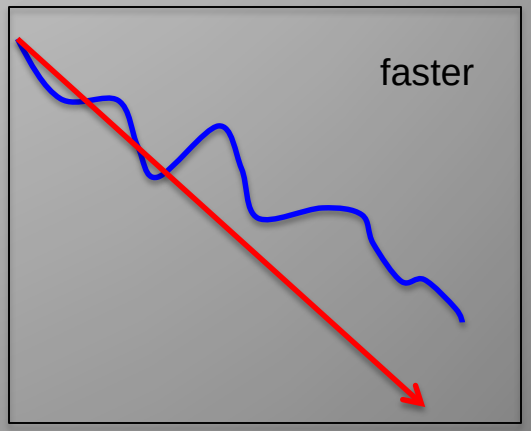

Multivariate Autoregressive State Space Models (MARSS)

$$\mathbf{x}_t = \mathbf{B}_t \mathbf{x}_{t-1} + \mathbf{u}_t + \mathbf{C}_t \mathbf{c}_t + \mathbf{w}_t$$

Process model

x = state, what we think is actually there

$$\mathbf{y}_t = \mathbf{Z}_t \mathbf{x}_t + \mathbf{a}_t + \mathbf{D}_t \mathbf{d}_t + \mathbf{v}_t$$

Observation model

y = observations, what we count

-- a time-series

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$$\mathbf{x}_t = \mathbf{B}_t \mathbf{x}_{t-1} + \mathbf{u}_t + \mathbf{C}_t \mathbf{c}_t + \mathbf{w}_t$$

u = population growth rate*

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Observation model

*with log(y) data = discrete-time Gompertz model

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Process model

Going to ignore these:

C & D = covariates

B = density dependence and interspecific interactions

$$\mathbf{y}_t = \mathbf{Z}_t \mathbf{x}_t + \mathbf{a}_t + \mathbf{D}_t \mathbf{d}_t + \mathbf{v}_t$$

Observation model

C & D -> 0

B -> Identity matrix

Multivariate Autoregressive State Space Models (MARSS)

$$\mathbf{x}_t = \mathbf{B}_t \mathbf{x}_{t-1} + \mathbf{u}_t + \mathbf{C}_t \mathbf{c}_t + \mathbf{w}_t$$

Process model

Multiple states

u = population growth rate

x_t = the state

x_{t-1} = autoregressive

w = process variance

Multiple time series

$$\mathbf{y}_t = \mathbf{Z}_t \mathbf{x}_t + \mathbf{a}_t + \mathbf{D}_t \mathbf{d}_t + \mathbf{v}_t$$

Observation model

y = the data

Z = state process: space, gear

a = scaling term ~ catchability

v = observation variance

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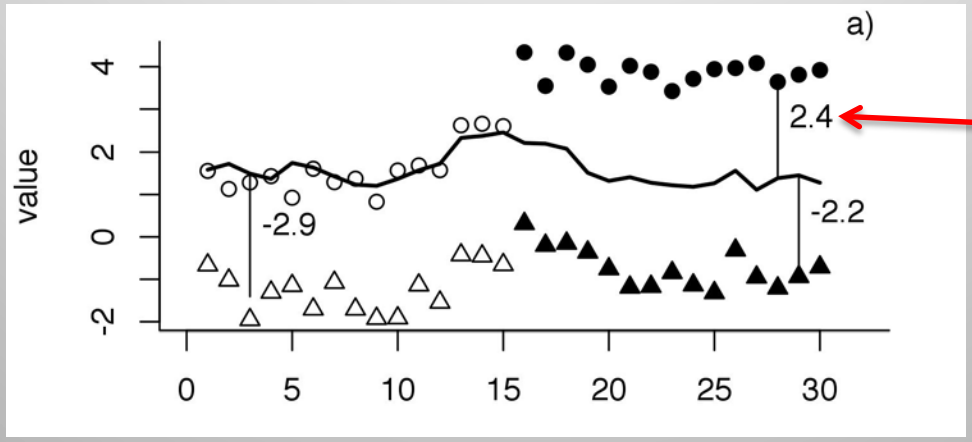
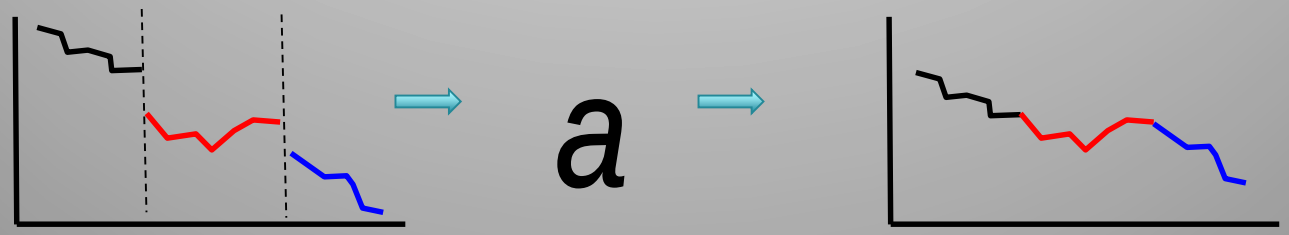
‘*a*’ lets us combine times-series within a state (Z)

eg, different areas within Puget Sound



a



For Total Rockfish

Fit a whoe bunch of models...

Three combinations of the data

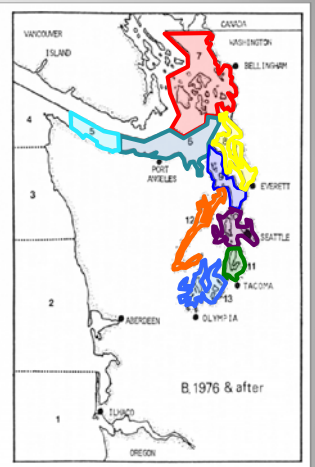
- Recreational data only
- Recreational + REEF data
- Recreational + REEF + Trawl data

Different combinations of space and survey

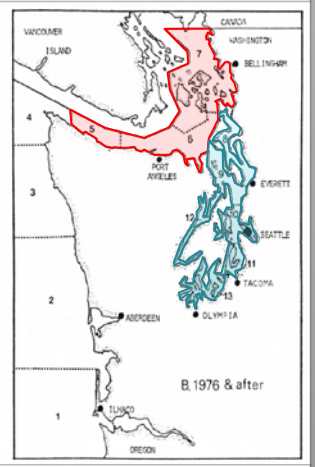
- Combined or different states (trajectories) (**Z**)
- Combined or different growth rates (*u*)
- Covariation or no covariation (**Q**)

Z = MCA, Region, GPS, MCA x Survey, Region x Survey, GPS x Survey, combined surveys, separate surveys…et al.

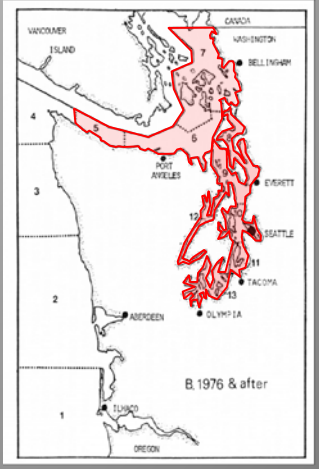
By MCA



By Region
North Puget Sound (NPS)
South Puget Sound (PSP)



Greater Puget Sound (GPS)



Model selection with AICc to choose best model

….(within a combination of data)

Rec

Data	Trajectories Z (x0, a)	Growth rate u	Process varia	No. Parameters	AIC	delta AIC
Rec	Region (2, 52)	GPS (1)	cov (3)	67	401.752	0.000
Rec	Region (2, 52)	GPS (1)	no cov (2)	66	401.953	0.201
Rec	Region (2, 52)	Region (2)	cov (3)	68	404.730	2.978
Rec	Region (2, 52)	Region (2)	no cov (2)	67	404.935	3.182
Rec	GPS (1, 53)	GPS (1)	no cov (1)	65	405.992	4.239
Rec	MCA (9, 45)	GPS (1)	no cov (9)	73	433.409	31.656
Rec	MCA (9, 45)	Region (2)	no cov (9)	74	435.567	33.815
Rec	MCA (9, 45)	MCA (9)	no cov (9)	81	447.615	45.862
Rec	MCA (9, 45)	GPS (1)	cov (45)	109	522.857	121.105
Rec	MCA (9, 45)	Region (2)	cov (45)	110	527.154	125.402
Rec	MCA (9, 45)	MCA (9)	cov (45)	117	549.046	147.294

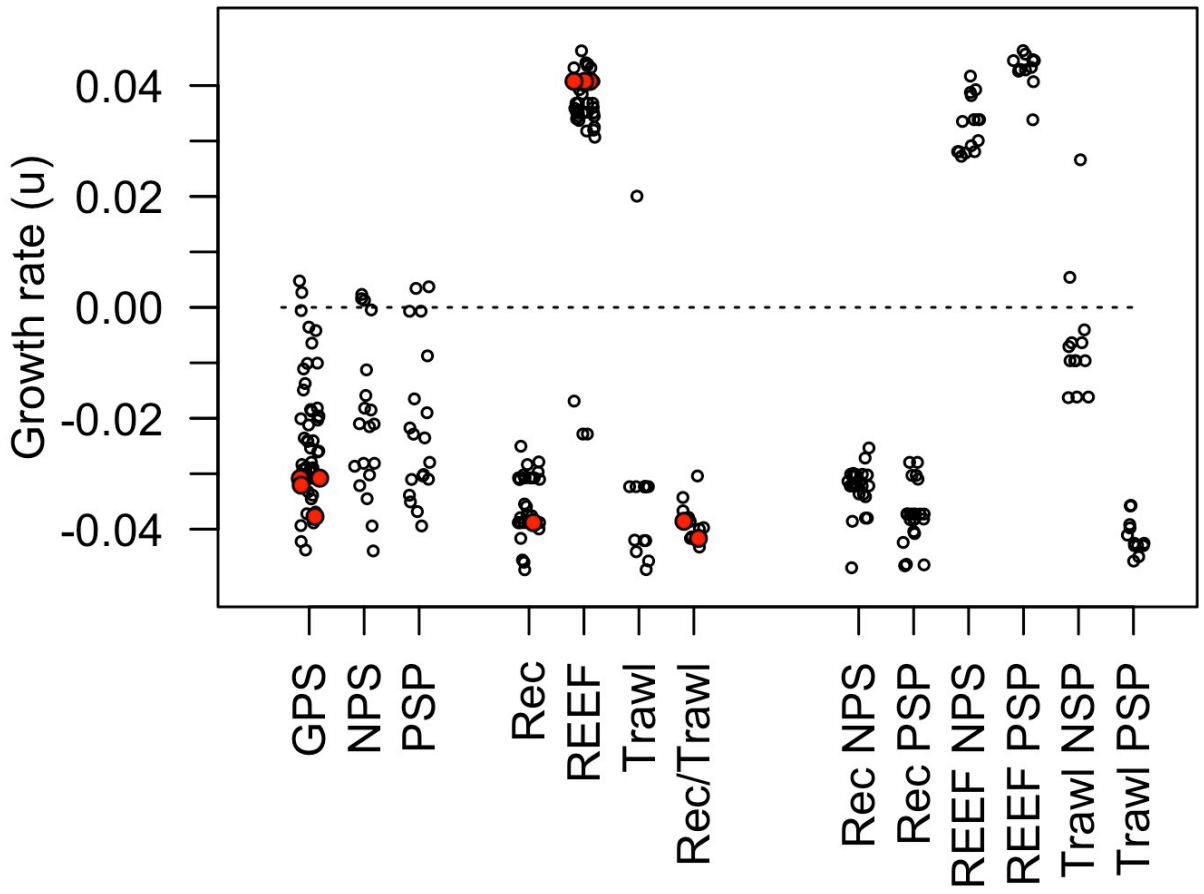
Rec + REEF

Data	Trajectories Z (x0, a)	Growth rate u	Process variance Q	No. Parameters	AIC	delta AIC
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	Survey (2)	Rec btw Regions (4)	87	602.5573146	0
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	Survey (2)	no cov (3)	86	602.7700178	0.212703136
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	GPS (1)	no cov (3)	85	603.6751856	1.117870969
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	GPS (1)	Rec btw Regions (4)	86	603.9576724	1.400357723
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	RecNPS, RecPSP,REEF (3)	Rec btw Regions (4)	88	605.4516382	2.894323539
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	RecNPS, RecPSP,REEF (3)	no cov (3)	87	605.6988283	3.141513682
Rec+REEF	Survey (2, 61)	Survey (2)	no cov (2)	85	606.8554611	4.298146488
Rec+REEF	Region x Survey (4, 59)	Survey (2)	Survey w/in Regions (6)	89	607.0666184	4.509303737
Rec+REEF	Survey (2, 61)	GPS (1)	no cov (2)	84	607.6796313	5.122316698
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	Survey (2)	cov (6)	89	607.9914568	5.434142209
Rec+REEF	Region x Survey (4, 59)	GPS (1)	Survey w/in Regions (6)	88	608.2841113	5.726796653
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	Survey (2)	no cov (3)	86	608.5635856	6.006271013
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	GPS (1)	cov (6)	88	609.1064323	6.549117692
Rec+REEF	Region x Survey (4, 59)	Survey (2)	Surveys btw Regions (6)	89	609.1704506	6.613135955
Rec+REEF	Survey (2, 61)	Survey (2)	cov (3)	86	609.7319713	7.174656624
Rec+REEF	Survey (2, 61)	GPS (1)	cov (3)	85	610.0645262	7.507211539
Rec+REEF	Region x Survey (4, 59)	Region x Survey (4)	no cov (4)	89	610.4192969	7.861982298
Rec+REEF	RecNPS, RecPSP,REEF (3, 60)	RecNPS, RecPSP,REEF (3)	cov (6)	90	610.6184669	8.061152253
Rec+REEF	Region x Survey (4, 59)	Region (2)	Surveys btw Regions (6)	89	611.1720922	8.614777527
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	Survey (2)	REEF btw Regions (4)	87	611.3074939	8.750179234
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	Rec,REEFNPS,REEFPSP (3)	no cov (3)	87	611.4090844	8.851769813
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	GPS (1)	REEF btw Regions (4)	86	611.9863823	9.429067634
Rec+REEF	Region x Survey (4, 59)	GPS (1)	no cov (4)	86	612.2579581	9.700643442
Rec+REEF	Region x Survey (4, 59)	GPS (1)	Surveys btw Regions (6)	88	612.2590798	9.701765184
Rec+REEF	Region x Survey (4, 59)	Region (2)	no cov (4)	87	612.5855399	10.02822523
Rec+REEF	Region x Survey (4, 59)	Region x Survey (4)	Survey w/in Regions (6)	91	612.6254192	10.06810461
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	Survey (2)	cov (6)	89	613.5817465	11.02443183
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	GPS (1)	no cov (3)	85	613.6083059	11.05099129
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	Rec,REEFNPS,REEFPSP (3)	REEF btw Regions (4)	88	613.8994334	11.34211877
Rec+REEF	Region x Survey (4, 59)	Region (2)	Survey w/in Regions (6)	89	614.5049594	11.94764481
Rec+REEF	Region x Survey (4, 59)	Region x Survey (4)	Surveys btw Regions (6)	91	614.7589997	12.20168511
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	Rec,REEFNPS,REEFPSP (3)	cov (6)	90	615.7012801	13.14396546
Rec+REEF	Rec,REEFNPS,REEFPSP (3, 60)	GPS (1)	cov (6)	88	617.9903262	15.4330116
Rec+REEF	Region x Survey (4, 59)	Survey (2)	cov (10)	93	618.5282796	15.97096499
Rec+REEF	Region x Survey (4, 59)	GPS (1)	cov (10)	92	619.5362932	16.97897856
Rec+REEF	Region x Survey (4, 59)	Region (2)	cov (10)	93	623.1247046	20.56738993
Rec+REEF	Region x Survey (4, 59)	Region x Survey (4)	cov (10)	95	623.6953897	21.13807504
Rec+REEF	Region (2, 61)	GPS (1)	no cov (2)	84	625.5454942	22.98817959
Rec+REEF	Region (2, 61)	GPS (1)	cov (3)	85	626.4837592	23.92644461
Rec+REEF	GPS (1, 62)	GPS (1)	no cov (1)	83	626.7773126	24.21999795
Rec+REEF	Region (2, 61)	Region (2)	no cov (2)	85	627.9672035	25.40988891
Rec+REEF	Region (2, 61)	Region (2)	cov (3)	86	628.7948493	26.23753468
Rec+REEF	MCA x Survey (18, 45)	Survey (2)	no cov (18)	101	668.7709635	66.21364883
Rec+REEF	MCA x Survey (18, 45)	Survey (3)	no cov (18)	102	671.8498438	69.29252921
Rec+REEF	MCA x Survey (18, 45)	Region x Survey (4)	no cov (18)	103	673.1717063	70.61439164
Rec+REEF	MCA x Survey (18, 45)	GPS (1)	no cov (18)	100	681.6127557	79.05544112
Rec+REEF	MCA x Survey (18, 45)	Region (2)	no cov (18)	101	688.8946713	86.33735669
Rec+REEF	MCA x Survey (18, 45)	MCA x Survey (18)	no cov (18)	117	698.9690166	96.41170195
Rec+REEF	MCA x Survey (18, 45)	Survey (2)	cov (171)	254	1318.647661	716.0903465
Rec+REEF	MCA x Survey (18, 45)	Survey (3)	cov (171)	255	1325.28499	722.7276752
Rec+REEF	MCA x Survey (18, 45)	GPS (1)	cov (171)	253	1328.137691	725.5803768
Rec+REEF	MCA x Survey (18, 45)	Region x Survey (4)	cov (171)	256	1335.893663	733.336348
Rec+REEF	MCA x Survey (18, 45)	Region (2)	cov (171)	254	1336.129996	733.5726816
Rec+REEF	MCA x Survey (18, 45)	MCA x Survey (18)	cov (171)	270	1452.005755	849.44844

Rec + REEF + Trawl

Data	Trajectories Z (x0, a)	Growth rate u	Process variance Q	No. Parameters	AIC	delta AIC
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	Rec/Trawl + REEF (2)	Rec btw Regions (5)	104	834.1937456	0
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	GPS (1)	no cov (4)	102	835.3004391	1.106693515
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	GPS (1)	Rec btw Regions (5)	103	835.5854507	1.391705045
Rec+REEF+Trawl	Region x Survey (4, 67)	GPS (1)	Surveys btw Regions (5)	103	835.6806391	1.486893494
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec/Trawl + REEF (2)	Rec and trawl btw Regions (7)	106	836.1527991	1.959053445
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	GPS (1)	cov (10)	108	836.9001494	2.706403787
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	Survey (3)	Rec btw Regions (5)	105	837.1550818	2.961336191
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	Region (2)	cov (10)	109	837.564369	3.370623387
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	GPS (1)	Rec and trawl btw Regions (7)	105	837.8612606	3.667515015
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	Rec/Trawl + REEF (2)	no cov (4)	103	838.1502154	3.95646981
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Survey (3)	Rec and trawl btw Regions (7)	107	838.8513723	4.657626642
Rec+REEF+Trawl	Survey (3, 68)	GPS (1)	no cov (3)	101	839.3033208	5.109575223
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	RecNPS, RecPSP,REEF, Trawl (4)	Rec btw Regions (5)	106	840.0708631	5.877117512
Rec+REEF+Trawl	Region x Survey (4, 67)	RecNPS, RecPSP,REEF, Trawl (4)	Surveys btw Regions (5)	106	840.1153318	5.921586217
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	RecNPS, RecPSP,REEF, Trawl (4)	no cov (4)	105	840.2965955	6.102849873
Rec+REEF+Trawl	Region x Survey (6, 65)	NA (2)	Survey w/in Regions (9)	108	840.7275775	6.533831912
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	Survey (3)	no cov (4)	104	841.0959377	6.902192084
Rec+REEF+Trawl	Survey (3, 68)	Survey (3)	no cov (3)	103	841.4040662	7.210320624
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec,REEF, TrawlNPS, TrawlPSP (4)	Rec and trawl btw Regions (7)	108	841.6991907	7.505445096
Rec+REEF+Trawl	Survey (3, 68)	GPS (1)	cov (6)	104	842.6929223	8.49917666
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec/Trawl + REEF (2)	Rec btw Regions (6)	105	843.288919	9.095173422
Rec+REEF+Trawl	Region x Survey (6, 65)	Survey (3)	Surveys btw Regions (9)	109	843.4509845	9.257238852
Rec+REEF+Trawl	Region x Survey (6, 65)	Survey (3)	Surveys btw Regions (9)	109	843.5389301	9.345184444
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	RecNPS, RecPSP,REEF, Trawl (4)	cov (10)	111	843.672841	9.479095395
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec/Trawl + REEF (2)	no cov (5)	104	844.1333226	9.939576969
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5)	Rec and trawl btw Regions (7)	109	844.6521075	10.45836186
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	GPS (1)	Rec btw Regions (6)	104	845.2652573	11.07151171
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	GPS (1)	no cov (5)	103	845.5730438	11.37929821
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Survey (3)	Rec btw Regions (6)	106	846.0664604	11.87271474
Rec+REEF+Trawl	Region x Survey (6, 65)	NA (2)	no cov (6)	105	846.1703318	11.97658615
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Survey (3)	no cov (5)	105	846.3318821	12.13813653
Rec+REEF+Trawl	Survey (3, 68)	Survey (3)	cov (6)	106	846.5569753	12.36322965
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, Trawl (4, 67)	Survey (3)	cov (10)	110	847.1097434	12.91599778
Rec+REEF+Trawl	Region x Survey (6, 65)	Survey (3)	no cov (6)	106	848.1211366	13.92739095
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	GPS (1)	cov (15)	113	848.4093349	14.21558927
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	Rec/Trawl, Reef (2)	Survey w/in Regions (4)	103	848.8104259	14.61668033
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec,REEF, TrawlNPS, TrawlPSP (4)	Rec btw Regions (6)	107	848.8946826	14.70093699
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec/Trawl + REEF (2)	cov (15)	114	849.0934787	14.89973309
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec,REEF, TrawlNPS, TrawlPSP (4)	no cov (5)	106	849.1491364	14.95539081
Rec+REEF+Trawl	Region x Survey (6, 65)	NA (2)	Surveys btw Regions (12)	111	849.3200541	15.12630852
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	Rec/Trawl, Reef (2)	no cov (3)	102	849.6474096	15.45366403
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	GPS (1)	Survey w/in Regions (4)	102	850.7972981	16.60355249
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	GPS (1)	no cov (3)	101	851.0758778	16.8821322
Rec+REEF+Trawl	Region x Survey (6, 65)	RecNPS, RecPSP,REEF, Trawl (4)	no cov (6)	107	851.1577976	16.96405194
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3)	Survey w/in Regions (4)	104	851.4138053	17.22005971
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5)	Rec btw Regions (6)	108	851.8351439	17.64139828
Rec+REEF+Trawl	Region x Survey (6, 65)	Region x Survey (6)	Surveys btw Regions (9)	112	852.0639536	17.87020796
Rec+REEF+Trawl	Region x Survey (6, 65)	NA (3)	Surveys btw Regions (12)	112	852.1128033	17.91905767
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3)	no cov (3)	103	852.5384809	18.34473525
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Survey (3)	cov (15)	115	852.594415	18.4006094
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	GPS (1)	cov (6)	104	852.73485	18.5411044
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	Rec/Trawl, Reef (2)	cov (6)	105	853.3123205	19.11857491
Rec+REEF+Trawl	Region x Survey (6, 65)	Region (2)	no cov (6)	105	854.5787946	20.38504901
Rec+REEF+Trawl	Region x Survey (6, 65)	GPS (1)	no cov (6)	104	854.7014084	20.50766274
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	Rec,REEF, TrawlNPS, TrawlPSP (4)	cov (15)	116	855.1228651	20.92911944
Rec+REEF+Trawl	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3, 68)	Rec/Trawl NPS, Rec/Trawl PSP,REEF (3)	cov (6)	106	856.0114017	21.81765605
Rec+REEF+Trawl	Region x Survey (6, 65)	Region x Survey (6)	no cov (6)	109	856.8469733	22.65322765
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	Rec,REEFNPS,REEFPSP, Trawl (4)	no cov (4)	105	857.2165756	23.02282995
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5)	no cov (15)	117	858.1992602	24.00551457
Rec+REEF+Trawl	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5, 66)	RecNPS, RecPSP,REEF, TrawlNPS, TrawlPSP (5)	cov (15)	117	858.1992602	24.00551457
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	Region (2)	Survey w/in Regions (5)	104	859.4636349	25.26988925
Rec+REEF+Trawl	Region x Survey (6, 65)	GPS (1)	Surveys btw Regions (12)	110	859.7611378	25.5673922
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	Region (2)	no cov (4)	103	859.7923857	25.59864008
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	NPS, PSP, REEFNPS, REEFPSP (4)	Survey w/in Regions (5)	106	860.0579075	25.86416184
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	GPS (1)	no cov (4)	102	860.1571273	25.96338164
Rec+REEF+Trawl	Region x Survey (6, 65)	Region x Survey (6)	Surveys btw Regions (12)	115	860.9197097	26.7259641
Rec+REEF+Trawl	Region x Survey (6, 65)	Region x Survey (6)	Survey, Rec btw Regions (5)	108	861.7990897	27.60534406
Rec+REEF+Trawl	Region x Survey (6, 65)	Region (2)	Surveys btw Regions (12)	111	862.9667584	28.7730128
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	GPS (1)	cov (10)	108	864.1738931	29.98014752
Rec+REEF+Trawl	Region x Survey (6, 65)	NA (2)	cov (21)	120	864.9809437	30.78719808
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	Region (2)	cov (10)	109	867.333583	33.13983737
Rec+REEF+Trawl	Region x Survey (6, 65)	GPS (1)	cov (21)	119	868.7172713	34.51797567
Rec+REEF+Trawl	Region x Survey (6, 65)	Survey (3)	cov (21)	121	868.7617541	34.56800843
Rec+REEF+Trawl	NPS, PSP, REEFNPS, REEFPSP (4, 67)	Rec,REEFNPS,REEFPSP, Trawl (4)	cov (10)	111	869.798144	35.60439834
Rec+REEF+Trawl	Region x Survey (6, 65)	RecNPS, RecPSP,REEF, Trawl (4)	cov (21)	122	872.0492614	37.85551581
Rec+REEF+Trawl	Region x Survey (6, 65)	Region (2)	cov (21)	120	872.680176	38.48643039
Rec+REEF+Trawl	Region x Survey (6, 65)	Region x Survey (6)	cov (21)	124	877.5216843	43.32793872
Rec+REEF+Trawl	Region (2, 69)	GPS (1)	no cov (2)	100	900.6911249	66.49737925
Rec+REEF+Trawl	Region (2, 69)	Region (2)	no cov (2)	101	903.1457813	68.95203565
Rec+REEF+Trawl	Region (2, 69)	GPS (1)	cov (3)	101	903.5648807	69.37113509
Rec+REEF+Trawl	Region (2, 69)	Region (2)	cov (3)	102	906.0491064	71.85536082
Rec+REEF+Trawl	GPS (1, 70)	GPS (1)	no cov (1)	99	919.7106444	85.51689874

Model structure and estimates of population growth rate (*u*)



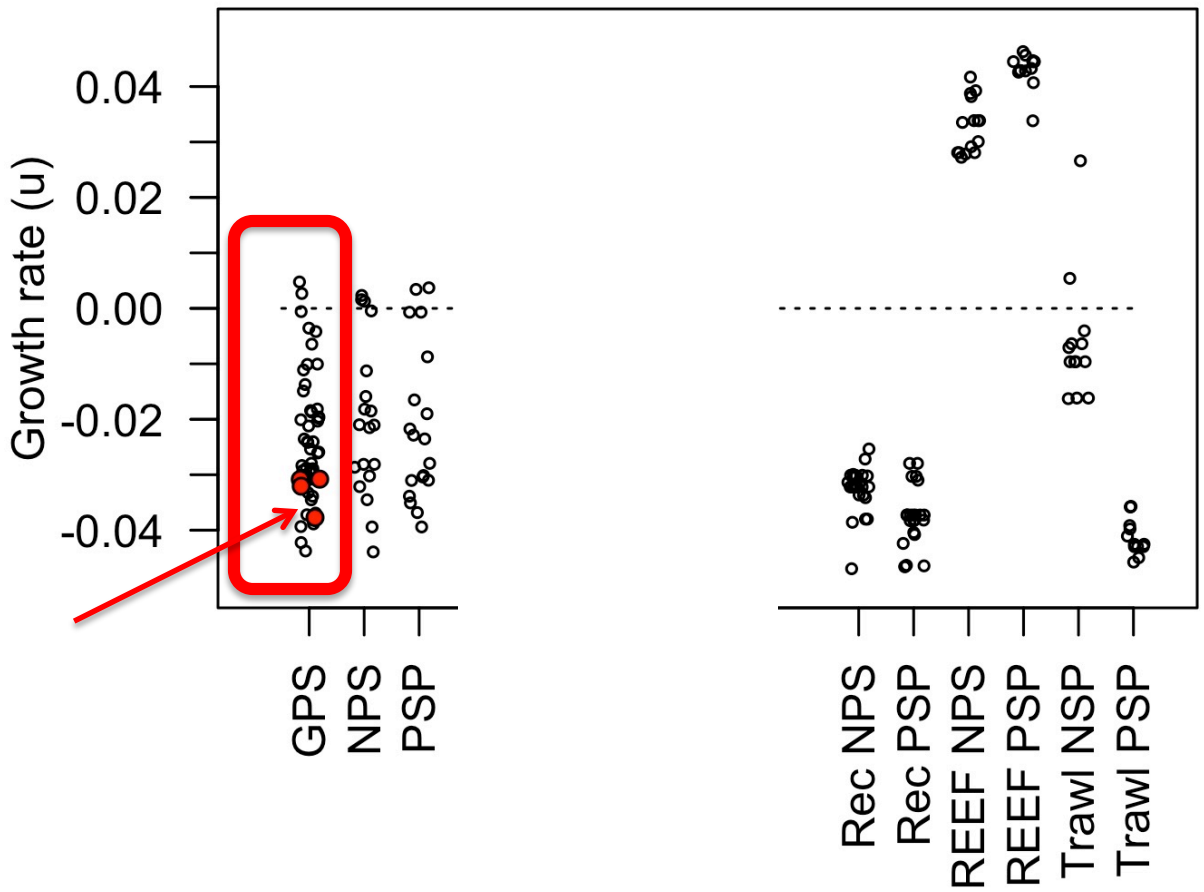
u spatial and/or survey structure

Common top models

- Single *u* for GPS
- Z has RecNPS, RecPSP
- Q has cov btw RecNPS and RecPSP

Top models in RED

Model structure and estimates of population growth rate (*u*)

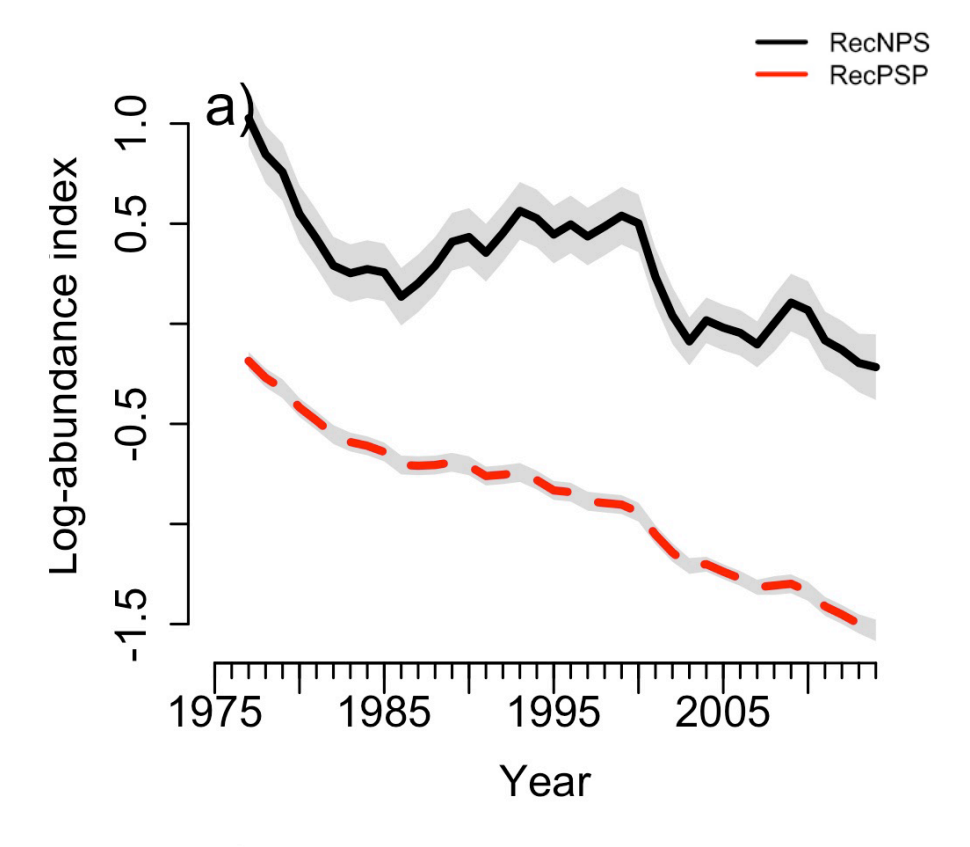


u spatial and/or survey structure

Common top models

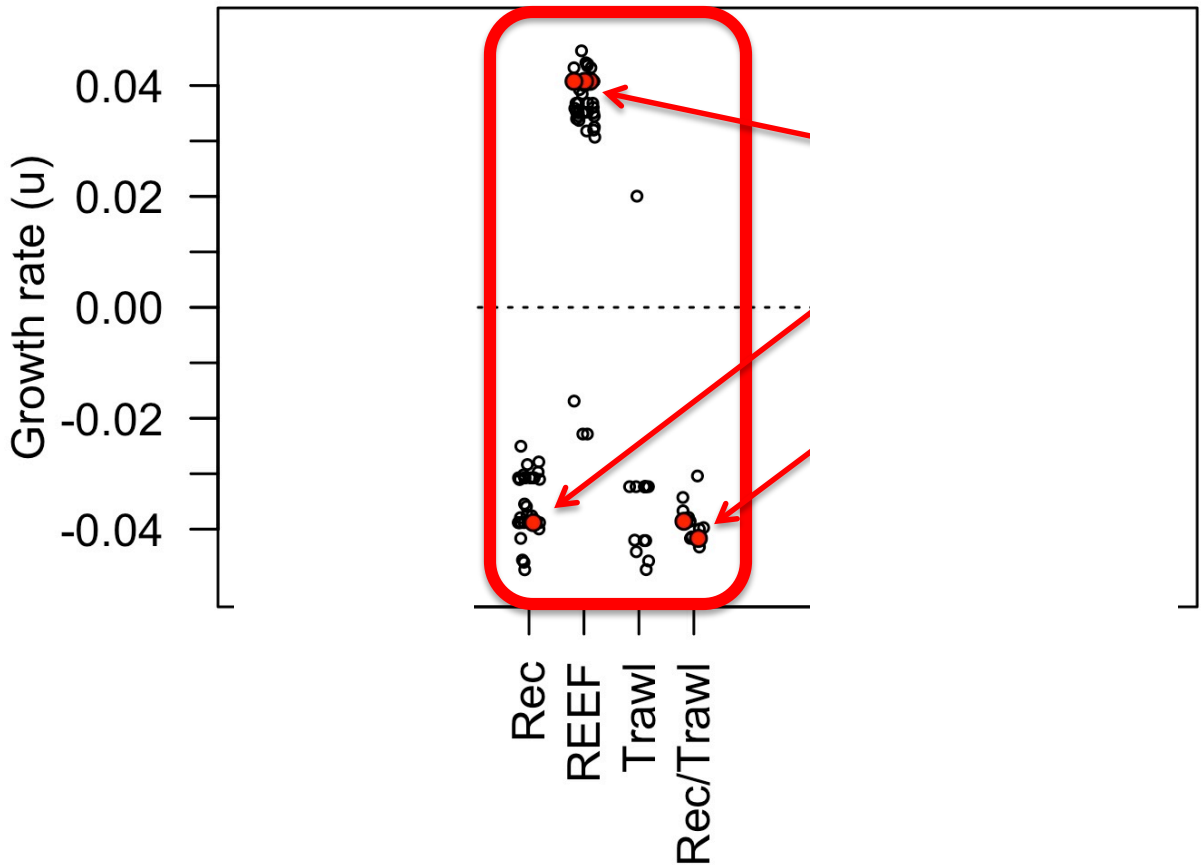
- Single *u* for GPS
- Z has RecNPS, RecPSP
- Q has cov btw RecNPS and RecPSP

Recreational survey data only



- *u* = -0.038
- *3.8% decline annually since*
- *= 76% total decline since 1977*
- *Higher abundance in NPS*
- *More process variance in NPS*
- *Covariance between NPS and PSP*

Model structure and estimates of population growth rate (*u*)



u spatial and/or survey structure

Common top models

- Single *u* for GPS
- Z has RecNPS, RecPSP
- Q has cov btw RecNPS and RecPSP

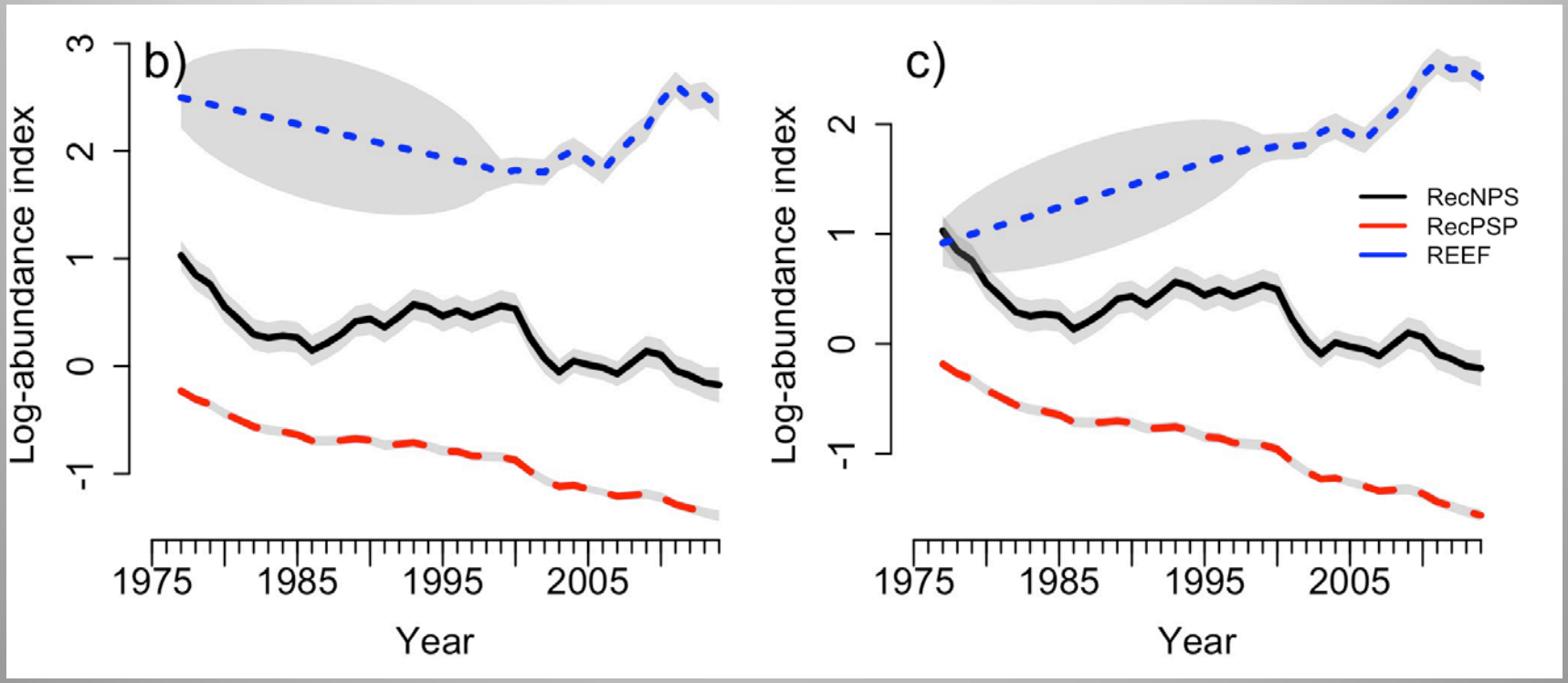
Strong evidence for

- Separate *u* for REEF vs Rec & Trawl
- Rec & Trawl ~ same growth rate (*u* = -0.031)

Rec + REEF

One *u*

Rec *u* and REEF *u*



***u GPS* = -0.031**

***u Rec* = -0.039**

u REEF = 0.041

Summary / Conclusions

- MARSS overcomes various data challenges
  - Multiple surveys, regulatory changes, gappy data
- MARSS allows for spatial management

- All species declined as a proportion of the assemblage

- Model fitting cannot tell us which are the appropriate data to include
- Rec/Trawl data estimate a ~3-4% annual decrease
- REEF data suggest an increase BUT
  - Depth limited to max of 130 ft; ~60 ft more common depth.
  - Listed species more common > 200 ft
- Rec/Trawl 3-4% decrease is probably the better estimate of population trends for the listed species