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Yield Assessment for the Small Pelagics Fishery Occurring Along the Northwest, West and South Coasts of Sri Lanka

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Abstract

This study utilized two separate approaches for assessing the current exploitation status for small pelagics in the northwest, west, and south coasts of Sri Lanka. In the first approach, modified Schaefer and Fox models were applied to a time series of annual catch (all species) and catch rate data. In the second approach, a length-based Thompson and Bell model was used with life history data for the trenched sardine *(Amblygaster sirm)*. This species comprises about 60% of the catches of small pelagics. The more convincing results were from the modified Fox and the Thompson and Bell models. The conclusion from these is that the small pelagics are not yet fully exploited, and that in-creased yields are possible. It is suggested (on theoretical grounds) that modest in- creases are unlikely to have negative impact on recruitment. This was not tested by analysis, nor was there an assessment of the socio-economic impact of increased exploi-tation. In view of these uncertainties, additional studies are required, along with contin-ued monitoring of the fishery.

Introduction

The annual landings of small pelagics in Sri Lanka are presently about 65,000 t. This represents some 40% of coastal production from all species. In respect to the eight districts comprising the study area (Puttalam to Tangalle), landings increased substantially from about 32,000 t in the early 1980s to around 44,000 t in the early 1990s. The major increase was during the mid-1980s following the arrival of additional fishermen, displaced due to civil disturbances in the north and east of the country.

Sardines and herrings are the most abundant in the catches, followed by anchovies, mackerels, barracudas, pony fish, scombrids, and small carangids. They are caught in the nearshore waters using beach seine nets, and further offshore with gill nets (stretched mesh size generally from 2.5 to 3.8 cm; Dayaratne 1988). Previously, there was also some purse seining, mostly in the southwest, but this method has been banned since 1993. Gill nets now contribute about 80% to the landings while beach seines account for most of the remainder.

Based on a fishery survey undertaken in 1986, there are thought to be about 11,000 craft presently engaged in catching small pelagics within the study area. This includes motorized 'introduced' craft (45%), motorized traditional craft (5%), non-motorized traditional craft (45%), and craft used exclusively in beach seining (5 %). With respect to the first three categories, these are operated throughout the year with gill nets, or seasonally with gill nets in combination with handlines and longlines.

The matter considered in this paper is whether scope exists to increase the landings, in the event of further increases in the fishing effort. This has involved the conduct of two separate analyses. The first provides an assessment for the small pelagic species combined, and utilizes annual landings and catch rate data. The second is a single species assessment for the trenched sardine (*Amblygaster sirm*), which comprises about 60% of the landings (Dayaratne 1990). The inputs required for this included the parameters describing growth, the probabilities of capture, individual fecundity, and the mortality rates.

Methods

Schaefer and Fox

The Schaefer and Fox models are described in Sparre and Venema (1992). In the Schaefer model, yield per unit effort (i.e. mean annual catch rate) is assumed to decline linearly with increase in the annual fishing effort; this decline is assumed to occur exponentially in the Fox model. In the application described here, both models were modified (by the authors) with the inclusion of an additional constant in the operative equations. This was done to improve the 'goodness of fit'. The resulting equations are as follows:

$CPUE = a + b \cdot X^m$	modified Schaefer
$LN(CPUE) = c + d \cdot X^n$	modified Fox

where CPUE is the catch rate, X is the fishing effort, and a, b, c, d, m and n are constants. The values for the constants were determined iteratively using a least-squares criterion (see later section).

The models were applied to the annual catch rate and effort data for twelve years from 1979 to 1994 (Table 1). Catch rate data for the years not represented were unavailable. The catch rates are in respect to gill nets used from motorized 'introduced' craft. The annual efforts (in gillnet units) were estimated by dividing annual landings by the catch rates. Annual landings, in turn, were estimated from official statistics. As the small pelagics are not separately identified within these statistics, this was done by assuming they comprised 70% of the 'others' category and 95% of the 'shore fish' category. These percentages are based on unpublished findings from catch sampling by the National Aquatic Resources Research & Development Agency (NARA).

Thompson and Bell

The method of Thompson and Bell (1934) is also described in Sparre and Venema (1992). The principal outputs (as applied here) were the yield, annual catch rate, mean individual weight, the length frequency distribution in the catches, and population fecundity, for fishing effort multipliers from zero to twice the effort applying in the early 1990s. Annual recruitment was assumed to be constant. As such, the outputs are reflective of the average performance of the fishery, for each level of fishing effort.

Annual catch weights and fishing efforts by gear type (Table 2) were utilized, as well as length frequency data (Table 3). Values for the parameters describing (post juvenile) natural mortality, growth and individual fecundity are from the literature (Table 4). These were used in the prior estimation of the relationship between natural mortality and age (Table 5), and the probability of capture ogives (Tables 6 and 7). An application of the model is shown (Table 8), along with the inputs, outputs, and associated equations (Table 9).

Some of the inputs were determined internally from the model. This included the number of recruits of zero length, the catchability coefficients with respect to each gear type, and the probability of capture ogive for beach seines. The 'best choice' values for the parameters were those which minimized the sum of the squared differences between the estimated and observed

Table 1. Annual catch (all species) and effort series.

Year	Catch weight (in tons)	CPUE (kg/gill net boat-day)	Fishing effort ('000 gill net boat-days)
1979	39,442	95.2	414
1980	32,623	65.5	498
1981	30,553	57.2	534
1984	35,796	29.8	1,201
1985	33,670	24.5	1,374
1986	41,462	22.9	1,811
1987	41,359	27.2	1,521
1988	56,436	49.3	1,145
1989	45,282	36.5	1,241
1990	38,596	34.3	1,125
1991	37,657	27.2	1,384
1992	50,188	40.5	1,239
1993	48,337	33.8	1,430

Source: Department of Fisheries and Aquatic Resources Development (DFARD).

Table 2. Annual catch and effort by gear type.

Gear	Catch weight (in tons)		Nominal fishing effort (boat-days)	CPUE (kg/boat-day)	
Gill net	35,200	(26,400)	1,035,000	34.0	(25.5)
Beach seine	8,140	(407)	180,889	45.0	(2.25)
Purse seine	660	(330)	12,692	52.0	(26.0)
Total	44,000	(27,137)	-		

Note: Above values are averages for the three years 1991/92/93. Figures for trenched sardine are given in parentheses.
Source: National Aquatic Resources Research & Development Agency (NARA).

Table 3. Length frequency distributions (in the early 1990s) by gear type.

Total length interval (cm) L1	L2	Gill net	Frequency (%) beach seine	Purse seine
4	5	-	1.72	-
5	6	-	39.26	0.30
6	7	-	28.59	-
7	8	-	12.76	1.80
8	9	-	10.10	0.33
9	10	9.80	5.77	1.17
10	11	4.94	0.87	2.13
11	12	12.94	0.29	1.33
12	13	8.14	-	3.00
13	14	3.13	0.26	2.20
14	15	1.15	-	1.10
15	16	2.16	0.09	2.07
16	17	2.75	0.19	6.97
17	18	6.71	-	17.84
18	19	14.16	-	20.61
19	20	23.17	-	18.97
20	21	13.39	-	13.77
21	22	5.60	-	6.27
22	23	0.73	-	0.13
23	24	0.24	-	-

Note: The gill net frequencies are for the south and west coast districts. Their bi-modality reflects fishing inshore for small sizes, and offshore for larger fish. The frequencies for beach seine and purse seine are for the south-west. All are averaged from data collected from 1991-1993.
Source: National Aquatic Resources Research & Development Agency (NARA).

Table 4. Literature values of selected stock assessment parameters for *A. sirm*.

Item	Source
Natural mortality coefficient (annual):	
M = 2.1	Dayaratne (1985)
M = 1.4	Siddeek et al. (1985)
M = 1.8	Karunasinghe (1986)
M = 1.3	Karunasinghe and Wijeyaratne (1991)
M = 2.9 - 3.2	Dayaratne (1990)
M = 2.2	Dayaratne & Sivakumaran (1994)
M = 1.9	Dayaratne *et al* (1995)
Total length at age growth constants: (L∞ in cm. and K annual)	
L∞ = 24.8 , K = 0.95	Siddeek *et al* (1985)
L∞ = 23.8 , K = 0.95	Karunasinghe (1986)
L∞ = 22.5 - 23.5 , K = 1.93 - 2.15	Dayaratne (1990)
L∞ = 24.9 - 25.8 , K = 1.10 - 1.48	Karunasinghe & Wijeyaratne (1991)
L∞ = 24.6 , K = 1.3	Dayaratne & Sivakumaran (1994)
L∞ = 25.8 , K = 1.06	Dayaratne *et al* (1995)
Total length – weight relationships: (W in gm. and L in cm.)	
log W = 3.02 log L - 2.086 (female) log W = 2.92 log L - 1.980 (male)	Karunasinghe (1990)
Total length and age at 50% sexual maturity:	
L_m50 (female) = 15.0 cm t_m50 (female) = 10.2 mth. L_m50(male) = 15.9 cm. t_m50 (male) = 11.5 mth.	Karunasinghe (1990)
Individual fecundity at total length relationship: (L in cm.)	
log fecundity = 1.5315 + 2.603 log L (est. 75% of eggs are released at spawning)	Karunasinghe and Wijeyaratne (in press)

Table 5: Estimation of natural mortality with age for *A. sirm*.

Total length interval (cm)		Age at length (year)	Mean age (year)	Natural mortality coefficient (/year)	Population number
L1	L2	t1,t2	t'	Mt'	N1,N2
0.0001	1	0.000	0.003	207.80	117,891.0
1	2	0.032	0.047	16.43	155.2
2	3	0.065	0.081	9.87	89.8
3	4	0.100	0.117	7.18	63.7
4	5	0.137	0.155	5.71	49.0
5	6	0.175	0.194	4.77	39.4
6	7	0.215	0.236	4.12	32.5
7	8	0.258	0.279	3.65	27.3
8	9	0.303	0.326	3.28	23.2
9	10	0.350	0.375	2.99	19.8
10	11	0.401	0.428	2.76	17.0
11	12	0.456	0.485	2.56	14.6
12	13	0.515	0.546	2.40	12.6
13	14	0.578	0.612	2.26	10.8
14	15	0.648	0.685	2.13	9.2
15	16	0.724	0.765	2.02	7.8
16	17	0.808	0.855	1.93	6.6
17	18	0.904	0.957	1.84	5.5
18	19	1.012	1.074	1.76	4.5
19	20	1.138	1.213	1.68	3.6
20	21.1	1.290	1.392	1.60	2.8
21.1	22	1.500	1.612	1.53	2.0
22	23	1.729	1.909	1.46	1.4
23	24	2.102	2.460	1.38	0.8
24	24.6	2.857	7.280	1.19	0.3

Objective: Estimate A and B in the relationship Mt'=A+B/t' where Mt' is the natural mortality coefficient at mean age t' [=(t2-t1)/LN(t2/t1)] and A and B are constants (see Caddy 1991).
Method: Input values for the von Bertalanffy growth constants L∞ and K were used to estimate t1 and t2; and these latter used to estimate t'. Next, estimates of Mt' were obtained based on assumed values for A and B. The latter were improved by 'iteration' with the best choice being when the mean lifetime fecundity (MLF) of an individual female is reduced to two offspring at the mean parental age (MPA), with the mean mortality for lengths >9 cm constrained at M=1.9 (Table 4). The MLF was taken as the sum of the eggs released by a parent at ages 1.0 and 1.5 yr, with these latter determined using the individual fecundity relationship (Table 4).
Inputs: L∞=24.6 cm, K=1.30, MLF=117,891 eggs, and MPA=1.5 yr.
Outputs: A = 1.08953 and B = 0.71479.

Note: Mean Parental Age (MPA) is the age attained by an average parent; and Mean Lifetime Fecundity (MLF) is the eggs released during the lifetime of an average parent; see Caddy (1991 and 1996).
The Solver routine in EXCEL was used.

Table 6. Estimation of the probability of capture ogives for gill nets and purse seines.

Total length interval (cm)		Probability of capture ogives	
		gill net	purse seine
L1	L2	Og	Op
0	1	0	0
1	2	0	0
2	3	0	0
3	4	0	0
4	5	0	0
5	6	0	0.0032
6	7	0	0.0072
7	8	0	0.0071
8	9	0	0.0045
9	10	0.0134	0.0160
10	11	0.0794	0.0302
11	12	0.2035	0.0198
12	13	0.1283	0.0476
13	14	0.0508	0.0381
14	15	0.0197	0.0212
15	16	0.0403	0.0458
16	17	0.0582	0.1830
17	18	0.1681	0.5776
18	19	0.4423	1.0000
19	20	1.0000	1.0000
20	21	1.0000	1.0000
21	22	1.0000	1.0000
22	23	1.0000	1.0000
23	24	1.0000	1.0000
24	24.6	1.0000	1.0000

Objective: Estimate the probabilities of capture within each length interval, defined as the ratio of the number actually caught to the number expected to be caught.
Method: The numbers expected to be caught were estimated from backward projection using the following relationship $LN(Cj/\Delta tj) = a + b.tj$ where Cj is the number caught in length class j, Δtj is the time needed to grow through length class j, tj is the age (or relative age) which corresponds to the mid-length of class j, and a and b are constants (Pauly, 1984). The prior estimation of the a and b was from the regression of $LN(Cj/\Delta tj)$ against tj. $L\infty$ and K were used to estimate Δtj and tj for each length interval. Use was made of the trawl net selection routine in the FISAT suite of software of Gayanilo *et al.* (1994).
Inputs: The length frequencies for gill nets and purse seine nets are from the sampling of commercial catches (Table 3), and $L\infty = 24.6$ cm and $K = 1.3$ are from the literature (Table 4). The regressions of $LN(Cj/\Delta tj)$ against tj were undertaken over the fully recruited length intervals. After getting estimates for a and b, these were used in the equation to estimate the numbers expected to be caught for the partially recruited length intervals.
Outputs: The ogives determined in respect to each gear are as shown.

Note: Based on visual examination of the data (Table 3), it was assumed that the largest fish in the gill net catches were the same as the frequencies in the population, as the consequence of the wide range of mesh sizes used.

Table 7: Estimation of the probability of capture ogive for beach seines.

Total length interval (cm)		Observed frequency	Estimated frequency
L1	L2	(%)	(%)
0	1	0	0.01
1	2	0	0.01
2	3	0	0.14
3	4	0	1.39
4	5	1.72	7.53
5	6	39.26	21.56
6	7	28.59	32.17
7	8	12.76	24.89
8	9	10.20	9.99
9	10	5.77	2.07
10	11	0.87	0.22
11	12	0.29	0.01
12	13	0.00	0.00
13	14	0.26	0.00
14	15	0.00	0.00
15	16	0.09	0.00
16	17	0.19	0.00

Objective:Estimate Ls and s in the ogive relationship 0=exp(-((((L1+L2)/2)-Ls)^2)/(2.5^2)) where O is the probability of capture, Ls is the optimum selection length and s is the standard deviation of the selection length, with symmetrical gill net type selection assumed (Sparre and Venema, 1982).
Method: Best choice values for Ls and s were obtained by 'iteration,' as when the sum of the squared differences between the estimated and observed length frequency percentages was minimized. The estimated frequency was generated internally within the Thompson and Bell model depiction of the fishery (Tables 8 and 9).
Inputs: The observed length frequency is from sampling the commercial catches, and is an average from data collected in the early 1990s (Table 3). The other inputs to the model are as shown.
Outputs: Ls=6.8 and s=1.22.

Note: The beach seine frequencies were assumed to reflect gill net type selection. This is based on a visual examination of the data (Table 3), and is presumed the consequence of only the smaller fish being available for exploitation in the shallow waters where beach seines are operated.

Table 8: Spreadsheet depiction of the Thompson and Bell model.

Total length (cm) L1	L2	Age (yr) t1,t2	mean t'	Probability of capture ogives: gill net Og	beach seine Ob	purse seine Op	Fishing mortality coefficients Fg	Fb	Fp	Natural mort. coef. Mt'	Population (mil N1,N2
0.0001	1	0.000	0.003	0	0.0000	0	0	0.0000	0	6.63	19,925,748
1	2	0.032	0.047	0	0.0000	0	0	0.0000	0	0.55	26,226
2	3	0.065	0.081	0	0.0020	0	0	0.0000	0	0.34	15,176
3	4	0.100	0.117	0	0.0258	0	0	0.0002	0	0.26	10,762
4	5	0.137	0.155	0	0.1691	0	0	0.0015	0	0.22	8,281
5	6	0.175	0.194	0	0.5668	0.0032	0	0.0052	0.0000	0.19	6,647
6	7	0.215	0.236	0	0.9702	0.0072	0	0.0094	0.0000	0.18	5,456
7	8	0.258	0.279	0	0.8482	0.0071	0	0.0087	0.0000	0.16	4,536
8	9	0.303	0.326	0	0.3788	0.0045	0	0.0041	0.0000	0.16	3,816
9	10	0.350	0.375	0.0134	0.0864	0.0160	0.0019	0.0010	0.0000	0.15	3,249
10	11	0.401	0.428	0.0794	0.0101	0.0302	0.0119	0.0001	0.0000	0.15	2,781
11	12	0.456	0.485	0.2035	0.0000	0.0198	0.0329	0.0000	0.0000	0.15	2,363
12	13	0.515	0.546	0.1283	0	0.0476	0.0225	0	0.0001	0.15	1,967
13	14	0.578	0.612	0.0508	0	0.0381	0.0097	0	0.0001	0.16	1,651
14	15	0.648	0.685	0.0197	0	0.0212	0.0041	0	0.0000	0.16	1,398
15	16	0.724	0.765	0.0403	0	0.0458	0.0094	0	0.0001	0.17	1,183
16	17	0.808	0.855	0.0582	0	0.1830	0.0152	0	0.0005	0.18	988
17	18	0.904	0.957	0.1681	0	0.5776	0.0502	0	0.0016	0.20	810
18	19	1.012	1.074	0.4423	0	1.0000	0.1539	0	0.0033	0.22	630
19	20	1.138	1.213	1.0000	0	1.0000	0.4167	0	0.0039	0.25	431
20	21	1.290	1.382	1.0000	0	1.0000	0.5193	0	0.0049	0.30	220
21	22	1.478	1.600	1.0000	0	1.0000	0.6894	0	0.0065	0.38	96
22	23	1.729	1.909	1.0000	0	1.0000	1.0285	0	0.0097	0.55	33
23	24	2.102	2.460	1.0000	0	1.0000	2.0778	0	0.0196	1.04	7
24	25	2.857	7.280	1.0000	0	1.0000	33.0620	0	0.3125	14.26	0
sums											

Number lion) mean N'	Catch number ('000) gill net Cg'	beach seine Cb'	purse seine Cp'	Natural death number (million) D	Mean indiv. weight (gm) w'	Catch weight (tonne) gill net Yg'	beach seine Yb'	purse seine Yp'	Sexual maturity ogive H	Eggs released (billion) E
3,000,072	0	35	0	19,899,522	0	0	0	0	0	0
20,200	0	12	0	11,050	0	0	0	0	0	0
12,843	0	204	0	4,413	0	0	0	0	0	0
9,468	0	2,028	0	2,479	0	0	1	0	0	0
7,434	0	10,969	0	1,623	1	0	9	0	0	0
6,032	0	31,390	20	1,159	1	0	47	0	0	0
4,982	0	46,833	40	873	2	0	113	0	0	0
4,166	0	36,240	35	684	4	0	132	0	0	0
3,524	0	14,543	20	553	5	0	76	0	0	0
3,008	5,658	3,019	64	459	7	41	22	0	0	0
2,566	30.627	321	110	386	10	295	3	1	0	0
2,159	71.082	17	65	325	13	891	0	1	0	0
1,804	40.549	0	142	275	16	647	0	2	0	0
1,521	14,755	0	105	238	20	294	0	2	0	0
1,287	5,325	0	54	209	25	131	0	1	0	0
1,082	10.165	0	109	185	30	302	0	3	1	17,376
895	13.650	0	405	164	36	487	0	14	1	17.156
716	35,965	0	1,167	143	42	1,521	0	49	1	16,467
524	80,690	0	1.723	116	50	4,010	0	86	1	14,865
313	130.639	0	1,234	80	58	7,562	0	71	1	11,713
149	77,556	0	733	45	67	5,190	0	49	1	6.817
59	40,464	0	382	23	77	3,108	0	29	1	3,385
16	16,814	0	159	9	88	1,474	0	14	1	1,297
2	4,230	0	40	2	99	421	0	4	1	298
0	201	0	2	0	110	22	0	0	1	14
	578,369	145,613	6.609			26,394	402	329		

Table 9. Spreadsheet inputs, outputs, and equations.

Inputs:					
Contemporary fishing effort (annual)	- gill net	Xg	=	1,035,294	boat-days
	- beach seine	Xb	=	180,889	boat-days
	- purse seine	Xp	=	12,692	boat-days
Fishing effort multiplier	- gill net	e1	=	1	
	- beach seine	e2	=	1	
	- purse seine	e3	=	1	
Catchability coefficient	- gill net	q1	=	2.66E-06	
	- beach seine	q2	=	1.26E-06	
	- purse seine	q3	=	2.05E-06	
Probability of capture ogive	- gill net	see spreadsheet			
	- purse seine	see spreadsheet			
Optimum selection length	- beach seine	Ls	=	6.8	cm
Std. Deviation of selection length		s	=	1.22	cm
Number of zero-length recruits		R	=	19,925,748	million/yr
Asymptotic length		L∞	=	24.6	cm
Curvature coefficient		K	=	1.30	/yr
Natural mortality at age constants		A	=	1.0895	
		B	=	0.7148	
Total length/total weight constants (when w in gm and L in cm)		a	=	0.0105	
		b	=	2.90	
Individual fecundity at length constants (when L in cm)		a'	=	34	
		b	=	2.603	
Sexual maturity ogive		see spreadsheet			
Outputs:					
Catch number (annual)	- gill net	Cg	=	578,369	'000
	- beach seine	Cb	=	145,613	'000
	- purse seine	Cp	=	6,609	'000
Catch weight (annual)	- gill net	Yg	=	26,394	tonne
	- beach seine	Yb	=	402	tonne
	- purse seine	Yp	=	329	tonne
Mean individual fish weight	- gill net	wg	=	46	gm
	- beach seine	wb	=	3	gm
	- purse seine	wp	=	50	gm
Mean catch rate (annual)	- gill net	CPUEg	=	25.5	kg/boat/day
	- beach seine	CPUEb	=	2.2	kg/boat/day
	- purse seine	CPUEp	=	25.9	kg/boat/day
Eggs released (by cohorts aged 1, 1.5 and 2 yr)		E	=	22,366	billion

Equations:

t1 = -(1/k).LN(1-L1/L∞)
t' = (t2-t1)/LN(t2/t1)
Ob = exp(-((((L1+L2)/2)-Ls)^2)/(2.s^2))
Fg = (t2-t1).e1.q1.Og.Xg
Fb = (t2-t1).e2.q2.Ob.Xb
Fp = (t2-t1).e3.q3.Op.Xp
Mt'= (t2-t1).(A+B/t')
N2 = N1.exp(-(Fg+Fb+Fp+Mt'))
N' = (N1-N2)/(Fg+Fb+Fp+Mt')
Cg' = Fg.N'
Cb' = Fb.N'
Cp' = Fp.N'
D = Mt'.N'
w' = (1/(L2-L1)).(a/(b+1)).(L2^(b+1)-L1^(b+1))
Yg' = Cg'.w'
Yb' = Cb'.w'
Yp' = Cp'.w
E' = H.(N1/2).(a'.L1^b').(0.75)

Note: The fishing efforts for the early 1990s are indicated by effort multipliers of unity.

annual catch weights and length frequencies (as percentages) for each gear type. This was done with the effort multipliers set at unity as shown in Table 8. The Solver routine in the Microsoft Excel spreadsheet software was used for the minimizations.

Results

Schaefer and Fox

The estimation of the constants in the modified Schaefer and Fox model equations is shown in Table 10. The sum of the squared differences (between the estimated and observed catch rates) is lower in the modified Fox model. A selection of estimated yields and catch rates for a range of fishing efforts is given in Table 11. The yields from the modified Schaefer model display a maximum, while those from the modified Fox model increase over a wide range of effort. These differences are reflected in the associated estimates for the catch rates. Those from the modified Schaefer model are much lower at the higher levels of fishing effort. Some additional comments on the relative merits of the two models (as applied here) are given in a later section.

Thompson and Bell

A selection of results from the Thompson and Bell model are shown in Table 12. They are estimates of the likely outcome from increasing the fishing effort from gill nets, while keeping the effort from the other gears constant at the level in the early 1990s. It seems that a modest increase in the yield of trenched sardine could be obtained from further increases in effort. The associated decrease in the catch rates, the sizes of fish in the catches, and the numbers of eggs released annually are shown.

Separate estimates (not shown) were obtained for the likely yields in the event that the fishing efforts from all gears were progressively increased (in the same proportions). These were then used to estimate the all-species yields and associated catch rates, on the assumption that the proportion of trenched sardine in the small pelagics catches remained constant for each gear type (at the levels for the early 1990s as shown in Table 2). These estimates were plotted with those from the modified Schaefer and Fox models (Figs. 1 and 2). There is closest agreement between those from the Thompson and Bell and modified Fox models at the higher levels of fishing effort.

Discussion

In the application of the Thompson and Bell model, it was assumed that the annual recruitment of young fish remains constant for all of the tested levels of fishing effort. The Fox and Schaefer models contain no such explicit assumptions concerning the relationship between stock size and recruitment.

Table 10. Estimation of yield relationships using the modified Schaefer and Fox models.

Objective: Estimate the constants a, b, c, d, m and n in the following modified Schaefer and Fox model relationships:

$CPUE = a + b.X^m$ modified Schaefer

$LN(CPUE) = c + d.X^n$ modified Fox

Where CPUE (= Y/X) is the annual catch rate, X is the annual fishing effort, and Y is the yield.

Method: Trial values for the constants were used to estimate CPUEs for each observed fishing effort. The values were progressively improved by 'iteration' (using the Solver routine in EXCEL) until the sums of the squared differences between the observed and estimated CPUEs were minimized. The CPUEs and efforts used were for the period 1980 to 1993 (Table 1) with the efforts averaged for the same and previous year (to approximate the fishery at equilibrium).

Inputs:				Estimation:			
				Modified Schaefer		Modified Fox	
Year	Observed yield ('000 tonne)	Observed av. Effort ('000 gill net boat day)	Observed CPUE (kg/gill net boat-day) A	Estimated CPUE (kg/gill net boat day) B	Differences squared $(A-B)^2$	Estimated CPUE (kg/gill net boat-day) C	Differences squared $(A-C)^2$
1980	32,623	456	71.54	66.28	28	68.29	11
1981	30,553	516	59.21	62.43	10	62.70	12
1984	35,796	868	41.26	46.16	24	43.75	6
1985	33,670	1,288	26.15	33.71	57	33.25	50
1986	41,462	1,593	26.04	26.97	1	28.68	7
1987	41359	1,666	24.83	25.54	1	27.79	9
1988	56,436	1,333	42.34	32.61	95	32.46	98
1989	45,282	1,193	37.96	36.12	3	35.06	8
1990	38,596	1,183	32.63	36.39	14	35.27	7
1991	37,657	1,255	30.02	34.53	20	33.86	15
1992	50,188	1,312	38.27	33.13	26	32.83	30
1993	48,337	1,335	36.22	32.58	13	32.44	14
				sums	293		267

Outputs:

Schaefer model	$CPUE = a + b.X^m$	a = 2,060.4	b = -1,812.3	m = 0.01561
Fox model	$LN(CPUE) = c + d.X^n$	c = 122.4	d = -113.8	n = 0.00586

Table 11. Outputs from the modified Schaefer and Fox models.

Effort multiplier	Fishing effort ('000 gill net boat-day)	Estimated catch rated (kg/gill net boat-day) Modified Schaefer	Modified Fox	Estimated yields ('000 tonne) Modified Schaefer	Modified Fox
0.00	0	—	—	0	0
0.25	325	77	86	25	28
0.50	650	55	53	36	35
0.75	975	42	40	41	39
1.00	1,300	33	33	43	43
1.25	1,625	26	28	43	46
1.50	1,950	21	25	40	49
1.75	2,275	16	22	36	51
2.00	2,600	11	20	30	53

Note: The fishing effort for the early 1990s is indicated by an effort multiplier of unity.

Table 12: Outputs from the Thompson and Bell model.

Item	Gear	Units	Gill net effort multiplier								
			≈ 0	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0
Catch weight	- gill net	tonne	0	14,573	20,909	24,321	26,394	27,756	28,702	29,385	29,892
	- beach seine	tonne	402	402	402	402	402	402	402	402	402
	- purse seine	tonne	987	643	483	390	329	286	253	227	206
	- all gears	tonne	1,389	15,618	21,795	25,113	27,125	28,444	29,356	30,014	30,500
Mean individual fish weight	- gill net	gm	67	59	53	49	46	43	41	39	37
	- beach seine	gm	3	3	3	3	3	3	3	3	3
	- purse seine	gm	67	60	55	52	50	48	47	45	45
Fishing effort	- gill net	'000 boat-days	0	259	518	776	1,035	1,294	1,553	1,812	2,071
	- beach seine	'000 boat-days	181	181	181	181	181	181	181	181	181
	- purse seine	'000 boat-days	13	13	13	13	13	13	13	13	13
Mean catch rate	- gill net	kg/boat-day	90.9	56.3	40.4	31.3	25.5	21.4	18.5	16.2	14.4
	- beach seine	kg/boat-day	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	- purse seine	kg/boat-day	77.7	50.7	38.1	30.7	25.9	22.5	19.9	17.9	16.3
Length frequency percent	- gill net	9 - 10 cm	0	1	1	1	1	1	1	1	1
		10 - 11	2	3	4	5	5	6	7	7	8
		11 - 12	5	7	9	11	12	14	15	16	17
		12 - 13	3	4	5	6	7	8	8	9	10
		13 - 14	1	2	2	2	3	3	3	3	3
		14 - 15	0	1	1	1	1	1	1	1	1
		15 - 16	1	1	1	2	2	2	2	2	2
		16 - 17	1	1	2	2	2	3	3	3	3
		17 - 18	3	4	5	6	6	7	7	8	8
		18 - 19	7	10	11	13	14	15	15	16	16
		19 - 20	15	19	21	22	23	22	22	21	20
		20 - 21	15	16	16	15	13	12	10	9	8
		21 - 22	14	13	11	9	7	5	4	3	2
		22 - 23	13	10	7	5	3	2	1	1	0
		23 - 24	12	6	3	2	1	0	0	0	0
		24 - 25	7	2	0	0	0	0	0	0	0
Eggs released		billion	38,693	32,207	27,809	24,684	22,366	20,581	19,159	17,995	17,018

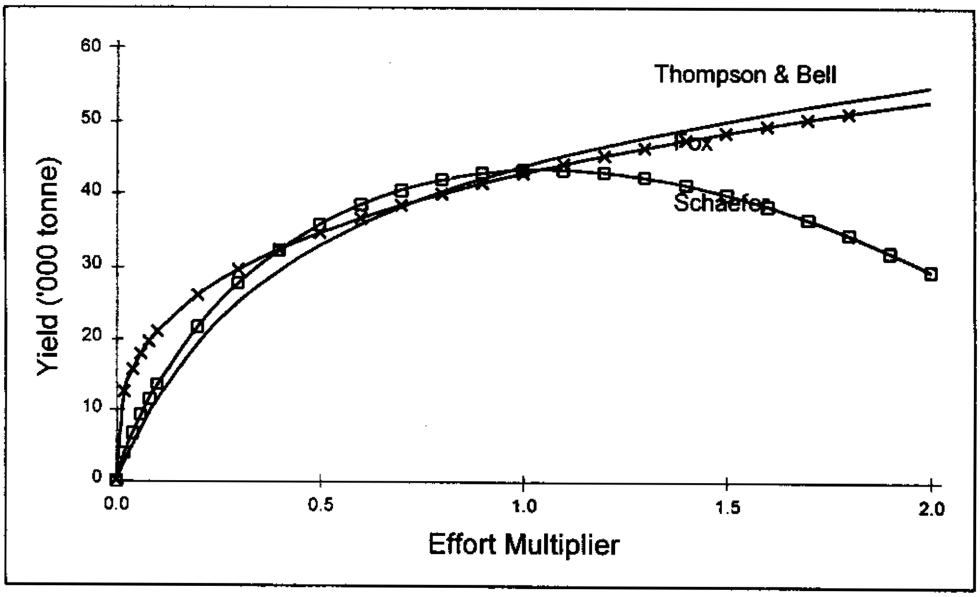

Figure 1. Plot of yield (all species) against effort multiplier.

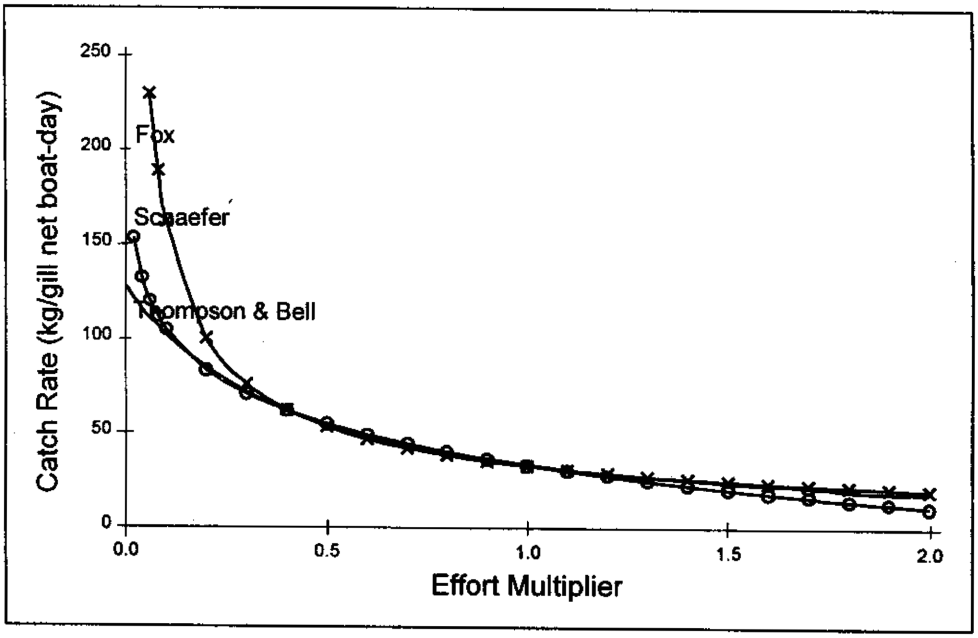

Figure 2. Plot of catch rate (all species) against effort multiplier.

Nevertheless, the Schaefer model, in particular, tends to be most appropriate where a strong stock-recruitment relationship can be established (or presumed). It is this feature which is believed to account for much of the difference between the results from the modified Schaefer model, and those from the other two models. The output from the Thompson and Bell model provides some further insight into this matter.

In the case of stocks for which there are data, it has generally not been possible to demonstrate impairment to recruitment success, even when stock sizes are reduced to 30% (of that prior to exploitation). The estimates for the number of eggs released annually by the trenched sardine are substantially higher than this 30%. (In the unlikely extreme of doubling the fishing effort, for example, the estimate for the eggs released is 44% of the pre-exploitation value). As such, the assumption of constant recruitment (over the tested levels of fishing effort) seems reasonable. Accordingly, the results from the Thompson and Bell and modified Fox models were taken as more likely than those from the modified Schaefer model.

In the analysis, there was no consideration of the likely socio-economic effects from increased fishing effort. Nevertheless, it is possible to make some general comments. Apart from the increase in yields, increased fishing efforts would be associated with reduced catch rates and smaller fish in the catches. Each of these could be expected to impact negatively on the fishers' already low profit levels. Consumers would benefit from increased fishing effort, in the event of increased supply and lower fish prices. Other beneficiaries would be previously unemployed persons gaining entry into an expanded fishery. Those benefiting, however, would be doing so at the expense of the existing fisherfolk.

An aspect of the assessment not previously discussed concerns the inclusion of a natural mortality with age relationship in the Thompson and Bell model. This was done to inject a greater realism into the analysis, in recognition of the tendency of juvenile fish to suffer higher natural mortalities than adults. The additional relevance is in the sense that the beach seine component of the fishery is targeted on juvenile fish. While the results are not shown, it was found that substantial increase in the fishing effort with beach seines has negligible impact on estimated yields from gill nets and purse seines. The main consequence (within the model) was to reduce the number of natural deaths. This finding has little practical application, however, due to the relatively few sites suitable for beach seines being already fully utilized.

The final comment concerns the need for a precautionary approach when considering the management implications from this work. It was suggested (on theoretical grounds) that a modest increase in the overall fishing effort was unlikely to impair the success of recruitment. This was not tested, and hence remains a matter of uncertainty which should not be ignored. If recruitment success were impaired, then future yields from increased effort would be less than predicted here. Unfortunately, studies on the relationship between stock size and recruitment are notoriously difficult, and many years may be required for full understanding. In the interim, the more pragmatic approach of closely monitoring the performance of the fishery during periods of change will be crucial.

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