

GROUND FISH MANAGEMENT TEAM (GMT) REPORT ON ASSIGNING
VULNERABILITY SCORES TO ALL SPECIES IN THE GROUND FISH FISHERY
MANAGEMENT PLAN (FMP)

The GMT evaluated the vulnerability (V) of all groundfish species found in the groundfish FMP in order to address the following goals contained in Amendment 23 of the FMP:

- 1) Defining species as either “in the fishery”, an “ecosystem component”, or neither.
- 2) Identify stock complexes for management purposes
- 3) Quantify buffers for ultimately determining ACLs from OFLs and ABCs.

There are several factors that potentially complicate the use of vulnerability scores in the formulation of ACL buffers, so the GMT set aside this task for future consideration.

Regarding goals 1 and 2, the GMT chose the productivity-susceptibility analysis (PSA) of Patrick et al. (2009) to quantify vulnerability. The PSA approach defines vulnerability in two dimensions: 1) productivity, which characterizes the life history of each stock and 2) the susceptibility, or the potential a stock is impacted by the fishery (ies) in question. There are 10 productivity and 12 susceptibility attributes scored on a three point scale representing bins of low, medium, and high (Table 1). In addition to scoring the attributes, one also scores the data quality intended to capture the confidence the scorer has in the attribute bin score (1-5 scale, with more confidence represented as a lower score). Once the average scores across all attributes are calculated, an x-y plot is produced to visualize productivity versus susceptibility. Vulnerability is defined as the Euclidean distance from the origin in the plot (Patrick et al. 2009).

The PSA analysis is a generalized and flexible approach to defining vulnerability that allows the user to specify bin definitions/values, and attribute weighting to allow the analysis to capture the most pertinent aspects of productivity and susceptibility among the species in question. The GMT updated the definition of the “management strategy” susceptibility attribute bins to reflect specific qualities of managing U.S. west coast groundfishes while capturing the general ideas of relative susceptibility from the Patrick et al. 2009 bin definitions (Table 1). Default bin definitions/values for the other attributes were maintained.

The GMT considered an alternative attribute weighting scheme for some species rather than the default weighting system provided in Patrick et al. (2009) (Table 1). In some cases, the maximum length and/or fecundity productivity attributes were downweighted by half because these attributes were inconsistently indicative of productivity across groundfishes in the FMP. The management strategy susceptibility attribute was upweighted 50% because the GMT felt this attribute contributed to susceptibility more strongly than other attributes. Two susceptibility attributes (“F relative to M” and “Relative Spawning Biomass”) are derived stock assessment quantities, so the team

decided not to use the scores of these attributes for non-assessed stocks, thus weighting their contribution as zero when a Council-approved assessment was not available.

The GMT took an iterative approach to assign productivity and susceptibility scores for each of the species considered. All individuals on the GMT received species to score. The major sources used to inform scoring were available stock assessments, Cailliet et al (2001), Love et al. (2002), the Pacific Shark Research Center (Moss Landing Marine Laboratories) elasmobranch life history matrix¹, and Fishbase². Given the range of experience on the GMT with each species, team members were encourage to score all attributes, but record the data quality to reflect their belief in their score. Once all species were scored, the team evaluated some examples to ensure a consistent scoring approach prevailed (especially among the more subjective susceptibility attributes), rectified any discrepancies uncovered, and indentified species with poor data quality scores for further scoring consideration. The team then assigned two groups of two members to review and update either the productivity or susceptibility scorings. Teams were assigned based on their expertise in each of the vulnerability dimensions. Once this update was made, the team reviewed and finalized the PSA scores. The PSA for groundfish in the FMP are provided in Table 2 and visualized in Figure 1.

Areas of concern on the PSA plot were determined to help interpret scores (Figure 1). Patrick et al. (2009) noted that vulnerability scores above 1.8 were often associated with species undergoing overfishing or in an overfished state. A more detailed analysis of their results indicates a vulnerability of 2.0 was more generally associated with species currently considered overfished. Given species currently overfished are often in rebuilding phases with associated reductions in the current susceptibility to fisheries, susceptibility scores based on current conditions may underestimate the relationship between vulnerability and becoming overfished. To gain better resolution in the relationship between vulnerability and being in an overfished state, the susceptibilities of species currently designated ‘overfished’ were re-scored to reflect conditions under major population decline (defined as reference year 1998 and found at the end of Table 1). This exercise delineated an upper vulnerability of 2.4 (Figure 1).

The following guidance in interpreting vulnerability scores is offered given the above insight:

- $V \geq 2.4$ indicate species of major concern.
- $2.0 \leq V < 2.4$ indicate species of high concern
- $1.8 \leq V < 2.0$ indicate species of medium concern
- $V < 1.8$ indicate species of low concern.

In order to lower vulnerability, one has the greatest influence in altering susceptibility scores (vertical axis) via management. Productivity scores (horizontal scores) are unlikely to change, unless improvements in the data quality alter scoring.

¹ <http://psrc.mlml.calstate.edu/recommended-reading-list/life-history-data-matrix/> October 2009

² <http://www.fishbase.org> August 2009

Figure 2 illustrates the data quality for species productivity and susceptibility. Data quality scores range from 1 to 5, with 5 being the poorest data quality. The plotted horizontal and vertical lines at a score of 3 indicate the midpoint between 1 and 5; this line is treated as a pivot to interpret data quality as more or less informed. Therefore, values near or above 3 are considered of poor quality.

Applying PSA to management interests

Once both the PSA score and its data quality are calculated, one can begin to address the goals specified in Amendment 23. We will briefly address the first two goals and examples of applying the groundfish PSA.

“In the fishery”, “Ecosystem Component”, or Neither?

PSAs give direct insight into the relationship of a species to a fishery, and therefore can address the most appropriate designation as defined in amended National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. Most species in the FMP have PSA scores indicating significant interaction with fisheries, though there are a few that may more appropriately be deemed as ecosystem components. For example, shortbelly rockfish have low vulnerability ($V=1.13$) and no target or retention fishery, fitting the definition of an ecosystem component. Other examples of species fitting this designation (low vulnerability and fishery potential) are the calico, freckled, halfbanded, Puget Sound, and pygmy rockfishes (see ‘Proposed Stock Designation’ column in Table 1).

Likewise, there are two species that fit neither the “in the fishery” or “ecosystem components” definition. Dusky and dwarf-red rockfish are not found in significant numbers within the area covered by the groundfish FMP, and thus are not susceptible to the fisheries, nor in numbers significant enough to be considered ecosystem components. Both accounts support the need for removal from the FMP. Additionally, the PSA could be used to identify other species not already contained in the FMP, but vulnerable to being overfished (thus “in the fishery”). Such species with high vulnerabilities could be appropriate additions to the FMP. Given the possibility of emergent and/or developing fisheries, identification of such species is an ongoing relevant consideration.

Identifying stock complexes

In order to identify stock complexes using vulnerabilities, current complexes were re-evaluated via cluster analysis in the following manner: a) clustering species based on latitudinal and depth distribution, b) clustering within distributional grouping based on productivity and susceptibility scores and c) evaluating the final clusters in terms of fishery interactions. All rockfish currently in complexes were analyzed together. The current ‘other fish’ and ‘other flatfish’ complexes were analyzed separately.

We approached defining stock complexes by species co-occurrence as well as by its vulnerability. This requires classifying a species core depth and latitudinal range. The Pacific Coast Ocean Observing System website³ was used to identify core minimum and maximum depth and latitudinal distributions. For each cluster analysis, a k-medoids

³ <https://www.webapps.nwfsc.noaa.gov/pacoos/faces/FishData.jsp>

partitioning analysis using Euclidean distances applying silhouette and Hubert's gamma cluster validity diagnostics was used (Cope and Punt 2009). Clusters were made first on the latitudinal and depth variables and separated into ecological groups. These groups were then clustered by productivity and susceptibility scores. Results for the final complexes are given in Tables 3 and 4 and summarized in Table 1 (see 'Proposed complex').

Several notable changes are apparent from the previous complex designations. The biggest differences are the inclusions of shallow and deep shelf rockfish complexes (Table 3) and an Elasmobranch complex (Table 4) separated from the 'Other fish' complex. The remaining species in the 'Other fish' category demonstrate two disparate ecological distributions, necessitating two additional complexes. The 'Other flatfish' contains the same species as before, but with an added layer based on ecological distribution. Additional changes include a few rockfish that switched complexes (Table 1).

The PSA contributes further by identifying vulnerability groupings within each co-occurring complex. Most of the members of the rockfish complexes show medium to high vulnerabilities, but none are above $V=2.4$. The group with the greatest vulnerability is the nearshore trio of China, copper, and quillback rockfishes, all of which are longer-lived, deeper-dwelling nearshore rockfishes. In general, there is no significant relationship of vulnerability with latitudinal distribution, though the deeper species contain relatively the most species with high vulnerabilities. The 'Other Flatfish' complex is composed exclusively of flatfishes with low vulnerability, while the newly proposed 'Elasmobranch' complex contains species with mostly medium to high vulnerabilities. The deep elasmobranch group demonstrates the greatest vulnerability within this complex.

Additional applications of PSA to groundfish management

The PSA results offer further applications relevant to the support of groundfish management beyond the two goals outlined above. Vulnerability scores can help rapidly identify species of interest for either scientific emphasis or management attention. Data quality scores can identify species in need of basic biological or fisheries data, helping to prioritize data collection. And productivity and/or susceptibility scores may lend additional information to the setting of catch levels in data-limited situations.

References

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Table 1. List of productivity and susceptibility attributes with bin definitions and score weightings for different species groups and those with and without Council-approved assessments. Default weights for all attributes are 2.

Productivity Attributes	Bins			Weight (0 - 4)		
	High (3)	Moderate (2)	Low (1)	Elasmobranchs	Flatfish	Rockfish & other fish
r	>0.5	0.5-0.16	<0.16	2	2	2
Maximum Age	< 10 years	10 - 30 years	> 30 years	2	2	2
Maximum Size	< 60 cm	60-150 cm	> 150 cm	1	2	1
von Bertalanffy Growth Coefficient (k)	> 0.25	0.15-0.25	< 0.15	2	2	2
Estimated Natural Mortality	> 0.40	0.20-0.40	< 0.20	2	2	2
Measured Fecundity	> 10e4	10e2-10e3	< 10e2	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 & <8 per decade)	infrequent recruitment success (≤ 1 per decade)	2	2	2
Age at Maturity	< 2 years	2-4 years	> 4 years	2	2	2
Mean Trophic Level	<2.5	2.5-3.5	>3.5	2	2	2
Susceptibility Attributes	Low (1)	Moderate (2)	High (3)	No Assessment	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	< 25% of stock occurs in the area fished	Between 25% and 50% of the stock occurs in the area fished	> 50% of stock occurs in the area fished	2	2	
Geographic Concentration	stock is distributed in > 50% of its total range	stock is distributed in 25% to 50% of its total range	stock is distributed in < 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	> 50% of stock occurs in the depths fished	2	2	
F relative to M	<0.5	0.5 - 1.0	>1	2	0	
Relative Spawning Biomass	B is > 40% of B0 (or maximum observed from time series of biomass estimates)	B is between 25% and 40% of B0 (or maximum observed from time series of biomass estimates)	B is < 25% of B0 (or maximum observed from time series of biomass estimates)	2	0	
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 > 67%	33% < survival probability < 67%	Survival probability < 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	

Table 2. Overall scores and results of the Productivity-Susceptibility Analysis (PSA), core minimum and maximum latitudinal and depth ranges (used in the cluster analyses), proposed stock designation, and species complex assignments for each species in the groundfish FMP. InF: in the fishery; EC: ecosystem component; N: neither. Green: $V < 1.8$; Orange: $1.8 \leq V < 2.0$; Red: $V \geq 2.0$.

Stock identity	Stock Name	Productivity	Data		Vulnerability	Preferred latitude		Preferred depth		Proposed Stock			
			Quality	Susceptibility		Quality	minimum	maximum	minimum	maximum	Designation	Current Complex	Proposed Complex
1	Arrowtooth Flounder	1.95	1.90	1.60	2.96	1.21	42.8	55	50	500	InF		
2	Aurora rockfish	1.33	2.11	2.29	1.19	2.10	32.5	46.3	300	500	InF	Slope rockfish	Slope rockfish
3	Bank rockfish	1.25	2.00	2.00	2.00	2.02	27.5	39.5	100	270	InF	Slope rockfish	Shelf rockfish- deep
4	Big Skate	1.37	2.68	2.14	2.57	1.99	34.5	46	50	200	InF	Other fish	Elasmobranchs-shallow
5	Black rockfish	1.33	2.00	2.00	1.44	1.94	38	54	0	55	InF		
6	Black-and-yellow rockfish	1.89	1.89	2.29	1.33	1.70	34.5	39.5	1	18	InF	Nearshore rockfish	Nearshore rockfish
7	Blackgill rockfish	1.22	1.78	2.08	1.40	2.08	36.7	42	250	600	InF	Slope rockfish	Slope rockfish
8	Blackspotted rockfish	1.17	2.83	1.71	1.48	1.97	42	60	150	450	InF		Slope rockfish
9	Blue rockfish	1.39	1.89	2.20	1.52	2.01	33	46.5	25	90	InF	Nearshore rockfish	Nearshore rockfish
10	Bocaccio	1.28	2.11	1.88	1.56	1.93	32.5	42	100	250	InF		
11	Bronzespotted rockfish	1.22	1.94	2.16	1.92	2.12	31	37	200	290	InF	Shelf rockfish	Shelf rockfish- deep
12	Brown rockfish	1.61	2.33	2.43	1.48	1.99	23	38	1	120	InF	Nearshore rockfish	Nearshore rockfish
13	Butter Sole	2.45	2.80	2.05	3.52	1.18	34.3	55	2	150	InF	Other flatfish	Other flatfish- shallow
14	Cabezon	1.72	1.89	2.08	1.42	1.68	34	46	0	25	InF	Other fish	Other fish- shallow
15	Calico rockfish	1.75	2.44	1.95	2.05	1.57	28	37.6	60	120	EC	Nearshore rockfish	
16	California scorpionfish	1.83	2.00	1.80	1.44	1.41	22.9	34.4	2	50	InF		
17	California Skate	1.21	3.21	2.14	2.57	2.12	32.5	39	18	671	InF	Other fish	Elasmobranchs-deep
18	Canary rockfish	1.28	1.78	2.04	1.56	2.01	34.5	54	50	250	InF		
19	Chameleon rockfish	1.39	2.61	2.24	2.81	2.03	33.6	34.5	174	274	InF	Shelf rockfish	Shelf rockfish- deep
20	Chilipepper	1.83	1.78	1.68	1.36	1.35	32.5	39.3	50	250	InF		
21	China rockfish	1.33	2.22	2.48	1.48	2.23	36	59.5	18	92	InF	Nearshore rockfish	Nearshore rockfish
22	Copper rockfish	1.36	2.11	2.57	1.48	2.27	32	34.5	0	90	InF	Nearshore rockfish	Nearshore rockfish
23	Cowcod	1.06	1.44	1.88	1.88	2.13	32.5	34.5	150	244	InF		
24	Curlfin Sole	2.45	3.80	2.10	3.52	1.23	31	55	7	90	InF	Other flatfish	Other flatfish- shallow
25	Darkblotched rockfish	1.39	1.67	2.04	1.24	1.92	34.5	54.3	140	210	InF		
26	Dover Sole	1.80	1.90	1.96	2.56	1.54	34	48	200	500	InF		
27	Dusky rockfish	1.28	2.33	0.00	0.00	1.99	54	60	100	300	N	Shelf rockfish	Remove from FMP
28	Dwarf-red rockfish	1.83	3.17	0.00	0.00	1.54	32.5	34.4	58	167	N	Shelf rockfish	Remove from FMP
29	English Sole	2.25	2.10	1.92	2.64	1.19	32.5	60	0	250	InF		
30	Finescale codling	1.72	3.89	1.75	2.38	1.48	23	55	500	950	InF	Other fish	Other fish- deep
31	Flag rockfish	1.33	2.61	2.05	1.48	1.97	30	37.8	60	200	InF	Shelf rockfish	Shelf rockfish- shallow
32	Flathead sole	2.30	2.40	1.76	2.86	1.03	36.5	65	0	366	InF	Other flatfish	Other flatfish- deep
33	Freckled rockfish	1.78	3.17	1.95	1.48	1.55	27.2	34	44	180	EC	Shelf rockfish	

Table 2 (continued)

Stock identity	Stock Name	Productivity	Data		Data		Preferred latitude		Preferred depth		Proposed Stock		
			Quality	Susceptibility	Quality	Vulnerability	minimum	maximum	minimum	maximum	Designation	Current Complex	Proposed Complex
34	Gopher rockfish	1.56	2.22	2.00	1.64	1.76	32.5	39.5	12	37	InF	Nearshore rockfish	Nearshore rockfish
35	Grass rockfish	1.61	2.67	2.29	1.48	1.89	30	43	0	15	InF	Nearshore rockfish	Nearshore rockfish
36	Greenblotched rockfish	1.28	1.78	2.24	1.71	2.12	28	38	61	396	InF	Shelf rockfish	Shelf rockfish- deep
37	Greenspotted rockfish	1.39	2.44	2.14	1.90	1.98	28	36.7	90	179	InF	Shelf rockfish	Shelf rockfish- shallow
38	Greenstriped rockfish	1.28	1.56	1.76	2.00	1.88	31	54	100	250	InF	Shelf rockfish	Shelf rockfish- deep
39	Halfbanded Rockfish	2.00	1.89	1.95	2.00	1.38	27.7	38	60	150	EC	Shelf rockfish	
40	Harlequin Rockfish	1.31	2.83	1.95	3.00	1.94	49	60	100	350	InF	Shelf rockfish	Shelf rockfish- deep
41	Honeycomb Rockfish	1.36	2.50	2.10	2.76	1.97	27	34.5	45	60	InF	Shelf rockfish	Nearshore rockfish
42	Kelp greenling	1.83	2.11	2.04	1.52	1.56	34.5	55	0	20	InF	Other fish	Other fish- shallow
43	Kelp rockfish	1.83	2.11	2.12	1.48	1.62	32	38	18	24	InF	Nearshore rockfish	Nearshore rockfish
44	Leopard shark	1.26	1.89	2.00	2.57	2.00	32.5	42	0	4	InF	Other fish	Elasmobranchs-shallow
45	Lingcod	1.75	2.22	1.92	1.96	1.55	34.5	58	100	150	InF		
46	Longnose skate	1.53	1.95	1.80	2.64	1.68	46	53.5	100	150	InF		
47	Longspine Thornyhead	1.47	1.67	1.00	2.40	1.53	33	55	500	1300	InF		
48	Mexican Rockfish	1.50	3.17	2.00	2.95	1.80	22.5	36.3	100	256	InF	Shelf rockfish	Shelf rockfish- deep
49	Olive rockfish	1.69	2.22	2.33	1.48	1.87	34.3	39	0	75	InF	Nearshore rockfish	Nearshore rockfish
50	Pacific cod	2.11	2.11	2.00	1.57	1.34	40	65	50	300	InF		
51	Pacific ocean perch	1.44	2.50	1.67	2.43	1.69	42	55	100	450	InF		
52	Pacific grenadier	1.44	2.50	1.95	1.95	1.82	38	55	1500	2825	InF	Other fish	Other fish- deep
53	Pacific sanddab	2.40	3.80	2.10	2.76	1.25	22.8	55	50	150	InF	Other flatfish	Other flatfish- shallow
54	Pacific whiting	2.00	2.22	2.36	2.04	1.69	24.5	50	50	500	InF		
55	Petrable sole	1.70	1.50	2.44	1.80	1.94	38	49	50	300	InF		
56	Pink Rockfish	1.33	2.72	2.14	3.10	2.02	27.8	35	80	366	InF	Shelf rockfish	Shelf rockfish- deep
57	Pinkrose Rockfish	1.31	2.72	1.67	2.48	1.82	28.9	34.4	150	320	InF	Shelf rockfish	Shelf rockfish- deep
58	Puget Sound Rockfish	1.89	2.39	2.14	2.29	1.59	42	58.1	11	366	EC		
59	Pygmy Rockfish	1.78	2.67	1.95	2.48	1.55	32.5	60	60	150	EC	Shelf rockfish	
60	Quillback rockfish	1.31	2.06	2.43	1.48	2.22	34.5	60	44	66	InF	Nearshore rockfish	Nearshore rockfish
61	Ratfish	1.63	2.89	2.05	2.71	1.72	28.5	58	100	150	InF	Other fish	Elasmobranchs-shallow
62	Redbanded Rockfish	1.28	2.39	2.05	2.48	2.02	34.5	60	150	450	InF	Slope rockfish	Slope rockfish
63	Redstripe Rockfish	1.31	2.50	2.33	2.57	2.16	42	60	150	275	InF	Shelf rockfish	Shelf rockfish- deep
64	Rex sole	2.05	2.70	1.86	3.67	1.28	28	62	50	450	InF	Other flatfish	Other flatfish- deep
65	Rock greenling	1.78	2.67	2.29	1.48	1.77	34	64.6	0	80	InF		
66	Rock sole	1.95	3.00	1.95	3.86	1.42	32	55	0	300	InF	Other flatfish	Other flatfish- deep

Table 2 (continued)

Stock identity	Stock Name	Productivity	Data		Data		Preferred latitude		Preferred depth		Proposed Stock		
			Quality	Susceptibility	Quality	Vulnerability	minimum	maximum	minimum	maximum	Designation	Current Complex	Proposed Complex
67	Rosethorn Rockfish	1.19	1.94	2.05	2.86	2.09	34.5	60	100	300	InF	Shelf rockfish	Shelf rockfish- deep
68	Rosy Rockfish	1.61	3.11	2.29	3.52	1.89	31	40	40	150	InF	Shelf rockfish	Shelf rockfish- shallow
69	Rougheye rockfish	1.17	1.78	2.33	3.19	2.27	42	60	150	450	InF	Slope rockfish	Slope rockfish
70	Sablefish	1.61	1.78	1.88	1.88	1.64	28	55	200	1200	InF		
71	Sand sole	2.35	2.80	2.05	3.95	1.23	33.5	55	0	73	InF	Other flatfish	Other flatfish- shallow
72	Sharpchin rockfish	1.36	1.94	2.24	3.71	2.05	36.5	60	100	350	InF	Slope rockfish	Shelf rockfish- deep
73	Shortbelly rockfish	1.94	1.89	1.40	1.12	1.13	34.5	48.5	150	200	EC		Ecocsystem component
74	Shortraker rockfish	1.22	2.17	2.38	2.90	2.25	48.5	58.5	100	600	InF	Slope rockfish	Slope rockfish
75	Shortspine thornyhead	1.33	2.22	1.68	2.00	1.80	32	50	100	850	InF		
76	Silvergrey rockfish	1.22	1.78	1.95	2.19	2.02	42	60	100	300	InF	Shelf rockfish	Shelf rockfish- deep
77	Soupin shark	1.11	1.42	1.71	3.33	2.02	32.5	38	2	471	InF	Other fish	Elasmobranchs-deep
78	Speckled rockfish	1.33	2.22	2.29	2.52	2.10	32	38	76	152	InF	Shelf rockfish	Shelf rockfish- shallow
79	Spiny Dogfish	1.11	1.00	1.98	3.24	2.13	30	55	0	350	InF		Elasmobranchs-deep
80	Splitnose rockfish	1.28	1.78	1.60	2.00	1.82	32.5	54.3	150	450	InF	Slope rockfish	Slope rockfish
81	Squarespot rockfish	1.61	2.94	2.24	2.29	1.86	30	38	36	150	InF	Shelf rockfish	Shelf rockfish- shallow
82	Starry flounder	2.15	2.60	1.56	1.84	1.02	33.7	70	0	150	InF		
83	Starry rockfish	1.25	2.11	2.14	2.38	2.09	23	36.5	60	150	InF	Shelf rockfish	Shelf rockfish- shallow
84	Stripetail rockfish	1.39	2.56	1.81	2.48	1.80	33	49	10	350	InF	Shelf rockfish	Shelf rockfish- deep
85	Swordspine rockfish	1.33	2.33	2.00	2.19	1.94	31	32.5	60	200	InF	Shelf rockfish	Shelf rockfish- shallow
86	Tiger rockfish	1.25	2.50	2.10	2.19	2.06	41	55	55	274	InF	Shelf rockfish	Shelf rockfish- deep
87	Treefish rockfish	1.67	2.33	2.10	2.05	1.73	28	34.5	3	60	InF	Nearshore rockfish	Nearshore rockfish
88	Vermilion rockfish	1.22	1.67	2.02	2.24	2.05	28	43	50	150	InF	Shelf rockfish	Shelf rockfish- shallow
89	Widow rockfish	1.31	1.44	2.16	2.08	2.05	38	54	100	350	InF		
90	Yelloweye rockfish	1.22	1.44	1.92	2.00	2.00	38	54	91	180	InF		
91	Yellowmouth rockfish	1.61	1.89	2.38	2.33	1.96	42	58.5	275	366	InF	Slope rockfish	Slope rockfish
92	Yellowtail rockfish	1.33	1.78	1.88	2.00	1.88	42	48	90	180	InF		
10_H	Cowcod, S. levis	1.06	1.44	2.68	2.36	2.57	32.5	34.5	150	244			
18_H	Yelloweye rockfish	1.22	1.44	2.80	2.00	2.53	38	54	91	180			
23_H	Canary rockfish	1.28	1.78	2.84	1.56	2.52	34.5	54	50	250			
25_H	Bocaccio	1.28	2.11	2.72	1.56	2.43	32.5	42	100	250			
51_H	Darkblotched rockfish	1.39	1.67	2.76	1.24	2.39	34.5	54.3	140	210			
92_H	Pacific ocean perch	1.39	2.06	2.32	2.04	2.08	32.8	55	100	450			

Table 3. Four proposed rockfish complexes with vulnerability groupings informed by ecological distribution, PSA score, and fisheries. Cells in gray are ‘northern’ species. Vulnerability levels are low ($V < 1.8$), medium ($1.8 \leq V < 2.0$), and high (≥ 2.0).

Species	Vulnerability	
	Score	Level
NEARSHORE		
China rockfish	2.23	High
Quillback rockfish	2.22	High
Copper rockfish	2.27	High
Blue rockfish	2.01	Medium/High
Brown rockfish	1.99	Medium/High
Grass rockfish	1.89	Medium
Honeycomb Rockfish	1.97	Medium
Olive rockfish	1.87	Medium
Black-and-yellow rockfish	1.70	Low
Gopher rockfish	1.76	Low
Kelp rockfish	1.59	Low
Treefish rockfish	1.73	Low
SHELF- SHALLOW		
Speckled rockfish	2.10	High
Starry rockfish	2.09	High
Vermilion rockfish	2.05	High
Yellowtail rockfish	1.88	Medium
Flag rockfish	1.97	Medium
Greenspotted rockfish	1.98	Medium
Rosy Rockfish	1.89	Medium
Squarespot rockfish	1.86	Medium
Swordspine rockfish	1.94	Medium
SHELF- DEEP		
Redstripe Rockfish	2.16	High
Rosethorn Rockfish	2.09	High
Sharpchin rockfish	2.05	High
Silvergrey rockfish	2.02	High
Tiger rockfish	2.06	High
Bank rockfish	2.02	High
Bronzespotted rockfish	2.12	High
Chameleon rockfish	2.03	High
Pink Rockfish	2.02	High
Greenstriped rockfish	1.88	Medium
Harlequin Rockfish	1.94	Medium
Stripetail rockfish	1.80	Medium
Greenblotched rockfish	1.92	Medium
Mexican Rockfish	1.80	Medium
Pinkrose Rockfish	1.82	Medium
SLOPE		
Redbanded Rockfish	2.02	High
Rougheyeye rockfish	2.27	High
Yellowmouth rockfish	1.96	High
Aurora rockfish	2.10	High
Blackgill rockfish	2.08	High
Shortraker rockfish	2.25	High
Splitnose rockfish	1.82	Medium

Table 4. Proposed species complexes with vulnerability groupings informed by ecological distribution, PSA score, and fisheries. Vulnerability levels are low ($V < 1.8$), medium ($1.8 \leq V < 2.0$), and high (≥ 2.0).

Species	Vulnerability	
	Score	Level
SHALLOW		
Butter Sole	1.18	Low
Curlfin Sole	1.23	Low
Pacific sanddab	1.25	Low
Sand sole	1.23	Low
DEEP		
Flathead sole	1.03	Low
Rex sole	1.28	Low
Rock sole	1.42	Low

Species	Vulnerability	
	Score	Level
OTHER FISH- SHALLOW		
Cabazon	1.68	Low
Kelp greenling	1.62	Low
OTHER FISH- DEEP		
Finescale codling	1.48	Low
Pacific grenadier	1.82	Medium
ELASMOBRANCHS- SHALLOW		
Big Skate	1.99	Medium/High
Leopard shark	2.00	Medium/High
Ratfish	1.72	Low
ELASMOBRANCHS- DEEP		
California Skate	2.12	High
Soupfin shark	2.02	High
Spiny Dogfish	2.13	High

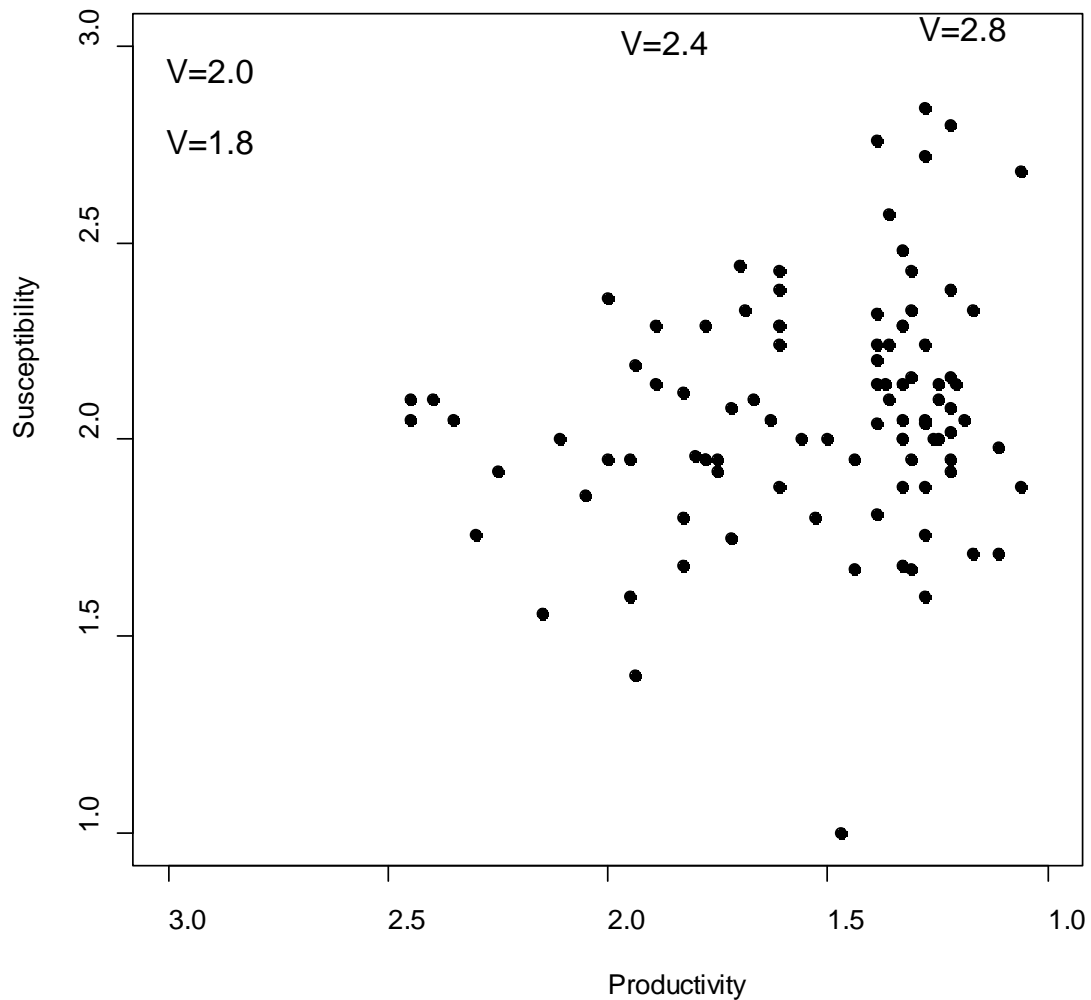


Figure 1. Productivity-Susceptibility Analysis (PSA) plot for species in the west coast groundfish FMP. Contours delineate areas of relative vulnerability (V , i.e. distance from the origin), with the highest vulnerability stocks above the solid red line ($V = 2.4$), high vulnerability above the orange broken line ($V=2$), medium vulnerability above the green dotted line ($V=1.8$) and the lowest vulnerability below the green dotted line. The maximum vulnerability ($V=2.8$) is indicated with the solid black line. Solid circles are based on current PSA scores. Open circles are based on PSA scores circa 1998. Numbers refer to the species identifier in Table 2.

