Rockfish Management:
Are We Circling the Wagons Around the Wrong Paradigm?

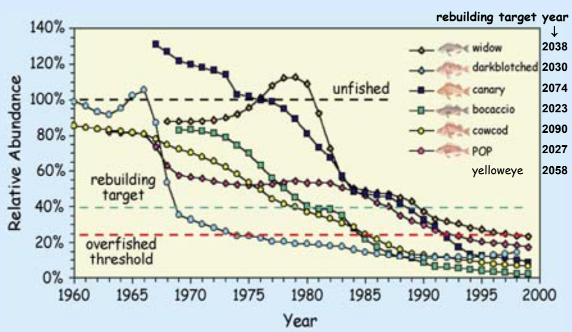
Steven Berkeley, Long Marine Lab, U. C. Santa Cruz
Mark Hixon, Department of Zoology, Oregon State University
Ralph Larson, San Francisco State University
Milton Love, U.C. Santa Barbara

Rockfish species whose status has been assessed:

Black	Pacific Ocean Perch
Bocaccio	Shortbelly
Canary	Shortspine Thornyhead
Chilipepper	Splitnose
Cowcod	Widow
Darkblotched	Yelloweye
Longspine Thornyhead	Yellowtail

Red = overfished (7 = 50%)
Blue = not overfished (7 = 50%)
Total rockfish species in FMP = 63 (22% assessed)

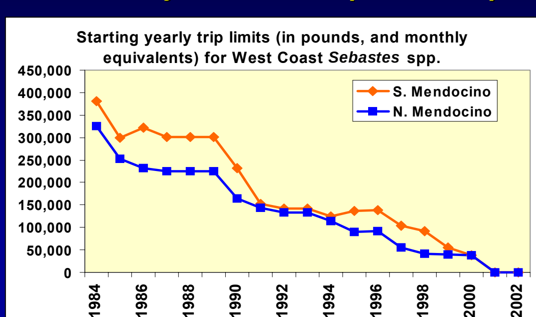
Decline of West Coast Rockfishes



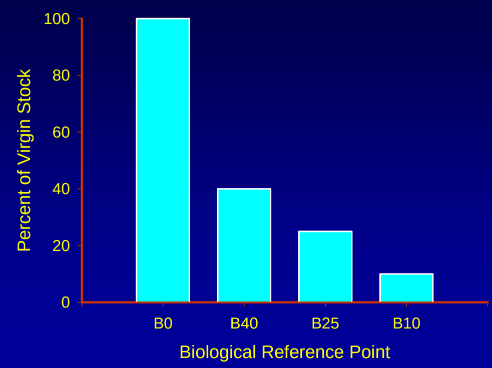
NOAA Fisheries

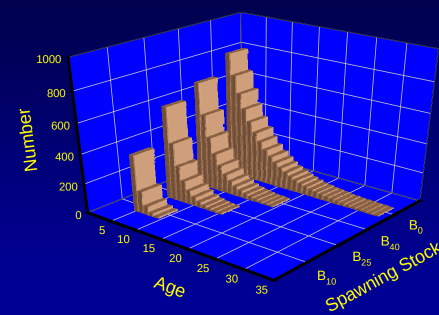
Species	Maximum Age	Age at 50% Maturity
Black	40	6
Bocaccio	50	?
Canary	84	8
Cowcod	55	?
Darkblotched	105	8
Pacific Ocean Perch	100	8
Widow	60	6
Yelloweye	118	19

"Folly, the perverse persistence in a policy demonstrably unworkable" (Smith 1998)



Current management is based on controlling fishing mortality to maintain the spawning biomass at 40% of the level that would exist without fishing.





For at least those stocks with highly episodic recruitment, the consequences of age-class truncation may be catastrophic, but this possibility is ignored by conventional fish stock management techniques.

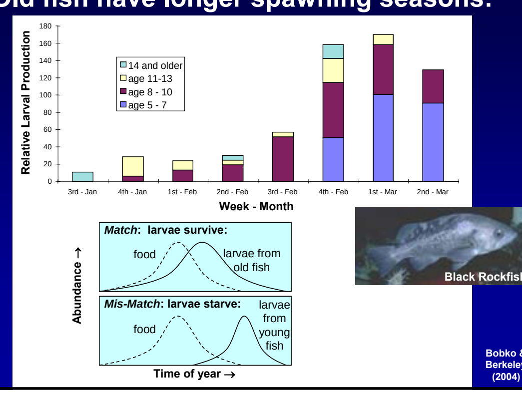
Longhurst, 2002.

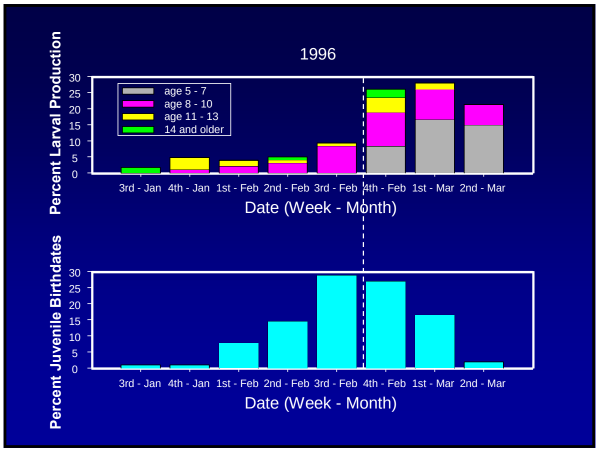
Fundamental Assumptions of Conventional Fisheries Management:

1. Larvae of all females have an equal probability of survival regardless of maternal age, or time or location of spawning.

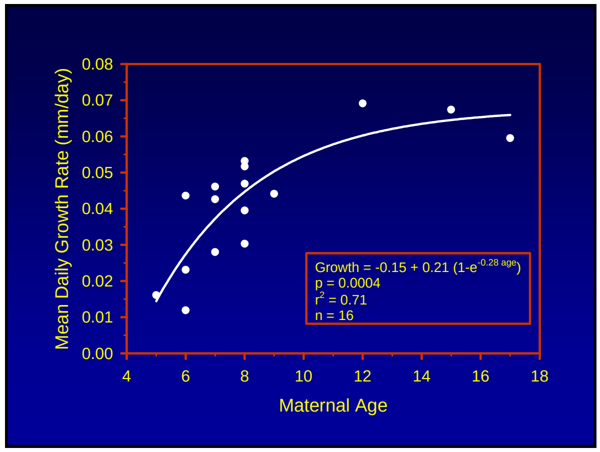
2. Stocks are well-mixed, so it makes no difference where fish are caught, only how many.

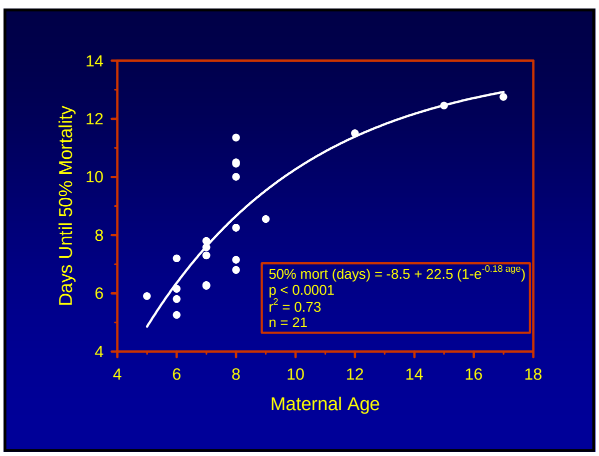
Old fish have longer spawning seasons:





What about larval quality?
Do older fish produce more competent larvae?





So, all spawning biomass is not equivalent. Maternal age affects the time of larval production and the length of the spawning season.

And all larvae are not equivalent. Larvae of older females are more competent and almost certainly more likely to survive.

Assumption of conventional fisheries biology:

Stocks are well-mixed.

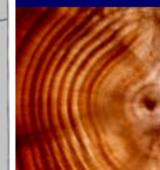
New data:

Stocks are actually comprised of multiple, reproductively distinct units.

Multiple stocks per rockfish species

4 population subdivisions off Oregon and southern Washington:

identified from chemical signatures in daily growth rings of otoliths



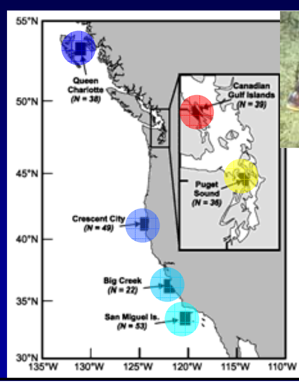
otolith (ear stone) rings

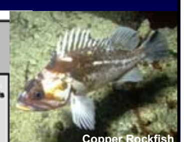
Miller & Shanks (2004)

Multiple stocks per rockfish species

3 population subdivisions between Puget Sound and Pacific Coast, with a genetic gradient along the open coast:

identified from microsatellite DNA at 6 loci



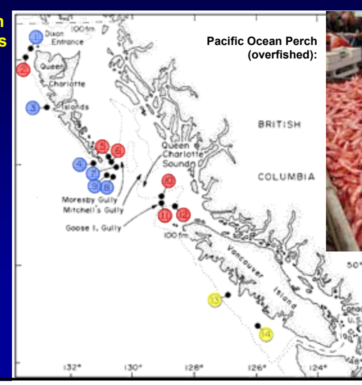


Buonaccorsi et al. (2002)

Multiple stocks per rockfish species

3 population subdivisions off British Columbia:

identified from microsatellite DNA at 5 loci

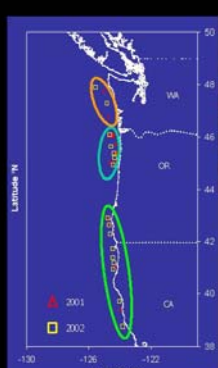


Withler et al. (2001)

Multiple stocks per rockfish species

3 population subdivisions along West Coast:

identified from microsatellite DNA at 7 loci



Gomez-Uchida & Banks (2004)

But, it may be more complicated than that. Recruitment may come from restricted temporal and spatial oceanographic windows which vary from one year to the next (i.e. the sweepstakes-chance matching hypothesis, Hedgecock, 1994).

Shortbelly rockfish
Genetic Diversity Within Samples (Nei's H statistic: Diagonal)
Genetic Differentiation Between Samples (Nei's G: Off-Diagonal)

	Adults	Larvae	March Juveniles	Total June Juvs	Farallon June Juvs
Adults	***0.6844***				
Larvae	0.0070	***0.7355***			
Mar. Juv.	0.0148	0.0161	***0.6211***		
Tot. June Juvs.	0.0549*	0.0447*	0.0247	***0.5887***	
Farallon Juvs	0.0677**	0.0572**	0.0316*	--	***0.5532***

Larson, R. J, C. Orrego and R.W. Julian, 1995. (* p<0.10; ** p < 0.05)

N_e estimates for cohort pairs

Cohorts	F_k	S	N_e	95% CI
1995-1996	0.0028	48-82	2,073	1,456-2,798
1996-1997	-0.0002	82-123	∞	-
1997-1998	0.0012	123-67	4,807	3,367-6,500
1998-1999	-0.0015	67-627	∞	-
1999-2000	0.0001	627-140	101,728	73,470-134,513
Mean	0.0005		12,345	8,692-16,416

N = 16.7 x 10^6 (spawning population)[1]; $N_e / N \approx 10^{-3}$

1. Mean estimate (1964-2003) from Rogers et al. (2000) Status of the darkblotched resource in 2000. PFMC (www.pcouncil.org)

Gomez-Uchida & Banks (2004)

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2. Stocks are well-mixed, so it makes no difference where fish are caught, only how many.

So, what do we know that suggests a new management approach may be needed?

For at least some species, we know:
1. Older fish spawn earlier than younger fish.
2. Larvae of older females are more likely to survive.
3. Stocks are much more complex than previously thought so local depletions might not be replenished from other areas.
4. Recruitment may come from distinct time/area windows that vary from year to year.

So, what do we do about these findings? Can conventional management approaches accommodate this new information and if not, what tools are most appropriate?

Looking only at how different fishing strategies affect age structure which in turn affects larval survival:

1. B_{40}
2. Slot limit w/25% release mortality
3. 20% marine reserve
4. Reduced fishing mortality rate

Mgmt Strategy	**Spawning Age Classes**	**% Virgin SSB**	**% Yield Relative to B_{40}**	**% of Virgin Age 12+ SSB**
B_0	29	100	0	100
B_{40} (F=0.177)	15	40	100	12.5
Slot (w/25% rel. mort)	19	40	94	18.3
20% MR (F outside = 0.316)	29	40	96	22.3
F adj to MR on table (F=0.124)	17	50	85	22.3
20% MR off table (F outside = 0.177)	29	52	80	30.0
F adj to MR off table (F=0.0982)	19	56	75	30.0

Management Strategy	Effective Larval Output (% of B_{40})
B_0	314
B_{40}	100
Slot (w/25% release mort.)	103
20% MR on table	107
F adj to 20% MR on table	132
20% MR off table	143
F adj to MR SSB off table	154

Mgmt Strategy	Recruitment (% of B_{40})	Yield (% of B_{40})
B_{40} (F=0.177)	100	100
Slot w/25% release mort.	103	97
20% MR on table	107	103
F adj to 20% MR on table (F=0.1635)	107	103
20% MR off table	143	115
F adj to 20% MR off table (F=0.110)	143	115

Conclusions:

	Fishing Mortality	Marine Reserves	Slot Limit
Time of spawning	Maybe	Yes	Probably not
Age structure	Maybe	Yes	Probably not
Stock spatial complexity	No	Yes (if networked)	No
Hedgecock effect	No	Yes (if networked)	No