is determined, so U.S. fishers are not penalized directly for Mexican harvests. Harvest in U.S. waters does, however, depend on current biomass, so U.S. harvest will be reduced if the stock is depleted by fishing in either Mexico or the U.S.

A disadvantage in prorating total harvest by the portion in U.S. waters is that biomass estimates, based on U.S. and Mexican fishery data, for the whole stock may be required. It is possible that Mexican fishing data might not be available at some future date, but experience indicates that serious problems with data availability are unlikely.

The most serious disadvantage in prorating ABC for the stock in U.S. waters is that the portion of each stock in U.S. waters has to be estimated. Portion in U.S. waters may be more difficult than total biomass to estimate, because the portion of CPS stocks in U.S. waters varies with season and is affected by a number of variables. During the winter and spring, water temperatures are cool, and stocks move south to spawning areas off southern California and Mexico. During the summer and fall, when water temperatures are highest, CPS move north and away from Mexico. The amount of seasonal movement depends on the species, environmental conditions (warm water encourages movement to the north), biomass levels (sardine may undertake northern feeding migrations when biomass is high), and age composition (large old fish tend to move farther north).

If it proves too difficult to estimate the portion in U.S. waters, then other approaches to adjusting ABC for stock biomass outside of U.S. waters may be employed. For example, it may be more practical to use an MSY control rule with a high CUTOFF than to try and estimate the portion of the stock in U.S. waters. It is also possible that surveys could be conducted in U.S. waters to estimate the biomass actually occurring there.

It is likely that estimates of the portion of CPS stocks in U.S. waters will be controversial. Managers and scientists may decide to choose, as a matter of policy and based on limited information, a season on which to base estimation of portion in U.S. waters and calculation of harvest levels for U.S. fisheries. A number of different estimates of the portion in U.S. waters may have to be reconciled, and the decision about which estimate to use or how estimates are to be combined may result in a policy decision. Managers may choose estimates of the portion in U.S. waters strategically if bilateral discussions about allocating CPS between the U.S. and Mexico develop. If the U.S. and Mexico do not agree on the portions in U.S. and Mexican waters for a particular stock, then too much harvest may occur.

Prorating total harvest by the portion in U.S. waters will not protect CPS stocks against high combined U.S. and Mexican harvest rates if harvest rates are too high in Mexico, but harvest in U.S. waters will automatically decrease if biomass decreases. In any given year, combined U.S. and Mexican harvest rates may be higher than desirable, and biomass and fishery yields may be reduced due to too much fishing. Another disadvantage is that U.S. fisheries may be preempted by large scale fisheries in Mexican waters since relatively conservative management of U.S. fisheries may result only in higher Mexican harvests.

4.1.3.2 Portion in U.S. Waters and Available Data

Estimates of the portion in U.S. waters for most stocks will likely be based on California Cooperative Fishery Investigation (CalCOFI) and fish spotter data. CalCOFI data are quantitative collections of eggs and larvae made during the spawning season at a regular grid of sampling stations from 1951 to the present time (Hewitt 1988). Surveys made during the spawning season when adults are generally at the southern end of their distribution, therefore, have a south bias. The current sampling pattern is confined to the California Bight, but a more extensive sampling pattern that extended farther north and into Mexican waters was carried out during 1951 through 1985. From time to time, cooperative transboundary surveys are conducted by U.S. and Mexican scientists that provide useful information about CPS eggs, larvae, and spawning biomass on both sides of the border (Arenas et al. 1996). Fish spotter data are collected by pilots in small planes that are employed by the fishery to locate fish schools (Lo et al. 1992). Fish spotters fly over Mexican waters during the summer while searching for tuna, but seldom fly north of Pt. Conception.

Estimates of the distribution of CPS larvae between the U.S. and Mexico based on CalCOFI larval data for 1951 through 1985 are given below. CPS spawn mostly during the winter and spring, so portions from CalCOFI data are treated as winter-spring estimates of the portion of CPS stocks in U.S. waters.

CalCOFI (Winter-Spring) Larval Distribution

Species	United States	Mexico
Pacific (Chub) Mackerel	55%	45%
Jack Mackerel	54%	46%
Pacific Sardine	31%	69%
Northern Anchovy	65%	35%

The portions are based on larval abundance north and south of CalCOFI line number 100, which corresponds approximately to the U.S.-Mexican border and are subject to the following caveats:

1. The seasonal and spatial distribution of CalCOFI sampling effort has varied over the years in response to changes in survey objectives and budgets (Hewitt 1988). During years of diminished sampling effort, surveys have generally concentrated in those months and areas where spawning activity was most likely to occur. The estimates of larval distribution described above were based on raw rather than seasonally adjusted data, and it is not known whether this results in any systematic bias.

2. The portions probably underestimate the true proportion of jack mackerel larvae in U.S. waters, because (a) CalCOFI surveys have generally not extended far enough north or offshore to cover the full range of the jack mackerel resource. The offshore range of jack mackerel tends to diminish as one moves from the northern to southern end of the range, so the surveys probably "missed" a larger proportion of the larvae present in U.S. waters than in Mexican waters; and (b) An unknown portion of the larvae sampled in Mexican waters likely originated in U.S. waters, since jack mackerel larvae exhibit a marked tendency to drift southward on the California Current.

3. The Pacific sardine distribution described in the table pertains to years during which the biomass was very low. The proportion of sardine larvae and spawning biomass in U.S. waters would be higher in medium to high biomass years. Results, for example, of a cooperative U.S./California/Mexico daily egg production survey indicated that most of the biomass of spawning sardine was in U.S. waters during 1994 (Lo et al. 1996). Sardine biomass was much higher in 1994 then when historical CalCOFI data were collected.

4. CalCOFI data for U.S. and Mexican waters from surveys off both countries were collected primarily before the late 1970s when water conditions were cool and most CPS had a more southerly distribution. Water temperatures along the coast increased after the late 1970s (MacCall and Prager 1988) and have remained high (Roemmich and McGowan 1995). It is likely that proportions of CPS in U.S. (and Canadian) waters have increased as proportions in Mexican waters have decreased.

Estimates of the portion of CPS stocks in U.S. waters from CalCOFI data are probably reliable for the central stock of northern anchovy and Pacific (chub) mackerel during the winter and spring when spawning occurs. Portions for jack mackerel and Pacific sardine, as indicated above, likely underestimate the portion in U.S. waters under current biomass and environmental conditions.

Estimates of the average distribution of CPS between the U.S. and Mexico based fish spotter data for 1964 through 1992 are given below. Fish spotters seldom enter Mexican waters during the winter and spring when CPS are most abundant in southern areas and search effort in Mexican waters has been limited in recent years. Portions in the table are, therefore, best thought of as summer-fall estimates.

Fish Spotter (Summer-Fall) Distribution

Species	United States	Mexico
Pacific (Chub) Mackerel	84%	16%
Jack Mackerel	75%	25%
Pacific Sardine	87%	13%
Northern Anchovy	98%	02%

Portions based on fish spotter data were obtained by calculating average relative abundance for each CPS in each of six regions using log-normal linear models (Lo et al. 1992). The boundary between regions 2 and 3 in the north and region 5 in the south corresponds approximately to the border between the U.S. and Mexico.

Following the notation and approach in Lo et al. (1992), average relative abundance in region r (Ir) is:

$$I_r = d_r P_r A_r$$

where Ir is relative abundance in region r, dr is the density in positive flights, Pr is the proportion of positive flights, and Ar is the area searched. The terms for density (dr) and proportion positive (Pr) were calculated from main effects for regions estimated using the log-normal linear models. Interactions between season and region (which would account for seasonal migration) were not included, because insufficient data were available to estimate all of the required interaction parameters. Area searched (Ar) was approximated as the number of unique blocks searched by fish spotters during 1963 to 1992. Corrections to eliminate bias due to log transformation in Lo et al. (1992) were not used in order to simplify calculations. Regions 5 and 6 were combined, because there was too little data to obtain parameter estimates for region 6 from the log-normal linear models. The portion of each CPS stock in U.S. waters shown in the table above was calculated as the sum of Ir for region one through three (U.S. only) divided by the sum of Ir for region one through region six (Mexico+U.S.).

Portions based on fish spotter data are subject to the following caveats:

1. The portions probably underestimate the proportion of jack mackerel in U.S. waters, because fish spotters do not sample the entire northern and offshore range of jack mackerel.

2. The Pacific sardine distribution described in the table pertains mostly to years during which biomass was very low. The proportion of sardine in U.S. waters would be higher in medium to high biomass years.

"Best" estimates of portions of most CPS in U.S. waters during the whole year are averages of the CalCOFI estimates for winter through spring and the fish spotter estimates for summer through winter (see below). The best estimates for Pacific sardine (87%) are based on fish spotter data only since the average for fish spotter and CalCOFI (59%) seems too small for the stock as a whole under current conditions. The State of California assumed that the portion of sardine in U.S. waters was 59% in setting California quotas for 1998, but the proportion was applied to a regional biomass estimate that included sardine off the area between Baja California and San Francisco only. The 59% figure is probably a reasonable estimate of the fraction of sardine biomass in U.S. waters based on the region surveyed.

It is not possible at the present time to estimate the portion of any CPS in U.S. waters on an annual basis, and it is unlikely that estimates of portion of CPS in U.S. waters could be updated frequently.

Best Estimates of Average Distribution

Species	United States	Mexico
Pacific (Chub) Mackerel	70%	30%
Jack Mackerel	65%	35%
Pacific Sardine[1]	87%	13%
Pacific Sardine[2]	59%	41%
Northern Anchovy	82%	18%

1/ Whole stock.
2/ Southern region only.

The best estimate for the central stock of northern anchovy based on CalCOFI and fish spotter data (82%) is larger than the 70% value assumed in the Northern Anchovy Fishery Management Plan (Council 1983) which was based on CalCOFI data only. These estimates should be refined as additional data become available or conditions in the fishery change. In particular, the estimate for Pacific sardine should be reevaluated if the biomass of the stock continues to increase or declines, and the best estimate for jack mackerel should be reevaluated if a significant fishery develops. Both should be reevaluated if new data become available. The southern stock of northern anchovy does not enter U.S. waters, and the northern stock does not enter Mexican waters.

4.1.4 Analysis of MSY Control Rules by Simulation

As described below for Pacific sardine, MSY control rule options are best analyzed using a species and fishery-specific simulation model. The general approach is to simulate the stock and fishery over a long period of time and using a large number of MSY control rule parameter values (e.g., CUTOFF, FRACTION, and MAXCAT). The purpose of the simulations is generally not to find the combination of CUTOFF, FRACTION, and MAXCAT that is "optimal" (Ruppert et al. 1984). Instead, results are typically used to find MSY control rules and parameters that give good results for most measures of performance (MacCall et al. 1985).

Simulation models used to explore MSY control rule options should be as realistic as possible. Each model should be based on results and parameter estimates from recent stock assessments and include a realistic degree of density dependence and year-to-year variability in production or recruitment. Simulated biomass estimates should include realistic amounts of measurement error. Current conditions in the fishery can be used to initialize simulations.

4.1.4.1 Measures of Performance

A number of measures of performance are useful in simulation analysis of MSY control rule options for CPS (see below). The value of each performance measure can be computed for each MSY control rule option or combination of control rule parameters based on simulation results. The list of performance measures given below is not exhaustive, and other performance measures may be desirable in any given situation. In addition, not all measures may be useful in all analyses.

Performance Measure

1. Average catch.
2. Standard deviation of catch.
3. Average biomass.
4. Standard deviation of biomass.
5. Percent of years with no catch.
6. Percent of years with biomass > specified level.
7. Average log catch.
8. Median catch.
9. Average log midyear biomass.
10. Median biomass.