

Natural mortality of blue rockfish, *Sebastes mystinus*, during their first year in nearshore benthic habitats

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Much of the variation in year-class strength among marine fishes has been attributed to high mortality during the egg and larval stages (Ricker, 1954; Cushing, 1973; Beverton, 1984). However, for groundfish species that migrate from a pelagic to a benthic juvenile stage, there has been increasing suggestion that natural mortality during the early benthic juvenile stage may control year-class strength (Beverton, 1984; Sissenwine, 1984). These arguments stem from the following: 1) demonstration of density-dependent natural mortality of juvenile groundfish (Lockwood, 1980; Meyers and Cadigan, 1993); 2) cases where larval abundance and later year-class strength are uncorrelated (Bakun and Parrish, 1980; Saville and Schnack, 1981; and Fogarty et al., 1987); and 3) the reasoning that total natural mortality during the juvenile stage may be greater than during the egg or larval stage, because the juvenile stage lasts much longer (Sissenwine, 1984). These arguments were reviewed specifically for rockfish (*Sebastes* spp.) by Love et al. (1991), but the results were inconclusive.

Materials and methods

Off northern California, young of blue rockfish, *Sebastes mystinus*, released in the winter spend three

to five months offshore as pelagic larvae and early juveniles and then settle to the benthos. During the course of monitoring annual recruitment of these benthic nearshore juveniles, data were collected from which mortality rates could be estimated for juvenile blue rockfish during their first year in the benthic stage. Annual population density estimates were the averaged counts made between July (when recruitment to nearshore habitats was complete) and mid-September of each year. The mortality estimates were based on counts from July through the following April. Exceptionally high or low counts were excluded when the distribution of juveniles was influenced by unusual oceanic conditions. Because the sampling began after settlement was complete, these estimates do not include mortality that occurs during or immediately following settlement.

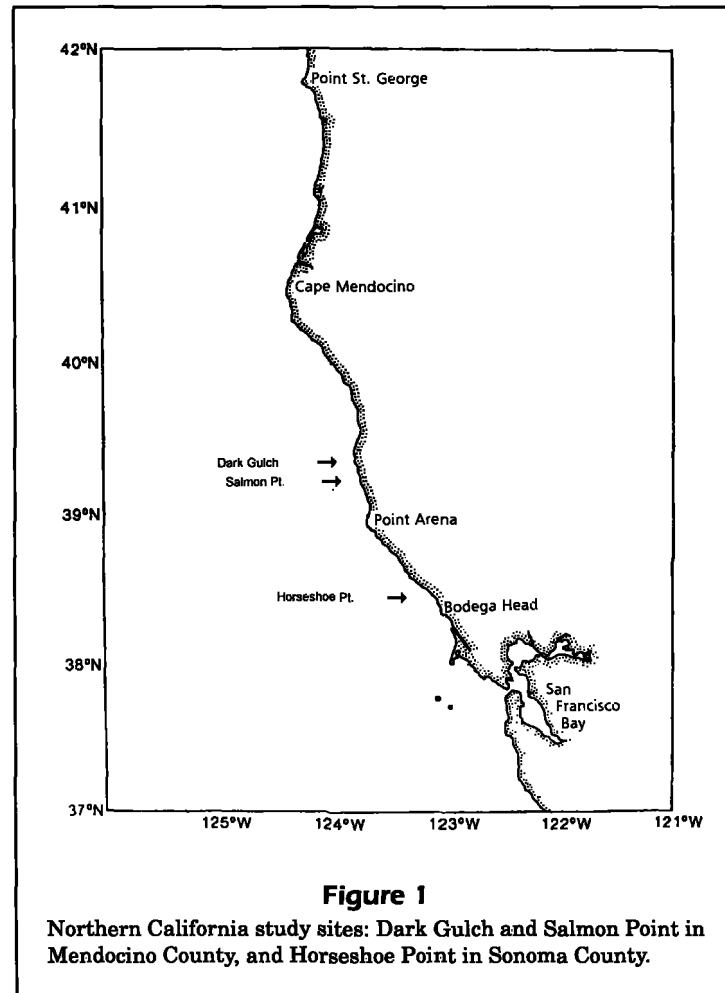
First-year juvenile blue rockfish were counted along strip transects at three northern California sites during different years. Dark Gulch was sampled from 1985 to 1989, Salmon Point in 1987 and 1988, and Horseshoe Point in 1988 (Fig. 1). Each site covers approximately 10,000 m² and consists of high-relief rocky reefs surrounded by lower reefs and boulders with occasional sand patches interspersed. Rock surfaces shallower than 15 m were

covered with benthic algae and bull kelp (*Nereocystis luetkeana*) from July through November, after which time the bull kelp was ripped up by winter storms.

One-minute strip-transect counts were made by two observers using SCUBA over bottom depths between 5 and 22 m (Fig. 2). Transects always began in the offshore portion of the study site and moved inshore. Direction changes were made perpendicular to the previous course, usually after one to three counts on the same heading. Observers swam 2 m off the bottom and counted first-year juvenile blue rockfish within 3 m in any direction during one-minute transects. Counts were made only when horizontal visibility was greater than 4 m. Twenty counts were made at each site (average total counts=19, range 10–35). All counts were made between 1000 and 1400 hours.

Results and Discussion

Natural mortality was estimated by using a catch-curve analysis based on the exponential decrease in fish abundance with age (Ricker, 1975; Vetter, 1988). Juvenile blue rockfish density during each one-minute count was transformed to $\ln(x+1)$ and plotted against age (days). The slope of the least-squares regression through the decreasing portion of the log-transformed density was the instantaneous rate of decrease, or natural mortality, provided there was no significant movement either into or out of the area. The mortality coefficients were calculated from the transformed one-minute counts rather than from daily averages in order to demonstrate the patchy nature of the data where a large portion of zero counts occurred ran-



domly throughout each day's sampling. Mortality coefficients from individual counts and daily averages are nearly identical (because the daily sample size is consistent). For the individual counts, the coefficients of determination (r^2) are very small (because counts range from zero to a maximum number each day). However, if the daily averages were used, the coefficients of determination would be high (because the daily variation has been removed), but the probabilities of the tests of regression lines would be much lower (because of fewer degrees of freedom).

Estimates of daily natural mortality for first-year juvenile blue rockfish range from 0.001 to 0.008 day⁻¹ (Table 1; Fig. 3) over the three sites and four years. The fit of data to the mortality model was good; five of the seven regressions were significant at the 99% level, and a sixth significant at the 92% level. The coefficients of determination were low owing to the large variability in the dependent variable (log-transformed density, ranging from zero to the maximum number) on each sampling date. The consistency of all the estimates, ranging over only a narrow span,

from different years and locations, despite the large variance within the daily sampling, was probably the strongest validation of the mortality estimates.

Our estimates of natural mortality of juvenile blue rockfish are much lower than published values of natural mortalities for other juvenile fishes (Table 2). The values in Table 2 include all juvenile fish mortality coefficients estimated from catch-curve analysis and represent both different types of fishes (i.e. flatfish and roundfish) and different types of habitats (marine, estuarine, and freshwater). The low juvenile natural mortality is consistent with the estimates of low adult natural mortality based on the extreme longevity of this species (Leaman, 1991).

Mortality estimates were higher during years with stronger juvenile recruitment (Fig. 4). There was a positive relationship between mortality estimates and the strength of the annual population density estimates, with an eight-fold difference in mortality rate estimates corresponding to a twenty-four-fold difference in density. The relationship of natural mortality with population density seems to increase

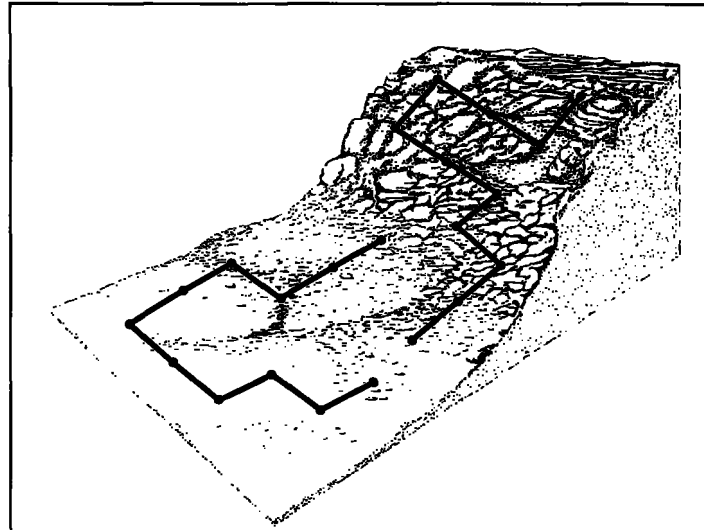


Figure 2

A sampling diagram depicting the 20 one-minute transects where juvenile blue rockfish, *Sebastes mystinus*, were counted. Counts began offshore and ended inshore.

to a certain point and then levels off to an asymptote. We feel that the asymptotic level-off is real, but because of the large variability in the daily counts (see Fig. 3), it may be a sampling artifact. Both Lockwood (1980) and Meyers and Cadigan (1993) found that density-dependent mortality occurred in juvenile marine fishes. Lockwood (1980) proposed a two-stage density-dependent mortality mechanism for juvenile plaice where normally piscivorous predators cause a baseline level of natural mortality and, in years when juvenile numbers are high, other

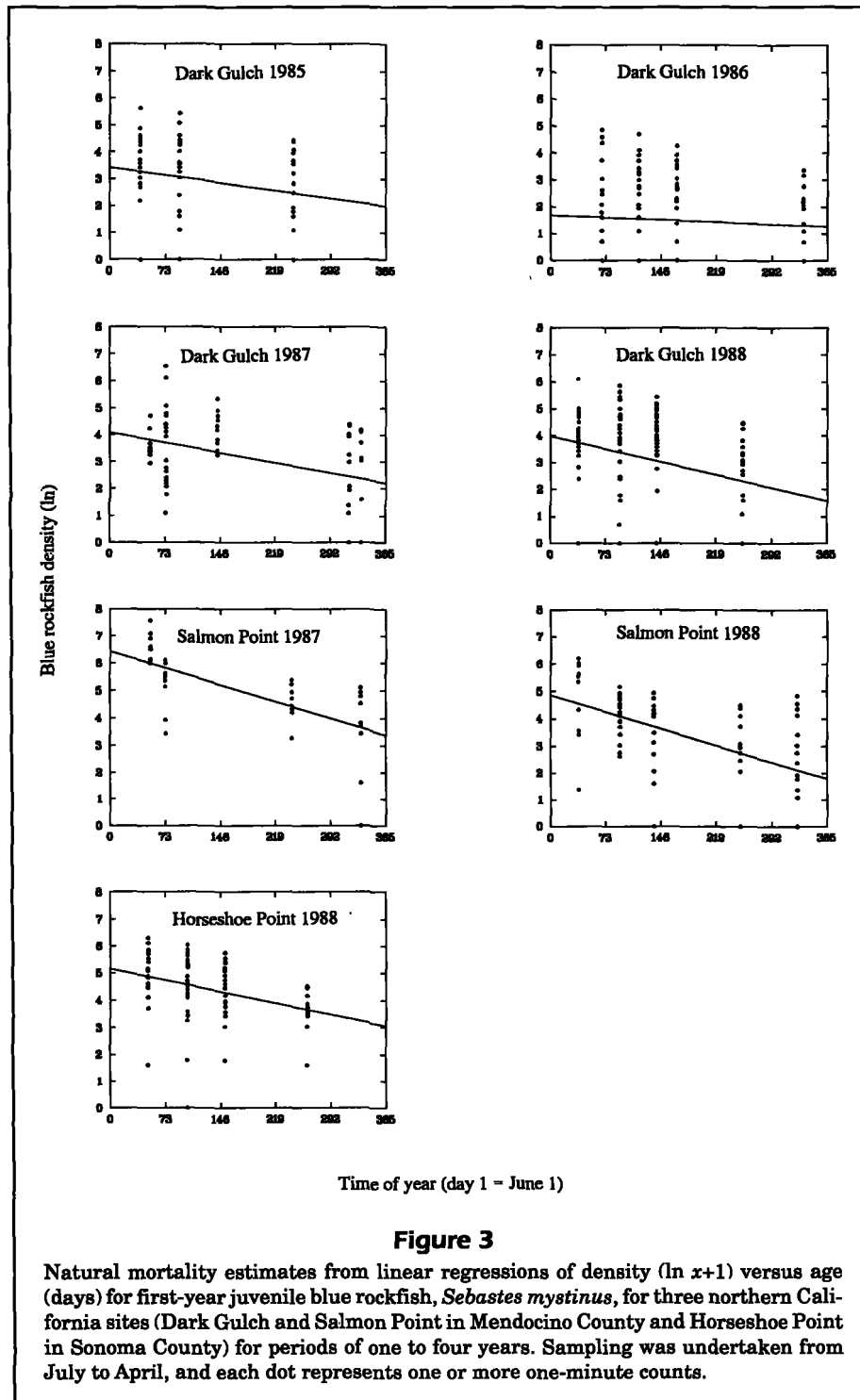
predators switch to preying on juveniles. We feel that a similar process may occur with juvenile blue rockfish and that the natural mortality asymptote is the point at which these secondary predators are saturated.

For blue rockfish, density-dependent mortality in the benthic juvenile stage would reduce the interannual variation between subsequent adult year classes. An example of how density-dependent mortality would reduce interannual variation can be made by using the 1986 (a weak year class, see Fig. 4) and 1987 (a strong year class) data from Dark

Table 1

Instantaneous daily natural mortalities (M) for juvenile blue rockfish, *Sebastes mystinus*, during the period of July to April from three northern California sites by year. The analysis of variance of the fit of the estimate (F), degrees of freedom (df), probability (P), and coefficient of determination (r^2) are also included.

Site	Year class	M	F	df	P	r^2
Mendocino County Dark Gulch	1985	0.004	3.08	1,69	0.084	0.029
	1986	0.001	2.77	1,121	0.429	0.003
	1987	0.005	11.97	1,63	0.001	0.149
	1988	0.007	10.08	1,116	0.002	0.022
Salmon Point	1987	0.008	29.78	1,36	0.001	0.438
	1988	0.008	40.77	1,85	0.001	0.316
Sonoma County Horseshoe Point	1988	0.006	8.95	1,102	0.003	0.072



Gulch. At the beginning of the benthic stage in mid-July, the ratio between the 1986 and 1987 Dark Gulch annual density estimates is 1/23. After these two year classes experience their respective mortality rates (0.001-day^{-1} for 1986, 0.005-day^{-1} for 1987, Table 1) from mid-July until the following April, the ratio

between the year classes is reduced to 1/7.7. Although there are no published values for variability in adult blue rockfish year-class strength, the 1/7.7 ratio in the example is consistent with ratios between small and large adult year classes in other rockfish species. For example, Hightower and Lenarz (1989)

found a 1/6.5 ratio between the smallest and largest year classes of widow rockfish (*S. entomelas*).

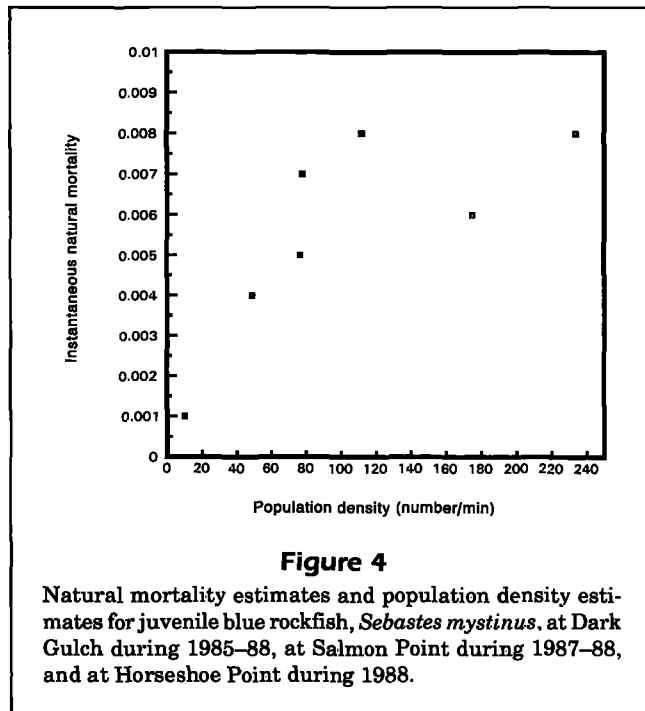
Density-dependent natural mortality during the benthic juvenile stage reduces interannual variation in numbers but does not change the rank order of abundance between years. Since year-class strength ratios at the end of year one are similar to those of

adults, we feel that year-class strength is set before this period. However, by removing some of the variation in estimates caused by year-class strength, density-dependent mortality increases the relative contribution to variation from the underlying patchiness and reduces one's ability to distinguish between different estimates (i.e. reduces statistical power).

Table 2

Published values of instantaneous daily natural mortalities in juvenile fishes. This also includes fishes that are estuarine and freshwater species. Mortalities are either a single value or a mean if followed by a range in parentheses.

Species	Instant. daily mortality	Reference
Blue rockfish (<i>Sebastes mystinus</i>)	0.006 (0.001–0.008)	This study
Shad (<i>Alosa sapidissima</i>)	0.019	Crecco et al. (1983)
Winter flounder (<i>Pseudopleuronectes americanus</i>)	0.012	Pearcy (1962)
Atlantic herring (<i>Clupea harengus</i>)	0.017	Dragesund (1969)
Plaice (<i>Pleuronectes platessa</i>)	0.018 (0.007–0.052)	Bannister et al. (1974) Lockwood (1980), Zijlstra et al. (1982) Iles and Beverton (1991)
Dab (<i>Limanda limanda</i>)	0.019 (0.011–0.035)	Iles and Beverton (1991)
Turbot (<i>Scophthalmus maximus</i>)	0.025	Iles and Beverton (1991)
Atlantic cod (<i>Gadus morhua</i>)	0.023 (0.012–0.038)	Sundby et al. (1989)
Largemouth bass (<i>Micropterus salmoides</i>)	0.029	Timmons et al. (1981)
Striped bass (<i>Morone saxatilis</i>)	0.015	Dey (1981)
Spot (<i>Leiostomus xanthurus</i>)	0.042	Currin et al. (1984)
Atlantic croaker (<i>Micropogonias undulatus</i>)	0.023	Currin et al. (1984)
Northern anchovy (<i>Engraulis mordax</i>)	0.015	Smith (1985)
Pink salmon (<i>Oncorhynchus gorbuscha</i>)	0.030	Parker (1968)



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