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Quantitative and qualitative assessment of exploitation of juvenile cephalopods from the Arabian Sea and Bay of Bengal and determination of minimum legal sizes

*K. S. Mohamed, M. Joseph, P. S. Alloycious, G. Sasikumar, P. Laxmilatha, P. K. Asokan, V. Kripa, V. Venkatesan, S. Thomas, S. Sundaram and G. S. Rao

Central Marine Fisheries Research Institute, PO Box 1603, Cochin 682018, Kerala, India.
** E-mail: ksmohamed@vsnl.com*

Abstract

Using the minimum size at maturity (MSM) as a biological reference point and relatively low reproductive loads and generation times of the studied animals, the minimum legal sizes (MLS) for the Indian squid *Loligo duvauceli*, the pharaoh cuttlefish *Sepia pharaonis* and for the webfoot octopus *Octopus membranaceous* was fixed at 80, 115 and 45 mm Dorsal Mantle Length (DML) respectively with corresponding minimum legal weights at 25, 150 and 15 g. For *L. duvauceli*, during 1997-2001, 12.8% of the average catch was constituted by juveniles, the proportion being higher along the west coast. In 2002-05, the proportion of juveniles was lower at 5.3% and the total weights were also much less (1817 t as compared to 5354 t). In the case of *S. pharaonis*, 6.9% (2281 t) of the catch was constituted by juveniles, but the proportion was very high (22.4%) along the east coast. In *O. membranaceous* during 2002-04, an estimated 527 t (5.9%) of the total catch comprised of juveniles. The present L_{mean} in the fishery is lower than the L_{opt} and their difference is considerably high at 60 mm for *L. duvauceli*. However, in the case of *S. pharaonis* this difference is only 10 mm and in the case of *O. membranaceous* the L_{mean} is higher than the L_{opt}. If the juveniles are permitted to grow to L_{mean} by implementing the MLS, the estimated economic gain is to the tune of Rs. 426 crores per annum. The present study shows that harvest weights can be improved by up to 34 times and would result in higher incomes to trawl fishers.

Keywords: Cephalopods, juvenile, maturity, economic loss

Introduction

Cephalopods are a marine fishery resource exploited by trawlers from throughout the Indian coast (Arabian Sea and Bay of Bengal). Although they form only 4-5% of the total marine fish landings of India cephalopod stocks are under heavy fishing pressure because of their high value as an exportable product (Mohamed *et al*., 2007). Annual exports were worth more than Rs. 1000 crores in 2005-06 and they constitute nearly a third of the total marine products exported in terms of value and volume. Cephalopods exploited from Indian seas can be broadly divided into three, *viz*., squids (Order: Teuthoidea), cuttlefishes (Order: Sepiiodea) and octopuses (Order: Octopodida). The dominant species occurring in commercial catches are the Indian squid *Loligo duvauceli*, the Pharaoh cuttlefish *Sepia pharaonis* and the webfoot octopus *Octopus membranaceous.* These 3 species together form more than 75% of the total cephalopod production. In India cephalopods are principally caught by bottom trawlers operating up to 200 m depth zones. While most of the catch was earlier taken as by-catch from the shrimp and fish trawls, of late there is a targeted fishery for cephalopods using off-bottom high opening trawls along the southwest and northwest coasts (Mohamed *et al*., 2007).

Trawl is a gear which sweeps the sea bottom very effectively, capturing all organisms in its path with some degree of selectivity based on the cod-end mesh size. Based on studies on mesh selectivity of the trawl (Panicker and Sivan, 1965) all maritime states in India have regulations fixing the cod-end mesh size of trawls at 35 mm. However, in reality this is not practiced and the mesh sizes of trawls in India range from 10 to 25 mm. This results in capture of large quantities of juveniles of target and non-target species. Recently Najmudeen and Sathiadhas (2008) estimated the economic loss due to juvenile fishing in India as Rs. 85,558 crores. Good fisheries management generally requires that fishing gears retain large fish while allowing small juveniles to escape (Armstrong *et al.,* 1990). This also avoids recruitment over-fishing by allowing animals to spawn at least once before becoming vulnerable to capture.

Exploitation of juveniles of fast growing and high value species like cephalopods also results in considerable economic loss, in terms of what could have been obtained had the trawl fishers waited for a few months and allowed the animal to grow in size and weight. Although this phenomenon called as growth over-fishing has been reported by many (Pauly, 1988), assessments of economic loss due to such fishing are few (Najmudeen and Sathiadhas, 2008). A minimum legal size (MLS) is seen as a fisheries management tool with the ability to protect juvenile fish, maintain spawning stocks and control the sizes of fish caught. The MLS sets the smallest size at which a particular species can be legally retained if caught (Hill, 1992). Winstanley (1992) suggested that a MLS could be used to protect immature fish ensuring that enough fish survive to spawn, control the numbers and sizes of fish landed, maximize marketing and economic benefits and promote the aesthetic values of fish.

This study aims to quantify the amount of juvenile cephalopods (*L. duvauceli*, *S. pharaonis* and *O. membranaceous*) caught by trawlers along the east and west coasts of India (Arabian Sea and Bay of Bengal) and arrive at minimum legal sizes for the three main species exploited. Besides an assessment on the economic loss to the fishers by exploitation of these juvenile cephalopods is attempted.

Material and methods

To determine the proportion of juveniles exploited the size (Dorsal Mantle Length – DML) at transition from juveniles to adult has to be determined. The method used to decide this size was by plotting the size-wise percentages of mature males and females and determining the size at first maturity (SFM – size at which 50% of the animals are mature) and also the minimum size at maturity (MSM – size of the smallest mature individual). The MSM which can be considered as the size of transition from juvenile to adult was taken as the cut-off length for fixing the MLS. In doing so, it is assumed that most animals in the population would have an opportunity to become mature and spawn without prejudice to the selection factor of the trawl net. In most cephalopods males mature earlier than females and therefore, as a conservative measure the female MSM was taken as the MLS (rounded to the nearest 5 mm). The minimum legal weights were determined by converting lengths into weight using the standard L-W relationships already determined for the species and cross-checking with observed weights.

The size frequency datasets of *L. duvauceli, S. pharaonis* and *O. membranaceous* (pertaining to Mumbai, Mangalore, Calicut and Cochin along the west coast; and Mandapam, Kakinada and Visakhapatnam along the east coast) were averaged and weighted to the west and east coast catch to make a quantitative assessment of the proportion of juveniles in all India production. For *L. duvauceli* two datasets, *viz.*, 1997-2001 and 2002-05 (DML range 15-375 mm; n = 1784); for *S. pharaonis* 2002-06 (DML range 25-325 mm; n = 1447) and for *O. membranaceous* 2002-04 (DML range 25-95 mm; n = 658) were used. For *L duvauceli* and *S. pharaonis* 10 mm DML class intervals were used and in the case of *O. membranaceous*, 5 mm class intervals were used. For *O. membranaceous*, the sex-ratio in the exploited population was grossly in favour of males with very few females, and therefore, only male length frequency data was used in the study.

For determining the optimum length of capture (L_{opt}) and mean generation time, the VBGF parameters estimated earlier for *L. duvauceli* (Mohamed and Rao, 1997), *S. pharaonis* and *O. membranaceous* (Mohamed *et al*., unpublished) were used as input parameters in the formula of Froese and Binohlan (2000). The same input parameters along with length-weight constants were used to derive size-age and age-weight keys for the 3 species. The reproductive load, which is the ratio between SFM and L_∞, was determined to gain an insight into the relationship between growth and reproduction of these animals (Froese and Pauly, 2000).

The economic loss due to capture of juveniles was estimated from the average size-wise price of the 3 species averaged across landing centres and the relative time taken for each species to reach the L_{mean} from the MSM (taken as the cut-off length when a juvenile transforms to an adult) of the species. The estimated losses were reduced by 20% to account for losses due to natural mortality. In the case of *O. membranaceous*, the economic loss was not estimated because the data pertained only to males and the mean length in the fishery was above the L_{opt}.

Results

The growth parameters (L_∞ and K) and the optimum length of capture (L_{opt}) of the 3 species are shown in Table 1. The L_{opt} values range from 59 to 66% of the L_∞ values. The plot of percentage mature males and females against mantle length of the 3 species is shown in Fig.1. In *L. duvauceli* (Fig.1&2 A) the smallest size at which males mature is 55 mm and that of females is 77 mm, and therefore, the MLS was taken as 80 mm DML. The SFM, however, is higher at 115 and 125 mm for males and females respectively. From 165 mm (males) and 185 mm (females) mantle length onwards all animals are in mature condition. The proportion of lengths *L. duvauceli* spends in mature condition is high (51%). The reproductive load is very small (0.33) in this species. In *S. pharaonis* (Fig.1&2 B) the MSM for males is 75 mm DML and that for females it is considerably higher at 115 mm, and therefore, the MLS was set at 115 mm DML. The SFM for males was determined as 110 mm and that for females was 200 mm DML. The differences in size at sexual maturity for males and females were wider in *S. pharaonis* than *L. duvauceli*. The reproductive load was comparatively higher (0.52). The *O. membranaceous* dataset had only male size frequencies (Fig. 1&2 C) and therefore the MSM and SFM were determined as 30 and 35 mm respectively. Since, the samples contained only males; the MLS was set higher at 45 mm DML as a conservative measure. The MLS and corresponding weights of the three species is shown in Table 2.

The length class-wise average harvest weights of *L. duvauceli* along west and east coasts of India during 1997-2001 and 2002-2005 are shown in Table 3. More than 93% of the catch was from the west coast of India and besides the length distribution was very narrow along the east coast (between 32 and 46% of the total [37] length classes observed). During 1997-2001, 12.8% of the catch was

Table 1. Growth and population parameters estimated for *L. duvauceli, S. pharaonis* and *O. membranaceous* used in the study

Species	Population parameters				
	Asymptotic Length (L_∞) mm	Growth Rate (K)	Optimum Length of capture (L_{opt}) mm	Mean Generation time (t_g) yr	Reproductive Load (SFM/ L_∞)
Loligo duvauceli	374	1.4	247.0	0.77	0.33
Sepia pharaonis	387	0.63	240.0	1.54	0.52
Octopus membranaceous	107	0.81	63.5	1.11	0.30*

* Male reproductive load

Table 2. Minimum legal size and corresponding live weights of the 3 species

Species	Minimum Legal Size (MLS) DML (mm)	Corresponding Total Live Weight (g)
Loligo duvauceli	80	25
Sepia pharaonis	115	150
Octopus membranaceous	45	15

Table 3. Length class wise average harvest weights (in tonnes) of *L. duvauceli* along west and east coast of India during 1997-2001 and 2002-2005 periods*

Mid-Length (DML)	2002-2005			1997-2001		
	W Coast	E Coast	Total	W Coast	E Coast	Total
25	0		0	3		3
35	1		1	15	2	16
45	7	1	8	80	3	83
55	42	19	61	216	4	220
65	238	86	323	530	12	543
75	395	155	550	1684	38	1722
85	627	247	874	2615	152	2767
95	1059	318	1377	4742	275	5017
105	1227	261	1488	5145	408	5553
115	1607	255	1862	4512	453	4964
125	1813	162	1975	3583	393	3975
135	1798	89	1886	2383	290	2673
145	2130	563	2692	2310	233	2543
155	1622	12	1634	1953	133	2085
165	1737		1737	1597	114	1711
175	1582		1582	1282	60	1343
185	1543		1543	1492	23	1515
195	1802		1802	1253	1	1254
205	1264		1264	932		932
215	1191		1191	822		822
225	883		883	531		531
235	839		839	376		376
245	918		918	434		434
255	926		926	204		204
265	806		806	225		225
275	523		523	94		94
285	773		773	51		51
295	622		622	85		85
305	515		515	12		12
315	591		591	26		26
325	487		487	81		81
335	350		350	10		10
345	647		647	1		1
355	460		460	7		7
365	405		405	10		10
375	408		408	8		8
385	0		0	2		2
TOTAL	31837	2167	34004	39307	2592	41899

*85 mm was set as the MLS (horizontal line), juveniles constituted 12.8% of the fishery in 1997-01 and only 5.3% of the fishery in 2002-05.

constituted by juveniles, the proportion being higher along the west coast. In 2002-05, the proportion of juveniles was lower at 5.3% and the total weights were also much less than those observed in the previous data-set (1817 t as compared to 5354 t). The proportion of juveniles along the east coast was higher (23%) because of the narrow length ranges exploited.

In *S. pharaonis* during 1998-2004 more than 85% of the estimated catch was from the west coast and the length range along the east coast was 61% of the total 38 length classes observed (Table 4).

In total 6.9% (2281 t) of the catch was constituted by juveniles but the proportion was very high (22.4%) along the east coast. However, very small sizes (35-65 mm) were not observed in the fishery along the east coast as observed along the west coast. In *O. membranaceous* during 2002-04, an estimated 527 t (5.9%) of the total catch was comprised of juveniles (Table 4). However this dataset consisted of only the male population and therefore has to be judged with caution.

Table 4. Length class wise average harvest weights (in tonnes) of *S. pharaonis* and *O. membranaceous* along west and east coast of India during 1998-2004 and 2002-2004 periods respectively*

Mid-Length	*S. pharaonis*			*O. membranaceous*	
(DML)	W Coast	E Coast	Total	(DML)	W Coast
35	3		3	25	1
45	29		29	30	40
55	77		77	35	102
65	112		112	40	203
75	171	49	220	45	181
85	218	172	390	50	931
95	178	309	487	55	1129
105	111	298	409	60	974
115	280	274	554	65	1322
125	355	232	587	70	362
135	527	269	796	75	1120
145	672	378	1050	80	993
155	653	347	1000	85	508
165	673	509	1182	90	712
175	1120	355	1474	95	225
185	1099	491	1590		
195	1175	276	1452		
205	1246	194	1439		
215	1336	201	1536		
225	1249	156	1405		
235	1681	120	1801		
245	1840	87	1927		
255	1453	39	1493		
265	1639	76	1715		
275	1719	15	1735		
285	1422	46	1468		
295	1407	23	1431		
305	710		710		
315	1101		1101		
325	1368		1368		
335	766		766		
345	1082		1082		
355	327		327		
365	233		233		
375	35		35		
385	5		5		
395	6		6		
405	3		3		
Total	28078	4917	32995		8803

* Horizontal line indicates the set MLS for each species and for *S. pharaonis* 6.9% of estimated catch was juveniles, while for *O. membranaceous* it was 5.9%.

The size line graphs showing the various life history landmarks of the 3 species are shown in Fig. 2A, B and C. The life history landmarks indicated are the length at recruitment (L_r), MSM for male and female, SFM for male and female, mean length in the fishery (L_{mean}), optimum length of capture (L_{opt}) and asymptotic length (L_∞). In the case of *L. duvauceli* the difference in MSM and SFM on an average for males and females is nearly 50 mm or 2 months age. The difference between the present L_{mean} in the fishery and the L_{opt} is considerably high at 60 mm (Fig. 2A). However, in the case of *S. pharaonis* this difference is only 10 mm (Fig. 2B) and in the case of *O. membranaceous* the L_{mean} is higher than the L_{opt} (Fig. 2C).

If *L. duvauceli* juveniles are not caught and allowed to grow for 3.5 months more, additional revenue of Rs. 181 crores may be realized (Table 5). However, for *S. pharaonis* juveniles, 10 more months of freedom is necessary to get additional revenue of Rs. 245 crores. The difference in average

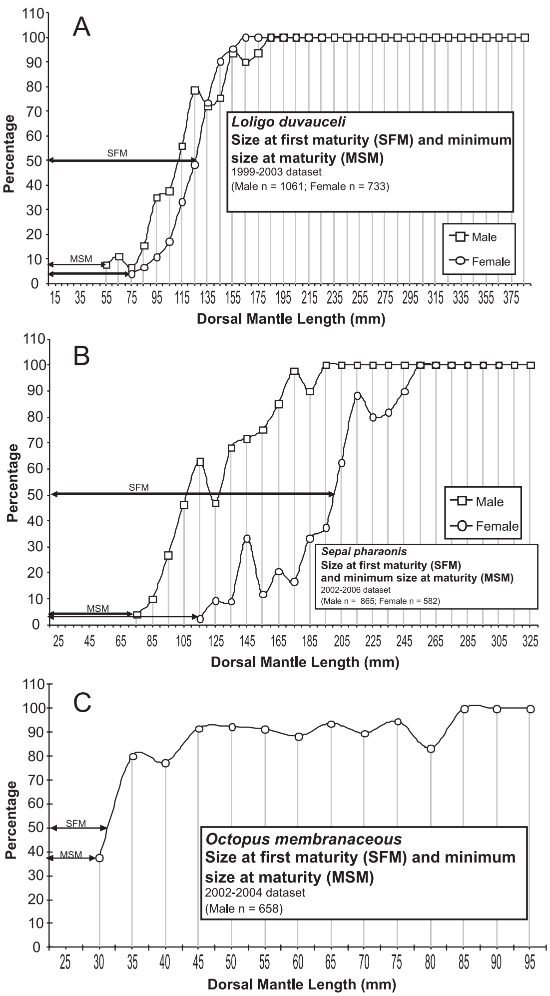

Fig. 1. Size at first maturity (SFM) and minimum size at maturity (MSM) for male and female *L. duvauceli* (A), *S. pharaonis* (B) and *O. membranaceous* (C). For *O. membranaceous*, only male samples were used as female samples were inadequate to draw a curve. Number of samples (n) used for the determination is shown in box

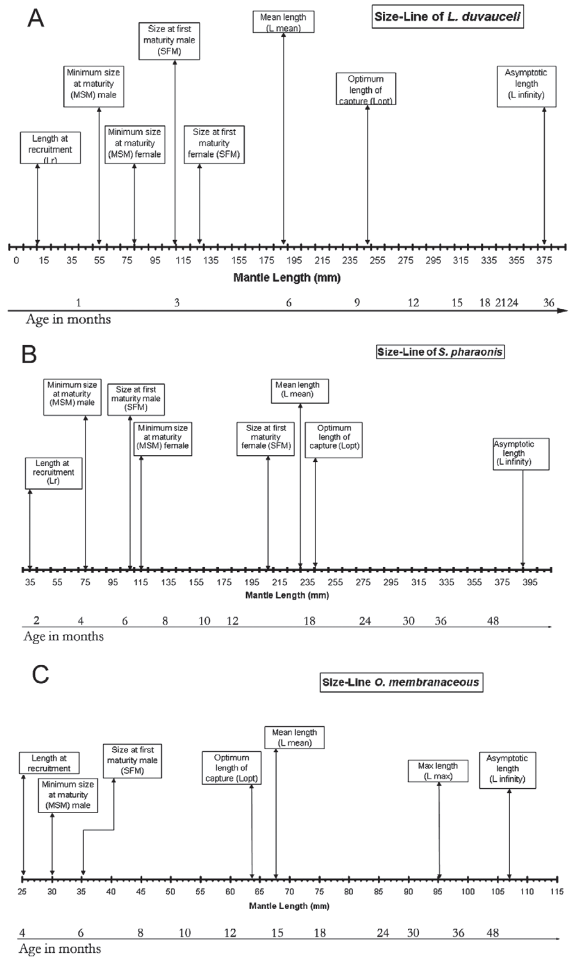

Fig. 2. Size-line graphs of *L. duvauceli* (A), *S. pharaonis* (B) and *O. membranaceous* (C) showing life history landmarks. The second X-axis indicates age in months based on VBGF parameters

Table 5. Estimates of current revenue realized for juveniles and projections of revenue that will be realized (economic advantage) if allowed to grow to L_{mean}

Species	Price realized for juveniles (<MSM)	Estimated price if allowed to grow to L_{mean}	Age at L_{mean}	Average no of months to L_{mean}	Average price of juveniles (range in brackets)	Average price of adults (range in brackets)	Economic advantage	Number of times increase in unit price/total revenue
	Rs.crores	Rs.crores	Months	Months	Rs	Rs	Rs.crores	Number
L. duvauceli	7.25	188.32	5.8	3.5	20 (10-30)	75 (40-110)	181.0	3.75/25
S. pharaonis	7.17	252.16	17.2	10.0	25 (15-35)	95 (40-120)	245.0	3.80/34

unit price of juveniles and adult is about 3.8 times and the increase in total revenue is 25 and 34 times for *L. duvauceli* and *S. pharaonis* respectively.

Discussion

Among the three species of cephalopods studied, the difference between MSM and SFM is substantial in the case of *L. duvauceli* (45 mm) and *S. pharaonis* (92 mm) and very small in the case of *O. membranaceous* (5 mm). Most studies use SFM as a reference point to differentiate between juveniles and adults. However, this is fraught with the error of including a substantial portion of adults as juveniles especially when the difference between MSM and SFM is large. Indeed, when the objective is protection of juveniles and prevention of growth over-fishing, the MSM is a more apt metric to fix the MLS. MLSs have the advantage of being relatively simple to understand (Hill, 1992). They also have the capacity to reduce such problems as recruitment over-fishing by allowing fish to spawn once before being vulnerable to capture. As the effectiveness of a MLS is adversely impacted by the mortality of discarded fish, information on both the selectivity of different fishing methods and the mortality of discarded fish is essential to properly evaluate different MLS strategies (Harley *et al.*, 2000). In the case of cephalopods, trawl catches are invariably brought on to the deck in live condition, especially that of octopus. Trawl codend escape survival is reportedly better than discards from the deck of the vessel and more so for demersal species than pelagics (Suuronen, 2005). Moreover, survival of discards of cephalopods is apparently very poor (Hill and Wassenberg, 1990) and needs to be better investigated.

The proportion of juveniles of *L. duvauceli* was observed to decrease from 1997-2001 to 2002-05. This augurs well for the fishery although the exact reasons for it are unclear particularly when the cod-end mesh sizes of trawls has not increased over the years. Because of the narrow size spectra exploited along the east coast the proportion of juveniles in the total catch was higher for *L. duvauceli* and *S. pharaonis*. This raises the doubt whether the stocks exploited along both coasts are the same. But in the case of *S. pharaonis* recent studies indicate that the stocks are genetically similar from the east and west coasts of India (Andersen *et al*., 2007). It is likely that the growth potential for both these species in the Arabian Sea and Bay of Bengal are different on account of the differences in overall productivity of the water masses (Nair and Gopinathan, 1981). In such a case separate growth parameter estimates and MLS determination would be needed for east and west coast.

Minimum legal sizes have been used as an effective fisheries management tool for more than 100 years with the chosen sizes being reviewed but not always changed from time to time. In Australia the total usage of minimum legal sizes involves 125 species (Hancock, 1992). In India minimum legal weight (MLW) has been officially notified for export only for the very valuable rock lobsters based on SFM (Radhakrishnan *et al*., 2005). The purpose for setting legal sizes in Australia was reviewed by Hancock (1992) and he found that protection of immature animals or juveniles and allowing individuals to spawn at least once as the chief reasons. Control of fishing until optimum market size was cited next in importance followed closely by the objective of controlling harvesting. In most cases the fixation of MLS appears to be based on empirical information and in some cases on specific scientific studies on the SFM.

In tropical waters where growth and maturity in fishes are relatively faster, fishes mature at very small sizes as evident from the very low reproductive loads for female *L. duvauceli* and male *O. membranaceous*. In fishes generally the reproductive load values range between 0.4 and 0.7 with higher values being characteristic of smaller fishes (Froese and Pauly, 2000). In the case of *S. pharaonis* the reproductive load was relatively higher probably because of the relatively high SFM, but it was still lower than that observed for a tropical shrimp *Metapenaeus dobsoni* (Jayawardane *et al*., 2003). It is apparent that the reproductive loads in the cephalopods studied presently are comparatively very low indicating their resilience to high fishing pressure and their relative success in the ecosystem.

The economic advantage of preventing growth over-fishing in Indian cephalopods is very clear from this study. Such a conclusion was also brought out by Najmudeen and Sathiadhas (2008). However they estimated the losses using SFM as the criteria to differentiate between juveniles and adults, wherein the percentage of juvenile cuttlefish was taken as 20%. The present study showed that the percentage of juveniles in cuttlefish catches was only 6.9% for the whole of India and therefore, the estimate of losses due to juvenile fishing made by Najmudeen and Sathiadhas (2008) would be an over estimate by a factor of 3 for cuttlefishes. It is quite probable that the entire estimate of losses (Rs. 85,558 crores) by Najmudeen and Sathiadhas (2008) is an over-estimate because of the use of SFM as the biological reference point for demarking juveniles and adults.

Setting a MLS and implementing the same would increase the economic efficiency of the fishery besides affording protection to juveniles and allowing them to grow in weight and length. Because of the relative fast growth rates particularly in squid, higher weights can be reached very quickly within a few months resulting in higher harvest biomass. The present study shows that harvest weights can be improved by up to 34 times and would result in higher incomes to trawl fishers. Other benefits on account of increased egg laying have not been estimated.

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