Appendix D – Depletion-Adjusted Average Catch

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Unlike the classic fishery problem of estimating MSY, data-poor fishery analysis must be content simply to estimate a yield that is likely to be sustainable. While absurdly low yield estimates would have this property, they are of little practical use. Here, the problem is to identify a moderately high yield that is sustainable, while having a low chance that the estimated yield level greatly exceeds MSY and therefore is a dangerous overestimate that could inadvertently cause overfishing and potentially lead to resource depletion before the error can be detected in the course of fishery monitoring and management.

Perhaps the most direct evidence for a sustainable yield would be a prolonged period over which that yield has been taken without indication of a reduction in resource abundance. The estimate of sustainable yield would be nothing more than the long-term average annual catch over that period. However, it is rare that a resource is exploited without some change in underlying abundance. If the resource declines in abundance (which is necessarily the case for newly-developed fisheries), a portion of the associated catch stream is derived from that one-time decline, and does not represent potential future yield supported by sustainable production. If that non-sustainable portion is mistakenly included in the averaging procedure, the average will tend to overestimate the sustainable yield. This error has been frequently made in fishery management.

Based on these concepts, we present a simple method for estimating sustainable catch levels when the data available are little more than a time series of catches. The method needs extensive testing, both on simulated data and on cases where reliable assessments exist for comparison. So far, test cases indicate that it may be a robust calculation.

The Windfall/Sustainable Yield Ratio

The old potential yield formula $Y_{pot} = 0.5*M*B_{unfished}$ (Alverson and Pereyra,1969; Gulland, 1970) is based on combining two approximations: 1) that B_{msy} occurs at $0.5*B_{unfished}$, and 2) that $F_{msy} = M$. In this and the following calculations fishing mortality rate (F) and exploitation rate are treated as roughly equivalent.

However, it is possible to take the potential yield rationale one step farther, and calculate the ratio of the one-time “windfall” harvest (W) due to reducing the abundance from $B_{unfished}$ to the assumed B_{msy} level. After that reduction in biomass has occurred, a tentatively sustainable annual yield Y is given by the potential yield formula. So we have the following simple relationships:

$Y = 0.5*M*B_{unfished}$, and

$W = 0.5*B_{unfished}$.

Under the potential yield assumptions, the ratio of one-time windfall yield to sustainable yield is the windfall/sustainable yield ratio (or simply the “windfall ratio”) W/Y = 1/M. For example, if M = 0.1, the windfall is equal to 10 units of annual sustainable yield.

An Update

The assumptions underlying the potential yield formula are out-of-date, and merit reconsideration. Most stock-recruitment relationships indicate that MSY of fishes occurs somewhat below the level of $0.5*B_{unfished}$. We replace the value of 0.5 with a value of 0.4 as a better approximation of common stock-recruitment relationships.

The F_{msy} = M assumption also requires revision, as fishery experience has shown it tends to be too high, and should be replaced by a F_{msy} = c*M assumption (Deriso, 1982; Walters and Martell, 2004). Walters and Martell suggest that coefficient **c** is commonly around 0.8, but may be 0.6 or less for vulnerable stocks. Figure 1 shows the distribution of **c** values for West Coast groundfish stocks assessed in 2005. The average of **c** for those West Coast species is 0.62, but there is a substantial density of lower values. Because the risk is asymmetrical (ACLs are specifically intended to prevent overfishing), use of the average value is risk-prone. Consequently, we have used a value of c=0.5 in the following calculations.

The yield that is potentially sustainable under these revised assumptions is

$Y = 0.4^* B_{unfished} {}^*c^*M$,

or for c = 0.5,

$Y = 0.2^* B_{unfished} {}^*M$.

The windfall is based on the reduction in abundance from the beginning of the catch time series to the end of the series,

$W = B_{begin} - B_{end} = DELTA^*B_{unfished}$,

where DELTA is the fractional reduction in biomass from the beginning to the end of the time series, relative to unfished biomass. The analogous case to the potential yield formula is $B_{begin} = B_{unfished}$, and $B_{end} = 0.4^*B_{unfished}$, in which case DELTA = 0.6. In practice, B_{begin} is rarely $B_{unfished}$, and DELTA is unlikely to be known explicitly. Although data may be insufficient for use of conventional stock assessment methods, an estimate (or range) of DELTA based on expert opinion is sufficient for this calculation. The windfall ratio is now

W/Y = DELTA/(0.4*c*M),

or in the case of c=0.5,

W/Y = DELTA/(0.2*M).

For example, in the case of fishing down from $B_{unfished}$ to near B_{msy} where DELTA=0.6, if c = 0.5, W/Y = 3/M. Thus the revised calculation gives a much larger estimate of the windfall ratio. For the previous example of M = 0.1, the windfall ratio is now estimated at 30 units of sustainable annual yield.

A Sustainable Yield Calculation

Assume that in addition to the windfall associated with reduction in stock size, each year produces one unit of annual sustainable yield. The cumulative number of annual sustainable yield units harvested from the beginning to the end of the time series is n + W/Y, where n is the length of the series. In this calculation it should not matter when the reduction in abundance actually occurs in the time series because assumed production is not a function of biomass. Of course, in view of the probable domed shape of the true production curve, the temporal pattern of exploitation may influence the approximation.

The estimate of annual sustainable yield (Y_{sust}) is

Y_{sust} = sum(C)/(n + W/Y).

In the special case of no change in biomass, DELTA = 0, W/Y = 0, and Y_{sust} is the historical average catch. If abundance increases, DELTA is negative, W/Y is negative, and Y_{sust} will be larger than the historical average catch.

Examples

The widow rockfish fishery began harvesting a nearly unexploited stock in 1981 and for the first three years, fishing was nearly unrestricted (Table 1). Reliable estimates of sustainable yield based on conventional stock assessments were not available for many years afterward. By the mid-1990s, stock assessments were producing estimates of sustainable yield ca. 5000 mtons, with indications that abundance had fallen to 20-33% of $B_{unfished}$.

Application of depletion-corrected catch averaging indicates good performance of the method within a few years of the beginning of the fishery. Two alternative calculations are given in Table 1. The first calculation assumes M = 0.15, c = 0.5, and that biomass was near B_{msy} at the end of the time period, so that DELTA = 0.6. The second calculation is closer to the most recent stock assessment (He et al., 2007) and assumes M = 0.125, c = 0.5, DELTA = 0.75 (ending biomass in year 2000 is about 25% of $B_{unfished}$).

Other examples would be worth exploring, especially were they can be compared with “ground truth” from a corresponding formal stock assessment.

Low biomasses

The yields given by these calculations can only be sustained if the biomass is at or above B_{msy}. If the resource has fallen below B_{msy}, the currently sustainable yield ($Y_{current}$) is necessarily smaller. A possible approximation would be based on the ratio of $B_{current}$ to B_{msy},

$$Y_{current} = Y_{sust}*(B_{current}/B_{msy}) \text{ if } B_{current}<B_{msy}$$

Implementation

This method is most useful for species with low natural mortality rates; stocks with low mortality rates tend to pose the most serious difficulties in rebuilding from an overfished condition. As natural mortality rate increases (M > 0.2), the windfall ratio becomes relatively small, and the depletion correction has little effect on the calculation.

The relationship between F_{msy} and M may vary among taxonomic groups of fishes, and among geographic regions, and would be a good candidate for meta-analysis. Uncertainty in parameter values can be represented by probability distributions. A Monte Carlo sampling system such as WinBUGS can easily estimate the output probability distribution resulting from specified distributions of the inputs.

With minor modifications, this method could also be applied to marine mammal populations. Although estimation of sustainable yields is not a central issue for marine mammals nowadays, the method would be especially well suited to analysis of historical whaling data, for example.

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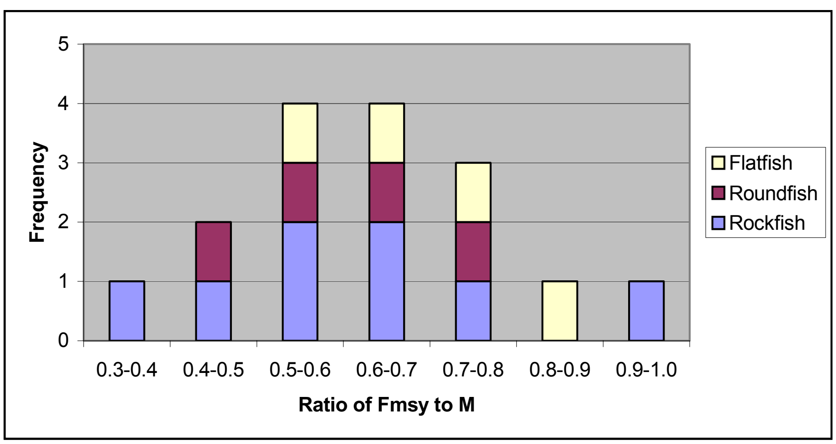
TABLE 1. Widow rockfish example of depletion-adjusted average catch, as if calculations were done in each year. Bold values indicate years when stock might have been assumed to be near B_{msy}. All calculations assume $B_{begin} = B_{unfished}$, and $B_{end} = 0.4*B_{unfished}$. Assumed natural mortality rate is 0.15, but is now thought to be lower. Widow rockfish was declared overfished in 2000.

year	annual catch	cumulative catch	cumulative production	estimated ABC(=MSY)
	1000 mtons		MSY units	1000 mtons
1981	22	22	21	1.0
1982	27	49	22	2.2
1983	26	75	23	3.2
1984	10	85	24	3.5
1985	10	95	25	3.8
1986	9	104	26	**4.0**
1987	13	117	27	**4.3**
1988	10	127	28	**4.5**
1989	12	139	29	**4.8**
1990	10	149	30	**5.0**
1991	6	155	31	**5.0**
1992	6	161	32	**5.0**
1993	8	169	33	**5.1**
1994	6	175	34	**5.1**
1995	7	182	35	**5.2**
1996	6	188	36	5.2
1997	7	195	37	5.3
1998	4	199	38	5.2
1999	4	203	39	5.2
2000	4	207	40	5.2



1. Distribution of ratios of F_{msy} to M for West Coast Groundfish species assessed in 2005. “Rockfish” is genus *Sebastes*. “Roundfish” represents remaining non-flatfish species.

Appendix E – A Probability-Based Approach to Setting Annual Catch Levels

A Probability-Based Approach to Setting Annual Catch Levels

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Authors' note: The manuscript on which this appendix is based will be submitted to Fishery Bulletin*. We have prepared this appendix under the American Fisheries Society's guidelines for extended abstracts, to avoid any question of duplicate publication.*

Recent reauthorization of the Magnuson–Stevens Fishery Conservation and Management Act requires each FMP to "establish a mechanism for specifying annual catch limits … at a level such that overfishing does not occur in the fishery …" Because this requirement is new, scientific practice for setting ACLs is not yet established.

We propose an approach that keeps the annual probability of overfishing P^* below some preset level (e.g., 0.1), presumably meeting the requirement to avoid overfishing. This probability-based approach to setting catch limits, which we call PASCL, is an extension of the REPAST algorithm (Prager et al. 2003) for setting fishing targets. That paper in turn extended the work of Caddy and McGarvey (1996) on targets and limits. When used for setting ACLs, PASCL can accommodate uncertainty in many areas, e.g., in estimated stock status, in the estimated limit reference point F_{lim} (typically F_{MSY} or a proxy), in future stock dynamics (whether due to single-species or ecosystem effects), and in implementation of management measures.

In PASCL, uncertainty in stock dynamics is represented by a stochastic projection model. This approach allows setting ACLs for more than one year and facilitates including uncertainty, as mentioned above. Modeling non-equilibrium population dynamics, as here, is critical in developing harvest strategies (Hauser et al., 2006).

Stock assessment results generally include estimates of uncertainty. A key result used in PASCL is the estimate of F_{lim}, the limit reference point in fishing mortality rate, and its associated uncertainty, described by a probability density function (PDF), either parametric or nonparametric. If a PDF on F_{lim} is unavailable, PASCL can use a point estimate, but ignoring that source of uncertainty can make overfishing more likely (Prager et al., 2003). Another basic assessment result, the estimate of stock status with its corresponding uncertainty, is used to initialize stock replicates in PASCL's stochastic projection.

In PASCL, the level of risk deemed acceptable by managers is quantified as P^*, where *risk* is defined as the probability of overfishing in year *t* [i.e., $\Pr(F_t > F_{\text{lim}})$]. A smaller P^* corresponds to more risk-averse management. Always, $P^* < 0.5$ should hold, since $P^* = 0.5$ equates limit and target, with overfishing expected in half of all years. When P^* is defined as a constant probability, as here, the risk of overfishing in at least one of T years grows with the time horizon (T) as $1-(1-P^*)^T$.

In a simpler formulation, F_{lim} would be represented by a point estimate. In that case, the probability of overfishing in year *t* would be a function of F_{lim} and the probability density function (ϕ_{F_t}) of F_t:

$$\Pr(F_t > F_{\text{lim}}) = \int_{F_{\text{lim}}}^{\infty} \phi_{F_t}(F)\,dF = 1 - \Psi_{F_t}(F_{\text{lim}}) \qquad (1)$$

where $\Psi_{F_t}(F_{\text{lim}})$ is the cumulative distribution of F_t evaluated at F_{lim}. The distribution of F_t can be shifted so that the desired risk is achieved; i.e., so that $\Pr(F_t > F_{\text{lim}}) = P^*$.