Example Estimations of Yield and Fishery Profit When Few Data are Available

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Abstract

Very preliminary bioeconomic assessments are reported in respect to fishery situations in Kenya. In the case of the shrimp fishery, it is concluded that the contemporary trawler fleet is substantially in excess of that required to maximize fishery profits. The second situation concerns the presently unexploited stock of quality demersal species on the North Kenya Bank. It is concluded that this stock might be sufficient to support a fishery, although involving probably no more than a few vessels.

Introduction

The objective of this short article is to demonstrate using selected examples the extent by which fishery assessments in support of management can be undertaken even when few data are available. The methodology is principally that described in Garcia et al. (1989). It is applied here to two fishery situations recently encountered by the author during a field mission to Kenya.

Materials and Methods

The first concerns the fishery for shallow water shrimp located in Ungwana Bay. The peak annual catch for the fishery was recorded in 1986 as 397 t, and subsequently has fluctuated around 350 t, despite a continuing and substantial increase in the number of vessels.

The 1986 catch was from six vessels. This number increased to 14 in 1989, while for 1990 around 20 vessels were licensed. The fishery has not so far been the subject of a research study, nor is it being managed, despite its substantial local importance.

The second situation concerns the stocks of high quality demersal fish (emperors, snappers and groupers) present on the North Kenya Bank. Up to the present these stocks have not been exploited.

These were surveyed using bottom set longlines by the now defunct East African Marine Fisheries Organization (EAMFRO) during the period 1969-1976. The mean catch rate obtained was used to estimate the mean density and biomass of these fish based on an assumed area of attraction of the baited hooks (Tarbit 1976).

The method of analysis used here is from Garcia et al. (1989) based on the surplus production model of Fox (1974). The underlying relationship can be written in the following forms:

$$Y = F^{*}\exp(c - dF) \qquad \text{...1)}$$

$$\text{or } \ln(Y/F) = c - dF$$

where Y is (sustainable) yield, F is the fishing mortality coefficient, and c and d are constants. As the fishing mortality coefficient is proportional to the fishing effort, the above equations can be used to estimate yields for given levels of fishing effort.[a]

Garcia et al. (1989) showed that in the event of having one observed value for each of the biomass and yield and knowledge or a guesstimate of F_{MSY} (or X and M, as $F_{MSY} = X^{*}M$ where X is a constant), estimates of c and d can be obtained using the following:

$$c = \ln(B_c) + Y_c/(B_c{}^{*}F_{MSY})$$

$$d = -2/F_{MSY}$$

Apart from the use of (1) to estimate yields for given levels of effort, c and d can be used in the following equation for direct estimation of MSY:

$$MSY = -(1/d)^{*}\exp(c-1)$$

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[a] The constant of proportionality, the catchability coefficient (q), is estimated later with reference to the relationship: q = a.p/A; where a is the area of seabed over which the gear is effective per unit fishing effort, p is the efficiency of the gear, and A is the area of seabed occupied by the stock in question.

Table 1. Estimates of fleet catch weight, catch rate and biomass, as well as catch value, cost and profit of North Kenya Bank demersal fish for a range of fleet size and other parameter values as shown.

Number of standard vessels	Catch weight (t)	Catch rate (kg'st day^{-1})	Biomass (t)	Catch value (US$'000)	Total cost (US$'000)	Fishery profit (US$'000)	Profit per vessel (US$'000)
v	Y	r	B	V	C	P	Pv
0	0.00	1,170.45	17,000.0	0.00	0.00	0.00	0.00
1	218.52	1,092.58	15,868.9	327.77	239.84	87.93	87.93
2	407.95	1,019.88	14,813.1	611.93	478.38	133.55	66.78
3	571.22	952.03	13,827.6	856.82	715.73	141.09	47.03
4	710.95	888.69	12,907.6	1,066.42	952.03	114.39	28.6
5	829.56	829.56	12,048.8	1,244.34	1,187.38	56.96	11.39
6	929.24	774.37	11,247.1	1,393.86	1,421.87	(28.01)	(4.67)
7	1,011.98	722.84	10,498.8	1,517.97	1,655.60	(137.63)	(19.66)
8	1,079.60	674.75	9,800.3	1,619.40	1,888.65	(269.25)	(33.66)
9	1,133.74	629.86	9,148.3	1,700.62	2,120.10	(420.48)	(46.72)
10	1,175.90	587.95	8,539.6	1,763.85	2,353.01	(589.15)	(58.92)
11	1,207.43	548.83	7,971.4	1,811.15	2,584.43	(773.29)	(70.30)
12	1,299.56	512.32	7,441.1	1,844.34	2,815.44	(971.10)	(80.92)
13	1,243.40	478.23	6,946.0	1,865.10	3,046.07	(1,180.97)	(90.84)
14	1,249.96	446.41	6,483.8	1,874.93	3,276.37	(1,401.44)	(100.10)
15	1,250.13	416.71	6,052.5	1,875.20	3,506.39	(1,631.19)	(108.75)
16	1,244.76	388.99	5,649.8	1,867.13	3,736.16	(1,869.02)	(116.81)

Equations:

Y = q.v.x.exp(c + (d.q.v.x))
r = Y.1,000/(v.x)
B = Y/(q.x)

V = Y.Pr
C = v.(C1+C3)/1,000 + Y.C2
P = V - C
Pv = P/v

Inputs:

			Symbols/equations:
Assumed line efficiency	=	1,000	p
Number of line hauls/hour	=	7.50	h
Number of hooks/line	=	30.00	h
Fishing hours/day	=	12.00	g
Fishing days/vessel/year	=	200.00	x
Attraction area/hook (m^2)	=	51.00	a
Area of grounds (km^2)	=	2,000.00	A
Observed catch rate (kg/100 hooks)	=	43.35	r'
Observed yield (t)	=	0.00	Y'
Assumed M	=	0.20	M
Fish price (US$/kg)	=	1.50	Pr
Variable costs/vessel (US$/year)	=	75,200	C1
(US$/kg)	=	0.045	C2
Fixed costs/vessel (US$/year)	=	154,809	C3

Estimates

Biomass (t)	=	17,000	B' = r'.A/(p.a.100/1,000)
MSY (t)	=	1,251	MSY' = M/B'.exp((Y'/(M.B'))-1)
Catchability coefficient	=	0.0000689	q = (a/1,000).h.n.g.p/(A/1,000)
c	=	9.7410	c = LN(B') + Y'/(B'.M)
d	=	(5.0000)	d = -1/M

which becomes $MSY = M*B_c \exp((Y_c/M.B_c) - 1))$ in the special case where $F_{MSY} = M$.

The analyses were undertaken using the spreadsheet formats shown in Tables 1 and 2. A description of the equations used within the spreadsheets, along with the values for the input parameters, are shown beneath the tables. In both cases the annual yields (in weight) were estimated in respect to a range of fishing efforts, with the latter being expressed as the number of vessels deployed.

The analysis for the demersal fish stock was rather conventional: it utilized inputs from Tarbit (1976) to derive an estimate of the (unexploited) biomass. This value, the known "yield" (= 0 tonnes) and the guesstimate of M (here assumed equal to F_{MSY}; from

Table 2. Estimates of fleet catch weight, catch rate and biomass, as well as catch value, cost and profit of Kenya shrimp for a range of fleet size and other parameter values as shown.

Number of standard vessels	Catch weight (t)	Catch rate (kg·st day^{-1})	Biomass (t)	Catch value (US$'000)	Total cost (US$'000)	Fishery profit (US$'000)	Profit per vessel (US$'000)
v	Y	r	B	V	C	P	Pv
0	0.00	705.12	396.4	0.00	0.00	0.0	0.00
1	121.6	607.98	341.8	851.17	474.05	377.1	377.12
2	209.69	524.22	294.7	1,467.81	905.54	562.3	281.13
3	271.20	452.00	254.1	1,898.40	1,303.28	595.1	198.37
4	311.78	389.73	219.1	2,182.49	1,674.45	508.0	127.01
5	336.04	336.04	188.9	2,352.27	2,024.87	327.4	65.48
6	347.69	289.74	162.9	2,433.85	2,359.29	74.6	12.43
7	349.76	249.83	140.5	2,448.31	2,681.53	(233.2)	(33.32)
8	344.66	215.41	121.1	2,412.59	2,994.67	(582.1)	(72.76)
9	334.32	185.73	104.4	2,340.25	3,301.17	(960.9)	(106.77)
10	320.29	160.15	90.0	2,242.05	3,602.97	(1,360.9)	(136.09)
11	303.78	138.08	77.6	2,126.49	3,901.63	(1,775.1)	(161.38)
12	285.75	119.06	66.9	2,000.22	4,198.34	(2,198.1)	(183.18)
13	266.91	102.66	57.7	1,868.39	4,494.04	(2,625.7)	(201.97)
14	247.84	88.52	49.8	1,734.91	4,789.44	(3,054.5)	(218.18)
15	228.96	76.32	42.9	1,602.75	5,085.08	(3,482.3)	(232.16)
16	210.58	65.81	37.0	1,474.08	5,381.36	(3,907.3)	(244.21)

Equations:

$Y = q.v.x.exp(c + (d.q.v.x))$

$r = Y/1,000/(v.x)$

$B = Y/(q.x)$

$V = Y.Pr$

$C = v.(C1+C3)/1,000 + Y.C2$

$P = V - C$

$Pv = P/v$

Inputs:

			Symbols/equations:
Assumed trawl efficiency	=	1.00	p
Fishing days/vessel/year	=	200.00	x
Trawling hours/day	=	12.00	g
Vessel speed (nm)	=	3.00	
(km/hour)	=	5.56	s
Width of nets (m)	=	14.70	w
Area of grounds (km^2)	=	551.00	A
Observed yield (t)	=	350.00	Y' (assumed = MSY)
Assumed M (annual)	=	2.40	M
Shrimp price (US$/kg)	=	7.00	Pr
Variable costs/vessel (US$/year)	=	155,120	C1
(US$/kg)	=	1.27	C2
Fixed costs/vessel (US$/year)	=	164,500	C3

Estimates

Biomass (t)	=	145.83	$B' = Y'/F' = MSY/Fmsy = MSY/M$
Catchability coefficients	=	0.0017787	$g = w.s.g.p/(A.1,000)$
c	=	5.9825	$c = LN(B') + Y'/(B'.M)$
d	=	(0.4167)	$d = -1/M$

Venema (1984)), were used to obtain estimates of c and d, and then to compute yields for each given number of vessels.

In contrast, the analysis for the shrimp fishery is nonstandard. Here, the assumption was made that the mean of the catches in recent years (about 350 t·year^{-1}) is equal to the MSY. This was then used to estimate the associated biomass, after which the procedure previously described was followed.

The prices and costs data for the financial overlay are largely the result of discussions held with industry personnel. In respect to both fishery situations, the costs are based on a hypothetical 24-m vessel, valued new at around US$650,000 (with gear), against which the owner has borrowed 85% for a term of 10 years at a net annual interest of 8.5%.

Results and Discussion

The results for the demersal fish stock are shown in Table 1. The estimate of MSY is 1,250 t, attainable by a fleet of 15 vessels with a mean catch rate of 417 kg·day^1.

When considering the financial aspects, it seems that allowing a fleet of more than five vessels would lead to negative fishery profit (other than in the short term). The estimated financial loss associated with the attainment of MSY is substantial.

Fishery profit is maximized with a fleet size of three vessels. With this number, the estimated catch rate is 952 kg·day^{-1} and the annual profit per vessel is close to US$47,000. The associated fishery yield of 571 t is some 46% of the estimate of MSY.

The obvious implication for management from these results is that the future exploitation of this stock should be limited to relatively few vessels, at least until there are more data upon which a comprehensive assessment can be based.

The results for the shrimp fishery, given in Table 2, indicate that MSY could be attained from a fleet of seven vessels. At this size, the fleet would operate at a loss, but this would be small.

The appropriate fleet size for maximizing profit was estimated as three vessels. With this number the estimated mean catch rate is 452 kg·day^{-1} and the annual profit per vessel is US$198,000. The estimated yield associated with this level of effort is 271 t, or 78% of the estimate of MSY.

This suggests that the number of vessels presently licensed for this fishery are excessive. Presumably the fishery should now be subjected to a management regime which would lead to a substantial reduction in the number of vessels.

Attempts at Validation

An important (if not essential) complement to the above is to test the sensivity of the results to different values for the input parameters.

An associated form of validation is to compare estimated MSY per area of fishing round to those estimated for other stocks of the same species in ecologically similar areas exploited under similar fishing regimes. This is possible in the case of the shrimp example.

The estimate for MSY/area from area given in Silva and Sousa (1988) for the industrial shrimp trawl fishery on the Sofala Bank (Mozambique) is 428 kg km^{-2}. In the case of the industrial trawl fishery of Tanzania the estimate is about 500 kg km^{-2} also close to the value estimated here for the Kenyan fishery.

In respect to line fisheries on demersal stocks, Lablache and Moussac (1987) utilized the results from trawling surveys along the outer edge of the Mahé Plateau (Seychelles) to estimate an MSY per unit area of 246 kg km^{-2} for large quality fish accessible to the local handline fishery. In the case of the industrial handline fishery on the Saya de Malha and Nazareth Banks (exploited mainly from Mauritius) if the estimate of 174 kg km^{-2} were the correct value to apply, then the estimate of MSY becomes 500 t.

The input parameters most likely to be associated with error in respect to this example are the assumed line efficiency and attraction area/hook. The values used in the analysis are both "guesstimates".

Using the spreadsheet shown in Table 1, it can be shown that the value for the attraction area per hook needed to achieve an MSY of 500 t, is 127 m^2 when the efficiency is assumed to be $p = 1$ and 255 m^2 when $p = 0.5$. These are equivalent to the distance of attraction either side of the longline being about 20 m and 40 m, respectively.

The meaning of these values is that on average, all the fish within a 20-m distance from the line will be caught, or 50% of the fish within a 40-m distance. Again, whether either of these scenarios is realistic can only be a matter of speculation at this stage.

Conclusion

The two assessments reported here have been undertaken with few data. While the results will be of interest to those responsible for management, they should nevertheless be considered as indicative only. In the case of the shrimp fishery, the present exploitation levels are almost certainly excessive. In the case of the quality demersal stocks on the North Kenya Bank, the yield from any exploitation in the future is likely to be small and justifying the use of only a few vessels.

References

Fox, W.W., Jr. 1974. An overview of production modelling. Collect. Vol. Sci. Pap. ICCAT 3: 1539-1542.

Garcia, S., P. Sparre and J. Csirke. 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fish. Res. 8:13-23.

Lablache, G. and G. de Moussac. 1987. A review of the artisanal fisheries of Seychelles. (MS).

Silva, C. and M.I. Sousa. 1988. Summary description of the marine fisheries and resources for Mozambique, p. 82-108. *In* Proceedings of the workshop on the assessment of the fishery resources in the Southwest Indian Ocean. FAO/UNDP RAF/79/065/WP/41/88/E.

Tarbit, J. 1976. Demersal fisheries research—terminal report, 1974-1976. EAMFRO Annual Report. 28 p. (mimeo).

Venema, S.C. 1984. Review of marine resources surveys in Kenyan waters, p. 61-82. *In* Proceedings of the NORAD-Kenya seminar to review the marine fish stocks and fisheries in Kenya, Mombasa, Kenya, 13-15 March 1984.