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[Article]

A Descriptive Example of Applying Vulnerability Evaluation Criteria to California Nearshore Finfish Species

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Abstract.—In light of ongoing crises in fisheries and marine ecosystem management, a growing body of literature has highlighted the need for biologists and resource managers to develop and apply methodologies that are capable of identifying species or populations at a relatively greater risk of overexploitation within a given assemblage or ecosystem. One increasingly popular approach is a productivity and susceptibility analysis (PSA), originally developed for Australian prawn fisheries, in which the vulnerability of a given stock is based on a combination of the estimated or perceived productivity of the stock plotted against the susceptibility to overfishing. This manuscript provides an example of this type of analysis developed for the 19 species included in California's Nearshore Fishery Management Plan (NFMP). The approach is based on the PSA approach developed by the NOAA Fisheries Vulnerability Evaluation Working Group (VEWG), which recently developed a methodology for conducting vulnerability assessments for species managed under Fishery Management Plans implemented by the regional Fishery Management Councils. Results of this case study in particular indicate that the more vulnerable species in the NFMP include China, copper, quillback and blue rockfishes, of which only the latter has been evaluated in a formal stock assessment. Additional and more rigorous analysis of these or other species managed by either (or both) the state of California and the Pacific Fishery Management Council may aid managers and stakeholders in setting research and assessment priorities, considering management alternatives and strategies, developing or revising species assemblages for multispecies management systems, and evaluating how precautionary catch limits should be based.

In light of ongoing crises in fisheries and marine ecosystem management, a growing body of literature has highlighted the need for biologists and resource managers to develop and apply methodologies that are capable of identifying species or populations at a relatively greater risk of significant population decline. Such needs are particularly acute in multispecies fisheries, where the large number of stocks or species subject to fishing impacts often overwhelms the capacity of biologists and resource managers to intensively research and assess each individual stock. For example, in the development of California's Nearshore Fishery Management Plan (NFMP), a total of 266 species were initially evaluated to determine which would be included in the plan (the final analysis included 124 species, due to a lack of basic life history information for many of these species). A matrix of criteria was developed and each species was ranked, based on these criteria, to provide an indication of species in greatest need of management attention (CDFG 2002).

Since that time, a growing number of case studies and approaches for assessing the vulnerability of either target or bycatch species to overexploitation have been developed and published (e.g., Musick et al. 2000; King and McFarlane 2003; Hobday et al. 2006; Smith et al. 2007; and references therein). Following the 2006 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act, a recommendation was made to consider vulnerability analysis as an aid to implementing sustainable management measures (Rosenberg et al. 2007), particularly with respect to implementing conservation and management measures that achieve the optimal yield from

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each fishery while preventing overfishing (National Standard 1). The National Marine Fisheries Service (NMFS) established a working group (the Vulnerability Evaluation Working Group, VEWG) to develop a vulnerability assessment methodology appropriate for federally managed fisheries in the U.S., based on the substantial foundation of both qualitative and quantitative risk assessments. That working group developed guidelines for conducting productivity and susceptibility analysis (PSA) (Patrick et al. 2009[1]), and evaluated the guidelines by developing a suite of case studies for federally managed fisheries throughout the U.S. Herein is a brief review of the PSA framework and presentation of the results for one of these case studies developed by Patrick et al. 2009, for species managed under California's NFMP.

Methods

The VEWG adapted a PSA based on the framework initially developed to assess the vulnerability of bycatch species in the Australian northern prawn fishery (Stobutzki et al. 2001) and subsequently recommended by Rosenberg et al. (2007) for potential application to U.S. fisheries. In the highly lucrative Australian northern prawn trawl fishery, more than 400 species of teleost fishes are encountered as bycatch, and the PSA allowed biologists to identify those species least likely to be sustainable with respect to bycatch impacts, in order to make them the focus of research and management measures. In this approach, vulnerability to overfishing is a two-dimensional assignment based on productivity and susceptibility scores, which in turn are based on a suite of attributes for each stock considered. One of the more interesting case studies in this fishery was developed further by Milton (2001), who assessed the vulnerability of 13 different species of sea snakes, described as an uncommon but highly visible component of the trawl fishery bycatch suspected of having a high vulnerability to overfishing, in order to identify the species most at risk as priorities for research and management. The VEWG refined the list of attributes through a collaborative process, but maintained the basic structure of the analysis.

In a vulnerability assessment based on the PSA method, productivity attributes are based on measures that reflect the potential for stock growth and recovery from perturbations, such as the von Bertalanffy growth coefficient (k), natural mortality rate (M), and mean age at 50 percent maturity. Stocks with low productivity are often typified by slow growth, low natural mortality, and late age at maturity; such stocks are assumed to be intrinsically more vulnerable to long term impacts of overexploitation than those with greater potential rates of increase, more rapid growth, and earlier ages at maturity.

The susceptibility attributes are based on an assessment of the impacts of fishing on stock abundance and habitat, such as the relative fishing mortality rate (when known), the survival rates of bycatch,[2] and behavioral responses of the stock that may contribute to overall vulnerability (such as hyperstability of catch rates with schooling behavior for many coastal pelagic species[3]). Thus, for a stock to be highly vulnerable to exploitation, it should be characterized by low productivity and high susceptibility; stocks that are of low productivity but with little or no susceptibility to fisheries are not considered highly vulnerable to exploitation (under current conditions).

Stock specific scores of productivity and susceptibility are calculated as each attribute is ranked on a score of one to three for low to high productivity, and one to three for low to high susceptibility, respectively. Species-specific empirical estimates for these attributes are used to assign a score when available, with expert opinions or the values for comparable species used when data are not available. Table 1 shows the attributes adopted in the VEWG methodology, as well as the range for the scores of high, medium and low productivity evaluated for this exercise. Readers should note that the ranges for several attributes evaluated in this example (including maximum age, maximum size, natural mortality rate and growth rate) differ slightly from the guidelines recommended in the methodology developed by Patrick et al. (2009). Although the national guidelines recommend specific ranges for given attributes so that stocks can be scored consistently and compared among regions and ecosystems, the guidelines recognize that for localized comparisons within a region or assemblage, greater resolution is often beneficial in increasing the contrast among species within a more narrow range of life history characteristics. Addi-

[1]The technical report, a worksheet template, and a package for graphing the vulnerability frontiers are all available online at http://www.nmfs.noaa.gov/msa2007/vulnerability.htm.

[2]For this case study, bycatch survival rates are based on depth and species-specific discard mortality estimates for recreational fisheries as reported in the Pacific Fisheries Management Council (PFMC) "Groundfish management team (GMT) report on the development of a discard mortality matrix for ocean and estuary recreational fisheries," currently unpublished.

[3]Hyperstability of catch rates refers to cases in which the catch per unit of effort, CPUE, of a target species remains high even as abundance drops. This is frequently a problem in coastal pelagic fisheries (such as the California sardine or the Peruvian anchoveta) in which fish remain concentrated even as abundance declines, and effort can readily concentrate in the areas in which fish are more abundant (Hilborn and Walters 1992).

tionally, many of the attributes could have been more rigorously analyzed than time allowed for this study. For example, the effects of age-or size-dependent fecundity could have been addressed as an aspect of the fecundity attribute, as Sogard et al. (2008) found that winter-spawning nearshore rockfish species such as black, blue, olive and yellowtail were more likely to demonstrate maternal effects on larval survival than spring spawning species such as gopher and kelp rockfish.

TABLE 1.—Description and range of productivity and vulnerability attributes as used in this case study, based on those developed by the VEWG, and slightly adapted for this case study.

Productivity Attributes	**High (3)**	**Moderate (2)**	**Low (1)**
r (intrinsic rate of population increase)	>0.5	0.5-0.16 (mid-point 0.10)	<0.16
Maximum age	< 20 years	20–40 years	> 40 years
Maximum size	< 40 cm	40–80 cm	> 80 cm
von Bertalanffy Growth Coefficient (k)	> 0.20	0.10–0.20	< 0.10
Estimated natural mortality	> 0.20	0.10–0.20	< 0.10
Measured fecundity	> 10e4	10e2–10e3	< 10e2
Breeding strategy	0	between 1 and 3	≥4
Recruitment pattern	highly frequent recruitment success	moderately frequent recruitment success	infrequent recruitment success
Age at maturity	< 2 years	2–4 years (mid-point 3.0)	> 4 years
Mean trophic level	<2.5	2.5–3.5 (mid-point 3)	>3.5
Susceptibility Attributes	**Low (1)**	**Moderate (2)**	**High (3)**
Management strategy	Targeted stocks have catch limits and proactive accountability measures	Targeted stocks have catch limits and reactive accountability measures	Targeted stocks do not have catch limits or accountability measures
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
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
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
Fishing rate relative to natural mortality	<0.5	0.5–1.0	>1
Spawning stock biomass (SSB) level or other proxies	B is > 40% of B0 (or historical maximum)	B is between 25% and 40% of B0 (or historical maximum)	B is < 25% of B0 (or historical maximum)
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
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 increase catchability of gear [i.e., hyperstability of CPUE]
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.
Survival After Capture and Release	Probability of survival > 67%	33% < probability of survival < 67%	Probability of survival < 33%
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
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

The overall scores for productivity and susceptibility are based on the average of each attribute scores. The default assumption is to weigh every attribute equally, but up or downweighting attributes deemed more or less relevant is optional. For example, attributes that are extraneous in a given fishery or ecosystem can be weighted as zero, while those that are particularly informative to productivity or susceptibility status can be given increased weight. Additionally, the quality of the data used to inform each attribute is scored, offering a measure of the uncertainty about the attribute score.

A wide range of challenges confront any attempt to develop meaningful vulnerability assessments. Many of these attributes are inherently unknown for most data-poor species, particularly such metrics as the fishing rate relative to natural mortality, or the level of spawning stock biomass (SSB) relative to an unfished population. Approaches for addressing such problems vary. Possible approaches might be excluding such unknowns in a given analysis, the use of Delphi approaches for arriving at consensus-based qualitative estimates (Okoli and Pawlowski 2004), the assignment of "average" values for unknown species, or the use of other data-poor methodologies to develop proxies for such metrics. For example, in the absence of quantitative models or long-term survey estimates, abundance levels relative to unfished conditions might be inferred by length based methods, such as those developed by O'Farrell and Botsford (2006). Alternatively, relative fishing mortality rates might be inferred by using the length-based methods of Gedamke and Hoenig (2006) or the depletion-corrected average catch approach developed by MacCall (2009). In fact, developing a PSA in close coordination with the application of other data-poor approaches for a given assemblage is likely to be a beneficial undertaking, as the PSA is intended to integrate disparate information, and an integration of several data-poor approaches could potentially be more robust than any given approach individually. Any lingering uncertainty in these approaches can then be captured by scoring the data information quality.

Another concern is that there may be covariation among the different attributes, as life history invariants such as maximum age, mean age at maturity, and natural mortality are often correlated (Hoenig 1983; Beverton 1992; Froese and Binholan 2000). However, as anyone who has attempted to defend an estimate of natural mortality based on the maximum observed age can attest, such relationships often have low predictive power, and Stobutzki et al. (2001) found that redundancy among key attributes was typically minimal. Similarly, many attributes can be difficult to interpret meaningfully. For example, "fecundity" has been shown by Sadovy (2001) to relate poorly to the intrinsic vulnerability, with a general exception occurring when fecundity is very low (e.g., ~100 or fewer eggs or offspring), as is typical of many elasmobranchs. Thus, parental investment (Winemiller 1989) has been more frequently used as an index of productivity that scales to vulnerability. Despite this, most attributes are readily recognized as strong covariates to relative productivity or the recovery capacity of marine populations. In specific cases where these are not informative, the attributes can be removed from the analysis through downweighting.

The example developed here is of the California nearshore finfish assemblage (CDFG 2002), a complex of nineteen nearshore species with a unique history of landings comprising a mix of heavy recreational and lucrative commercial fisheries. Most of the species in this fishery are rockfishes (family Scorpaenidae, most within the genus *Sebastes*), but there are also two greenlings (family Hexagrammidae), one prickleback (family Stichaeidae), one sculpin (family Cottidae) and one wrasse (family Labridae) (Table 2). These species are typically associated with nearshore rocky reef or kelp forest communities, and have a range of life histories. Most are relatively long lived, slow growing, and either live-bearing (*Sebastes*) or egg-guarding (cabezon, greenlings); there is also one protogynous hermaphrodite (California sheephead). For additional perspective, attributes were scored from an additional thirteen species of groundfish from the PFMC FMP, which occupy deeper continental shelf or slope habitats, yet are often or occasionally encountered in either the recreational fishery or commercial fisheries and for which status determination and life history information is available from recent stock assessments. Table 2 also lists these 13 species, including their most recent status determination from assessments (above target levels, in the precautionary zone or rebuilding). Similar to the nearshore species, most of these are rockfish (*Sebastes* and *Sebastolobus*), with one hexagrammid (lingcod), one pleuronectid (starry flounder) and one anoplopomatid (sablefish).

Although the total volume of commercial landings in the nearshore groundfish fishery tends to be small (only 224 tons landed commercially in California waters in 2006), many of the premium/live-fish fishery targets are valuable with exvessel values of up to $10 per pound (and net revenues of $2.2 million in 2006). Through the 1990s, as commercial landings in the major offshore fisheries sectors decreased, the live-fish fishery harvest began to represent a greater proportion of landings and revenue in California. For example between 1989 and 1992 the nearshore, live-fish trap fishery developed in response to demand from high-end restaurants, increasing from 2 to 27 boats that landed more than 52,000 lbs of live fish

(Palmer-Zwahlen et al. 1993). Most of these species are also important recreational targets, and recreational catches are often greater than commercial catches for many species. Recreational effort is primarily from commercial passenger fishing vessels (CPFV), an important activity in many coastal communities for which the economic contribution can be comparable to the landed value of the commercial catch. Private boats, beach, pier, and jetty fishing, and spearfishing also contribute to the recreational effort targeting many of these species.

The complex is managed by the state of California under the NFMP implemented in 2002, with a nearly complete overlap with federally managed species under the jurisdiction of the PFMC groundfish FMP implemented in 1982 (PFMC 2008; see Table 2). The PFMC FMP has been the primary management vehicle for West Coast groundfish fisheries, comprised mostly of trawl fisheries targeting deeper water rockfishes, roundfishes and flatfishes. Management usually includes a mix of area and seasonal closures, gear restrictions, and, for the commercial sector,

TABLE 2.—Common and species names for stocks in this case study, Reference number refers to the number used in Figure 1. Species 1–19 are in both California's Nearshore FMP as well as the PFMC Groundfish FMP (unless denoted by *, to represent state-managed only species) and species 20–32 are shelf and slope species from the PFMC Groundfish FMP. Landings and revenue reflect commercial fisheries only; stock status refers to above target levels (tar), precautionary levels (pre), rebuilding (reb) and unassessed (ua) stock status as of 2008.

Ref no.	Common name	Species name	Family	Habitat	2006 landings (tons)	Revenue (1000s dollars)	Stock status
1	California sheephead*	*Semicossyphus pulcher*	Labridae	nearshore	38.8	367	prec
2	Cabezon	*Scorpaenichthys marmoratus*	Cottidae	nearshore	28.3	343	prec
3	Kelp greenling	*Hexagrammos decagrammus*	Hexagrammidae	nearshore	1.6	24	ua
4	Rock greenling*	*H. lagocephalus*	Hexagrammidae	nearshore	n/a	n/a	ua
5	California scorpionfish	*Scorpaena guttata*	Scorpaenidae	nearshore	2.7	17	tar
6	Monkyface prickleback*	*Cebidichthys violaceus*	Stichaeidae	nearshore	0.0	0.2	ua
7	Black rockfish	*Sebastes melanops*	Scorpaenidae	nearshore	62.8	253	tar
8	Black-and-yellow rock	*S. chrysomelas*	Scorpaenidae	nearshore	8.3	130	ua
9	Blue rockfish	*S. mystinus*	Scorpaenidae	nearshore	18.0	59	prec
10	Brown rockfish	*S. auriculatus*	Scorpaenidae	nearshore	20.6	272	ua
11	Calico rockfish	*S. dallii*	Scorpaenidae	nearshore	n/a	n/a	ua
12	China rockfish	*S. nebulosus*	Scorpaenidae	nearshore	3.0	46	ua
13	Copper rockfish	*S. caurinus*	Scorpaenidae	nearshore	3.8	32	ua
14	Gopher rockfish	*S. carnatus*	Scorpaenidae	nearshore	15.6	241	tar
15	Grass rockfish	*S. rastrelliger*	Scorpaenidae	nearshore	17.7	379	ua
16	Kelp rockfish	*S. atrovirens*	Scorpaenidae	nearshore	0.7	9	ua
17	Olive rockfish	*S. serranoides*	Scorpaenidae	nearshore	1.2	5	ua
18	Quillback rockfish	*S. maliger*	Scorpaenidae	nearshore	4.2	45	ua
19	Treefish rockfish	*S. serriceps*	Scorpaenidae	nearshore	0.8	13	ua
20	Bocaccio rockfish	*S. paucispinis*	Scorpaenidae	shelf	4.8	15	reb
21	Blackgill rockfish	*S. melanostomus*	Scorpaenidae	slope	67.2	165	tar
22	Canary rockfish	*S. pinniger*	Scorpaenidae	shelf	2.5	3.2	reb
23	Cowcod	*S. levis*	Scorpaenidae	shelf	2.0	n/a	reb
24	Chilipepper rockfish	*S. goodei*	Scorpaenidae	shelf	42.5	57	tar
25	Sablefish	*Anoplopoma fimbria*	Anoplopomatidae	slope	1614	4890	tar
26	Shortspine thornyhead	*Sebastolobus alascanus*	Scorpaenidae	slope	321	1525	prec
27	Starry flounder	*Platichthys stellatus*	Pleuronectidae	shelf	29.8	53	tar
28	Widow rockfish	*Sebastes entomelas*	Scorpaenidae	shelf	8.2	15	reb
29	Yelloweye rockfish	*S. ruberrimus*	Scorpaenidae	shelf	n/a	n/a	reb
30	Yellowtail rockfish	*S. flavidus*	Scorpaenidae	shelf	5.2	18	tar
31	Lingcod	*Ophiodon elongatus*	Hexagrammidae	shelf	64.2	197	tar
32	Longspine thornyhead	*Sebastolobus altivelis*	Scorpaenidae	slope	556	739	tar

cumulative trip limits (generally for two-month periods). Although the NFMP provides for the management of the nearshore species complex, joint management authority for these species continues to reside with both the PFMC and the state of California, with the state typically providing recommendations to the council. More recently, the state has and will continue to implement marine protected areas (MPAs) in state waters (three miles and closer) as a marine conservation and management tool. This implementation will result in the protection of some nearshore fisheries habitat, which is expected to reduce the vulnerability of nearshore stocks to overfishing, although these actions could potentially increase exploitation rates of species in habitats still open to fishing.

Most of the nearshore species are considered to be relatively data-limited; with modest research conducted on their life history and little or no fishery-independent survey data available for monitoring trends in abundance. This is in part a consequence of the relatively modest volume of landings of nearshore species when contrasted to the more abundant commercial and recreational shelf and slope species, which tend to account for a much greater proportion of total landings. The lack of abundant data is also a reflection of their habitat; the fishery independent bottom-trawl surveys that have provided relative abundance and life history information for many shelf and slope species of groundfish have traditionally excluded habitats in less than 50 meters, consequently the only data available for most nearshore species have historically been fisheries-dependent. As a result, only five of the 16 species (gopher rockfish, black rockfish, blue rockfish, cabezon and California scorpionfish) managed by the PFMC have formally adopted stock assessments that included part or all of their California populations. An assessment also exists for California sheephead (a state-managed species), although the results have not been directly applied in management. Most of these assessments have been considered to have moderate to poor data availability, and most of the remaining nearshore species have even less available data for potential assessments; such that alternative means of monitoring stock status and evaluating the vulnerability to overexploitation are key management priorities. Consequently, this assemblage is a prime candidate for an assessment of vulnerability using the framework in development by the VEWG. Attributes were scored based on data from stock assessments (where available) and published literature (e.g., Lea et al. 1999; Love et al. 2002; Eschmeyer et al. 1983).

Results

The attributes considered and attribute scores for each of the 19 nearshore species are shown in Table 3, along with the average (overall) values for productivity and susceptibility scores. All attributes were viewed to be equally applicable and were weighted equally. Productivity scores ranged from 1.3 (quillback rockfish) to 2.1 (California scorpionfish and calico rockfish) with an average value of 1.7, while susceptibility scores had a slightly more narrow spread, ranging from 1.6 (California scorpionfish) to 2.3 (California sheephead), with an average value of 2. The range of values was consistent with the range for the assessed shelf and slope species (Table 4). Cowcod, yelloweye rockfish and shortspine thornyhead were the lowest productivity species in that group (1.4), while starry flounder had the highest estimated productivity (2.4). Chilipepper rockfish, yellowtail rockfish and lingcod all had relatively high values as well (2.0). The slope species scored the lowest with respect to susceptibility, due to both their deep distribution (a substantial fraction of the stock is deeper than most fisheries can, or are permitted, to operate) as well as to relatively higher survival rates shown by sablefish and the thornyheads (*Sebastolobu*s spp.) as bycatch due to their lack of a swim bladder. Not surprisingly, the five rebuilding rockfish species included here (bocaccio, canary, widow, cowcod and yelloweye), ranked among the higher susceptibility scores for the assessed shelf and slope species, as did lingcod, which had been overfished but was determined to be rebuilt in 2006. Although most of these species are targeted coastwide, primarily by trawl fisheries operating in deeper water, the susceptibility scores were based on their vulnerability to California fisheries (both commercial and recreational) in order to make scores as comparable as possible. Consequently, the susceptibility scores may not reflect the susceptibility of the coastwide stock to all fishing activity.

The resulting scores for all 32 species are plotted in Figure 1 (diamond shapes denote the nearshore species, while squares denote the shelf and slope species). For the 19 species of which assessment information is available, the most recent depletion level is color coded, with green denoting biomass levels above PFMC target levels of more than 40 percent of the unfished spawning biomass, yellow denoting “precautionary” spawning biomass levels between 25 percent and 40 percent of the unfished biomass, and red denoting stocks that are currently undergoing rebuilding plans under PFMC management. Several of these currently have spawning biomass levels greater than 25 percent of the unfished spawning biomass, but were at lower levels at the time that rebuilding plans were

TABLE 3.—Attributes and scoring for California's 19 nearshore FMP species in this case study.

Productivity Attributes	**CA sheephead**	**Cabezon**	**Kelp greenling**	**Rock greenling**	**CA scorpionfish**	**Monkyface prickleback**	**Black rockfish**	**Black-and-yellow rockfish**	**Blue rockfish**	**Brown rockfish**	**Calico rockfish**	**China rockfish**	**Copper rockfish**	**Gopher rockfish**	**Grass rockfish**	**Kelp rockfish**	**Olive rockfish**	**Quillback rockfish**	**Treefish**
r	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maximum Age	1.0	3.0	3.0	3.0	2.5	2.0	2.0	3.0	1.0	2.0	3.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	2.0
Maximum Size	1.0	1.0	2.0	2.0	2.5	2.0	2.0	2.5	2.0	2.0	3.0	3.0	2.0	2.5	2.0	2.5	2.0	2.0	2.5
von Bertalanffy growth (K)	1.0	2.5	2.0	2.0	2.0	2.0	2.5	3.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	3.0	1.5	1.0	2.0
Estimated Natural Mortality	2.5	2.5	3.0	3.0	1.5	2.0	2.5	2.0	1.5	1.5	3.0	1.0	2.0	2.5	2.0	2.0	2.0	1.0	2.0
Measured Fecundity	1.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Breeding Strategy	3.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Recruitment Pattern	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Age at Maturity	1.0	2.0	2.0	2.0	2.5	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	1.5	1.5	1.0	2.0
Mean Trophic Level	2.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Average Productivity Scores	1.7	1.9	2.0	2.0	2.1	1.9	1.7	2.0	1.5	1.6	2.1	1.5	1.5	1.9	1.7	1.8	1.6	1.3	1.8
Susceptibility Attributes																			
Management Strategy	2.0	1.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0
Areal Overlap	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Geographic Concentration	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Vertical Overlap	3.0	3.0	3.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Relative fishing mortality	2.0	2.0	1.0	1.0	1.0	2.0	2.0	1.0	2.0	2.0	1.0	2.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0
Biomass of Spawners (SSB)	3.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Seasonal Migrations	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Behavioral Responses	3.0	3.0	2.0	2.0	2.0	1.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	1.0	1.0	3.0	3.0	3.0
Morphology Affecting Capture	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	1.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0
Survival	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0	3.0	1.0	3.0	2.0	1.5
Desirability/Value	2.0	2.0	2.5	2.0	1.5	1.5	1.0	2.5	1.0	2.5	1.0	2.5	2.0	2.5	3.0	2.5	1.0	2.0	3.0
Fishery Impact to Habitat	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Average Susceptibility Scores	2.3	2.1	1.9	1.9	1.6	1.8	1.8	2.2	2.1	2.1	1.8	2.2	2.2	2.0	2.2	1.8	2.2	2.2	2.1

implemented. The remaining points are grey, representing the thirteen species in the nearshore complex for which statistical stock assessments have not been performed (or accepted for management purposes) in California waters.

Discussion

There is no obvious clustering within this complex, although there is a general relationship between productivity and susceptibility among the nearshore complex such that the less productive species tend to be more susceptible. The less productive nearshore species include China, copper, quillback and blue rockfishes, with grass, olive, treefish, brown and black rockfish scoring only slightly higher on the productivity axis. All of these species cluster within the group of assessed species that are currently rebuilding, suggesting that these species may have conservation concerns, though it is unknown how vulnerability scores relate to stock status. Most of the least productive spe-

TABLE 4.—Attribute scores for thirteen species of shelf and slope groundfish managed by the PFMC, for which life history information is available from stock assessments.

Productivity Attributes	**Bocaccio**	**Blackgill rockfish**	**Canary rockfish**	**Cowcod**	**Chilipepper rockfish**	**Longspine thornyhead**	**Sablefish**	**Shortspine thornyhead**	**Starry flounder**	**Widow rockfish**	**Yelloweye rockfish**	**Yellowtail rockfish**	**Lingcod**
r	2	1	1	1	2	1	2	1	2	2	1	2	2
Maximum Age	1	1	1	1	2	1	1	1	3	1	1	1	2.5
Maximum Size	1	2	2	1	2	2.5	1	1	1	2	1	2	1
von Bertalanffy growth (K)	2	1	2	1	2.5	1	3	1	3	2	1	2	2
Estimated Natural Mortality	2	1	1	1	2	1	1	1	3	2	1	2.5	2
Measured Fecundity	3	3	3	3	3	3	3	3	3	3	3	3	3
Breeding Strategy	2	2	2	2	2	1	3	2	3	2	2	2	2
Recruitment Pattern	1	2	2	2	1	2	2	2	2	1	2	2	2
Age at Maturity	2	1	1	1	1.5	1	2	1	2	1	1	1	2
Mean Trophic Level	1	2	2	1	2	2	1	1	2	2	1	2	1
Average Productivity Scores	1.7	1.6	1.7	1.4	2.0	1.6	1.9	1.4	2.4	1.8	1.4	2.0	2.0
Susceptibility Attributes													
Management Strategy	1	1	1	1	1	1	1	1	1	1	1	1	1
Areal Overlap	2	1	2	2	2	1	1	1	2	2	2	2	2
Geographic Concentration	2	2	2	2	2	2	1	1	2	2	2	2	2
Vertical Overlap	2	1	2	2	2	1	1	1	3	2	2	2	2
Relative fishing mortality	1	2	1	1	1	1	2	2	1	2	2	1	2
Biomass of Spawners (SSB)	3	2	3	3	1	1	2	1	1	2	3	1	2
Seasonal Migrations	2	2	2	2	2	2	2	2	2	2	2	2	2
Behavioral Responses	2	2	2	2	2	2	2	2	2	2	2	2	2
Morphology Affecting Capture	2	2	2	2	2	2	2	2	2	2	2	2	2
Survival	3	3	3	3	2	1	1	1	1	3	2	1	1
Desirability/Value	2	2	3	3	2	2	2	3	2	1	3	2	3
Fishery Impact to Habitat	2	2	2	2	2	2	2	2	2	2	2	2	2
Average Susceptibility Scores	2.0	1.8	2.1	2.1	1.8	1.5	1.6	1.6	1.8	1.9	2.1	1.7	1.9

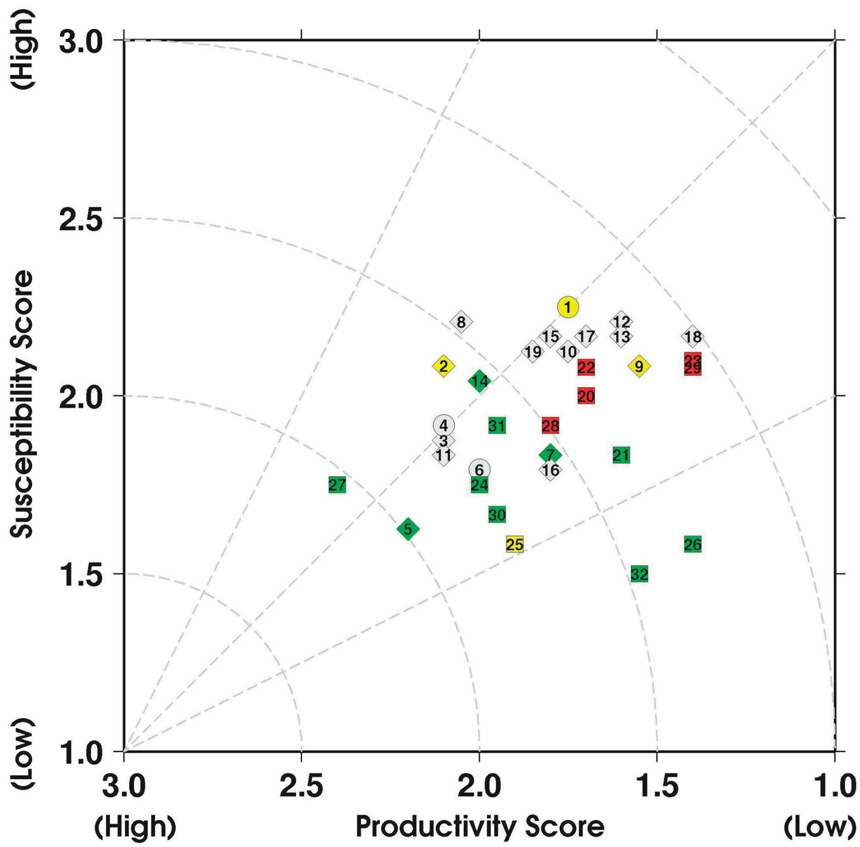

FIGURE 1.—Productivity and susceptibility scores for the 19 nearshore finfish species (diamonds, with circles for state managed only species) plus an additional 13 species of shelf and slope groundfishes (squares) commonly encountered in either recreational fisheries or the live-fish fishery. Grey points indicate species without assessment; red points indicate rebuilding stocks; yellow points indicate stocks that are in the precautionary zone (0.25SSB0 < SSB <0.4SSB0); green points indicate assessed stocks above the target reference point. Note that due to differences in the partitions for some attributes, scores may not be directly comparable to those in Patrick et al. (2009).

cies are *Sebastes*, and species with higher estimated productivity are almost exclusively non-*Sebastes* species. Of the five nearshore species that have had PFMC-approved stock assessments, all are considered to be currently above the overfished threshold, although blue rockfish, cabezon (south of Point Conception) and California scorpionfish populations were estimated to have been retrospectively below the overfished threshold in the relatively recent past (Cope and Punt 2006; Maunder et al. 2006; Key et al. 2008). Both blue rockfish and cabezon barely climbed above contemporary overfished thresholds in recent years, primarily in response to reduced fishing mortality rates and strong year classes in the late 1990s. Although virtually no stock status information is available for quillback or china rockfish in California waters, these and other nearshore species are considered to be at low levels of abundance in Canadian inshore waters (Fisheries and Oceans Canada 2001). Additionally, O'Farrell and Botsford (2006) reported that brown, copper and olive rockfish populations were likely to be below target levels in Southern California waters based on length frequency data and equilibrium egg production methods.

Most of the unassessed species in California's NFMP and another 40 or so species in the Pacific Coast Groundfish FMP lack the basic biological and statistical data needed to perform traditional assessments. Yet it is highly possible some may be in an overfished condition as a result of historical fishing pressure, and doubtlessly many are highly vulnerable to exploitation by virtue of the strong similarities between their productivity and susceptibility attributes and those of currently rebuilding species (Berkeley et al. 2004; Gunderson et al. 2007). This is consistent with the results of Levin et al. (2006), who found evidence for broad-scale changes in the community composition of California Current groundfish based on bottom trawl surveys from 1977–2001. For the species they included in their analysis, rockfish declined from more than 60 percent of the catch in 1977 to less than 17 percent of the catch in 2001, with flatfish catches increasing by a similar magnitude. Populations of larger sized rockfish (including primarily the rebuilding species) were estimated to have fallen at high rates (consistent with the results of stock assessments), while those of smaller species, particularly those associated with soft substrate, had generally increased in abundance. Additional concerns over the possible consequences of intraguild competition or top-down forcing in rocky reef communities have been raised based on empirical data (Love et al. 2009; Jagielo et al. 2003; Yoklavich et al. 2002; Yoklavich et al. 2000) and in simulation models (Walters and Kitchell 2001; MacCall 2002; Baskett et al. 2006).

This example represents only a fraction of the growing literature available that describe a range of methods and approaches for conducting assessments of vulnerability for either target or bycatch species. A more comprehensive review of this approach and alternatives is provided in Patrick et al. (2009), and vulnerability scores using a comparable approach are available for most finfish species on fishbase (www.fishbase.org) based on a fuzzy logic algorithm developed by Cheung et al. (2005).

Likewise, a more rigorous analysis of these or other unassessed species in the Pacific Coast Groundfish FMP—or a more focused evaluation of the additional nearshore species groups identified by the Nearshore FMP as having management concerns (subtropical residential species[4], nearshore sharks and surf perches)—could be useful continuations of this effort. Results may aid managers and decision makers in setting research and assessment priorities, considering management alternatives and strategies, developing or revising species assemblages for multispecies management systems, and evaluating how precautionary catch limits should be based on vulnerability estimates.

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[4]Subtropical resident species include giant sea bass (*Stereolepis gigas*), white sea bass (*Atractoscion nobilis*), kelp bass (*Paralabrax clathratus*) and barred sand bass (*P. nebulifer*), all of which are important commercial and recreational targets.

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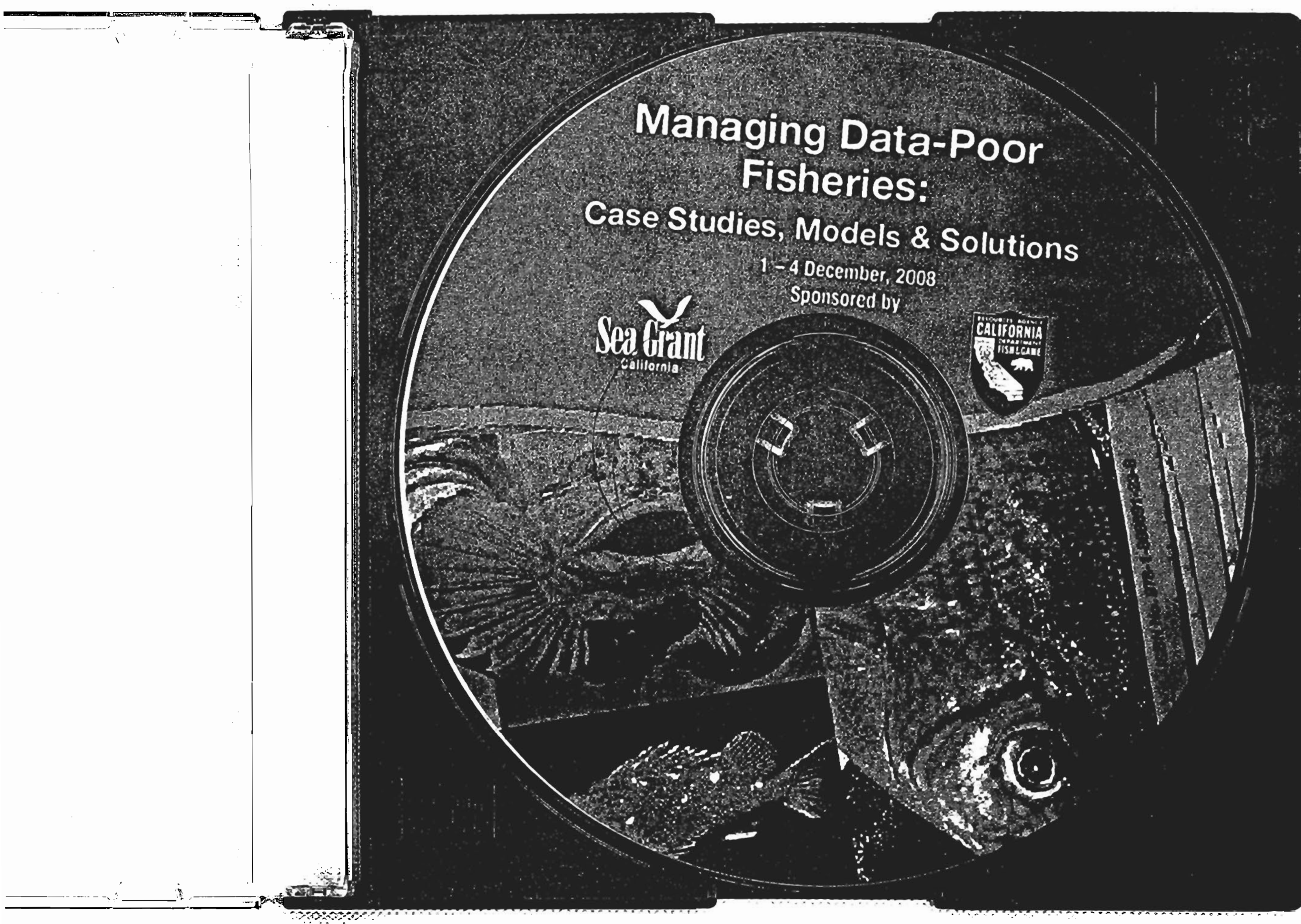
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