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Management of the Indo-Pacific Spanish mackerel (*Scomberomorus commerson*) in Oman

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ABSTRACT

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Growth data for *Scomberomorus commerson* in Oman were coupled with other information about the fishery to provide preliminary management recommendations. Length data collected from the commercial catch were used in conjunction with counts of daily and annular growth marks on otoliths to determine growth rate. These data revealed that *S. commerson* grow very rapidly, reaching a size of about 80 cm in 1 year and between 100 and 110 cm in 2 years, after which growth slows considerably. A tabular yield model indicates that protection of rapidly growing young *S. commerson* could have significant benefits for the fishery. This protection could be accomplished by instituting moderate mesh regulations.

INTRODUCTION

Scomberomorus commerson (the Indo-Pacific or narrow barred Spanish mackerel) is of significant importance in Oman where it accounts for 15–20% of the catch. *S. commerson* are caught from a variety of boats ranging from small fiberglass and wooden vessels to 25 m dhows. Gillnets are the primary means of catching *S. commerson*. Some are set in a trap configuration, especially along Oman's northern coast. Drift gillnetting at night from dhows with 1000–2000 m of net is common in the area from Sur to Duqm, especially near Masirah Island (Fig. 1). Although *S. commerson* are caught throughout the year, catches are substantially higher in September through early December. A smaller peak in landings is usual in late February through April.

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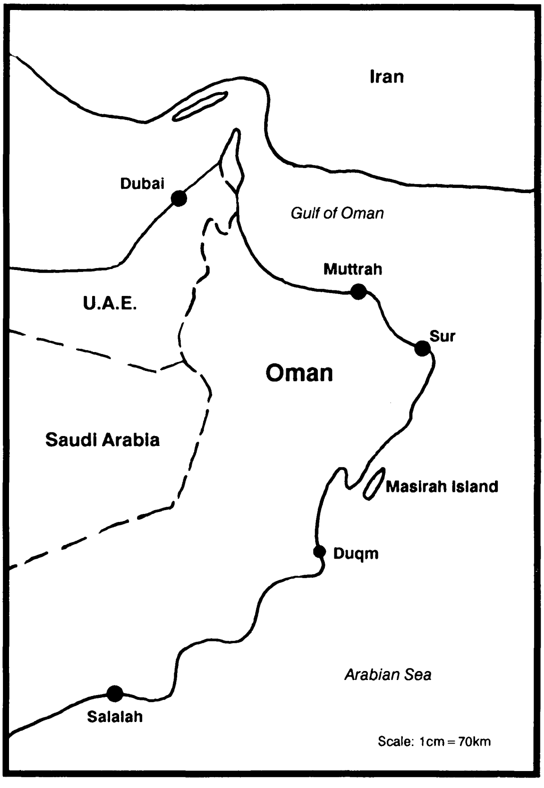

Fig. 1. The Sultanate of Oman and surroundings. The major catches of *S. commerson* are from the area between Sur and Duqm, but the species is a major component of the catch over a much wider area.

During periods of high catches, fishing is carried out at night with the catch landed the following morning. During the less favorable periods some dhows make 7–14 day trips keeping fish iced in the hold and in a large box on deck (Al-Barwani et al., 1989). In Oman *S. commerson* are usually marketed whole, ungutted. Many are exported, iced, by road to other Gulf countries. A small quantity is exported, frozen, from fish processing companies. Because it is a major source of income for traditional fishermen and traders, no large scale mechanized fishery for *S. commerson* has been encouraged.

S. commerson is primarily a coastal species which, in Oman, reaches a maximum size of 2 m and about 40 kg. However, fish larger than 1.5 m were uncommon during this study, and most fish in the catch were between 60 and 120 cm long. Between 15 000 and 30 000 t of *S. commerson* have been reported in Oman's catch statistics in recent years (Rasch and McClure, 1986; McClure and Moussalli, 1987; Moussalli and Bouhlel, 1989). Reported catches for 1985 (18 500 t), 1986 (14 300 t), 1987 (25 500 t) and 1988

(27 000 t) seemed to indicate that the fishery was expanding, although improved statistics could have caused apparent increases in landings. Unpublished statistics for 1989 indicated that the *S. commerson* catch had dropped to about 12 000 t. Regional statistics indicate that Oman lands considerably more *S. commerson* than adjacent countries do. There is some evidence that year to year fluctuations in year-class abundance occur.

Because *S. commerson* is a dominant component of Oman's catch, it was selected as a priority species for research during the first years of operation of Oman's Marine Science and Fisheries Center (MSFC) which opened in 1986.

METHODS

Several research approaches helped provide an overall view of the biology and management of *S. commerson* in Oman. Because this research was carried out during the first years of operation of the MSFC, and staff numbers were limited, most sampling was confined to public landing places and markets: situations where fish were marketed whole and where vendors and fishermen were reluctant to have their fish handled or examined. In keeping with these limitations relatively simple sampling and analysis techniques were used.

Starting in February 1987 length data were collected at the capitol area fish market, at Muttrah, during the first 10 days of each month. Fork lengths of *S. commerson* at the market were measured to the nearest cm below using 1.5 or 2.0 m calipers. On most sampling days all *S. commerson* at the market were measured. On sampling days when *S. commerson* were very abundant, a representative sample of specimens from each vendor selling this species was measured. Supplemental length data were collected at Masirah Island, Sur, Duqm, Musandam and other locations as time and personnel permitted. These data were not combined with those from Muttrah, but were examined to detect possible regional variations in length frequency modes. On selected occasions fish were also weighed, and gonads and otoliths collected. *S. commerson* length frequency data included in this analysis cover 3 years, February 1987 through January 1990, including that reported by Dudley and Arundhati (1989).

Obtaining skulls of *S. commerson* for otolith extraction was hindered because the fish were expensive and marketed whole. Skulls were collected from the capitol area fish market, where fish were butchered for individual customers. The Oman Fishing Company also provided some fish samples. Of the 38 otoliths examined by electron microscopy, 17 were collected from specimens for which only the skull, with no fork length measurement, was available. In these cases fork length of the specimen was estimated from the upper jaw length. Upper jaw length was shown to be a good predictor of fork length in a sample of 172 specimens for which both fork and jaw length were measured: fork length $= -34.41 + (15.86 \times \text{jaw length}) - (0.3177 \times \text{jaw length}^2)$, $R^2 = 0.98$).

Because specimens usually could not be cut open, an effort was made to determine their sex from various head measurements. This effort was unsuccessful. Occasional large samples of *S. commerson* for which sex could be determined did not reveal obvious differences in size distribution of male and female fish. Devaraj (1981) did not report growth differences for male and female *S. commerson* from India. However, McPherson (1992) found that Australian female *S. commerson* grew more rapidly than males did, though the differences were 5 cm or less through age 4. It is possible that Omani male and female *S. commerson* growth rates differ. Future research should address this question.

We attempted to use annular marks on otoliths to determine the growth rates of *S. commerson* following the method of Devaraj (1981). Otoliths were collected from several hundred *S. commerson* starting in February 1987. These were stored in xylene for several months and later examined with a low power (12–25 diameter magnification) microscope. We felt that apparent annual marks, as seen by this method, were not consistent enough to accurately determine age. Subsequently, a small sample of otoliths was examined in detail using electron and high power light microscopy. The method of otolith examination followed that of Brothers (1987), Brothers and Mathews (1987) and Prince et al. (1991). Specifics of the analysis are available in Brothers (1990).

Two types of data were available for the investigation of *S. commerson* growth: otolith ages and length frequency distributions. The latter consisted of both the raw length frequency data and also the means and variances of normal curves, which were fitted to length frequency modes by the Bhattacharya (1967) method using only clearly definable modes.

A Von Bertalanffy (1938) growth function (VBGF) was fitted to the raw length frequency data using the ELEFAN computer package (Pauley, 1987; Gayanilo et al., 1988). Also, a non-linear curve fitting technique (Saila et al., 1988) was used to fit a VBGF to (1) the length frequency mode data, (2) the otolith data (daily mark and annulus information), and (3) the combined set of otolith and length frequency mode data. A conjoined segmented regression line was also fitted to the combined otolith and mode data set using the computer package of Saila et al. (1988).

Measurements of *S. commerson* girth were made during 1988, 1989 and 1990. Fork length and girth at the eye, back of the head, and just in front of the second dorsal fin were measured on specimens at the Muttrah fish market. The latter measurement was made on a diagonal from the front of the second dorsal fin to the front of the anal fin, as suggested by the work of Ehrhardt and Die (1988). Girth was measured with a device consisting of a loop of heavy monofilament line which passed through a hole in a metal rectangle fixed perpendicular to the end of a metric ruler. Using this device we measured one-half the girth to the nearest half centimeter. Half girth is comparable to the maximum stretch mesh size that would catch the fish at this point.

Concurrent studies provided information about views of traditional fishermen (Al-Mamry, 1989; Colfer and Al-Mamry, 1989), and genetic stock structure of *S. commerson* (Shaklee and Shaklee, 1990).

RESULTS AND DISCUSSION

General findings based on otolith and length data

Omani *S. commerson* exhibited very distinct length frequency modes and a very clear progression of these modes over time. In general these modes remained distinct from a length of about 45 cm until the fish were about 100 cm long. During most of the year the mode representing the youngest year-class was easily distinguished. These fish first entered the fishery between September (1988) and November (1989). Usually three modes were evident during October through February (Table 1, Fig. 2). Normal curves were fitted to 58 length frequency modes.

Daily growth rings and annular marks were easily identified on sectioned otoliths when using electron and high power light microscopy. Microstructural patterns and counts of rings between presumed annual zones were completely consistent with the hypothesis that the counted structures were daily rings and that the presumed annular marks were formed yearly, even though the latter were not consistently visible on unsectioned otoliths. These microstructural features are identical to those found in *S. commerson* from Kuwait (Brothers and Mathews, 1987). Both daily ring counts and annuli were used in determining the age of fish at given lengths (Tables 2 and 3).

Sizes at age estimated from otoliths did not agree with ages originally assumed from our length data (Dudley and Arundhati, 1989). For young fish, our length data suggested ages of 18 months and 2 years for fish 60 cm and 75–80 cm, respectively. Otolith data disclose extremely rapid growth during the first 2 years followed by much slower but steady growth (Fig. 3). These data permitted us to assign absolute ages to length frequency modes. When this was done the otolith daily ring data and length frequency modes show reasonable agreement from fish sizes of 40–110 cm (Fig. 4). We conclude that *S. commerson* growth is extremely rapid during the first 3–5 months of life, and remains very rapid until an age of about 2 years. Accordingly, *S. commerson* reach 60 cm at an age of 6 months, approximately 70–80 cm at an age of 1 year (in June) and about 100–110 cm at age 2.

The spawning time of *S. commerson* agrees well with the start of otolith growth. Our observations at fish markets and processing facilities indicate fish ripening in March and April while the otolith derived ages for individual

TABLE 1

Summary of *S. commerson* length frequency data

Fork length (cm)	1987										
	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
40	0	0	0	0	0	0	0	0	1	0	0
42	0	0	0	0	0	0	0	0	4	0	0
44	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	9	3	0
48	0	0	0	0	0	0	0	0	16	4	2
50	0	1	0	0	0	0	0	0	15	17	10
52	0	2	1	0	0	0	0	0	6	35	13
54	0	3	1	0	0	0	0	0	0	39	23
56	2	12	3	0	0	0	0	0	0	8	58
58	8	30	7	0	0	0	0	0	0	3	40
60	14	34	12	0	0	0	0	0	0	0	23
62	4	24	27	0	0	1	0	0	0	0	5
64	1	20	29	1	0	0	0	0	0	1	1
66	3	7	23	0	0	0	1	0	0	1	2
68	1	5	5	5	3	2	0	0	1	0	1
70	0	2	4	5	5	4	1	1	0	0	3
72	0	5	1	3	5	11	11	2	2	0	1
74	1	1	0	1	3	13	11	12	2	0	3
76	0	2	1	3	5	10	31	20	9	0	2
78	0	0	0	0	1	9	36	39	19	4	4
80	0	0	0	0	0	2	33	35	28	14	8
82	1	0	0	0	0	2	19	43	35	33	8
84	0	2	0	0	0	2	17	33	33	40	31
86	0	1	0	0	0	0	7	25	28	47	47
88	5	3	0	0	0	0	5	16	28	46	25
90	5	8	4	2	0	0	2	7	21	26	29
92	14	10	3	3	0	0	4	7	12	23	27
94	8	22	5	3	0	2	3	2	7	23	25
96	11	11	5	2	2	2	0	3	11	19	13
98	19	14	2	5	2	6	4	6	2	7	5
100	8	15	7	1	1	2	1	8	2	7	4
102	6	6	9	0	3	9	3	5	3	3	8
104	10	6	14	3	7	4	5	4	10	9	9
106	9	4	9	0	6	5	2	7	10	15	9
108	10	10	7	0	4	9	4	2	9	14	12
110	9	8	20	0	7	8	8	13	12	11	18
112	13	7	16	0	10	7	2	7	16	9	17
114	10	9	4	0	5	11	3	12	17	11	13
116	10	4	6	0	8	7	11	13	9	7	7
118	8	5	1	0	7	5	5	7	12	12	12
120	5	6	2	0	4	4	12	5	10	10	16
122	0	5	2	0	0	1	8	2	12	7	6
124	0	6	0	0	1	0	0	3	11	8	4
126	0	2	1	0	3	2	2	2	9	5	2
128	0	6	1	0	2	0	7	3	6	5	1

Fork length (cm)	1987 Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
130	0	2	2	0	1	1	3	0	2	3	2
132	0	2	0	0	1	0	1	0	3	3	1
134	0	5	0	0	0	1	0	0	2	4	0
136	0	3	1	0	1	0	0	1	0	2	0
138	0	1	1	0	1	0	0	0	2	0	0
140	0	0	1	0	0	0	0	1	0	1	0
142	0	2	0	0	0	1	0	0	1	1	2
144	0	1	0	0	0	0	0	0	0	5	0
146	0	0	0	0	0	1	0	0	1	1	0
148	0	0	0	0	0	0	0	0	1	1	1
150	0	0	0	0	0	0	0	0	0	3	1
152	0	0	0	0	0	1	1	0	0	0	0
154	0	0	0	0	0	0	0	0	0	1	0
156	0	0	0	0	0	0	0	0	0	0	1
158	0	0	0	0	0	0	0	0	0	0	0
160	0	1	0	0	0	0	0	0	0	0	0
162	0	0	0	0	0	0	0	0	0	0	0
164	0	0	0	0	0	0	0	0	0	0	0
166	0	0	0	0	0	0	0	0	0	0	0
Total	195	335	237	37	98	145	263	346	449	551	555

Fork length (cm)	1988 Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
40	0	0	0	0	0	0	0	0	2	0	2	0
42	0	0	0	0	0	0	0	0	28	1	5	1
44	0	0	0	0	0	0	0	0	35	3	9	8
46	0	0	0	0	0	0	0	0	45	12	19	32
48	0	0	0	0	0	0	0	0	13	16	41	35
50	0	0	0	0	0	0	0	0	7	20	89	27
52	0	2	0	0	0	0	0	0	6	22	110	52
54	2	7	3	0	0	0	0	0	1	6	97	50
56	12	9	7	0	0	0	0	0	0	2	40	51
58	25	27	15	1	1	0	0	0	0	0	14	55
60	38	36	23	1	0	1	0	0	1	0	3	26
62	12	37	25	9	3	0	0	0	0	0	0	7
64	6	20	15	15	15	0	0	0	5	1	0	2
66	6	10	10	11	17	0	0	1	0	0	1	0
68	4	4	8	13	25	5	0	0	0	0	0	1
70	4	1	1	4	29	7	2	6	0	1	0	1
72	2	3	2	3	38	16	0	12	1	1	0	0
74	4	2	2	0	10	10	2	26	4	3	0	0
76	1	4	0	0	10	10	1	52	3	3	0	0
78	1	1	0	0	7	4	3	73	11	10	0	0

TABLE 1 (continued)

Fork length (cm)	1988											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
80	4	1	0	2	5	0	1	72	16	22	2	1
82	6	5	0	0	2	1	1	45	27	17	1	3
84	11	7	1	3	3	0	2	21	32	45	7	2
86	17	22	5	4	2	1	0	6	31	60	10	5
88	24	29	11	16	4	0	0	4	16	51	35	4
90	25	28	15	23	5	2	0	4	9	31	43	13
92	27	43	14	26	6	0	2	4	6	29	62	20
94	26	33	12	42	8	0	2	13	2	17	43	12
96	17	18	21	33	5	6	3	19	10	18	38	12
98	11	6	10	30	8	1	5	15	10	4	28	3
100	6	9	9	28	5	1	6	19	7	12	17	1
102	1	4	3	15	1	2	2	15	17	26	11	2
104	1	4	6	22	0	0	4	11	15	12	27	3
106	8	1	3	15	0	3	5	13	15	29	18	9
108	8	3	8	20	1	1	3	11	11	24	19	6
110	14	6	13	21	1	2	5	19	10	16	17	10
112	15	5	17	35	1	4	6	18	10	10	13	5
114	14	10	13	22	1	4	2	27	9	11	6	6
116	8	8	32	17	0	1	3	13	13	15	6	9
118	11	12	16	12	0	11	2	12	13	20	10	10
120	7	7	22	6	0	7	1	14	8	16	14	11
122	8	6	17	5	0	2	4	8	6	11	6	10
124	6	4	13	3	0	6	2	6	11	11	7	7
126	6	0	11	3	0	3	0	1	6	17	11	7
128	1	1	2	1	0	0	2	2	3	6	12	8
130	0	0	3	3	0	1	0	2	0	1	11	1
132	2	1	2	0	0	2	0	2	0	5	7	4
134	1	0	1	0	0	1	0	0	1	4	5	2
136	4	2	3	0	0	1	0	0	2	1	9	2
138	3	0	1	0	0	0	2	0	0	2	5	5
140	0	0	0	0	0	0	0	1	0	3	4	1
142	0	0	0	0	0	0	0	0	0	0	1	0
144	0	0	0	0	0	0	0	0	1	0	1	0
146	1	0	0	0	0	0	0	0	0	0	2	0
148	1	0	1	0	0	0	0	0	0	0	4	1
150	0	0	1	0	0	0	1	0	0	0	0	0
152	0	0	0	0	0	0	0	0	0	0	1	0
154	0	1	0	0	0	0	0	0	0	0	0	0
156	0	0	0	0	0	0	0	0	0	0	1	0
158	0	0	0	0	0	0	0	0	0	0	0	1
160	0	0	0	0	0	0	0	0	0	0	0	0
162	0	0	0	0	0	0	0	0	0	0	0	0
164	0	0	0	0	0	0	0	0	0	0	0	0
166	0	0	0	0	0	0	0	0	0	0	0	0
Total	411	439	397	464	213	116	74	567	479	647	944	544

Fork length (cm)	1989 Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	1990 Jan.	Total number
40	0	0	0	0	0	0	0	0	0	0	0	0	0	5
42	0	0	0	0	0	0	0	0	0	0	0	0	0	39
44	1	0	0	0	0	0	0	0	0	0	0	0	0	56
46	6	1	0	0	0	0	0	0	0	0	0	2	0	129
48	30	2	0	0	0	0	0	0	0	0	0	1	0	160
50	53	12	9	0	0	0	0	0	0	0	0	5	0	265
52	52	25	24	0	0	0	0	0	0	0	0	8	0	358
54	40	25	47	0	0	0	0	0	0	0	0	16	3	363
56	40	10	47	0	0	0	0	0	0	0	0	34	8	343
58	55	16	38	4	1	0	0	0	0	0	0	30	14	384
60	39	15	9	13	4	1	0	0	0	0	0	20	25	338
62	17	17	10	10	13	1	0	0	0	0	0	5	22	249
64	11	10	4	6	14	1	0	0	0	0	1	2	6	187
66	2	10	2	0	19	7	1	0	0	0	2	0	3	139
68	3	12	1	5	15	10	1	0	0	0	0	0	0	130
70	1	8	1	2	7	19	5	7	1	0	0	0	1	133
72	1	4	0	4	11	11	27	11	5	1	0	0	0	194
74	1	1	0	2	12	6	20	19	13	1	0	1	0	186
76	0	2	0	5	8	8	12	33	22	10	0	0	0	267
78	0	0	0	1	10	7	6	23	35	14	2	2	0	322
80	1	0	0	0	10	3	4	22	44	25	5	8	6	374
82	1	1	0	2	2	3	1	10	38	15	7	14	9	352
84	3	1	1	0	0	4	0	9	26	24	9	6	19	394
86	9	1	0	1	1	1	1	6	26	20	10	12	13	419
88	14	2	1	2	0	0	0	3	15	29	14	6	18	426
90	11	9	7	2	1	3	1	2	7	22	11	12	29	419
92	11	5	11	9	0	3	2	0	6	11	12	5	16	433
94	27	8	13	20	0	3	0	0	6	11	5	4	10	417
96	18	13	13	28	0	2	3	1	8	4	5	5	6	385
98	16	13	17	35	6	4	6	0	10	4	2	2	3	321
100	8	9	18	55	2	5	8	2	9	4	0	3	4	303
102	3	10	12	47	1	6	9	4	14	12	1	4	5	282
104	7	7	18	38	2	4	17	4	10	16	3	3	3	318
106	7	16	34	34	2	2	9	2	9	22	8	4	10	354
108	13	6	24	34	0	6	6	6	10	23	5	4	11	344
110	13	10	35	33	1	6	12	5	10	15	2	11	11	412
112	9	8	31	30	0	3	13	6	7	10	7	6	8	381
114	4	13	35	26	0	5	15	1	10	13	6	10	12	370
116	7	3	24	18	0	5	5	7	10	9	7	7	21	330
118	3	13	18	13	0	8	2	3	11	8	6	10	13	311
120	13	14	19	13	0	7	7	5	6	11	7	3	14	306
122	6	11	18	3	0	9	3	2	4	2	6	4	14	208
124	9	18	18	6	0	10	1	1	6	3	1	2	17	201
126	4	8	17	8	0	9	4	0	1	6	2	8	19	179
128	7	9	12	1	0	2	0	0	1	10	4	3	10	128
130	4	6	5	2	0	5	1	0	2	3	3	4	11	84
132	1	7	4	1	0	6	0	0	0	2	3	3	4	67
134	0	4	6	1	0	3	1	0	0	4	1	1	5	53
136	0	3	1	0	0	2	1	0	1	2	3	1	8	54
138	1	2	1	0	0	1	1	0	0	0	1	0	5	35

TABLE 1 (continued)

Fork length (cm)	1989 Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	1990 Jan.	Total number
140	0	2	3	1	0	0	2	0	0	1	3	1	2	27
142	0	1	1	0	0	0	0	0	0	1	2	2	3	18
144	0	0	2	0	0	0	0	0	0	1	1	1	3	16
146	0	0	0	0	0	0	0	0	0	0	0	0	2	8
148	0	1	0	0	0	0	0	0	0	1	1	0	1	14
150	1	1	0	0	0	1	0	0	0	0	1	0	0	10
152	0	0	0	0	0	0	0	0	0	0	0	0	1	4
154	0	0	1	0	0	0	0	0	0	0	1	0	0	4
156	0	0	0	0	0	0	0	0	0	0	0	0	0	2
158	0	0	0	0	0	0	0	0	0	0	0	0	0	1
160	0	0	0	1	0	0	0	0	0	0	0	0	0	2
162	0	0	0	0	0	0	0	0	0	0	0	0	0	0
164	0	0	0	0	0	0	0	0	0	0	0	0	0	0
166	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	583	405	612	516	142	202	207	194	383	370	170	295	428	13013

specimens indicate fertilization dates between 15 April and 15 July with a mean of 1 July. Thus *S. commerson* entering the fishery in September through November are spawned primarily in April through July and are 4–6 months old.

Annular rings on otoliths of larger specimens indicated that growth is quite slow after the fish reach an age of 2 (between 100 and 110 cm). While it is possible that 'false annuli' could make fish appear older than their true age, this possibility appears unlikely. Otolith mass and thickness data of Brothers (1990) are consistent with a pattern of slow adult growth and longevities to 10 years or more.

Possible growth models

Two methods were used to fit a Von Bertalanffy growth function to our length frequency data: ELEFAN and a VBGF curve fit to means derived from modal data. While the results from these two methods differed, both resulted in relatively high $L_{\rm inf}$ values and relatively low growth constants (Table 4, Fig. 4). The pattern of growth derived from these data is determined primarily by the growth of fish during their first 2 years. Relatively little useful information is available from older specimens using these techniques because consistent, well-defined modes do not occur at larger sizes.

The Von Bertalanffy growth parameters of a curve fitted to otolith data alone differed considerably from those of the curves fitted to the length fre-

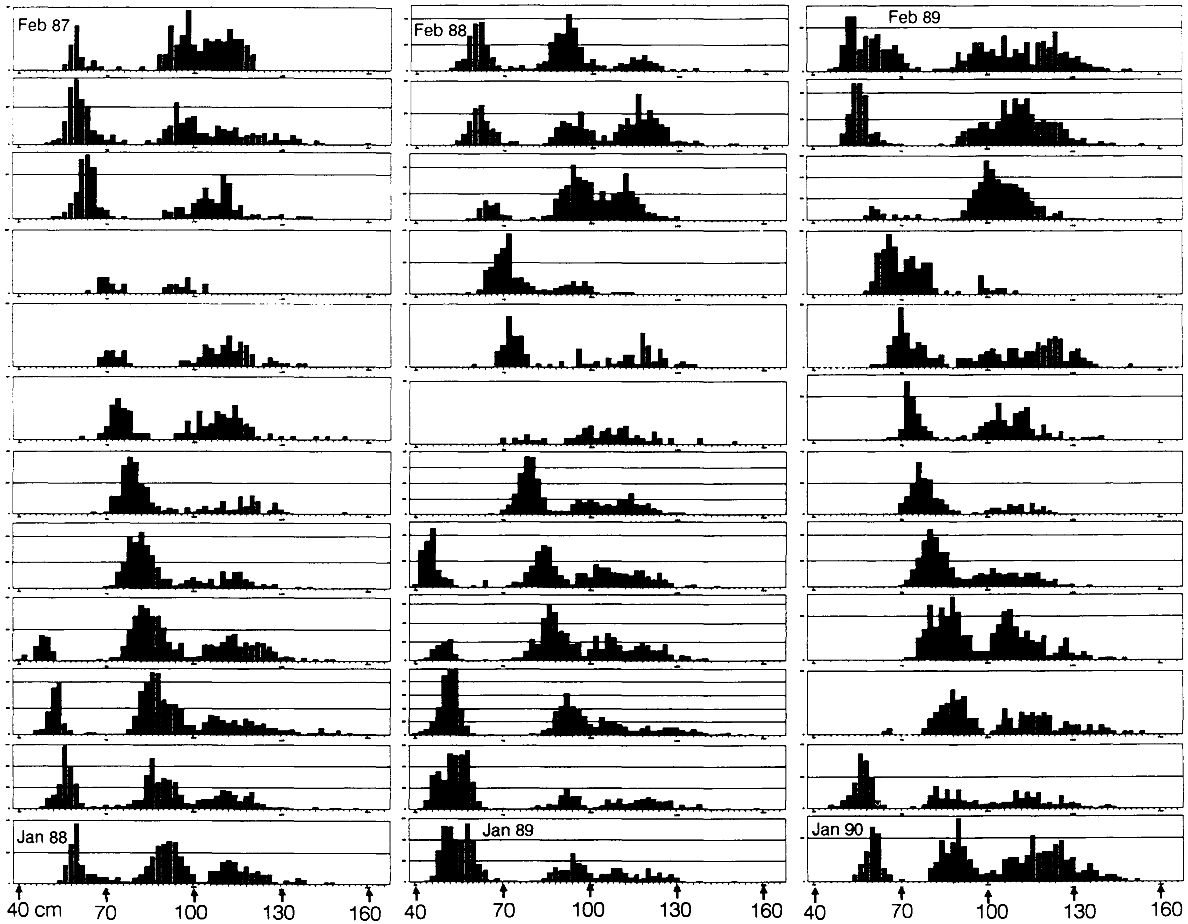

Fig. 2. Length frequency data collected from the fish market at Muttrah between February 1987 (upper, left) and January 1990 (bottom, right). The horizontal, scale, length, is from 40 to 166 cm. The vertical scale, numbers, varies: each horizontal line represents 20 fish, if no lines are present the maximum is 20 fish. The data are graphed in 2 cm intervals.

TABLE 2

Numbers of daily rings on otoliths of *S. commerson*

Date of capture	Number of daily rings	Age (years)	Length[1] (cm)	Number of annuli	Assumed fertilization data
13 Jan. 1987	165	0.45	51.7*	0	1 Aug. 1986
8 Jan. 1987	190	0.52	58.7*	0	2 July 1986
29 Jan. 1987	200	0.55	57.6*	0	13 July 1986
29 Jan. 1987	165	0.45	52.9*	0	17 Aug. 1986
15 April 1987	271	0.74	73.0	0	18 July 1986
27 April 1987	300	0.82	71.0	0	1 July 1986
27 June 1987	450	1.23	81.6*	1	3 April 1986
27 June 1987	365	1.00	89.5*	1	27 June 1986
27 June 1987	360	0.99	78.0	1	2 July 1986
15 Feb. 1988	470	1.29	99.0	1	2 Nov. 1986
31 Oct. 1987	430	1.18	95.0	1	27 Aug. 1986
15 Dec. 1987	483	1.32	84.0	1	19 Aug. 1986
15 Dec. 1987	480	1.32	88.0	1	22 Aug. 1986
14 Jan. 1988	200	0.55	64.4*	0	28 June 1986
14 Jan 1988	240	0.66	66.7*	0	19 May 1987
14 Jan. 1988	190	0.52	57.6*	0	8 July 1987
14 Jan. 1988	220	0.60	66.7*	0	8 June 1987
14 Jan. 1988	212	0.58	62.2*	0	16 June 1987
16 Oct. 1988	445	1.22	91.0	1	29 July 1987
8 Oct. 1987	192	0.53	51.7*	0	30 March 1987
8 Oct. 1987	197	0.54	52.9*	0	25 March 1987
21 Feb. 1988	233	0.64	65.0	0	3 July 1987
12 Jan. 1988	190	0.52	59.0	0	6 July 1987
14 Jan. 1988	186	0.51	63.3*	0	12 July 1987

[1]Lengths marked with an * indicate those that were estimated from jaw length.

quency data. Otolith data yield an asymptotic length very much smaller and a growth rate higher than the length data (Table 4, Fig. 4).

An even smaller L_{inf} and correspondingly higher k are obtained when a VBGF is fitted to the combined set of otolith and length frequency modal data (Table 4, Fig. 4). While this approach, using all available data, would seem to be the most appropriate, the low L_{inf} is somewhat troublesome given that *S. commerson* in Oman attain a size in excess of 200 cm and are fairly common up to a size of 150 cm. This discrepancy could be a consequence of natural variations in growth, since the parameters are mean values.

A second possibility for the discrepancy between the low L_{inf} values and the existence of larger fish is that the VBGF may not be an appropriate growth model for this species. Yamanaka (1990) found, for example, that yellowfin tuna growth was better described by two conjoined regression lines (segmented regression) than by the VBGF. Also, our examination of otolith structure indicates that incremental growth of *S. commerson* continued

TABLE 3

Data from otoliths examined for annular marks

Date of capture	Number of annuli	Calculated age (days)	Age (years)	Length[1] (cm)
17 Feb. 1987	5	2147	5.88	110.2*
18 Feb. 1987	5	2148	5.88	126.1*
15 April 1987	2	744	2.04	92.0
15 April 1987	4	1474	4.04	118.0
15 April 1987	5	1839	5.04	105.0
27 June 1987	7	2642	7.24	133.0
27 June 1987	4	1547	4.24	101.0
27 June 1987	11	4102	11.24	151.0
27 June 1987	10	3737	10.24	150.0
27 June 1987	5	1912	5.24	111.0
15 Dec. 1987	1	623	1.71	110.0
15 Dec. 1987	7	2813	7.71	126.0
15 Dec. 1987	12	4638	12.71	147.0
14 Jan. 1988	9	3573	9.79	136.3*

[1]Lengths estimated from jaw length are marked with an *.

throughout life. A segmented regression fitted to the combined data set fits the data well (Table 4, Fig. 4).

While all the possible growth curves are in general agreement when predicting size at age below a length of about 110 cm, their predictions of size at age for larger fishes differ considerably. Although fish smaller than 110 cm make up a significant portion of the catch, the potential for growth, and catches of fish larger than this size are important considerations. The VBGF fitted to the otolith and length frequency mode data predicts very little growth for fish above 110 cm. The VBGF fitted using ELEFAN, or that using the length frequency modes, predict considerable additional growth beyond that size. The segmented regression model predicts continued but slow growth, fits the available data well, and accounts for the existence of large *S. commerson*. This model seems most reasonable. It allows for very rapid growth prior to age 2, which is followed by a much slower but continuing growth. This growth pattern should be confirmed with more detailed studies of otoliths.

A variety of *S. commerson* growth parameters have been previously reported (see Thiagarajan (1989) and Cheunpan (1988) for summaries) with L_{inf} ranging from 47 to 208. Length data alone led us to believe that *S. commerson* entering the fishery at a length of about 40 cm were about 1 year old. This assumption was based on the shape of the growth curve and the size of the first mode in September. This estimate of size at age was in agreement with published data (e.g. Devaraj, 1981; Bouhlel, 1985; Cheunpan, 1988; Kedidi and Abushusha, 1987). However, size at age based on daily growth rings was found to be 50–60 cm for fish 6 months old.

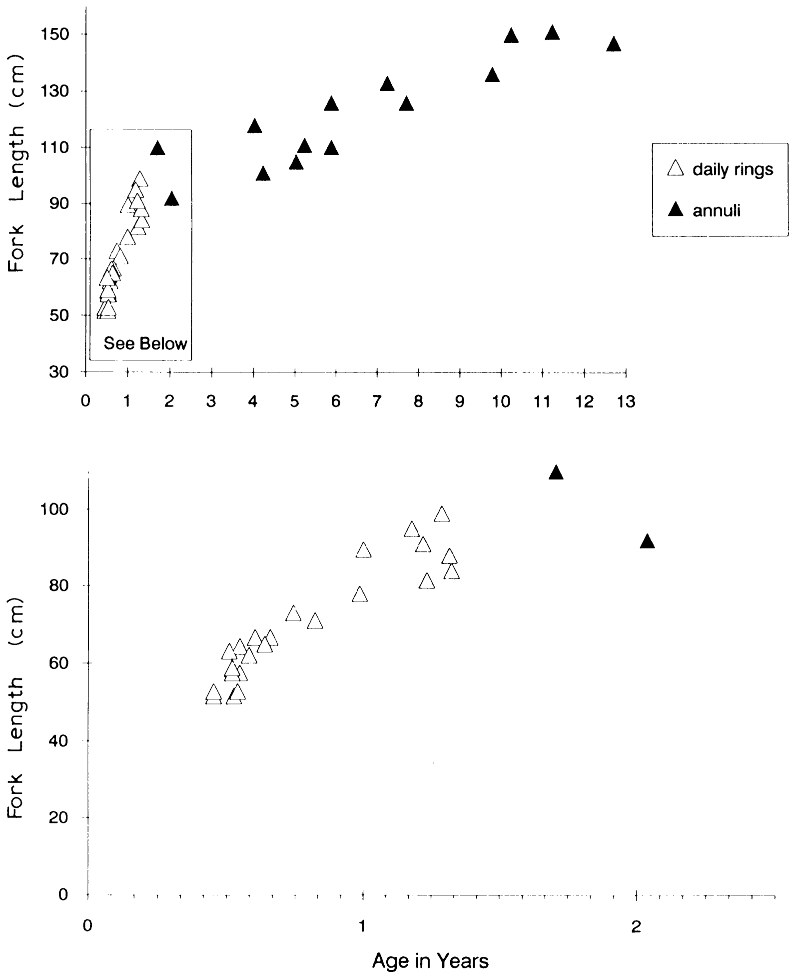

Fig. 3. Relation between *S. commerson* length and age as determined from otoliths.

Rapid growth of young *S. commerson*, similar to our finding, has been reported from Sri Lanka (Dayaratne, 1989), Australia (McPherson, 1992) and Kuwait (Brothers and Mathews, 1987). We conclude that a rapid growth phase also occurs in Omani *S. commerson*, but research in this area should be continued.

Girth

Girth measurements at the front of the second dorsal fin were used as a basis for suggesting preliminary mesh regulations (Fig. 5). This location on *Scomberomorus* has been identified as the major site of gillnet entanglement

TABLE 4

Summary of possible growth curves for *S. commerson*

Method	Type of model	L_{inf}	k	T_0
ELEFAN (2 year length data)	Von Bertalanffy	226.0	0.208	(−0.85)[1]
Least squares (length frequency modes from the Bhattacharya method)	Von Bertalanffy $R^2=0.96$	193.6	0.292	−0.678
Least squares (otolith data: daily rings and annuli)	Von Bertalanffy $R^2=0.88$	138.3	0.362	−1.16
Least squares (otolith and length frequency modes)	Von Bertalanffy $R^2=0.91$	131.2	0.614	−0.438
Least squares (otolith and length frequency modes)	Segmented regression Break point = 1.68 years (at length 100.2 cm) Segment 1: length = 36.21 age + 39.22 Segment 2: length = 4.70 age + 92.32 $R^2=0.955$			

[1]Graphically estimated.

in similar *Scomberomorus* species. Although a small proportion of individuals are caught by the head or jaws, most are caught between the back of the head and the front of the second dorsal fin (Ehrhardt and Die, 1988).

A simple yield model for S. commerson

A yield model of the type outlined by Ricker (1975) was used to investigate possible management strategies for *S. commerson*. That approach, when coupled with a standard computer spreadsheet program, has considerable flexibility. It conveniently permits exploration of seasonal variations in fishing rates, natural mortality and growth. This is important for investigating the *S. commerson* fishery since there is a strong seasonal component in the catches with significantly more fish landed in September through December of each year. Also, the effects of limiting fishing for the youngest fish (known locally as 'khabat') can be examined.

Ricker's approach is a table model with the inputs: length at age, fishing mortality at age, natural mortality at age, and a length/weight relationship. A computer spreadsheet version of this yield model was created following the format of Ricker (1975). Monthly lengths at age from the segmented regression model were input through the end of year 6 after which yearly lengths were used. We used the length/weight relationship W (kg) $=1.72\times10^{-6}\,L^{3.31}$ (cm) based on our data. The starting natural mortality rates were selected using Pauley's (1980) method as a guide, with a mean temperature of 25°C and growth parameters from the fitted VBGFs. A wide range of possible natural mortality rates was tested with the model.

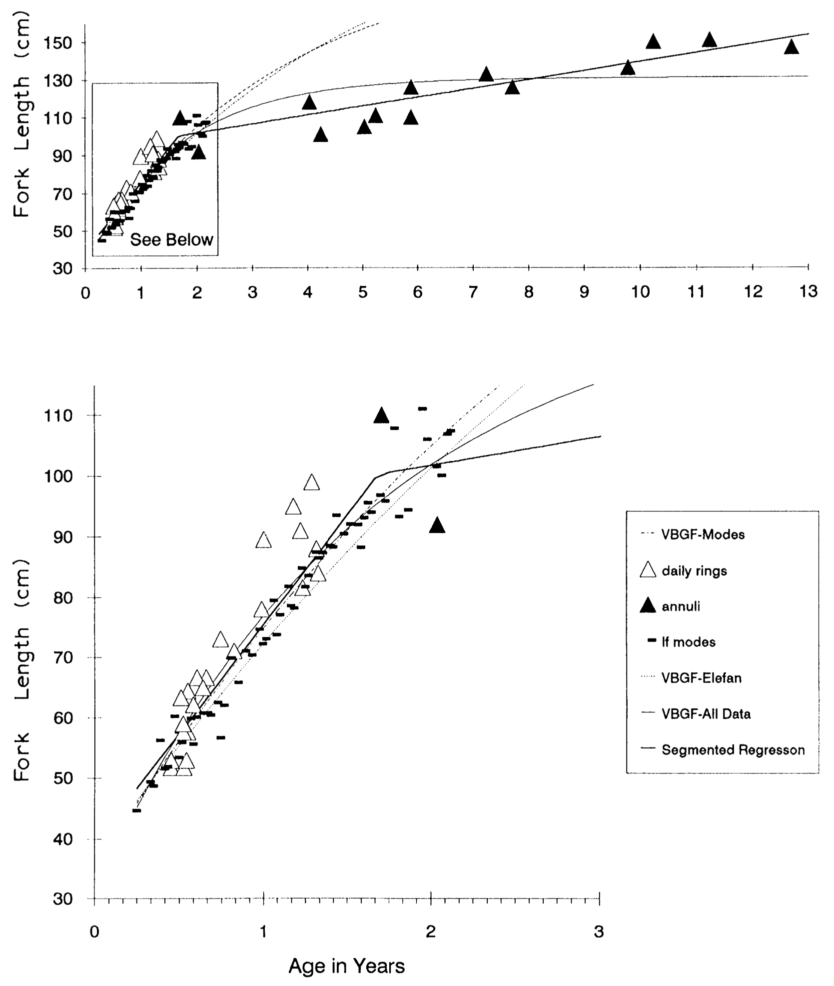

Fig. 4. Four possible growth models fitted to length frequency and otolith data. A Von Bertalanffy growth model was fitted to each of the following data sets: means of normal curves fitted to length frequency data (VBGF-Modes), raw length frequency data using ELEFAN (VBGF-Elefan), combined set of means of normal curves and otolith data (VBGF-All Data). A segmented regression was also fitted to the combined data set (Segmented Regression).

The primary output from the model is yield in weight vs. age group (by month through year 6 and by year through age 18). Yield in numbers can also be approximated (yield in weight of a given age group (by month) divided by mean individual weight within that age group). A portion of the model is presented in Table 5. Predicted yields, or catches, from the model are relative, not actual or recommended, catches. However, the model was adjusted to approximate the actual fish yield, and changes induced in the model (caused

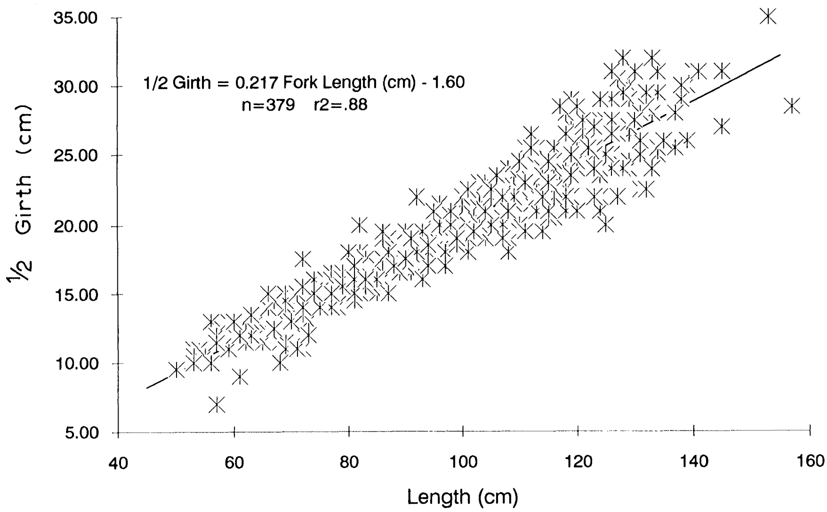

Fig. 5. Girth measurements and line fitted to them for use in estimating approximate gillnet mesh regulations.

by changes in fishing intensity, for example) should predict relative changes in the fishery.

A 'seasonality' sub-table adjusted monthly fishing mortality rates for seasonal changes in abundance of *S. commerson* in the fishery. These monthly values, which have a mean of one, proportionally adjust the values of fishing mortality prior to their incorporation into the main yield table. The starting values for the 'season ratios' were derived from monthly *S. commerson* catch statistics for 1988 and 1989 (Fig. 6).

A sub-table for 'fishing intensity' permitted simultaneous adjustment of fishing mortality in 6 month blocks (August through January and February through July) during the first 4 years fish are in the fishery and by year thereafter. The 6 month blocks roughly correspond to the major fishing seasons. This allowed the investigation of possible regulations during different seasons and for different age groups of fish. Varying the values in this table allowed us to test possible management strategies such as the protection of young *S. commerson*, and also allowed adjustment of natural mortality rates (Table 6).

A sub-table for 'khabat selection' permits the user to change multipliers to adjust the gradual entry of young *S. commerson* (khabat) into the size range vulnerable to the fishing gear (Table 7).

Annual fishing mortality rates entered in the fishing intensity table are mul-

TABLE 5

Example of a portion of the yield table based on the standard set of input variables. Calculations are based on Ricker (1975). An arbitrary stock size of 10000 mt was selected as the starting point

Age (months)	Age (years)	Length (cm)	Weight (kg)	Growth G	Natural mortality M	Fishing mortality F	G–F–M	Weight change factor	Weight of stock (t)	Average weight (t)	Yield (mt)	Corresponding yield in numbers
3	0.25	48.3	0.644						10000			
4	0.33	51.3	0.787	0.201	0.050	0.060	0.091	1.095	10948	10474	629	800049
5	0.42	54.3	0.950	0.189	0.050	0.088	0.051	1.052	11520	11234	992	1044022
6	0.50	57.3	1.137	0.179	0.050	0.116	0.013	1.013	11672	11596	1344	1182509
7	0.58	60.3	1.347	0.170	0.050	0.071	0.049	1.050	12259	11965	846	627804
8	0.67	63.4	1.583	0.162	0.050	0.053	0.059	1.060	12998	12629	669	422654
9	0.75	66.4	1.847	0.154	0.050	0.071	0.033	1.034	13439	13218	934	505884
10	0.83	69.4	2.139	0.147	0.050	0.026	0.071	1.073	14422	13931	369	172496
11	0.92	72.4	2.463	0.141	0.050	0.009	0.082	1.086	15656	15039	132	53731
12	1.00	75.4	2.820	0.135	0.050	0.018	0.068	1.070	16751	16204	285	101141
13	1.08	78.4	3.211	0.130	0.050	0.026	0.053	1.055	17669	17210	456	142006
14	1.17	81.5	3.638	0.125	0.050	0.035	0.040	1.040	18383	18026	636	174878
15	1.25	84.5	4.103	0.120	0.050	0.159	−0.089	0.915	16825	17604	2798	681955
16	1.33	87.5	4.609	0.116	0.050	0.300	−0.234	0.791	13312	15069	4526	982171
17	1.42	90.5	5.156	0.112	0.050	0.177	−0.114	0.892	11873	12592	2224	431405
18	1.50	93.5	5.747	0.109	0.050	0.155	−0.096	0.908	10786	11329	1751	304662
19	1.58	96.6	6.384	0.105	0.050	0.071	−0.016	0.985	10619	10702	756	118483
20	1.67	99.6	7.069	0.102	0.050	0.053	−0.001	0.999	10607	10613	562	79552
21	1.75	100.5	7.300	0.032	0.050	0.071	−0.088	0.915	9710	10158	718	98344
22	1.83	100.9	7.395	0.013	0.050	0.026	−0.064	0.938	9111	9410	249	33712
23	1.92	101.3	7.490	0.013	0.050	0.009	−0.046	0.955	8702	8906	78	10464
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
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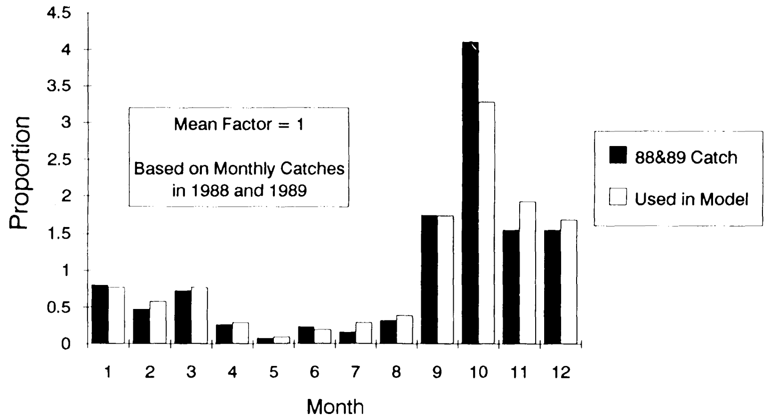

Fig. 6. Ratios of *S. commerson* landed each month and ratios used in yield model. The mean of monthly catches from 1988 and 1989, shown here, were used as a basis and were modified slightly for use in the model.

TABLE 6

Starting point standard inputs used for spreadsheet yield model

Age of fish		Annual rates	
Year No.	Months	*M*	*F*
Khabat (1)	Oct.–Jan.	0.6	1.1
1	Feb.–July	0.6	1.1
2	Aug.–Jan.	0.5	1.1
2	Feb.–July	0.5	1.1
3	Aug.–Jan.	0.5	1.1
3	Feb.–July	0.5	1.1
4	Aug.–Jan.	0.5	1.1
4	Feb.–May	0.5	1.1
5, 6, +		0.5	1.1

Annual rates (*M* and *F*) are natural and fishing mortality, respectively. *F* is later modified by seasonal factors and khabat selection factors.

tiplied by the seasonality factor and khabat factor prior to entry into the main table. If desired, fishing and natural mortality rates can be entered directly into the main table.

A standard set of input variables was selected (Tables 6 and 7). The output from these roughly corresponds to the current situation in the fishery, and was used as the basis for comparison with other fishing levels (Figs. 7–9). Predicted monthly catches (Fig. 7) mimic the actual catch (Fig. 6). Under these conditions, catches of fish older than about 1 year (larger than about 75 cm) make up most of the catch by weight (Fig. 8), but catch by numbers has

TABLE 7

Multipliers used to modify fishing mortality prior to entry into main table of model

Month No.	Season ratios	Khabat selection factors
1	0.77	1.00
2	0.58	Not used
3	0.77	Not used
4	0.29	Not used
5	0.10	Not used
6	0.19	Not used
7	0.29	Not used
8	0.39	Not used
9	1.73	Not used
10	3.28	0.20
11	1.93	0.50
12	1.69	0.75

Season ratios adjust catches to conform to current seasonality of catches in Oman. Khabat selection factors adjust fishing intensity for the current approximated mesh selection for young kingfish.

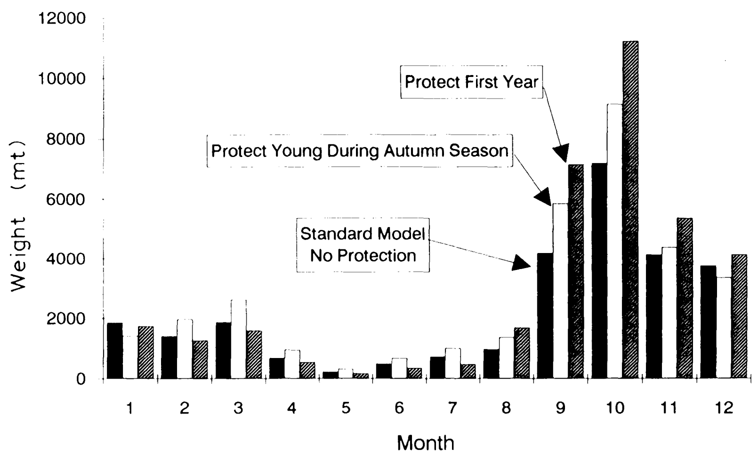

Fig. 7. A comparison of *S. commerson* catch per month under three management strategies: no special protection for young *S. commerson*, protection during the autumn season, and protection of young during their first year.

a significant proportion of *S. commerson* smaller than 75 cm caught during the autumn season (Fig. 9). Relative total catch was 27 477 t under this scenario (Table 8).

A reasonable management action would be to protect young, fast growing *S. commerson* (khabat). This possibility was tested with the model using two approaches: one which would protect khabat during the autumn season

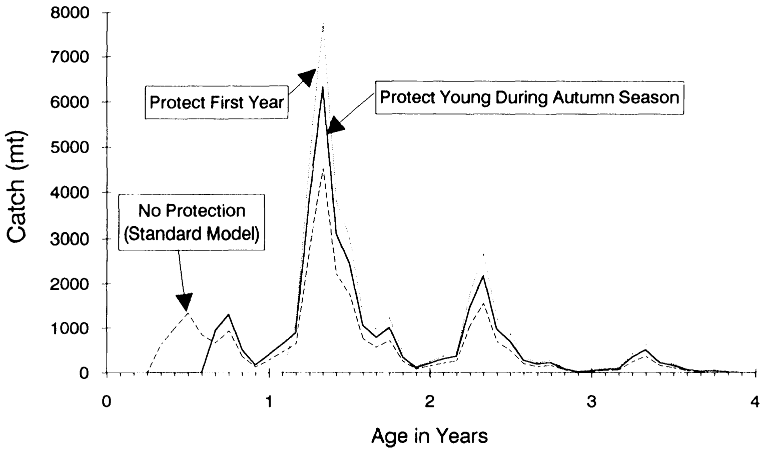

Fig. 8. Predicted relative catch in weight of *S. commerson* under three management strategies. A comparison with Fig. 9 indicates the importance of small fish in providing large numbers but comparatively little weight to the catch.

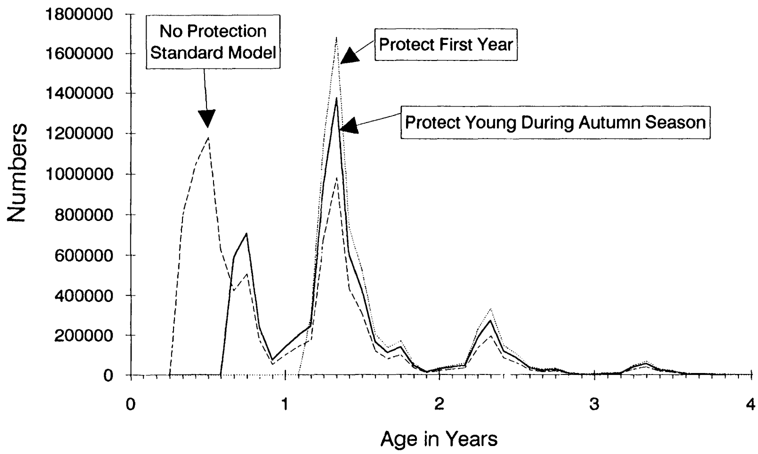

Fig. 9. Predicted relative catch in numbers of *S. commerson* under three management strategies. A comparison with Fig. 8 indicates the importance of small fish in providing large numbers but comparatively little weight to the catch.

(through January), and one which would protect *S. commerson* during their entire first year (through July). The first is more realistic of the two from a social perspective for reasons given below, but either could be accomplished via enforcement of minimum mesh regulations for gillnets which are used primarily for *S. commerson.*

Protection of rapidly growing young *S. commerson* during the autumn season would result in an overall increase in catch of 20%. In spite of the

TABLE 8

Effect of protecting young on relative monthly catch (t)

Month	No protection for young	Protect young during			
		Fall season		First year	
		tonnes	% change	tonnes	% change
1	1859	1417	−24	1735	−7
2	1407	1967	40	1264	−10
3	1866	2609	40	1596	−14
4	693	968	40	554	−20
5	234	327	40	175	−25
6	490	686	40	352	−28
7	732	1023	40	472	−35
8	981	1371	40	1680	71
9	4172	5833	40	7146	71
10	7179	9156	28	11217	56
11	4119	4372	6	5356	30
12	3744	3355	−10	4111	10
Total	27477	33083	20	35657	30

For 'no protection' F held at 1.1. For 'protection' $F=0$ during appropriate stated time period. M held at 0.6 during Years 1 and 2 and 0.5 thereafter.

reduced catch of young fish, the catch during the autumn season would increase, starting the autumn following the start of regulation, because of an increased catch of 2 year olds (Figs. 7–9, Table 8).

If fish were protected during their entire first year, by using a larger minimum mesh regulation, then yearly catch would increase by 30% (Figs. 6–8, Table 8). The catch under this scenario would be less uniformly distributed over the year than it is under the standard model. A much larger proportion of the catch would be taken in August through December and significant decreases would occur during several months (Table 8).

Although the standard model is assumed to approximate the fishery, the actual fishing mortality and natural mortality are not known. However, any reasonable guess of current fishing and natural mortality levels would lead to the same conclusion: protection of young *S. commerson* will lead to an increase in *S. commerson* catch. One can also conclude that, the more intense the fishing, the more beneficial the protection of young fish will be. In general lower natural mortality rates would also make the protection of young *S. commerson* from fishing more beneficial (Fig. 10).

In the absence of fishing, the critical size (the size at which a cohort has its maximum biomass) of Omani *S. commerson* is 108 cm at an age of about 2 years. However, at the assumed base fishing and natural mortality levels rel-

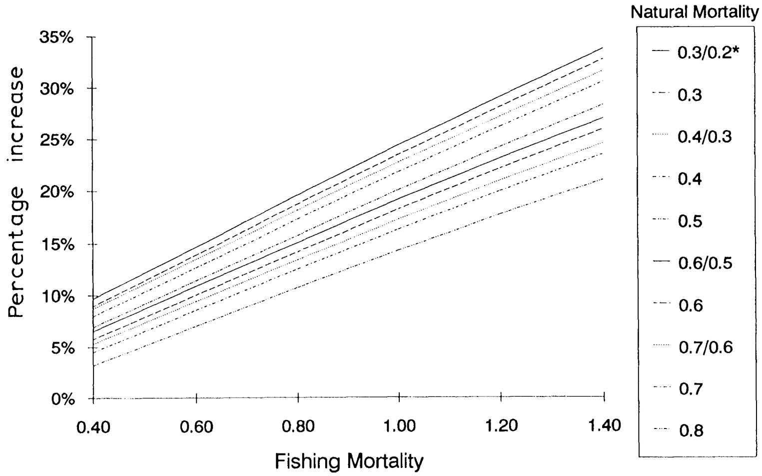

Fig. 10. Predicted increase in total catch by weight resulting from protection of young *S. commerson* during the autumn season under different assumed fishing and natural mortality rates. Current fishing mortality rates are perhaps between 0.8 and 1.2 and natural mortality rates between 0.4 and 0.7.

atively little benefit would be derived from protecting fish beyond approximately 1 year of age and a length of about 80 cm.

This model considers only numbers and growth. It does not deal with variations in reproductive success. Our observations indicate that some Omani *S. commerson* spawn at the end of their first year at a size of 75–80 cm, but a large proportion, perhaps 50%, first spawn when larger. Also, larger fish have more eggs. Based on Devaraj's (1983) equation for *S. commerson* in southern India we can conclude that 1-year-old (80 cm) *S. commerson* spawn an average of 590 000 eggs while age 2 fish (110 cm) spawn about 1 500 000. Thus, protection of young *S. commerson* could also enhance the stock's reproductive success. Using the yield model to approximate numbers at age in the stock, we can compare overall fecundity of the population under different management strategies. In comparison with the population under the standard input model, protection of young fish during the autumn season would increase overall production of eggs by 40%. While this may enhance the overall health of the population, it is quite likely that environmental factors, such as the strength of regional upwelling, play a major role in survival of eggs and larvae. Also, the form of the stock recruit relationship is not yet known.

Implications for management

The model of the *S. commerson* fishery reveals that increases in the weight of the total catch could be obtained by protecting young *S. commerson*. This finding is valid for a wide range of assumed fishing and natural mortality rates. The necessary protection could be accomplished by regulating mesh sizes in nets used primarily for *S. commerson*. Although some small *S. commerson* would continue to be caught in nets targeting other species, this incidental catch would probably be minimal. Minimum mesh regulations would also allow more *S. commerson* to reach spawning age.

A minimum mesh regulation requiring stretch mesh sizes of 4.75 in or 12 cm would protect some young *S. commerson* (khabat) during the autumn season. This is close to what is now normally used, except in special nets made specifically for khabat. Phasing out of the khabat nets might be a viable first step in increasing yields from the fishery. A second and more beneficial step would be establishment of a 5 in (12.7 cm) regulation which would provide more protection for these young *S. commerson* during the autumn season. This would probably be acceptable to fishermen if the benefits were made sufficiently clear.

In order to protect most *S. commerson* during their entire first year a mesh regulation of at least 5.5 in (14 cm) would be needed. This would provide the most benefit to the fishery if only increased yield is considered. A 6 in (15.24 cm) regulation might even be considered if sufficient additional evidence of its benefit is obtained.

Concurrent studies suggest that these mesh regulations would have little negative impact on catches of another important species, *Thunnus tonggol* (longtail tuna), which is caught with the same type of gear. Potential effects on catches of other species should be assessed, but are believed to be minimal.

Nevertheless, it may be difficult to convince fishermen of the benefits of a 5.5 or 6 in minimum mesh regulation. An important consideration from the fishermen's point of view may be the relative value of *S. commerson* of different sizes. Because *S. commerson* are usually marketed whole, small and intermediate size fish are generally more valuable on a per weight basis because they can be handled, transported and sold more easily. Larger fish, perhaps over 10 or 12 kg, are more difficult to sell and, in some instances, in areas away from major markets, may bring considerably less income to the traditional fishermen than several smaller fish with the same total weight. The higher value of smaller fish might make larger minimum mesh regulations less popular than would be expected. Also, catches under a 5.5 in regulation would vary even more from season to season than they do now. This may present difficulties in marketing since additional cold storage and transport facilities would be needed to handle the increased catch during a very restricted part of the year. At present fishermen sometimes experience difficulty marketing their catch during October and November.

Although primarily coastal, *S. commerson* are migratory and there is valid concern that benefits of improved management in Oman would not go only to local fishermen who would perceive themselves as having made substantial sacrifices. However, Oman harvests significantly more *S. commerson* than do adjacent countries so more benefits would be realized in Oman. Also, Shaklee and Shaklee (1990) found genetic differences between Gulf (samples from Dubai) and Omani (samples from Masirah Island) and Djibouti *S. commerson* populations and felt that management of *S. commerson* in the region should take this stock heterogeneity into account. Nevertheless, significant amounts of *S. commerson* are harvested in Iran and Pakistan and it is not yet known if these fish are from the same population.

At present a 5 in (12.7 cm) minimum mesh regulation for *S. commerson* nets would appear to provide significant benefits at minimal risk. In the future, after appropriate study, this might be increased to 5.5 in (14 cm). Possible complicating factors associated with such a regulation might be the lower relative value of larger compared to smaller *S. commerson*, possible increased variation in the *S. commerson* catch from season to season, and the fact that the *S. commerson* stock may be shared with other countries.

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