AGE AND GROWTH OF MARKET SQUID (*LOLIGO OPALESCENS*) OFF CALIFORNIA DURING 1998

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ABSTRACT

Daily increments in statoliths indicate that both male and female market squid (*Loligo opalescens*) mature as early as 6 months after hatching. An analysis of 192 statolith pairs revealed maximum ages of 238 days for females and 243 days for males during 1998. These ages indicate that market squid may be a semiannual species and that spawning peaks may occur twice in a calendar year. Growth rate derived from size-at-age information was best described by a linear equation, with no difference between sexes.

INTRODUCTION

Market squid (*Loligo opalescens*) has been the basis of an important commercial fishery in California since the 1850s. The fishery takes place in northern California and southern California at different times of the year. The northern fishery season (mainly in Monterey Bay) traditionally occurs from April through November (fig. 1); the southern fishery (mostly in the Channel Islands vicinity) begins in October and generally lasts through March (fig. 2). Most squid are caught by fishers using lights to attract aggregations to the surface, where the squid are netted with brails, lamparas, and purse seines. The method of capture differs significantly from that for other loliginid fisheries worldwide (Hatfield et al. 1990; Augustyn et al. 1993), because fishing is done directly on spawning sites.

In the last decade, increases in catch and price have combined to make market squid the most valuable fishery in the state. Landings peaked in the 1996–97 season (1 April through 30 March; fig. 3), totaling over 113,000 metric tons valued at approximately $41 million. As a result of elevated sea-surface temperatures attributable to the 1997–98 El Niño event (Leos 1998), landings declined dramatically during the 1997–98 season to below

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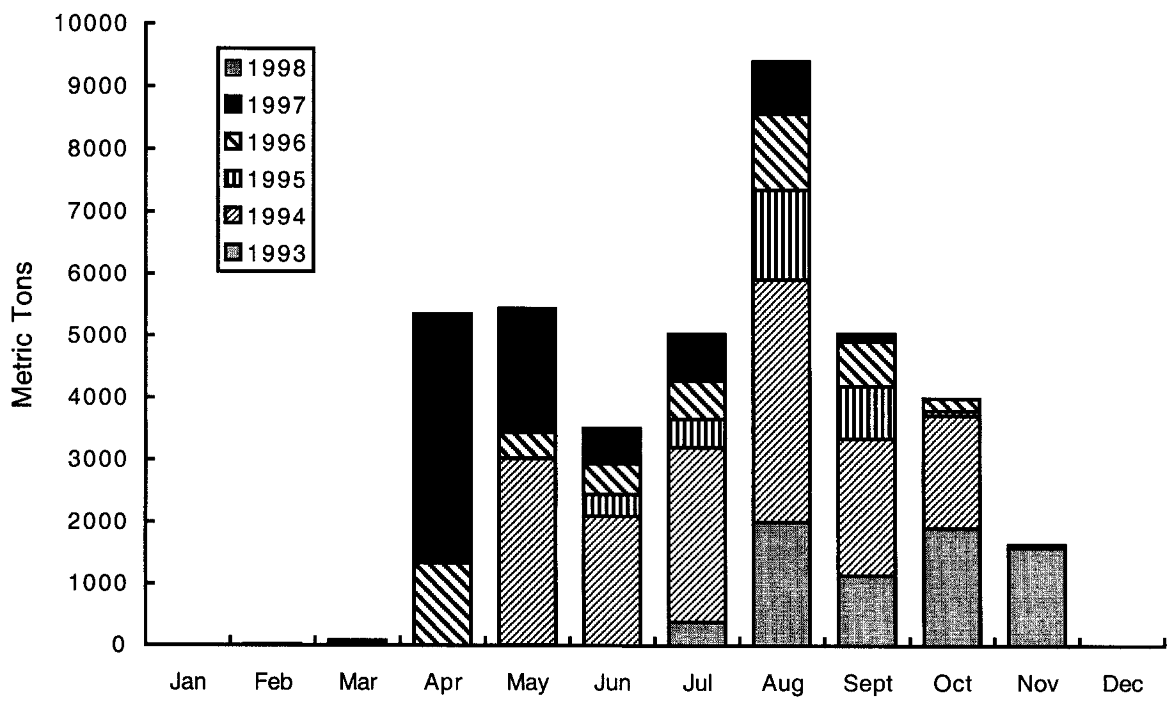

Figure 1. Monthly market squid landings in California north of Point Conception, 1993–98. Data for 1998 are preliminary.

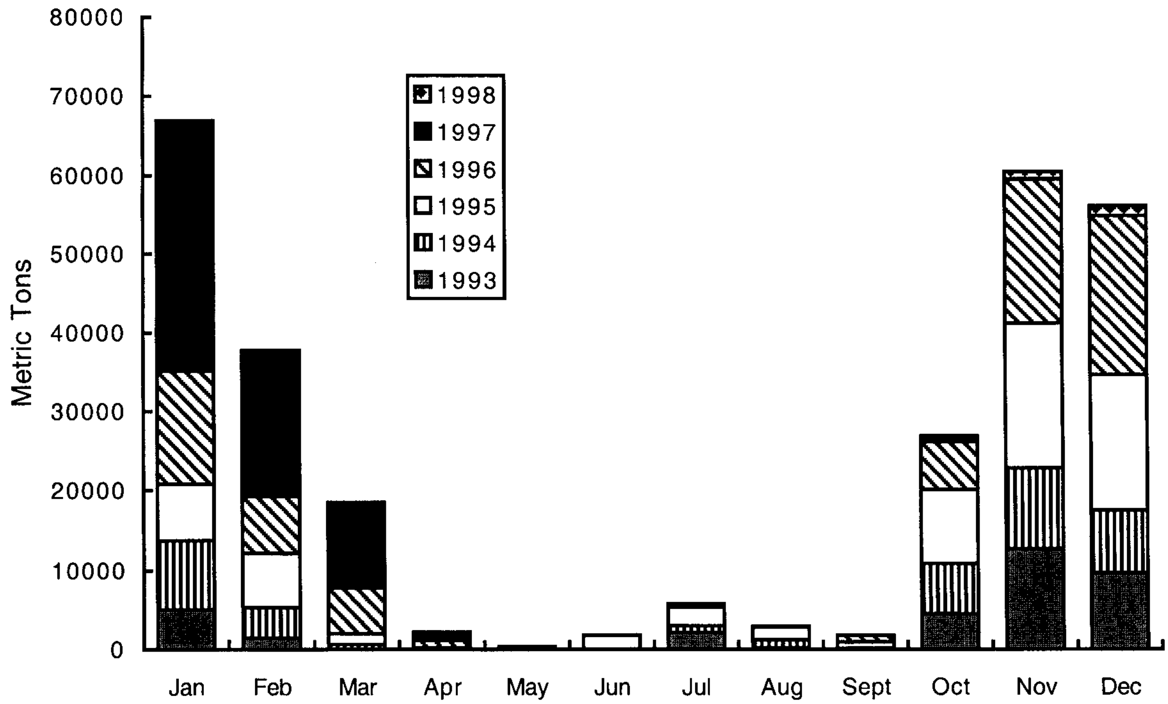

Figure 2. Monthly market squid landings in California south of Point Conception, 1993–98. Data for 1998 are preliminary.

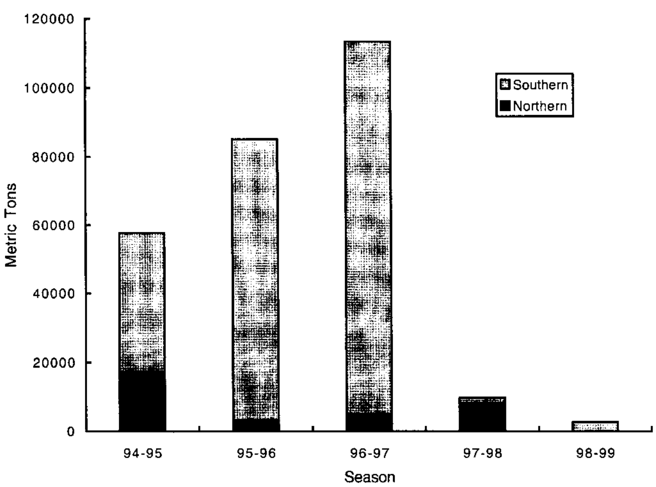

Figure 3. Seasonal (April through March) market squid landings in California, 1993–94 through 1998–99. Data for 1998–99 are preliminary.

10,000 t. In the first quarter of 1998, fewer than 40 t of squid were landed, compared with over 60,000 t landed for the same time period in the 1996–97 season.

Squid statoliths are calcareous structures analogous to fish otoliths (Rodhouse and Hatfield 1990a). Clarke (1966) first observed microincrements in squid statoliths and suggested that they might be useful for age determination. Although this observation predates Pannella's (1971) observation of microincrements in fish otoliths, the use of daily increments to age squid did not gain general acceptance until the mid-1980s (Hurley et al. 1985; Lipinski 1986; Jackson 1990a, b, 1994; Bettencourt et al. 1996; but see also Spratt 1978). Conversely, the application of daily increment analysis to fish otoliths was quickly accepted (Brothers et al. 1976; see also Campana and Neilson 1985, and Jones 1986 for reviews). The daily formation of microincrements has been validated in *Loligo opalescens* by Yang et al. (1980 and 1986). We adopted the daily ageing criteria of Yang et al. (1980 and 1986) and Jackson (1994) to age market squid.

Many aspects of the life history of market squid remain unknown. The California Department of Fish and Game and the National Marine Fisheries Service, recognizing the need for better scientific information on squid, held a meeting in August 1997 to identify priorities and develop a joint state and federal research protocol. Age and growth of squid ranked among the top objectives. This paper describes the age and growth of market squid and is the first contribution from the joint project. Although the data are preliminary and collection efforts spanned only one year (1998), knowledge of growth and longevity is crucial to management of the species.

MATERIALS AND METHODS

Market squid were collected with several gear types and at various times and locations throughout 1998 (table 1). We do not attempt to analyze variations in growth rate that may be attributable to these differences.

During a research cruise on the RV *David Starr Jordan* from 6 to16 January 1998, adult market squid were taken

TABLE 1
Squid Samples Collected in 1998 and Analyzed for Age and Maturity

Date	Number	Maturity	Gear type	Location
1/11/98	20	Juvenile	Midwater trawl	Off Santa Catalina Is.
1/12/98	111	Mature	Bottom trawl	Off Santa Cruz Is.
3/11/98	3	Juvenile	Commercial seine	Off Santa Catalina Is.
3/11/98	10	Mature	Commercial seine	Off Santa Catalina Is.
3/12/98	2	Juvenile	Commercial seine	Off Santa Catalina Is.
3/12/98	29	Mature	Commercial seine	Off Santa Catalina Is.
7/9/98	13	Juvenile	Midwater trawl	Off Purisima Pt.
7/10/98	7	Juvenile	Midwater trawl	Off Purisima Pt.

in bottom trawls at depths of 105, 225, and 440 m, at bottom temperatures of 8.3°–13.6°C. Juveniles were collected in one midwater trawl tow to depths of 95 m. In July 1998, squid were sampled with midwater trawls on the FV *Predator* at 34°31.02"N, 120°52.79"W. Additional samples were obtained from squid caught commercially by purse seine at Santa Catalina Island and landed in San Pedro on 12 and 16 March 1998. Light boats were used to aggregate the squid near the surface for those catches.

Daily growth increments in 192 statolith pairs were analyzed to back-calculate birth date. Statoliths were removed from all squid, stored dry in gelatin capsules, and later mounted on microscope slides with thermal plastic material. After polishing the statoliths, we enumerated daily increments by using Image Pro Plus software integrated with a spot CCD digital camera mounted atop a Leica DMLB compound microscope. The best images for analysis were obtained with a neutral-density light filter and no polarization.

Dorsal mantle length (mm) and weight information were taken from all specimens analyzed. Sex and state of maturity were observed in samples collected in the field, but we were unable to determine maturity in frozen samples. Females were considered to be mature if hydrated eggs were present in the ovary and oviduct; males were determined mature if spermatophores were present in the testes and spermatophoric sac.

RESULTS AND DISCUSSION

Catches

The onset of El Niño corresponds precisely with the decline in squid landings during 1997–98 (see Lynn et al. 1998 for complete documentation of El Niño conditions in the California Current). Additionally, El Niño conditions severely reduced squid catches during 1973, 1983–84, and 1992. Despite this, we believe the squid continued to reproduce during the 1997–98 El Niño, but avoided the warmer waters at the surface and traditional southern California spawning locations.

Market squid did not respond to commercial light boat efforts on traditional squid fishing locations near Santa Catalina Island, Santa Cruz Island, and Santa Rosa Island during January 1998, a month when peak fishing activity normally occurs in southern California. Similarly, during the January 1998 research cruise, no squid were seen at the surface under lights deployed to attract them. CTD profiles taken concurrently with the positive trawl efforts indicate that temperatures exceeded 17°C at depths shallower than 45 m, and exceeded 14° at depths shallower than 75 m (fig. 4). Squid were not taken in trawls at depths shallower than 95 m.

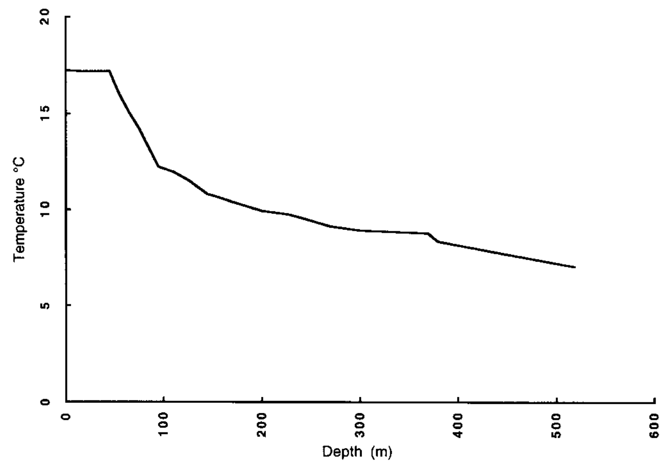

Figure 4. Temperature profile at CalCOFI station 90.37 on 14 January 1998.

Although adults collected at depths of 95 m and below were mature, no egg cases were collected concurrently in the trawls. However, commercial trawlers reported significant volumes of squid eggs in nets deployed at depths to 720 m off Carmel, California. These eggs were incubated and positively identified as market squid (Jerry Spratt, CDFG, pers. comm.). Thus it appears that squid were spawning in southern California but not at the normal depths of the traditional fishing grounds, probably because of warmer temperatures both at the surface and at depth. The extent of spawning compared to normal years is unknown.

Growth Rates

Size-at-age determined by statolith increment analysis indicates that market squid do not grow asymptoti-

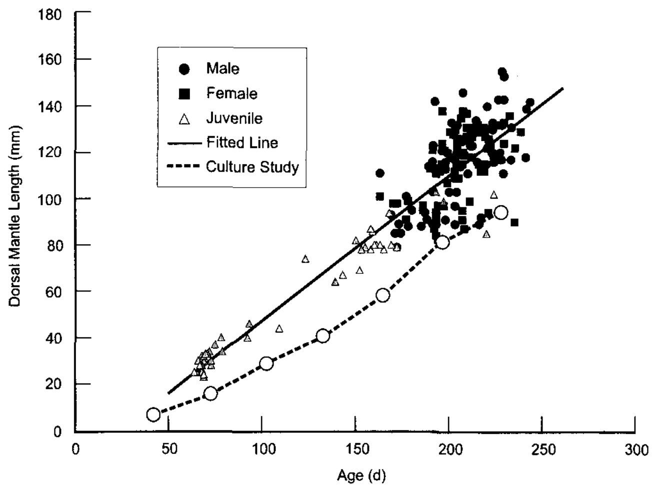

Figure 5. Size at age of male, female, and immature market squid (*Loligo opalescens*) taken in 1998. Solid line is DML = −14.7 + 0.627*Age. The dashed line is the trajectory of the reared specimens (Yang et al. 1986). R^2 value = 0.83.

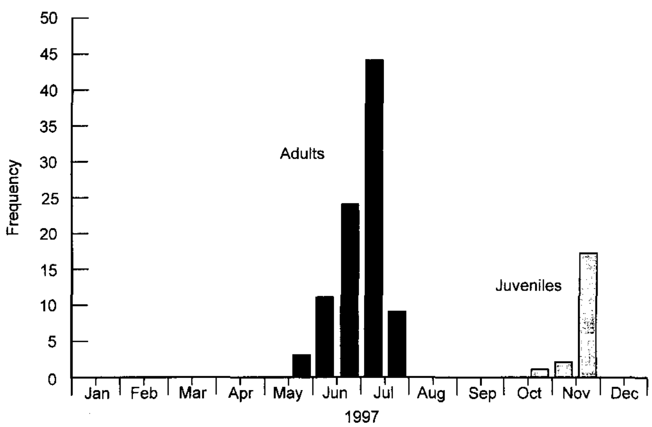

Figure 6. Distribution of hatching dates of market squid collected in 1998.

cally. Growth in length was best described with a linear equation (fig. 5), rather than an exponential or power function: DML = −14.7 + 0.627★Age, where DML is dorsal mantle length and Age is in days.

Growth averages about 0.6 mm DML per day. The youngest mature male and female aged were 163 days. The oldest female was 238 days, and the oldest male 243 days. There was no significant variation in growth rate between male, female, and indeterminate individuals.

The back-calculated birth dates of adult squid collected in January 1998 indicate that these squid hatched during May–July 1997 (fig. 6). Juvenile squid collected in January were born during November 1997. All of these squid were born during and survived El Niño conditions (Lynn et al. 1998), a period when little or no squid were landed, and no squid were observed on the shallow-water spawning grounds. We believe that our specimens were derived from eggs deposited at depth.

Growth rates reported here are similar to those determined for laboratory specimens (fig. 5). Jackson (1998) reviewed growth rates for market squid and concluded that early work by Fields (1965) and Spratt (1978) had underestimated growth and overestimated longevity, which had been determined at about 2 years. In more recent laboratory experiments (Yang et al. 1980, 1986) and supported by Jackson's (1994) 12 field specimens, squid demonstrated higher growth rates than previously reported, with maturation in less than 200 days and life spans of up to 300 days. Similarly, our study indicates maturation in less than 200 days, with life spans not exceeding 250 days.

Differences between our results and those of Jackson (1994) may be attributed to regional variation; his samples were collected from Monterey Bay and ours from southern California. Additionally, Jackson's (1994) samples were from a normal year in terms of water temperature, whereas ours were from an El Niño year. Seasonal variation may have affected our results as well; seasonal differences in growth rate have been reported for other loliginids, including the Patagonian squid (*Loligo gahi*; Rodhouse and Hatfield 1990b), long-finned squid (*Loligo pealei*; Brodziak and Macy 1996), and *Lolliguncula brevis* (Jackson et al. 1997).

The short life span and early maturation of market squid reported here are consistent with those reported for other species of *Loligo* (Collins et al. 1995; Bettencourt et al. 1996; Brodziak and Macy 1996). However, life spans of less than one year for California market squid would appear inconsistent with commercial fishery landings that show strong annual cycles.

Several scenarios could reconcile these inconsistencies. Strong seasonal landings trends may result from within-season cohorts who display different growth and survival rates. Brodziak (1998) and Brodziak and Macy (1996) have proposed this scenario for the long-finned squid in the northeast Atlantic.

However, the fact that the northern and southern California fisheries peak six months apart might suggest a second hypothesis: recruits from successful Monterey spawning activity may become the adults taken in the southern California fishery, and vice versa. The birth date distribution of adult squid spawning in southern California in January 1998 indicate that these individuals hatched from eggs deposited during the summer of 1997, which corresponds to the spawning period in northern California. This hypothesis is weakened somewhat by the fact that landings in northern California account for only about 12% of the statewide total. The northern California cohort would therefore probably exhibit a higher recruit-to-spawner ratio in order to perpetuate the population. At present there is no evidence to support a higher survival rate for eggs and larvae spawned in northern California.

A third hypothesis is that significant spawning activity may take place in southern California during the summer, but at depths which generally preclude commercial fishing with lights to attract squid to the surface. A research cruise aboard the RV *Mako* in August 1998 documented some summer egg-case deposition on southern California fishing grounds that in recent years have supported high-volume landings during winter. It is possible that additional spawning is occurring at greater depths.

The resolution of this paradox will require further study of the growth rates and life spans of cohorts from both northern and southern localities over several seasons as well as greater understanding of the depth distribution of squid spawning.

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