Reproductive-somatic relationships in *Loligo gahi* (Cephalopoda: Loliginidae) from the Falkland Islands

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Abstract: Samples of *Loligo gahi* from the Falkland Islands Interim Conservation and Management Zone collected in March 1987 were analysed to determine the relationships between mass of reproductive and somatic organs during maturation. There was a progressive increase in mass of the reproductive organs with growth in males, while in females these organs did not show a conspicuous increase in mass until a body mass of c. 40 g was reached. No change was found in the mass of the digestive gland in relation to body mass or in the water content of male and female somatic tissues during maturation. Growth of reproductive organs in *L. gahi* seems to be supported by diet and not at the expense of somatic tissue.

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Introduction

Cephalopods are very active organisms with high metabolic costs supported by high rates of food ingestion (O'Dor & Wells 1987). The food ingested has to provide enough energy and nutrients for their routine and active metabolism, rapid growth and reproduction. Feeding rate, growth and reproduction are strongly related in cephalopods. In female *Octopus vulgaris* gonad development constricts the gut preventing feeding (O'Dor & Wells 1978). Moreover, the posterior salivary glands degenerate as does the digestive gland; even if an *Octopus* did take a crab, it would be unable to digest it (Tait 1986, Mangold *et al.* 1993). Experimentally starved *Illex illecebrosus* accelerate their sexual maturation (Rowe & Mangold 1975). Increasing energy demand for gonad development can reduce or even halt somatic growth. Also, if food ingestion is limited, somatic tissues may be used for gonad production, sometimes leading to individuals being emaciated at spawning (Hamabe 1969, O'Dor & Wells 1987). The semelparous life cycle of many cephalopods favours this dramatic shift of nutrients and energy from growth to reproduction. Nevertheless, some species have been reported not to break down somatic tissues for gonad production but to derive all the necessary energy from food (Mangold *et al.* 1993).

Loligo gahi d'Orbigny 1835 is a neritic loliginid squid distributed over the continental shelf and the slope of the Eastern Pacific Ocean from southern Peru to southern Chile, and in the South Atlantic from the Gulf of San Matías to Tierra del Fuego (Roper *et al.* 1984, Brakoniecki 1986). It is caught commercially using both pelagic and bottom trawls during two fishing seasons, February–June and August–September, usually within the depth range 140–200 m (Hatfield *et al.* 1990). Catches inside the Falkland Islands Interim Conservation and Management Zone (FICZ) were 82500 t in 1987 (Anon. 1989). Hatfield *et al.* (1991) report recruitment of two or three broods into the fishery per year. The lifespan of the species approximates

one year (Patterson 1988, Hatfield 1991), although Arancibia & Robotham (1984) have estimated a lifespan of two or three years in southern Chile. There is evidence that *L. gahi* spawns and dies in shallow water and the next generation migrates offshore where it grows and matures (Hatfield *et al.* 1990). Females attain a larger size than males, but males mature earlier than females and attain full sexual maturity at a younger age and at a smaller size (Hatfield *et al.* 1990).

Few data are available on maturation of *L. gahi* males and females, and little is known about the expenditure of nutrients and energy for the development of reproductive organs. In both sexes of the ommastrephid squid *Illex argentinus* from the Patagonian shelf, production seems to shift from growth to reproductive organs during the course of maturation. The development of reproductive organs is supported by the squid's food and not at the expense of somatic tissue (Hatfield *et al.* 1992, Rodhouse & Hatfield 1992).

In this paper we examine whether somatic tissue is remobilized for growth of reproductive organs during maturation in male and female *L. gahi*.

Materials and methods

Loligo gahi were taken from a Spanish trawler fishing within the FICZ in March 1987. A total of 130 males and 189 females were examined. Size ranged from 70–170 mm mantle length, representing 95% of the size range present in the fishery during that fishing season (Hatfield *et al.* 1991). They were defrosted at room temperature. After dissection sex was determined and assigned a maturity stage I–IV according to the Ngoile's (1987) maturity scales for *Loligo forbesi*, but considering stages IV and V as stage IV. Thus, stage I is immature, II and III maturing and IV fully mature. The composition by maturity stages was: 141 immature, 46 maturing and two mature females; five immature,

Table I. Summary of mean $\pm$ SD values of body components and indices for *Loligo gahi* males and females and maturity stages. n = number of specimens; BM = total body mass; VI = Visceral Index (see text for definition); EBWC = percentage of water content in eviscerated body mass; DGI = Digestive Gland Index (see text for definition); DGWC = percentage of water content in digestive gland; RSI = Reproductive Somatic Index (see text for definition).

Maturity stages	n	BM	VI	EBWC	DGI	DGWC	RSI
Males							
I	5	25.7 $\pm$ 9.0	4.8 $\pm$ 1.1	80.4 $\pm$ 1.2	3.320.8	77.1 $\pm$ 0.9	0.9 $\pm$ 0.5
II	66	32.727.0	6.421.1	80.821.2	3.120.7	79.022.5	2.020.5
III	44	44.1 $\pm$ 13.9	6.621.7	80.521.2	3.020.7	77.7 $\pm$ 2.8	2.6 $\pm$ 1.1
IV	15	54.0216.5	9.2 $\pm$ 2.3	79.220.9	2.7k0.6	77.721.8	5.421.9
Females							
I	141	30.427.0	4.8 $\pm$ 1.4	81.3k1.1	3.2 $\pm$ 0.9	79.022.7	0.320.3
II	38	35.5k7.6	5.721.6	80.921.2	3.3 $\pm$ 0.8	79.221.9	0.9 $\pm$ 0.8
III	8	50.5 $\pm$ 9.9	7.8 $\pm$ 2.5	81.221.5	3.2 $\pm$ 1.0	79.023.0	2.720.9
IV	2	42.8 $\pm$ 0.8	7.6 $\pm$ 0.1	79.220.1	3.7 $\pm$ 0.0	75.5 $\pm$ 0.9	3.2 $\pm$ 0.2

114 maturing and 15 mature males. The following measurements were made: mantle length (ML); wet body mass (BM); wet digestive gland mass (DGM); reproductive organ mass (RM), comprising the testis, sperm duct, spermatophoric organ, spermatophoric duct, spermatophoric sac and penis in males, and ovary, proximal and distal ducts, accessory and nidamental glands in females; eviscerated wet mass (EBM), comprising mantle and head mass including arms and tentacles. Eviscerated dry mass and digestive gland dry mass were also recorded after drying both eviscerate specimens and digestive glands at 105°C for 24 h. Visceral mass (VM) was estimated by subtracting total eviscerate wet mass from body wet mass. The eviscerated body water content (EBWC) and the digestive gland water content (DGWC) are expressed as percentage.

The following indices were calculated: reproductive-somatic index ($RSI = RM \times 100/EBM$); digestive gland index ($DGI = DGM \times 100/EBM$); visceral index ($VI = VM \times 100/EBM$). Statistical comparisons between maturity stages of every sex were made for each variable using t tests.

Results

Table I shows the values of BM, VI, EBWC, DGI, DGWC and RSI for each sex and maturity stage. The EBM/RM relationships for *L. gahi* males (A) and females (B) are illustrated in Fig. 1. The mass of reproductive organs increased progressively with growth in males, while in females these organs did not show a conspicuous increase in mass until a certain body mass was reached. At similar eviscerated body mass, males attained higher reproductive organ mass than females.

RSI ranged between 0.9 and 5.4 in males and 0.3 and 3.2 in females. Reproductive organ mass increased with maturity in both sexes (Table I). Males mature at a smaller size than females. The smallest mature male measured 96 mm ML, while the smallest mature female was 128 mm ML.

Water content in the eviscerated body mass ranged between 79.2–80.8% in males and 79.3–81.3% in females (Table I). Water content of the EBM in immature/maturing males was significantly higher than in mature males ($p < 0.001$). No significant differences were found among females. DGI ranged between 2.7–3.3 in males and 3.2–3.7 in females (Table I).

Fig.1 Eviscerate Body Mass (EBM); Reproductive Organs Mass (RM) relationships for *Loligo gahi* males (a) and females (b).

Discussion

The number of mature females in the sample was very low, probably because the sample was taken in March when mature females are scarce in the fishery (Hatfield *et al.* 1991). During maturation here appears to be no shift from production in somatic tissues to reproductive organs. The squid's food apparently provides enough nutrients and energy for sexual development as observed in *Illex argentinus* (Hatfield *et al.* 1992, Rodhouse & Hatfield 1992). *L. gahi* captured at the time of the present study showed evidence of active feeding (Guerra *et al.* 1991).

Moreover, water content in *L. gahi* did not increase with maturation. Increase of water content in cephalopod somatic tissue usually indicates its utilization, as in *Sepia officinalis* during starvation (Castro *et al.* 1992).

A major decrease in digestive gland size during starvation has been shown in *Sepia officinalis* (Castro *et al.* 1992). This would be expected if this gland were used for storage and subsequent mobilization of material for reproductive production. The digestive gland shows no mass loss during maturation in *L. gahi*; the ratio of digestive gland mass to eviscerated body mass did not change significantly during maturation (Table I). Likewise, no rise in the water content of the digestive gland was observed.

The present data suggest that growth of reproductive organs in *L. gahi* takes place using energy and nutrients derived from the squid's food and not by mobilizing nutrients and energy from somatic tissue. *L. gahi* spawns in shallow water and migrates down the continental shelf and slope after hatching. It then returns to shallow waters to spawn (Hatfield *et al.* 1990). Further data are required on the feeding behaviour of this species at different stages of its life cycle, but *L. gahi* probably feeds during the migration, so having no need to utilize somatic reserves for gamete production.

Similarly, *Illex argentinus* feeds, grows and starts to mature on the feeding grounds. When the squid migrates to the spawning ground, they may continue feed during the journey having no need to shift somatic tissue to reproductive material (Rodhouse & Hatfield 1990, Hatfield *et al.* 1992, Rodhouse & Hatfield 1992). The loliginid squid *Alloteuthis subulata* seems to show a similar pattern (Rodhouse *et al.* 1988). In *Loligo opalescens* and *L. vulgaris reynaudii* feeding by females continues on the spawning grounds (Karpov & Caillet 1978, Sauer & Lipinski 1991).

Conversely, *Illex illecebrosus* matures during their 2000 km migration from the feeding to the spawning ground (O'Dor 1983). During this long trip the squid must pay the energetic cost for both maturation and locomotion (O'Dor & Wells 1987). Fuel to cover both costs could be obtained from their own somatic tissue or from cannibalism (O'Dor & Wells 1987). These patterns of reproductive/somatic relationships in cephalopods are probably closely related to the degree of semelparity/iteroparity of the species. Further research is necessary to determine how different reproductive patterns affect the investment of energy and nutrients in cephalopod somatic and reproductive tissues.

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