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An Approach to Defining Stock Complexes for U.S. West Coast Groundfishes Using Vulnerabilities and Ecological Distributions

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Abstract

The Magnuson–Stevens Fishery Conservation and Management Act (MSA) requires active management of all stocks at risk of overfishing or otherwise in need of conservation and management. In the Pacific Fishery Management Council groundfish fishery management plan, about two-thirds of the more than 90 managed stocks are currently without traditional assessments to help define stock status in relation to management targets. Stock complexes are often employed for management purposes in such situations. The guidelines issued in response to the 2006 MSA amendments defined a complex as a group of stocks with similar geographic distributions, life histories, and vulnerabilities to fisheries. This work uses productivity–susceptibility analysis (PSA) to measure the vulnerabilities of 90 managed groundfish stocks, 64 of which are currently managed within stock complexes. These stock complexes are reevaluated by first using a partitioning cluster analysis to group the stocks by depth and latitude. Vulnerability reference points are then established based on the PSA results to determine vulnerability groups of low, medium, high, and major concern within each ecological group. This method is a simple and flexible approach to incorporating vulnerability measures into stock complex designations while providing information with which to prioritize stock- and complex-specific management.

Managers of marine resources often confront the challenge of maintaining economically viable yet sustainable levels of removals over long periods of time. This challenge intensifies in marine fisheries where multiple stocks of varying resilience to fishing pressure are caught together (Murawski 1991; Essington et al. 2006). As the number of stocks in need of management increases, the data and resources available typically limit the level of stock analysis available to inform managers (Reuter et al. 2010). One approach to managing multiple stocks in data-limited situations is to form stock complexes (Jiao et al. 2009). Stock complexes are usually determined using some combination of taxonomy, life history, ecology, and relation to fisheries (Shertzer and Williams 2008); thus, common management measures can be assigned to a group of stocks that are both caught together and share similar population responses to removals.

Amendments made to the Magnuson–Stevens Fishery Conservation and Management Act (MSA) in 2006 require the regional fishery management councils in the United States to develop annual catch limits (ACLs) and accountability measures (AMs; i.e., management controls that either ensure the ACLs are not exceeded or outline procedures if they are exceeded) for each of their managed fisheries. Historically the question of which stocks were in need of management was left to regional interpretation. Fishery management plans (FMPs) established by the eight regional fishery management councils and the National Marine Fisheries Service (NMFS) before the ACL amendments therefore differed in their number of actively managed stocks, with some plans including hundreds of stocks, while others much fewer. For such multistock management plans, the questions became which specific stocks were suffi-

ciently in need of conservation and management to warrant catch limits.

Implementation guidelines issued by NMFS in response to the 2006 MSA amendments addressed this question by advising the councils to set ACLs for stocks “in the fishery” (USOFR 2009, 2010). Stocks “in the fishery” are those for which overfishing (i.e., current catch levels exceed the catch limit) or an overfished status (i.e., current population biomass is below the target biomass) would probably occur in the absence of conservation measures. The guidelines also suggest a second, optional category—“ecosystem component” (EC) stocks, defined as non-target and nonretained stocks not likely to become overfished or undergo overfishing in the absence of management. These EC stocks are not required to have either ACLs or AMs. The guidelines thus advised the councils to review the FMPs and reclassify all stocks as “in the fishery” or not. For a stock determined not to be “in the fishery,” the choice is to designate it as an EC stock, thus retaining it in the FMP without catch limits, or to remove it from the FMP altogether.

For stocks designated “in the fishery,” ACLs can be determined for individual stocks or stock complexes. The MSA implementation guidelines define a stock complex as “a group of stocks that are sufficiently similar in geographic distribution, life history, and vulnerability to the fishery such that the impact of management actions on the stocks is similar” (USOFR 2010). The term “vulnerability” in this context refers to a stock’s potential to become overfished under current fishery conditions and is defined by the guidelines as a combination of a stock’s biological productivity and its susceptibility to impact from the fishery (USOFR 2010). Determining a stock’s

vulnerability can distinguish both its relationship to a fishery (i.e., Is it “in the fishery?”) and its relationship to other stocks in a fishery (i.e., Do fisheries affect them similarly?).

The Pacific Fishery Management Council’s Groundfish FMP lists 90 stocks (see Table 3-1 in www.pcouncil.org/wp-content/uploads/fmpthru19.pdf), 64 of which reside in four major complexes (“Minor rockfish north,” “Minor rockfish south,” “Other flatfish,” “Other fish”), with the “Minor rockfish” categories being separated further into “nearshore,” “shelf,” and “slope” complexes (Table 1). Most stocks in complexes have not been assessed, thus their status relative to overfishing or being overfished is unknown. Currently, complex designations have relied on taxonomy and distribution (e.g., “slope rockfish”) as the main qualifiers. Including stock vulnerability in the factors used to define stock complexes will more fully realize the definition of “stock complex” given in the MSA guidelines while providing managers a tool to enhance organization of effective management measures.

This study conducts a vulnerability analysis on 90 groundfish stocks listed in the groundfish FMP and uses the vulnerability scores to revisit current stock complexes. Vulnerability scores are first used to indicate whether a stock is considered “in the fishery” or not. Vulnerability reference points are then determined in order to group stocks by vulnerability scores. These vulnerability groupings, along with ecological distributions, are then used to reclassify existing stock complexes. These updated stock complexes are compared with the former complexes and subsequent advice on interpreting and applying vulnerability scores to defining stock complexes is offered.

METHODS

Vulnerability analysis.—The productivity–susceptibility analysis (PSA) of Patrick et al. (2009, 2010) was used to quantify vulnerability (V) for 90 stocks in the PFMC groundfish FMP (Table 1). The PSA approach defines vulnerability in two dimensions: (1) productivity (P), characterized by the life history of each stock, and (2) susceptibility (S), characterized by how the stock is likely affected by the fishery in question. This study considers all gears that contribute to the overall susceptibility of each groundfish stock. There are 10 productivity and 12 susceptibility attributes scored on a three-point scale (low, medium, and high; Table 2), with each attribute assigned a weighting value (with a default of 2) relative to its perceived contribution to the overall productivity or susceptibility score. Details on attribute definitions and how each bin was determined are found in Patrick et al. (2009). The overall productivity and susceptibility scores are then calculated as the weighted average across all scored attributes. An x – y plot is also produced to visualize the productivity and susceptibility. Vulnerability is defined as the Euclidean distance from the origin in the plot (Patrick et al. 2009).

In addition, the level of confidence in each attribute bin score is obtained by scoring data quality on a five-point scale, with

lower scores reflecting increased confidence. This allows weakly scored stocks to be flagged as either needing revised scoring (in the case a more knowledgeable scorer can be found) or indicating information is generally lacking for that stock.

Owing to the large variety of stocks and fisheries worldwide, the PSA was developed as a flexible approach for defining vulnerability. Users may specify bin definitions and values that allow the analysis to capture the most pertinent aspects of productivity and susceptibility among the stocks in question. The definitions for the bins of the first susceptibility attribute (“management strategy”) were updated from Patrick et al. (2009) to reflect specific qualities of U.S. west coast groundfish management while maintaining the general objective for that attribute characterized by Patrick et al. (2009) (Table 2). Default bin definitions and values for all other attributes were maintained as in Patrick et al. (2009).

The approach of Patrick et al. (2009) also allows for differential weighting of attributes depending on the specific properties of species groups. We considered three species groups to coordinate attribute weighting for productivity attributes (“Elasmobranchs,” “Flatfishes,” and “Rockfishes and other fishes”) and two for susceptibility attributes (“Assessment” and “No Assessment”) (Table 2). Maximum length and fecundity productivity attributes were downweighted by half in two species groups because these attributes are inconsistently indicative of productivity within those species groups. Maximum length becomes inconsistently related to productivity when comparing elasmobranchs and rockfishes outside of their taxonomic families, while fecundity is a misleading measure for rockfishes, which often demonstrate low productivity despite large numbers of inconsistently spawned offspring (Love et al. 2002).

The management strategy susceptibility attribute was up-weighted by 50% in all cases because we believe this attribute contributed to true susceptibility more strongly than did other attributes. Two of the susceptibility attributes (“ F relative to M ” and “Relative Spawning Biomass”) are derived stock assessment quantities and not available for nonassessed stocks, thus were weighted as zero when a PFMC-approved assessment was not available. Alternatively, one could have scored these two attributes and assigned the data quality a score of 5 (poor information). This approach commonly applies the most risk-averse score (in this case, 3) to the attribute with no information (Hobday et al. 2007). We performed this sensitivity to our scores and it raised each stock’s vulnerability score by about 0.1. Such an approach can obscure the interpretation of vulnerability scores (e.g., Is the vulnerability score high because the stocks’ vulnerability is high, or because information to score the attributes is lacking?). We therefore chose to decouple vulnerability and data quality by not scoring attributes for which we had no information. Thus, vulnerability scores are our “best estimates” while the data quality score measures the information content in that best estimate.

An iterative approach was used to assign productivity and susceptibility scores for each attribute of the stocks

TABLE 1. Species and assessment weighting groups, minimum (Min) and maximum (Max) latitudinal and depth ranges (used in the cluster analyses), overall scores and results of the productivity–susceptibility analysis (PSA), proposed stock designation, and current and proposed stock complex assignments for each stock in the groundfish fishery management plan. Abbreviations are as follows: *P* = productivity score; *PDQ* = productivity data quality score; *S* = susceptibility; *SDQ* = susceptibility data quality; *V* = vulnerability; *EC* = ecosystem component; and *N* = neither. Shading indicates different degrees of vulnerability, as follows: white, $V < 1.8$; light gray, $1.8 < V < 2.0$; dark gray, $2.0 < V < 2.2$; and black, $V > 2.2$. Letter designations of species denote retrospective susceptibility scorings based on the year 1998.

Species	Weighting group		Preferred latitude		Preferred depth (m)		PSA				Designation	Current complex	Proposed complex
	Species	Assessment?	Min	Max	Min	Max	<i>P</i>	<i>PDQ</i>	<i>S</i>	<i>SDQ</i>	<i>V</i>		
1. Arrowtooth flounder <i>Atheresthes stomias</i>	Rockfishes	Yes	42.8	55	50	500	1.95	1.90	1.60	2.96	1.21	In the fishery	
2. Aurora rockfish <i>Sebastes aurora</i>	Rockfishes	No	32.5	46.3	300	500	1.33	2.11	2.29	1.19	2.10	In the fishery	Slope rockfish
3. Bank rockfish <i>Sebastes rufus</i>	Rockfishes	Yes	27.5	39.5	100	270	1.25	2.00	2.00	2.00	2.02	In the fishery	Slope rockfish
4. Big skate <i>Raja binoculata</i>	Elasmobranchs	No	34.5	46	50	200	1.37	2.68	2.14	2.57	1.99	In the fishery	Shelf rockfish, deep
5. Big skate <i>Sebastes melanops</i>	Rockfishes	Yes	38	54	0	55	1.33	2.00	2.00	1.44	1.94	In the fishery	Elasmobranchs, shallow
6. Black-and-yellow rockfish <i>Sebastes chrysomelas</i>	Rockfishes	No	34.5	39.5	1	18	1.89	1.89	2.29	1.33	1.70	In the fishery	Nearshore rockfish
7. Blackgill rockfish <i>Sebastes melanostomus</i>	Rockfishes	Yes	36.7	42	250	600	1.22	1.78	2.08	1.40	2.08	In the fishery	Slope rockfish
8. Blue rockfish <i>Sebastes mystinus</i>	Rockfishes	Yes	33	46.5	25	90	1.39	1.89	2.20	1.52	2.01	In the fishery	Nearshore rockfish
9. Bocaccio <i>Sebastes paucispinis</i>	Rockfishes	Yes	32.5	42	100	250	1.28	2.11	1.88	1.56	1.93	In the fishery	
10. Bronzespotted rockfish <i>Sebastes gilli</i>	Rockfishes	No	31	37	200	290	1.22	1.94	2.16	1.92	2.12	In the fishery	Shelf rockfish, deep
11. Brown rockfish <i>Sebastes auriculatus</i>	Rockfishes	No	23	38	1	120	1.61	2.33	2.43	1.48	1.99	In the fishery	Nearshore rockfish
12. Butter sole <i>Isopsetta isolepis</i>	Flatfishes	No	34.3	55	2	150	2.45	2.80	2.05	3.52	1.18	In the fishery	Flatfishes, shallow
13. Cabezon <i>Scorpaenichthys marmoratus</i>	Other fishes	Yes	34	46	0	25	1.72	1.89	2.08	1.42	1.68	In the fishery	Other fishes, shallow
14. Calico rockfish <i>Sebastes dallii</i>	Rockfishes	No	28	37.6	60	120	1.75	2.44	1.76	2.05	1.46	EC?	Shelf rockfish, shallow
15. California scorpionfish <i>Scorpaena guttata</i>	Rockfishes	Yes	22.9	34.4	2	50	1.83	2.00	1.80	1.44	1.41	In the fishery	
16. California skate <i>Raja inornata</i>	Elasmobranchs	No	32.5	39	18	671	1.21	3.21	2.14	2.57	2.12	In the fishery	Elasmobranchs, deep
17. Canary rockfish <i>Sebastes pinniger</i>	Rockfishes	Yes	34.5	54	50	250	1.28	1.78	2.04	1.56	2.01	In the fishery	

TABLE 1. Continued.

		No	33.6	34.5	174	274	1.39	2.61	2.24	2.81	2.03	In the fishery	Shelf rockfish	Shelf rockfish, deep
18. Chameleon rockfish <i>Sebastes phillipsi</i>	Rockfishes	No												
19. Chilipepper <i>Sebastes goodei</i>	Rockfishes	Yes	32.5	39.3	50	250	1.83	1.78	1.68	1.36	1.35	In the fishery		
20. China rockfish <i>Sebastes nebulosus</i>	Rockfishes	No	36	59.5	18	92	1.33	2.22	2.48	1.48	2.23	In the fishery	Nearshore rockfish	Nearshore rockfish
21. Copper rockfish <i>Sebastes caurinus</i>	Rockfishes	No	32	34.5	0	90	1.36	2.11	2.57	1.48	2.27	In the fishery	Nearshore rockfish	Nearshore rockfish
22. Cowcod <i>Sebastes levis</i>	Rockfishes	Yes	32.5	34.5	150	244	1.06	1.44	1.88	1.88	2.13	In the fishery		
23. Curlfin sole <i>Pleuronichthys decurrens</i>	Flatfishes	No	31	55	7	90	2.45	3.80	2.10	3.52	1.23	In the fishery	Other flatfish	Flatfishes, shallow
24. Darkblotched rockfish <i>Sebastes crameri</i>	Rockfishes	Yes	34.5	54.3	140	210	1.39	1.67	2.04	1.24	1.92	In the fishery		
25. Dover sole <i>Microstomus pacificus</i>	Flatfishes	Yes	34	48	200	500	1.80	1.90	1.96	2.56	1.54	In the fishery		
26. Dusky rockfish <i>Sebastes ciliatus</i>	Rockfishes	No	54	60	100	300	1.28	2.33	0.00	0.00	1.99		Shelf rockfish	Revisit FMP inclusion
27. Dwarf-red rockfish <i>Sebastes rofinatus</i>	Rockfishes	No	32.5	34.4	58	167	1.83	3.17	0.00	0.00	1.54		Shelf rockfish	Revisit FMP inclusion
28. English sole <i>Parophrys vetulus</i>	Flatfishes	Yes	32.5	60	0	250	2.25	2.10	1.92	2.64	1.19	In the fishery		
29. Pacific flatnose <i>Antimora microlepis</i>	Other fishes	No	23	55	500	950	1.72	3.89	1.75	2.38	1.48	In the fishery	Other fish	Other fishes, deep
30. Flag rockfish <i>Sebastes rubrivinctus</i>	Rockfishes	No	30	37.8	60	200	1.33	2.61	2.05	1.48	1.97	In the fishery	Shelf rockfish	Shelf rockfish, shallow
31. Flathead sole <i>Hippoglossoides elassodon</i>	Flatfishes	No	36.5	65	0	366	2.30	2.40	2.05	2.86	1.26	In the fishery	Other flatfish	Flatfishes, deep
32. Freckled rockfish <i>Sebastes lentiginosus</i>	Rockfishes	No	27.2	34	44	180	1.78	3.17	1.76	1.67	1.44	EC?	Shelf rockfish	Shelf rockfish, shallow
33. Gopher rockfish <i>Sebastes camatus</i>	Rockfishes	Yes	32.5	39.5	12	37	1.56	2.22	2.00	1.64	1.76	In the fishery	Nearshore rockfish	Nearshore rockfish
34. Grass rockfish <i>Sebastes rastrelliger</i>	Rockfishes	No	30	43	0	15	1.61	2.67	2.29	1.48	1.89	In the fishery	Nearshore rockfish	Nearshore rockfish
35. Greenblotched rockfish <i>Sebastes rosenblatti</i>	Rockfishes	No	28	38	61	396	1.28	1.78	2.24	1.71	2.12	In the fishery	Shelf rockfish	Shelf rockfish, deep
36. Greenspotted rockfish <i>Sebastes chlorostictus</i>	Rockfishes	No	28	36.7	90	179	1.39	2.44	2.14	1.90	1.98	In the fishery	Shelf rockfish	Shelf rockfish, shallow
37. Greenstriped rockfish <i>Sebastes elongatus</i>	Rockfishes	Yes	31	54	100	250	1.28	1.56	1.76	2.00	1.88	In the fishery	Shelf rockfish	Shelf rockfish, deep
38. Halfbanded rockfish <i>Sebastes semicinctus</i>	Rockfishes	No	27.7	38	60	150	2.00	1.89	1.76	2.00	1.26	EC?	Shelf rockfish	

(Continued on next page)

TABLE 1. Continued.

Weighting group			Preferred latitude		Preferred depth (m)		PSA					Stock		
Species	Assessment?	Species	Min	Max	Min	Max	P	PDQ	S	SDQ	V	Designation	Current complex	Proposed complex
39. Harlequin rockfish <i>Sebastes variegatus</i>	No	Rockfishes	49	60	100	350	1.31	2.83	1.95	3.00	1.94	In the fishery	Shelf rockfish	Shelf rockfish, deep
40. Honeycomb rockfish <i>Sebastes umbrosus</i>	No	Rockfishes	27	34.5	45	60	1.36	2.50	2.10	2.76	1.97	In the fishery	Shelf rockfish	Nearshore rockfish
41. Kelp greenling <i>Hexagrammos decagrammus</i>	Yes	Other fishes	34.5	55	0	20	1.83	2.11	2.04	1.52	1.56	In the fishery	Other fish	Other fishes, shallow
42. Kelp rockfish <i>Sebastes atrovirens</i>	No	Rockfishes	32	38	18	24	1.83	2.11	2.12	1.48	1.62	In the fishery	Nearshore rockfish	Nearshore rockfish
43. Leopard shark <i>Triakis semifasciata</i>	No	Elasmobranchs	32.5	42	0	4	1.26	1.89	2.00	2.57	2.00	In the fishery	Other fish	Elasmobranchs, shallow
44. Lingcod <i>Ophiodon elongatus</i>	Yes	Other fishes	34.5	58	100	150	1.75	2.22	1.92	1.96	1.55	In the fishery		
45. Longnose skate <i>Raja rhina</i>	Yes	Elasmobranchs	46	53.5	100	150	1.53	1.95	1.80	2.64	1.68	In the fishery		
46. Longspine thornyhead <i>Sebastolobus altivelis</i>	Yes	Rockfishes	33	55	500	1300	1.47	1.67	1.16	2.40	1.54	In the fishery		
47. Mexican rockfish <i>Sebastes macdonaldi</i>	No	Rockfishes	22.5	36.3	100	256	1.50	3.17	2.00	2.95	1.80	In the fishery	Shelf rockfish	Shelf rockfish, deep
48. Olive rockfish <i>Sebastes serranoides</i>	No	Rockfishes	34.3	39	0	75	1.69	2.22	2.33	1.48	1.87	In the fishery	Nearshore rockfish	Nearshore rockfish
49. Pacific cod <i>Gadus macrocephalus</i>	No	Other fishes	40	65	50	300	2.11	2.11	2.00	1.57	1.34	In the fishery		
50. Pacific ocean perch <i>Sebastes alutus</i>	Yes	Rockfishes	42	55	100	450	1.44	2.50	1.67	2.43	1.69	In the fishery		
51. Pacific grenadier <i>Coryphaenoides acrolepis</i>	No	Other fishes	38	55	1500	2825	1.44	2.50	1.95	1.95	1.82	In the fishery	Other fish	Other fishes, deep
52. Pacific sanddab <i>Citharichthys sordidus</i>	No	Flatfishes	22.8	55	50	150	2.40	3.80	2.10	2.76	1.25	In the fishery	Other flatfish	Flatfishes, shallow
53. Pacific hake <i>Merluccius productus</i>	Yes	Other fishes	24.5	50	50	500	2.00	2.22	2.36	2.04	1.69	In the fishery		
54. Petrale sole <i>Eopsetta jordani</i>	Yes	Flatfishes	38	49	50	300	1.70	1.50	2.44	1.80	1.94	In the fishery		
55. Pink rockfish <i>Sebastes eos</i>	No	Rockfishes	27.8	35	80	366	1.33	2.72	2.14	3.10	2.02	In the fishery	Shelf rockfish	Shelf rockfish, deep

TABLE 1. Continued.

56. Pinkrose rockfish <i>Sebastes simulatrix</i>	Rockfishes	No	28.9	34.4	150	320	1.31	2.72	1.67	2.48	1.82	In the fishery	Shelf rockfish	Shelf rockfish, deep
57. Pygmy rockfish <i>Sebastes wilsoni</i>	Rockfishes	No	32.5	60	60	150	1.78	2.67	1.71	2.48	1.42	EC?	Shelf rockfish	Shelf rockfish, shallow
58. Quillback rockfish <i>Sebastes maliger</i>	Rockfishes	No	34.5	60	44	66	1.31	2.06	2.43	1.48	2.22	In the fishery	Nearshore rockfish	Nearshore rockfish
59. Spotted ratfish <i>Hydrolagus colliei</i>	Elasmobranchs	No	28.5	58	100	150	1.63	2.89	2.05	2.71	1.72	In the fishery	Other fish	Elasmobranchs, shallow
60. Redbanded rockfish <i>Sebastes babcocki</i>	Rockfishes	No	34.5	60	150	450	1.28	2.39	2.05	2.48	2.02	In the fishery	Slope rockfish	Slope rockfish
61. Redstripe rockfish <i>Sebastes proriger</i>	Rockfishes	No	42	60	150	275	1.31	2.50	2.33	2.57	2.16	In the fishery	Shelf rockfish	Shelf rockfish, deep
62. Rex sole <i>Glyptocephalus zachirus</i>	Flatfishes	No	28	62	50	450	2.05	2.70	1.86	3.67	1.28	In the fishery	Other flatfish	Flatfishes, deep
63. Rock greenling <i>Hexagrammos lagocephalus</i>	Other fishes	No	34	64.6	0	80	1.78	2.67	2.29	1.48	1.77	In the fishery		
64. Rock sole <i>Lepidopsetta bilineata</i>	Flatfishes	No	32	55	0	300	1.95	3.00	1.95	3.86	1.42	In the fishery	Other flatfish	Flatfishes, deep
65. Rosethorn rockfish <i>Sebastes helvomaculatus</i>	Rockfishes	No	34.5	60	100	300	1.19	1.94	2.05	2.86	2.09	In the fishery	Shelf rockfish	Shelf rockfish, deep
66. Rosy rockfish <i>Sebastes rosaceus</i>	Rockfishes	No	31	40	40	150	1.61	3.11	2.29	3.52	1.89	In the fishery	Shelf rockfish	Shelf rockfish, shallow
67. Rougheye rockfish <i>Sebastes aleutianus</i>	Rockfishes	No	42	60	150	450	1.17	1.78	2.33	3.19	2.27	In the fishery	Slope rockfish	Slope rockfish
68. Sablefish <i>Anoplopoma fimbria</i>	Other fishes	Yes	28	55	200	1200	1.61	1.78	1.88	1.88	1.64	In the fishery		
69. Sand sole <i>Psettichthys melanostictus</i>	Flatfishes	No	33.5	55	0	73	2.35	2.80	2.05	3.95	1.23	In the fishery	Other flatfish	Flatfishes, shallow
70. Sharpchin rockfish <i>Sebastes zacentrus</i>	Rockfishes	No	36.5	60	100	350	1.36	1.94	2.24	3.71	2.05	In the fishery	Slope rockfish	Shelf rockfish, deep
71. Shortbelly rockfish <i>Sebastes jordani</i>	Rockfishes	Yes	34.5	48.5	150	200	1.94	1.89	1.40	1.12	1.13	EC		
72. Shortraker rockfish <i>Sebastes borealis</i>	Rockfishes	No	48.5	58.5	100	600	1.22	2.17	2.38	2.90	2.25	In the fishery	Slope rockfish	Slope rockfish
73. Shortspine thornyhead <i>Sebastolobus alascanus</i>	Rockfishes	Yes	32	50	100	850	1.33	2.22	1.68	2.00	1.80	In the fishery		
74. Silvergray rockfish <i>Sebastes brevispinis</i>	Rockfishes	No	42	60	100	300	1.22	1.78	1.95	2.19	2.02	In the fishery	Shelf rockfish	Shelf rockfish, deep
75. Tope <i>Galeorhinus galeus</i> ^a	Elasmobranchs	No	32.5	38	2	471	1.11	1.42	1.71	3.33	2.02	In the fishery	Other fish	Elasmobranchs, deep

(Continued on next page)

TABLE 1. Continued.

Species	Weighting group		Preferred latitude		Preferred depth (m)		PSA					Stock		
	Species	Assessment?	Min	Max	Min	Max	P	PDQ	S	SDQ	V	Designation	Current complex	Proposed complex
76. Speckled rockfish <i>Sebastes ovalis</i>	Rockfishes	No	32	38	76	152	1.33	2.22	2.29	2.52	2.10	In the fishery	Shelf rockfish	Shelf rockfish, shallow
77. Spiny dogfish <i>Squalus acanthias</i>	Elasmobranchs	No	30	55	0	350	1.11	1.00	1.98	3.24	2.13	In the fishery		Elasmobranchs, deep
78. Splitnose rockfish <i>Sebastes diploproa</i>	Rockfishes	No	32.5	54.3	150	450	1.28	1.78	1.60	2.00	1.82	In the fishery	Slope rockfish	Slope rockfish
79. Squarespot rockfish <i>Sebastes hopkinsi</i>	Rockfishes	No	30	38	36	150	1.61	2.94	2.24	2.29	1.86	In the fishery	Shelf rockfish	Shelf rockfish, shallow
80. Starry flounder <i>Platichthys stellatus</i>	Flatfishes	Yes	33.7	70	0	150	2.15	2.60	1.60	2.64	1.04	In the fishery		
81. Starry rockfish <i>Sebastes constellatus</i>	Rockfishes	No	23	36.5	60	150	1.25	2.11	2.14	2.38	2.09	In the fishery	Shelf rockfish	Shelf rockfish, shallow
82. Stripetail rockfish <i>Sebastes saxicola</i>	Rockfishes	No	33	49	10	350	1.39	2.56	1.81	2.48	1.80	In the fishery	Shelf rockfish	Shelf rockfish, deep
83. Swordspine rockfish <i>Sebastes ensifer</i>	Rockfishes	No	31	32.5	60	200	1.33	2.33	2.00	2.19	1.94	In the fishery	Shelf rockfish	Shelf rockfish, shallow
84. Tiger rockfish <i>Sebastes nigrocinctus</i>	Rockfishes	No	41	55	55	274	1.25	2.50	2.10	2.19	2.06	In the fishery	Shelf rockfish	Shelf rockfish, deep
85. Treefish <i>Sebastes serripes</i>	Rockfishes	No	28	34.5	3	60	1.67	2.33	2.10	2.05	1.73	In the fishery	Nearshore rockfish	Nearshore rockfish
86. Vermilion rockfish <i>Sebastes miniatus</i>	Rockfishes	Yes	28	43	50	150	1.22	1.67	2.02	2.24	2.05	In the fishery	Shelf rockfish	Shelf rockfish, shallow
87. Widow rockfish <i>Sebastes entomelas</i>	Rockfishes	Yes	38	54	100	350	1.31	1.44	2.16	2.08	2.05	In the fishery		
88. Yelloweye rockfish <i>Sebastes ruberrimus</i>	Rockfishes	Yes	38	54	91	180	1.22	1.44	1.92	2.00	2.00	In the fishery		
89. Yellowmouth rockfish <i>Sebastes reedi</i>	Rockfishes	No	42	58.5	275	366	1.61	1.89	2.38	2.33	1.96	In the fishery	Slope rockfish	Slope rockfish
90. Yellowtail rockfish <i>Sebastes flavidus</i>	Rockfishes	Yes	42	48	90	180	1.33	1.78	1.88	2.00	1.88	In the fishery		
A. Bocaccio	Rockfishes	Yes	32.5	42	100	250	1.28	2.11	2.72	1.56	2.43			
B. Canary rockfish	Rockfishes	Yes	34.5	54	50	250	1.28	1.78	2.84	1.56	2.52			
C. Cowcod	Rockfishes	Yes	32.5	34.5	150	244	1.06	1.44	2.68	2.36	2.57			
D. Darkblotched rockfish	Rockfishes	Yes	34.5	54.3	140	210	1.39	1.67	2.76	1.24	2.39			
E. Pacific ocean perch	Rockfishes	Yes	32.8	55	100	450	1.39	2.06	2.32	2.04	2.08			
F. Yelloweye rockfish	Rockfishes	Yes	38	54	91	180	1.22	1.44	2.80	2.00	2.53			

^aFormerly known as soupfin shark *G. Zyopterus*.

considered. Each of the authors received a set of unique stocks to score. The major sources used to inform scoring were available from stock-specific stock assessments, Cailliet et al. (2000), Love et al. (2002), the Pacific Shark Research Center (Moss Landing Marine Laboratories) elasmobranch life history matrix (<http://psrc.mlml.calstate.edu/recommended-reading-list/life-history-data-matrix/> [October 2009]), and Fish-Base (www.fishbase.org [August 2009]). Given the range of scorer experience, all scorers were encouraged to score every productivity and susceptibility attribute that was scoreable (regardless of confidence in that score), but to record the data quality to reflect their belief in their score. Attribute values that straddled two bins were given an intermediate bin score. Once all stocks were scored, all scores were evaluated by the entire scoring team to (1) ensure a consistent (i.e., agreed upon by all scorers) scoring approach prevailed (especially among the more subjective susceptibility attributes), (2) rectify any perceived discrepancies, and (3) identify stocks with poor data quality scores for further scoring consideration. Two scorers (J. M. Cope and E. J. Dick) again reviewed the resultant productivity scores, while another (J. DeVore) reviewed the resultant susceptibility scores, making any updates or corrections to scores as needed. The scoring team subsequently reviewed and finalized the PSA scores. All scoring was done using the Productivity–Susceptibility Analysis (version 1.4) module of the NOAA Fisheries Toolbox (<http://nft.nefsc.noaa.gov/PSA.html> [February 2010]).

Vulnerability scores are then applied to help identify stocks having significant interactions with fisheries (and are therefore “in the fishery”) or are EC stocks. Stocks are considered candidates as an EC stock if (1) an appreciable portion of their population is within the management area, (2) they have low vulnerability scores (defined below), and (3) they are neither targeted nor retained in a fishery. These three criteria (ecological presence, low vulnerability, and nontargeted–retained in fisheries) were applied to all stocks.

Identifying stock complexes.—Stock complex assignments for all stocks currently in stock complexes (Table 1) were reevaluated using grouping analysis in the following manner: (1) clustering stocks based on ecological distribution (e.g., depth and latitude), (2) grouping within ecological distributional clusters based on vulnerability scores, and (3) evaluating the final groups in terms of fishery interactions (i.e., separating groups further by associations in particular fisheries, if needed). All rockfish currently in complexes were analyzed together. Stocks in the Other flatfish and Other fish complexes were analyzed separately.

Ecological distributions for each stock were defined using the Pacific Coast Ocean Observing System (www.webapps.nwfsc.noaa.gov/pacoos/faces/FishData.jsp [February 2010]) to identify minimum and maximum depth and latitudinal distributions (four total variables; Table 1). For each cluster analysis, a k-medoids partitioning analysis based on Euclidean distances was used. The number of clusters best supported by

the data were identified using silhouette and Hubert’s gamma cluster validity diagnostics (see Cope and Punt 2009 for methods). It was reasoned that stocks should first be clustered based on ecological distributions so as to maintain spatial relations, then grouped by vulnerability scores. Attempts to cluster all variables at once (minimum and maximum depths and latitudes and vulnerability scores) generated some groups of stocks with common vulnerabilities, but that lacked spatial coherence. Clustering depth and latitude simultaneously also resulted in stocks with similar latitudinal ranges, but did not occur in similar depths. Given the current complexes are based primarily on depth co-occurrences, the following multistep grouping approach was implemented: cluster all stocks first by depth, then by latitude, and finally group by vulnerability reference points (see below). This approach allowed resultant groupings to be transparent and interpretable by depth, latitude, and vulnerability. An additional grouping level based on fishery interactions (i.e., grouping fish by the fisheries they are predominantly found in) was considered, but did not alter the results based on the above grouping analysis. All cluster analysis was performed in R 2.11.0 (R Development Core Team 2010).

To both help with general interpretation of vulnerability scores (V) and identification of vulnerability groupings for stock complexes, vulnerability reference points were defined. Patrick et al. (2009, 2010) noted that V greater than 1.8 was often associated with stocks undergoing overfishing or in an overfished state. A more detailed analysis of their results indicated that $V = 2.0$ was more generally associated with stocks currently considered overfished. Given that stocks currently overfished are often in rebuilding phases with substantial reductions in the current susceptibility to overfishing achieved through management response, susceptibility scores based on current conditions may thus underestimate the absolute value of vulnerability indicative of becoming overfished. To gain better resolution in the relationship between vulnerability and being in an overfished state, the susceptibilities of six PFMC groundfish stocks currently designated “overfished” were rescored to reflect conditions under a major population decline (defined as reference year 1998 and found at the end of Table 1). All of the updated scoring was made to susceptibility attributes 1–6 (Table 2). In addition to this retrospective consideration, comparisons were also made with the results of Dick and MacCall (2010) who estimated the probability of overfishing occurring among several data-limited stocks using the depletion-based stock reduction analysis (DB-SRA). Stocks with V greater than 2.2 demonstrated about a 50% chance of current catch exceeding the DB-SRA based estimate of the overfishing limit (OFL). Combining these two sources of information (the retrospective PSA and comparisons with DB-SRA), a minimum vulnerability of 2.2 was used to indicate stocks with high probabilities of being overfished or in the midst of overfishing (see Figure 1). The following guidance for interpreting vulnerability scores via vulnerability reference points

TABLE 2. Productivity and susceptibility attributes with bin definitions and score weightings for different species groups and those with and without Pacific Fishery Management Council-approved assessments. Default weights for all attributes are 2. Full descriptions of all attributes and the determination of binning values can be found in Patrick et al. (2009).

Productivity attributes	Bins			Weight (0 to 4)		
	High (3)	Moderate (2)	Low (1)	Elasmobranchs	Flatfishes	Rockfishes and other fishes
r	≥ 0.5	0.5 to 0.16	≤ 0.16	2	2	2
Maximum age	≤ 10 years	10 to 30 years	≥ 30 years	2	2	2
Maximum size	≤ 60 cm	60 to 150 cm	≥ 150 cm	1	2	1
von Bertalanffy growth coefficient (k)	≥ 0.25	0.15 to 0.25	≤ 0.15	2	2	2
Estimated natural mortality (M)	≥ 0.40	0.20 to 0.40	≤ 0.20	2	2	2
Measured fecundity	$\geq 10^4$	10^2 to 10^3	$\leq 10^2$	2	2	1
Breeding strategy	0	Between 1 and 3	≥ 4	2	2	2
Recruitment pattern	Highly frequent recruitment success (≥ 8 per decade)	Moderately frequent recruitment success (> 1 and < 8 per decade)	Infrequent recruitment success (≤ 1 per decade)	2	2	2
Age at maturity	≤ 2 years	2 to 4 years	≥ 4 years	2	2	2
Mean trophic level	≤ 2.5	2.5 to 3.5	≥ 3.5	2	2	2
Susceptibility attributes	Bins			Weight (0 to 4)		
	Low (1)	Moderate (2)	High (3)	Assessment	No assessment	
Management strategy	Proactive management; sort requirements; individual specification; discard monitoring; biological data; representative fishery-independent indices	Reactive management; decent catch records; some assessment data; weak spatial knowledge; weakly informed indices	High catch uncertainty; low assessment data; no sorting; inadequate discard monitoring; low confidence in control rule	3	3	
Areal overlap	$\leq 25\%$ of stock occurs in the area fished	Between 25% and 50% of the stock occurs in the area fished	$\geq 50\%$ of stock occurs in the area fished	2	2	
Geographic concentration	Stock is distributed in $\geq 50\%$ of its total range	Stock is distributed in 25% to 50% of its total range	Stock is distributed in $\leq 25\%$ of its total range	2	2	
Vertical overlap	$< 25\%$ of stock occurs in the depths fished	Between 25% and 50% of the stock occurs in the depths fished	$\geq 50\%$ of stock occurs in the depths fished	2	2	
F relative to M	≤ 0.5	0.5 to 1.0	≥ 1	2	0	
Relative spawning biomass	B is $\geq 40\%$ of B_0 (or maximum observed from time series of biomass estimates)	B is between 25% and 40% of B_0 (or maximum observed from time series of biomass estimates)	B is $\leq 25\%$ of B_0 (or maximum observed from time series of biomass estimates)	2	0	

TABLE 2. Continued.

Susceptibility attributes	Bins			Weight (0 to 4)	
	Low (1)	Moderate (2)	High (3)	Assessment	No assessment
Seasonal migrations	Seasonal migrations decrease overlap with the fishery	Seasonal migrations do not substantially affect the overlap with the fishery	Seasonal migrations increase overlap with the fishery	2	2
Schooling—aggregation and other behavioral responses	Behavioral responses decrease the catchability of the gear	Behavioral responses do not substantially affect the catchability of the gear	Behavioral responses (e.g., schooling) increase the catchability of the gear	2	2
Morphology affecting capture	Species shows low selectivity to the fishing gear	Species shows moderate selectivity to the fishing gear	Species shows high selectivity to the fishing gear	2	2
Survival after capture and release	Survival probability $\geq 67\%$	$33\% < \text{survival probability} < 67\%$	Survival probability $\leq 33\%$	2	2
Desirability—value of the fishery	Stock is not highly valued or desired by the fishery	Stock is moderately valued or desired by the fishery	Stock is highly valued or desired by the fishery	2	2
Fishery impact to EFH or habitat in general for non-targets	Adverse effects absent, minimal, or temporary	Adverse effects more than minimal or temporary but are mitigated	Adverse effects more than minimal or temporary and are not mitigated	2	2

is offered given the above insight: $V \geq 2.2$ indicates stocks of major concern; $2.0 \leq V < 2.2$ indicates stocks of high concern; $1.8 \leq V < 2.0$ indicates stocks of medium concern; and $V < 1.8$ indicates stocks of low concern.

RESULTS

Five stocks are found in the area of major concern ($V \geq 2.2$) and another 23 of the 90 stocks are in the area of high concern ($2.0 \leq V < 2.2$; Table 1; Figure 1). These stocks were exclusively rockfishes (*Sebastes* spp.) and elasmobranchs. Another 28 stocks are of medium concern ($1.8 \leq V < 2.0$). Patrick et al. (2010) provided additional guidance that stocks with susceptibility scores greater than 2.3 should also be of concern, regardless of the vulnerability score. There were 11 stocks with such susceptibilities, and all but one stock (Pacific hake) is included in our categories of medium to high concern. The median rockfish productivity score ($N = 59$) was 1.33 (with the lowest value possible being 1), meaning that relatively low susceptibility scores of 1.67 and 2.10 would cause 50% of the rockfish to have V of 1.8 or greater and V of 2.0 or greater, respectively, demonstrating the innate vulnerability of these stocks to being overfished based solely on life history traits. Flatfishes tended to have the lowest vulnerabilities (Table 1; Figure 1).

Productivity and susceptibility data quality scores (Table 1; Figure 2) are generally well informed (i.e., most data quality

scores reside in the bottom left quadratic) for most stocks. The susceptibility scoring is relatively less reliable than the productivity scoring. Flatfishes, although the least vulnerable group, were also the relatively least-informed group, with 6 of the 12 flatfish stocks having at least one of the vulnerability components (productivity and susceptibility) poorly informed. Of the seven elasmobranch stocks in the FMP, three had poorly informed vulnerability components. Only 7 of the 59 rockfishes had either poorly informed productivity or susceptibility attributes.

Applying PSA to the Needs of the MSA

Most of the stocks (88 of 90) occur significantly within the waters managed by the FMP, but only a minority of the stocks (35 of 90) in the FMP have low vulnerability scores (Table 1). Most (30 of 35) are affiliated with or are targeted by a fishery, so 85 of 90 stock are considered “in the fishery.” There are five stocks that fit the EC criteria of ecological presence, low vulnerability, and nontargeting—retainment in fisheries (see “Proposed Stock Designation” column in Table 1). Shortbelly rockfish commonly occur in FMP-managed waters, but have low vulnerability ($V = 1.13$) and no target or retention fishery. This stock’s extremely low vulnerability makes it a strong EC candidate. The remaining EC candidate stocks—calico, freckled, halfbanded, and pygmy rockfishes—have relatively higher

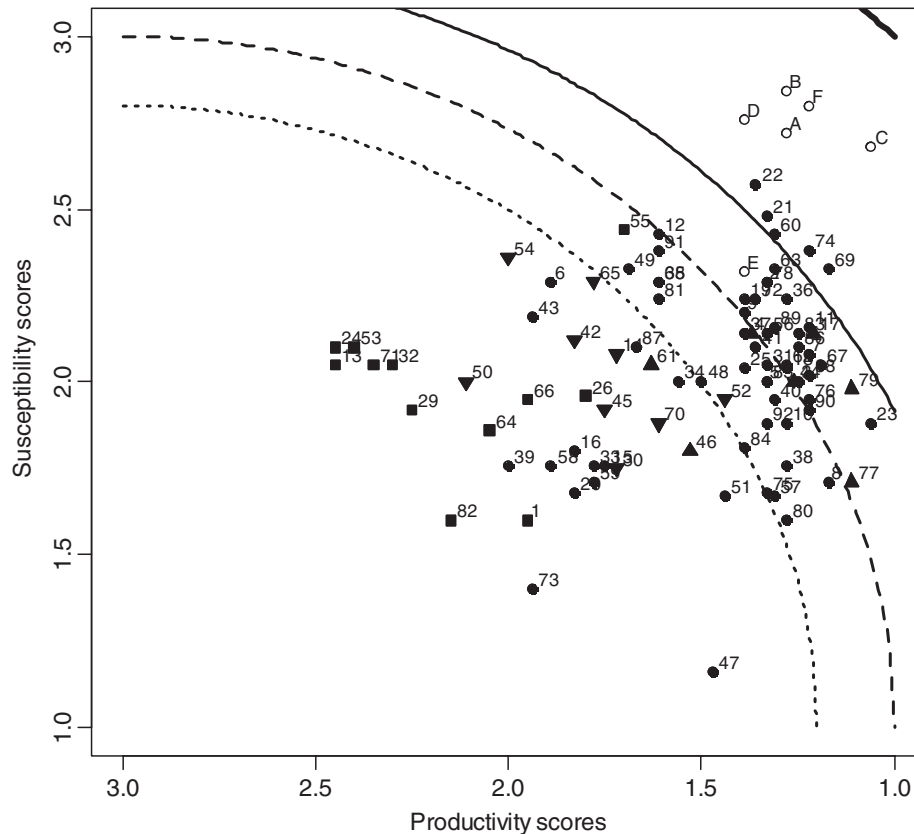


FIGURE 1. Productivity–susceptibility analysis (PSA) plot for species in the West Coast groundfish fishery management plan. Contours delineate areas of relative vulnerability (V , i.e., distance from the origin), with stocks of the highest vulnerability above the solid line ($V = 2.2$), those of high vulnerability above the dashed line ($V = 2.0$), those of medium vulnerability above the dotted line ($V = 1.8$), and those of the lowest vulnerability below the dotted line. The maximum theoretical vulnerability ($V = 2.8$) is indicated by the thickest solid line (top right corner). Solid symbols are based on current PSA scores. Open symbols are based on PSA scores circa 1998 for the rebuilding species only (“Retrospective”). Point labels refer to the species identifiers in Table 1. Note that the productivity axis is in descending value in order to make the top right quadrant of the plot the area of greatest vulnerability (i.e., the lowest productivity and highest susceptibility).

susceptibilities owing to minor interactions with recreational fisheries, but still generally fit the EC criteria. Susceptibilities for all EC candidate stocks were less than 1.8, which may be a useful preliminary criterion to characterize EC stocks from other stocks that have low vulnerabilities owing to high productivities.

The two remaining stocks—dusky and dwarf-red rockfish—did not fit either the “in the fishery” or any of the EC criteria. These stocks are not found in significant numbers within the area covered by the groundfish FMP, not susceptible to the fisheries, and thus not in danger of overfishing or being overfished. And despite having moderate (dusky rockfish) to low (dwarf-red rockfish) overall vulnerability (owing exclusively to low productivity scores), considering these stocks as either “in the fishery” or EC overstates their ecological presence in the system. Thus, the lack of both ecological and fishery relevance in the waters managed by the PFMC support potential revision of their inclusion in the groundfish FMP.

Defining Stock Complexes

In general, the ecological grouping analysis supported four rockfish complexes based mainly on depth categories, with two latitudinal groupings also apparent (Table 3). The Flatfishes, Elasmobranchs, and Other fishes complexes were defined by two depth categories (Table 4). Stocks in each of the ecological complexes were also grouped into one of four vulnerability categories (Tables 3, 4). Several notable changes to the current complex designations are apparent. The biggest differences are the inclusions of shallow- and deep-shelf rockfish complexes instead of one Shelf rockfish complex (Table 3) and an Elasmobranchs complex separated from the original Other fish complex (Table 4). The remaining stocks in the Other fish category demonstrate two disparate depth distributions, necessitating two additional complexes. The Flatfishes complex contains the same stocks as in Other flatfish, but with an added descriptor based on ecological distribution. Additional differences include four rockfishes (bank, calico, honeycomb, and sharpchin rockfish) that changed complexes (Table 1).

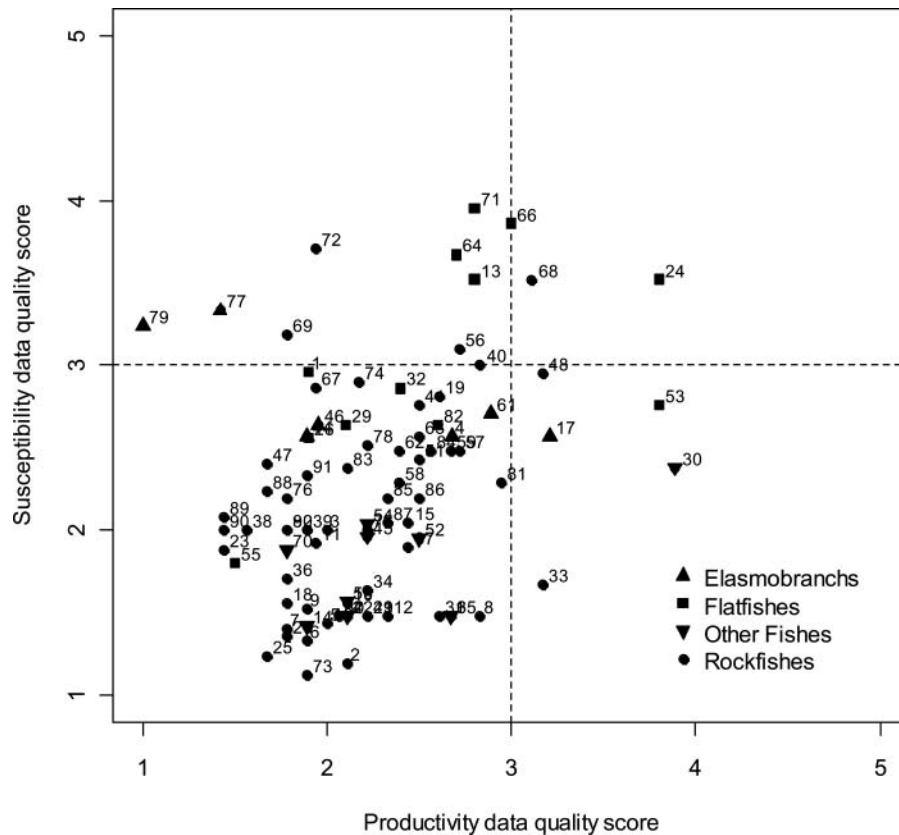


FIGURE 2. Data quality plots for the productivity and susceptibility scores in the productivity–susceptibility analysis for the stocks in the West Coast groundfish FMP. Higher scores indicate poorer data quality (e.g., a score of 5 on either axis means the overall data quality is poorest). Scores at the upper right corner therefore indicate the least-informed stocks. The vertical and horizontal lines provide a general guide to relative data quality, with values above 3 on either axis considered poorly informed scores.

Most of the members of the rockfish complexes show medium to high vulnerabilities, but most are below $V = 2.2$. Five rockfish stocks had V greater than 2.2, with three stocks in the nearshore rockfish (China, copper, and quill-back rockfish) and two in the slope (rougeye and shortraker rockfish), all of which are long-lived, deep-dwelling rockfishes. In general, there is no striking relationship of vulnerability with latitudinal distribution, though deep-dwelling stocks tend to exhibit relatively higher vulnerabilities (Table 3). The Flatfishes complex is composed exclusively of flatfishes with low vulnerabilities, while the newly proposed Elasmobranchs complex contains stocks with mostly medium to high vulnerabilities. The deep elasmobranchs complex demonstrates the greatest vulnerability of the non-rockfish complexes.

DISCUSSION

The PSA provided an accessible approach to two needs brought forth by the reauthorized MSA (2006). First, in conjunction with fleet-targeting behavior, vulnerability scores were able to shed light on which stocks should be considered “in the

fishery” or an EC stock, thus identifying the stocks for which ACLs and AMs are required. Secondly, for those stocks without council-approved stock assessments, stock complexes were established based on ecological distributions and vulnerabilities, incorporating both spatial considerations and population response to shared fishery interactions. The results are proposed stock complexes that offer managers focused attention on stocks that co-occur and exhibit similar responses to current fishing conditions.

One of the strengths of the PSA approach is the ease of scoring stocks with limited information. Despite the majority of the stocks in the groundfish FMP lacking fine biological resolution on many life history attributes, scoring a PSA requires only a general understanding of the attributes because bins are used rather than precise estimates. The generally high quality scores given to the information used to score each attribute even in data-limited situations attests to the practicality and usefulness of the PSA approach.

Scoring of the susceptibility attributes proved the most difficult, especially the attributes addressing areal and spatial overlap with the fishery, as well as geographic concentration of the stock, because such measures are inherently more difficult to estimate

TABLE 3. Proposed rockfish complexes informed by ecological distribution, productivity–susceptibility analysis score, and fisheries. Gray cells indicate “northern” stocks, white cells “southern” stocks.

Vulnerability (V)	Depth category			
	Nearshore	Shelf-shallow	Shelf-deep	Slope
Major ($V \geq 2.2$)	China rockfish (2.23)			Rougheye rockfish (2.27)
	Quillback rockfish (2.22)			Shortraker rockfish (2.25)
High ($2.0 \leq V < 2.2$)	Copper rockfish (2.27)	Speckled rockfish (2.1)	Redstripe rockfish (2.16)	Redbanded rockfish (2.02)
	Blue rockfish (2.01)	Starry rockfish (2.09)	Rosethorn rockfish (2.09)	Aurora rockfish (2.1)
		Vermilion rockfish (2.05)	Sharpchin rockfish (2.05)	Blackgill rockfish (2.08)
			Silvergrey rockfish (2.02)	
			Tiger rockfish (2.06)	
			Bank rockfish (2.02)	
			Bronzespotted rockfish (2.12)	
			Chameleon rockfish (2.03)	
			Pink rockfish (2.02)	
Medium ($1.8 \leq V < 2.0$)	Brown rockfish (1.99)	Yellowtail rockfish (1.88)	Greenstriped rockfish (1.88)	Splitnose rockfish (1.82)
	Grass rockfish (1.89)	Flag rockfish (1.97)	Harlequin rockfish (1.94)	Yellowmouth rockfish (1.96)
	Honeycomb rockfish (1.97)	Greenspotted rockfish (1.98)	Stripetail rockfish (1.80)	
	Olive rockfish (1.87)	Rosy rockfish (1.89)	Greenblotched rockfish (1.92)	
		Squarespot rockfish (1.86)	Mexican rockfish (1.80)	
		Swordspine rockfish (1.94)	Pinkrose rockfish (1.82)	
Low ($V < 1.8$)	Black-and-yellow rockfish (1.7)	Pygmy rockfish (1.42)		
	Gopher rockfish (1.76)	Calico rockfish (1.46)		
	Kelp rockfish (1.59)	Freckled rockfish (1.44)		
	Treefish rockfish (1.73)	Halfbanded rockfish (1.26)		

(Table 2). Maintaining a consistency in scoring these attributes when there are multiple scorers proved challenging and should be a focus when applying the PSA. Having all scorers clarify how each bin definition is treated during the first scoring iteration encouraged consistency. Data quality scoring was particularly useful in identifying such troublesome attributes in need of further consideration. Additional guidance to quantitatively

scoring the areal and spatial overlap attributes is found in Patrick et al. (2009).

The analysis confirmed an already well-documented supposition that the life histories of many rockfishes and elasmobranchs increase the probability of their being overfished (Musick et al. 2000; Parker et al. 2000; Berkeley et al. 2004). In particular, three of the nearshore rockfishes (China, copper, and quillback

TABLE 4. Proposed stock complexes of noninformed species by ecological distribution, productivity–susceptibility analysis score, and fisheries. Shading in depth category indicates different levels of vulnerability, as follows: black = major, dark gray = high, light gray = medium, and white = low.

Complex	Depth category	
	Shallow	Deep
Flatfishes		
	Butter sole (1.18)	Flathead sole (1.26)
	Curlfin sole (1.23)	Rex sole (1.28)
Elasmobranchs	Pacific sanddab (1.25)	Rock sole (1.42)
	Sand sole (1.23)	
	Leopard shark (2.00)	California skate (2.12)
		Southern spiny dogfish (2.02)
Other fishes		Spiny dogfish (2.13)
	Big skate (1.99)	
	Ratfish (1.57)	
		Pacific grenadier (1.82)
	Cabezon (1.48)	Finescale codling (1.48)
	Kelp greenling (1.59)	

rockfish) are identified as being of high concern to be overfished (O'Farrell and Botsford 2006; Field et al. 2010), as are several of the slope stocks. Similar conclusions were arrived at by Dick and MacCall (2010), who found that most of the same stocks considered of highest vulnerability in this study are also the most likely to have undergone overfishing from recent catch levels. Although the results from the PSA are not meant to be a substitute for a proper stock assessment, it appears the information contained in applying the proposed vulnerability references can draw attention to stocks in need of increased management attention despite data limitations.

The stock complexes provided in this analysis are desirable in many ways. The need for allowing flexibility in fisheries management is a preferred trait (Hanna 1999; Smith et al. 1999). Grouping in a step-wise fashion (by depth, then latitude, then vulnerability scores) rather than using all variables at once, then presenting the final stock complexes with each level of detail explicit (depth, latitudinal, and vulnerability groups) would allow managers to assemble the complexes in a manner most useful to their needs. For example, using the information contained in Table 3 for rockfish complexes, managers could decide whether management needs warrant the collapsing of some of the depth or latitudinal categories, while maintaining the vulnerability

groupings. They may also decide the vulnerability differences warrant distinct complexes, rather than just subcomplex distinction. The trade-off between too much detail (e.g., too many complexes) and enough to maintain management flexibility and applicability needs consideration. While the stock complexes suggested in this analysis add a layer in the form of vulnerability groupings, it is a resolution encouraged by the MSA and accessible to ways of assigning ACLs (Shertzer et al. 2008; Prager and Shertzer 2010).

The vulnerability reference points and contours introduced in this study provide guidance on how to interpret the vulnerability scores. Using the retrospective susceptibility scores to help define these reference points demonstrates a main attribute of interpreting vulnerabilities; management has the greatest influence in altering susceptibility when trying to reduce a stock's vulnerability. Productivity scores (Figure 1, horizontal axis) are usually static in the short term, thus are unlikely to change unless improvements in the data quality alter scoring. Most reduction in vulnerability via management will thus be realized on the susceptibility axis (Figure 1, vertical axis). Scoring should be updated on a regular basis to reflect any changes in susceptibility or increased knowledge of productivity attributes.

Additional Applications of PSA to Groundfish Management

Beyond the two objectives previously outlined, vulnerability scores can help rapidly identify stocks of interest for either scientific emphasis or management attention. Data quality scores can identify stocks in need of basic biological or fisheries data, helping to prioritize data collection. Productivity and susceptibility scores may lend additional information to the setting of catch levels in data-limited situations (Prager and Shertzer 2010) or prioritizing stock-assessment resources. Additionally, the PSA could be used to identify other species not already contained in the FMP, but vulnerable to being overfished. Just as two species were suggested for possible removal from the FMP, other species with high vulnerability scores could be appropriate additions to the FMP. Given the possibility of emergent and developing fisheries (Perry et al. 1999), identification of such species is an ongoing relevant consideration.

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