Agenda Item E.3
Attachment 5
November 2021

Evaluating available information to determine stock management delineation for copper rockfish (*Sebastes caurinus*) off the U.S. West Coast

by
Chantel R. Wetzel[1]

[1]Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, Washington 98112

September 2021

Correct citation for this publication:

Wetzel, C.R. 2021. Evaluating available information to determine stock management delineation for copper rockfish (*Sebastes caurinus*) off the U.S. West Coast. Pacific Fishery Management Council, Portland, Oregon. 12 p.

Contents

1 Status determination across area-based assessments

1.1 Dispersal

1.1.1 Recruitment and Dispersal

Evidence for Managing at Assessment Scale

Markel (2011) - Observed significant differences of recruitment among sites and years which were not consistent, indicating spatial differences in recruitment intensity during year of high recruitment within the Barkley Sound, British Columbia.

Buonaccorsi et al. (2004): Estimated the dispersal distance of copper rockfish recruits as 13km or less based on a stepping stone model. Caveat: This value can be highly sensitive to the ratio of total population size to effective population size.

While annual recruitment deviations were not estimated in the base model for the area south of Point Conception, model sensitivities to estimating annual recruitment deviations appeared to be little coherence with strong or weak recruitment years between the models south and north of Point Conception. The base model for the area south of Point Conception opted to not estimate annual recruitment deviations due to correlations with recent high catch years (i.e., estimated a series of years [2008 - 2014] with high recruitment proceeding recent years with high catches between). *Caveat*: length data may not be fully informative on recruitment and variation in growth can result in low or high recruitment years being attributed to multiple years.

Evidence for Alternative Management Scale

Field et al. (2021) - Determined that rockfish strong recruitments observed between 2014-2016 were largely coastwide events.

1.1.2 Adult Movement

Evidence for Managing at Assessment Scale

Lea et al (1999): Summarized tagging data that reported copper rockfish to have low to moderate degrees of movement and high site fidelity. Of 32 tagged copper rockfish that were recaptured the distance moved ranged between 0-1.5 nautical miles after 2-1,017 days at liberty.

Reynolds et al. (Reynolds, Powers, and Bishop 2010): Tagged copper rockfish in nearshore waters of Prince William Sound, Alaska exhibited long periods of residency with limited movements.

Tolimieri et al. (2009): Observed home ranges of copper rockfish in Puget Sound was relatively small (~1500 to ~2500m^2). Caveat: movement of copper rockfish in the Puget Sound may not be representative of movement of coastal populations.

Evidence for Alternative Management Scale

Lowe et al. (2009): Copper rockfish exhibited low degrees of site fidelity and had high variation in the percentage of days on which individuals were detected based on 7 tagged fish at petroleum platforms in the Santa Barbara Channel.

McGilliard et al. (2015): Fisheries managed by area closures impose spatial heterogeneity in fishing mortality, and simulations from generic operating models suggest that the accuracy of conventional stock assessments depends on movement rates.

1.2 Geographic variation

1.2.1 Variation in Genetic Composition

Evidence for Managing at Assessment Scale

Sivasundar and Palumbi (2010): Measured moderate differentiation mtDNA structure but no nuclear structure in coastal copper rockfish populations.

Buonaccorsi et al. (2002): Identified significant divergence along the U.S. West Coast when measured as variance in allele frequency or mean repeat number, indicting a substantial isolation between regions. Examined samples from Queen Charlotte, Puget Sound, Canadian Gulf Islands, Crescent City, Big Creek, San Miguel Island.

Johansson et al. (2008): Identified isolation by distance in coastal copper rockfish populations (F_{ST} = 0.006) similar to Buonaccorsi et al. (2002) (F_{ST} = 0.008). However, concluded that some of the genetic divergence may be related to habitat patchiness and not distance alone.

Evidence for Alternative Management Scale

Sivasundar and Palumbi (2010): The Oregon and Monterey Bay populations were both genetically differentiated from the Santa Barbara populations for mtDNA but the Monterey

Bay and Oregon populations could not be distinguished from each other. This could indicate that there is limited differentiation between northern California and Oregon copper rockfish populations indicating mixing between the areas.

Caveat

Waples and Gaggiotti (Waples and Gaggiotti 2006): Significant differences in neutral genetic characters indicate that the populations have been re-productively isolated for many generations,which is far longer than the ecological time scales that are relevant to stock assessment or fishery management.

1.2.2 Variation in Phenotypic Traits

Evidence for Managing at Assessment Scale

Minor differences measured in maturity-at-length between two areas of the coast: Oregon (Hannah 2014) and South of Point Conception (Melissa Head, NWFSC).

Punt et al.(2015): Conventional stock assessments produced significantly biased estimates when applied to an operating model of pink ling fisheries with spatial heterogeneity in fishing mortality, growth, and recruitment.

Evidence for Alternative Management Scale

Limited growth differences measured based on original age-length estimates between fish off the Oregon and Washington coast to those sample south of Point Conception. Caveat: Spatial gradients of growth across the coast are commonly observed in rockfish or other fish species along the U.S. west coast (A. A. Keller et al. 2012; Gertseva, Matson, and Cope 2017; A. Keller et al. 2018) and lack of measure growth variation may be due lack of spatial coverage of otoliths samples across the California coast.

1.3 Other Considerations

1.3.1 Abundance Trends

Evidence for Managing at Assessment Scale

Ying et al. (2011): The performance of stock assessments using an operating model to represent three connected sub-populations of small yellow croaker and observed that assessing and managing each sub-population as a unit led to overfishing and managing the metapopulation as a unit stock often led to local depletion.

The separate models for the areas south and north of Point Conception estimated two distinct stock trajectories with the stock in the north over recent years from low levels to at or around the management target and the stock in the south increasing from low levels between 2001 - 2014 and decreasing in recent years to levels below the minimum stock size threshold. The model for the area south of Point Conception did not estimate annual recruitment deviations which could contribute to stock trajectory differences to the stock to the north where strong recent recruitments have led to increases in stock size. However, in the model sensitivity for the south of Point Conception model that estimated annual recruitment deviations the stock trajectory remaining low (below the minimum stock size threshold) and did not show similar stock increases as observed in the north.

The trajectories across all model areas showed varying trajectories (Figure 1).

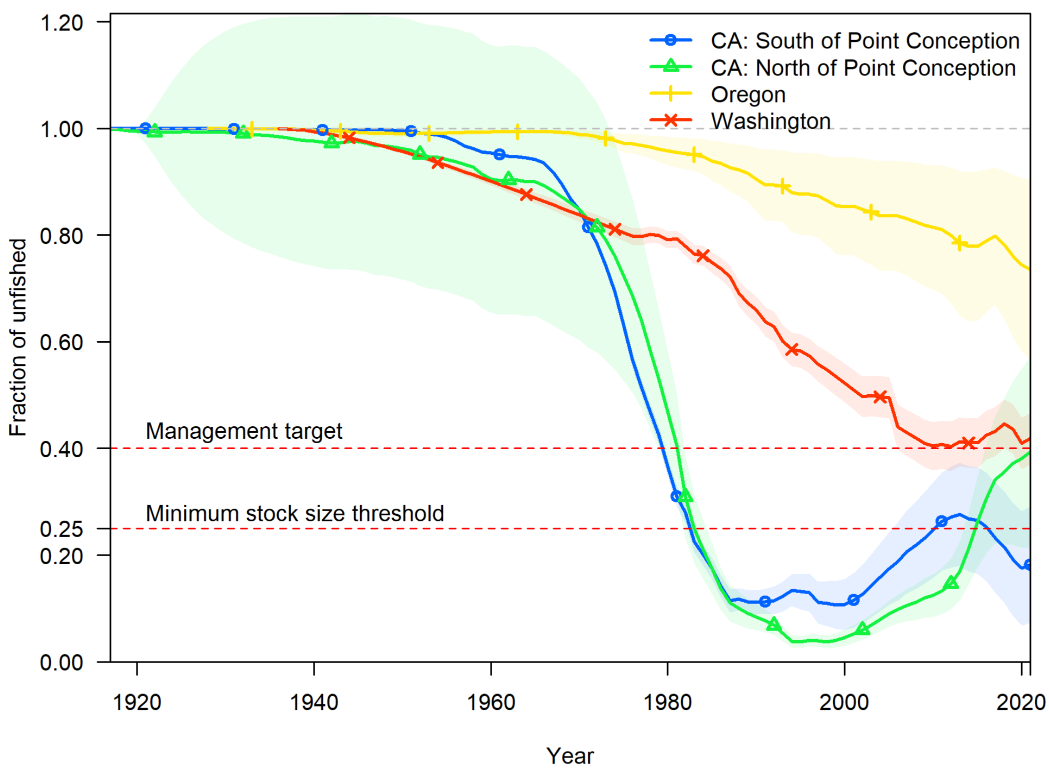

Figure 1: Estimate relative spawning output by assessed area.

Evidence for Alternative Management Scale

The areas of true population variation in relative stock size may not align with the assessment boundaries as currently defined. State based management is likely not the only factor impacting relative stock sizes across the coast where movement and recruitment patterns likely also influence potential differences in relative stock size.

Cope and Punt (2013): Conventional stock assessments failed to estimate differing spatial patterns and exploitation (localized depletion) but adequately estimated the overall stock status.

1.3.2 Size and Age Composition

Evidence for Managing at Assessment Scale

Distinct selectivity curves estimated between the recreational and commercial fisheries north and south of Point Conception. While to a lesser degree, the selectivity in Oregon and Washington commercial and recreation fleets also varied from selectivity estimated in other areas.

Bosely et al. (2019): Specifying the correct form spatial population structure may not e as critical as understanding movement patterns and spatial heterogeneity in fishery selectivity and life-history variation when developing reference points for management.

Berger et al. (2021): Aligning management assessment areas with with underlying population structure and processes is important, especially when fishing mortality is disproportionate to vulnerable biomass among management areas, demographic parameters (growth and maturity) are not homogeneous within management areas, and connectivity (via recruitment or movement) unknowingly exists among management areas. Bias and risk were greater for assessments that incorrectly span multiple population segments compared to assessments that cover a subset of a population segment, and these results were exacerbated when there was connectivity between population segments. Caveat: The variation is growth and connectivity between areas via recruitment for copper rockfish off the West Coast is currently unknown or uncertain.

Caveat

Rather than creating separate assessments to account for variation in exploitation or life-history variation across areas a more integrated approach could be to apply a spatial assessment that can provide both area- and coastwide population estimates. However, spatial assessments come at the cost of a larger number of parameters to estimate, but general guidance around the key decisions exists when moving to spatial assessments (Punt (2019)).

This approach should be evaluated to understand the trade-offs between adding parameters that may be poorly informed (e.g., movement, recruitment by area) via a spatial assessment approach versus either conducting separate assessments or applying the “fleets-as-areas” approach.

2 Summary of California stocks

The 2021 assessment of Copper rockfish off the coast of California assessed as two separate sub-stocks split at Point Conception. The spawning output by area and summed across California along with the relative spawning outputs for each area are provided in Table 1.

Table 1: Spawning output (SO) south and north of Point Conception in California, total spawning output across California, relative spawning output (Rel. SO) north and south of Point Conception, and relative spawning output across California.

Year	SO-North	SO-South	SO-CA	Rel. SO-North	Rel. SO-South	Rel. SO-CA
1914	415.81	233.04	648.86	1.000	1.000	1.000
1915	415.81	233.04	648.86	1.000	1.000	1.000
1916	415.81	233.04	648.86	1.000	1.000	1.000
1917	415.38	233.03	648.41	0.999	1.000	0.999
1918	414.73	233.00	647.74	0.997	1.000	0.998
1919	413.98	232.98	646.97	0.996	1.000	0.997
1920	413.57	232.97	646.54	0.995	1.000	0.996
1921	413.20	232.96	646.16	0.994	1.000	0.996
1922	412.99	232.95	645.94	0.993	1.000	0.996
1923	412.91	232.94	645.85	0.993	1.000	0.995
1924	412.85	232.93	645.78	0.993	1.000	0.995
1925	412.97	232.92	645.89	0.993	0.999	0.995
1926	412.98	232.90	645.88	0.993	0.999	0.995
1927	412.90	232.88	645.78	0.993	0.999	0.995
1928	412.99	232.86	645.86	0.993	0.999	0.995
1929	412.94	232.85	645.79	0.993	0.999	0.995
1930	412.80	232.83	645.63	0.993	0.999	0.995
1931	412.38	232.81	645.20	0.992	0.999	0.994
1932	411.77	232.79	644.57	0.990	0.999	0.993
1933	411.15	232.77	643.92	0.989	0.999	0.992
1934	410.55	232.76	643.31	0.987	0.999	0.991
1935	410.02	232.74	642.76	0.986	0.999	0.991
1936	409.20	232.68	641.88	0.984	0.998	0.989
1937	408.38	232.65	641.02	0.982	0.998	0.988
1938	407.35	232.52	639.88	0.980	0.998	0.986
1939	406.51	232.46	638.97	0.978	0.998	0.985
1940	405.99	232.42	638.41	0.976	0.997	0.984
1941	405.06	232.38	637.44	0.974	0.997	0.982
1942	404.32	232.35	636.67	0.972	0.997	0.981
1943	404.83	232.36	637.19	0.974	0.997	0.982
1944	405.35	232.37	637.72	0.975	0.997	0.983
1945	405.50	232.40	637.89	0.975	0.997	0.983

Table 1: Spawning output (SO) south and north of Point Conception in California, total spawning output across California, relative spawning output (Rel. SO) north and south of Point Conception, and relative spawning output across California. *(continued)*

Year	SO-North	SO-South	SO-CA	Rel. SO-North	Rel. SO-South	Rel. SO-CA
1946	404.16	232.42	636.58	0.972	0.997	0.981
1947	402.10	232.44	634.53	0.967	0.997	0.978
1948	402.37	232.39	634.76	0.968	0.997	0.978
1949	401.30	232.24	633.54	0.965	0.997	0.976
1950	400.14	232.01	632.15	0.962	0.996	0.974
1951	398.57	231.68	630.25	0.959	0.994	0.971
1952	395.58	231.04	626.62	0.951	0.991	0.966
1953	393.78	230.55	624.34	0.947	0.989	0.962
1954	393.19	230.11	623.30	0.946	0.987	0.961
1955	391.72	229.22	620.94	0.942	0.984	0.957
1956	389.95	227.43	617.38	0.938	0.976	0.951
1957	387.63	225.39	613.02	0.932	0.967	0.945
1958	385.83	224.09	609.92	0.928	0.962	0.940
1959	379.98	222.85	602.83	0.914	0.956	0.929
1960	376.56	222.23	598.79	0.906	0.954	0.923
1961	374.91	221.65	596.57	0.902	0.951	0.919
1962	375.64	220.89	596.52	0.903	0.948	0.919
1963	375.56	220.53	596.09	0.903	0.946	0.919
1964	374.29	220.21	594.50	0.900	0.945	0.916
1965	374.38	219.45	593.83	0.900	0.942	0.915
1966	371.29	218.10	589.39	0.893	0.936	0.908
1967	366.95	213.92	580.87	0.882	0.918	0.895
1968	362.38	208.73	571.11	0.872	0.896	0.880
1969	357.66	202.44	560.10	0.860	0.869	0.863
1970	352.64	197.30	549.94	0.848	0.847	0.848
1971	344.71	189.91	534.62	0.829	0.815	0.824
1972	338.84	182.81	521.65	0.815	0.784	0.804
1973	328.96	173.21	502.17	0.791	0.743	0.774
1974	316.36	161.58	477.94	0.761	0.693	0.737
1975	301.24	147.14	448.38	0.724	0.631	0.691
1976	285.72	132.18	417.90	0.687	0.567	0.644
1977	265.76	119.95	385.70	0.639	0.515	0.594
1978	242.71	109.12	351.84	0.584	0.468	0.542
1979	220.21	99.11	319.32	0.530	0.425	0.492
1980	195.23	85.44	280.68	0.470	0.367	0.433
1981	168.51	72.17	240.68	0.405	0.310	0.371
1982	128.65	65.18	193.83	0.309	0.280	0.299
1983	104.02	52.56	156.58	0.250	0.226	0.241
1984	87.13	46.53	133.66	0.210	0.200	0.206

Table 1: Spawning output (SO) south and north of Point Conception in California, total spawning output across California, relative spawning output (Rel. SO) north and south of Point Conception, and relative spawning output across California. *(continued)*

Year	SO-North	SO-South	SO-CA	Rel. SO-North	Rel. SO-South	Rel. SO-CA
1985	72.65	40.60	113.25	0.175	0.174	0.175
1986	56.82	33.06	89.88	0.137	0.142	0.139
1987	45.88	26.58	72.46	0.110	0.114	0.112
1988	41.70	27.31	69.01	0.100	0.117	0.106
1989	37.85	26.31	64.15	0.091	0.113	0.099
1990	34.82	25.95	60.77	0.084	0.111	0.094
1991	32.15	26.30	58.45	0.077	0.113	0.090
1992	28.39	26.79	55.18	0.068	0.115	0.085
1993	22.16	28.53	50.69	0.053	0.122	0.078
1994	16.05	31.21	47.26	0.039	0.134	0.073
1995	15.60	30.65	46.25	0.038	0.132	0.071
1996	16.79	30.29	47.08	0.040	0.130	0.073
1997	16.41	25.95	42.37	0.039	0.111	0.065
1998	15.44	25.45	40.89	0.037	0.109	0.063
1999	16.75	24.76	41.51	0.040	0.106	0.064
2000	18.93	24.98	43.90	0.046	0.107	0.068
2001	21.74	26.83	48.57	0.052	0.115	0.075
2002	24.84	29.53	54.38	0.060	0.127	0.084
2003	28.64	33.08	61.72	0.069	0.142	0.095
2004	32.70	36.82	69.52	0.079	0.158	0.107
2005	37.57	40.76	78.33	0.090	0.175	0.121
2006	41.04	43.68	84.72	0.099	0.187	0.131
2007	44.00	47.92	91.92	0.106	0.206	0.142
2008	46.33	50.77	97.10	0.111	0.218	0.150
2009	49.58	54.01	103.59	0.119	0.232	0.160
2010	51.80	57.50	109.30	0.125	0.247	0.168
2011	55.04	61.25	116.29	0.132	0.263	0.179
2012	60.66	63.22	123.88	0.146	0.271	0.191
2013	70.63	64.35	134.98	0.170	0.276	0.208
2014	88.01	62.52	150.53	0.212	0.268	0.232
2015	109.29	61.70	170.99	0.263	0.265	0.264
2016	127.02	58.89	185.91	0.305	0.253	0.287
2017	141.90	54.21	196.11	0.341	0.233	0.302
2018	147.97	50.17	198.14	0.356	0.215	0.305
2019	154.78	44.70	199.48	0.372	0.192	0.307
2020	158.56	40.81	199.37	0.381	0.175	0.307
2021	163.51	42.28	205.79	0.393	0.181	0.317

3 Proposed Allocation of Yield Among Federal Management Areas

The 2021 northern California base model for copper rockfish represents U.S. waters between 34° 27' N. lat. and the California-Oregon border 42° 00' N. lat. Federal management of the nearshore rockfish complex, that includes copper rockfish, is based on areas north and south of 40° 10' N. lat. Therefore, yield estimates from the California base model must be divided between the norther and southern management areas in order to determine the contribution of copper rockfish to the nearshore rockfish overfishing limit (OFL).

Ideally, allocation by area would be based on calculations of habitat by area and/or estimates of biomass by area. Unfortunately neither of these estimates were available for copper rockfish to inform allocations by area. In lieu of this information, historical catches by each region were used to recommend allocation percents by area. Total removals from the recreational and commercial fleets between 2005 - 2020 by areas north and south of 40° 10' N. lat. were calculated. During this period a total of 3.9 percent of all removals were from areas north of 40° 10' N. lat. Based on this the recommend allocations of the OFLs from the northern California model 3.9 percent should be allocated to the north nearshore rockfish complex with 96.1 percent to the southern complex.

4 References

Berger, Aaron M, Jonathan J Deroba, Katelyn M Bosley, Daniel R Goethel, Brian J Langseth, Amy M Schueller, and Dana H Hanselman. 2021. "Incoherent Dimensionality in Fisheries Management: Consequences of Misaligned Stock Assessment and Population Boundaries." Edited by Valerio Bartolino. *ICES Journal of Marine Science* 78 (1): 155–71. https://doi.org/10.1093/icesjms/fsaa203.

Bosley, Katelyn M., Daniel R. Goethel, Aaron M. Berger, Jonathan J. Deroba, Kari H. Fenske, Dana H. Hanselman, Brian J. Langseth, and Amy M. Schueller. 2019. "Overcoming Challenges of Harvest Quota Allocation in Spatially Structured Populations." *Fisheries Research* 220 (December): 105344. https://doi.org/10.1016/j.fishres.2019.105344.

Buonaccorsi, V. P., M. Westerman, J. Stannard, C. Kimbrell, E. Lynn, and R. D. Vetter. 2004. "Molecular Genetic Structure Suggests Limited Larval Dispersal in Grass Rockfish, Sebastes Rastrelliger." *Marine Biology* -1 (1): 1–1. https://doi.org/10.1007/s00227-004-1362-2.

Buonaccorsi, Vincent P, Carol A Kimbrell, Eric A Lynn, and Russell D Vetter. 2002. "Population Structure of Copper Rockfish (*Sebastes Caurinus*) Reflects Postglacial Colonization and Contemporary Patterns of Larval Dispersal." *Canadian Journal of Fisheries and Aquatic Sciences* 59 (8): 1374–84. https://doi.org/10.1139/f02-101.

Cope, Jason, E. J. Dick, Alec MacCall, Melissa Monk, Braden Soper, and Chantel Wetzel. 2013. "Data-Moderate Stock Assessments for Brown, China, Copper, Sharpchin, Stripetail, and Yellowtail Rockfishes and English and Rex Soles in 2013." 7700 Ambassador Place NE, Suite 200, Portland, OR: Pacific Fishery Management Council. http://www.academia.edu/download/44999856/CopeetalDataModerate2013.pdf.

Field, John C., Rebecca R. Miller, Jarrod A. Santora, Nick Tolimieri, Melissa A. Haltuch, Richard D. Brodeur, Toby D. Auth, et al. 2021. "Spatiotemporal Patterns of Variability in the Abundance and Distribution of Winter-Spawned Pelagic Juvenile Rockfish in the California Current." Edited by Geir Ottersen. *PLOS ONE* 16 (5): e0251638. https://doi.org/10.1371/journal.pone.0251638.

Gertseva, Vladlena, Sean E. Matson, and Jason Cope. 2017. "Spatial Growth Variability in Marine Fish: Example from Northeast Pacific Groundfish." Edited by Emory Anderson. *ICES Journal of Marine Science* 74 (6): 1602–13. https://doi.org/10.1093/icesjms/fsx016.

Hannah, Robert W. 2014. "Length and Age at Maturity of Female Copper Rockfish (*Sebastes Caurinus*) from Oregon Waters Based on Histological Evaluation of Ovaries." Information Reports 2014-04. Oregon Department of Fish; Wildlife.

Johansson, M. L., M. A. Banks, K. D. Glunt, H. M. Hassel-Finnegan, and V. P. Buonaccorsi. 2008. "Influence of Habitat Discontinuity, Geographical Distance, and Oceanography on Fine-Scale Population Genetic Structure of Copper Rockfish (*Sebastes Caurinus*)." *Molecular Ecology* 17 (13): 3051–61. https://doi.org/10.1111/j.1365-294X.2008.03814.x.

Keller, Aa, Ph Frey, Jr Wallace, Ma Head, Cr Wetzel, Jm Cope, and Jh Harms. 2018. "Canary Rockfishes Sebastes Pinniger Return from the Brink: Catch, Distribution and Life History Along the US West Coast (Washington to California)." *Marine Ecology Progress Series* 599 (July): 181–200. https://doi.org/10.3354/meps12603.

Keller, Aimee A., Kyle J. Molton, Allan C. Hicks, Melissa Haltuch, and Chantell Wetzel. 2012. "Variation in Age and Growth of Greenstriped Rockfish (Sebastes Elongatus)

Along the U.S. West Coast (Washington to California)." *Fisheries Research* 119-120 (May): 80–88. https://doi.org/10.1016/j.fishres.2011.12.012.

Lea, Robert N, Robert D McAllister, and David A VenTresca. 1999. "Biological Sspects of Nearshore Rockfishes of the Genus Sebastes from Central California with Notes on Ecologically Related Sport Fishes." Fish Bulletin 177. State of California The Resources Agency Department of Fish; Game.

Lowe, Christopher G., Kim M. Anthony, Erica T. Jarvis, Lyall F. Bellquist, and Milton S. Love. 2009. "Site Fidelity and Movement Patterns of Groundfish Associated with Offshore Petroleum Platforms in the Santa Barbara Channel." *Marine and Coastal Fisheries* 1 (1): 71–89. https://doi.org/10.1577/C08-047.1.

Markel, Russell Wayne. 2011. "Rockfish Recruitment and Trophic Dynamics on the West Coast of Vancouver Island: Fishing, Ocean, Climate, and Sea Otters." *Dissertation, University of British Columbia*, 146.

McGilliard, Carey R., André E. Punt, Richard D. Methot, and Ray Hilborn. 2015. "Accounting for Marine Reserves Using Spatial Stock Assessments." Edited by Larry Jacobson. *Canadian Journal of Fisheries and Aquatic Sciences* 72 (2): 262–80. https://doi.org/10.1139/cjfas-2013-0364.

Punt, AndrÃ© E., Malcolm Haddon, and Geoffrey N. Tuck. 2015. "Which Assessment Configurations Perform Best in the Face of Spatial Heterogeneity in Fishing Mortality, Growth and Recruitment? A Case Study Based on Pink Ling in Australia." *Fisheries Research* 168 (August): 85–99. https://doi.org/10.1016/j.fishres.2015.04.002.

Punt, André E. 2019. "Spatial Stock Assessment Methods: A Viewpoint on Current Issues and Assumptions." *Fisheries Research* 213 (May): 132–43. https://doi.org/10.1016/j.fishres.2019.01.014.

Reynolds, Brad F., Sean P. Powers, and Mary Anne Bishop. 2010. "Application of Acoustic Telemetry to Assess Residency and Movements of Rockfish and Lingcod at Created and Natural Habitats in Prince William Sound." Edited by Daniel J. Rankin. *PLoS ONE* 5 (8): e12130. https://doi.org/10.1371/journal.pone.0012130.

Sivasundar, Arjun, and Stephen R. Palumbi. 2010. "Life History, Ecology and the Biogeography of Strong Genetic Breaks Among 15 Species of Pacific Rockfish, Sebastes." *Marine Biology* 157 (7): 1433–52. https://doi.org/10.1007/s00227-010-1419-3.

Tolimieri, N, K Andrews, G Williams, S Katz, and Ps Levin. 2009. "Home Range Size and Patterns of Space Use by Lingcod, Copper Rockfish and Quillback Rockfish in Relation to Diel and Tidal Cycles." *Marine Ecology Progress Series* 380 (April): 229–43. https://doi.org/10.3354/meps07930.

Waples, Robin S., and Oscar Gaggiotti. 2006. "What Is a Population? An Empirical Evaluation of Some Genetic Methods for Identifying the Number of Gene Pools and Their Degree of Connectivity." *Molecular Ecology* 15 (6): 1419–39. https://doi.org/10.1111/j.1365-294X.2006.02890.x.

Ying, Yiping, Yong Chen, Longshan Lin, Tianxian Gao, and Terrance Quinn. 2011. "Risks of Ignoring Fish Population Spatial Structure in Fisheries Management." *Canadian Journal of Fisheries and Aquatic Sciences* 68 (12): 2101–20. https://doi.org/10.1139/f2011-116.