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VARIATIONS IN CONDITION INDICES OF MACKEREL ICEFISH AT SOUTH GEORGIA FROM 1972 TO 1997

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Abstract

Mackerel icefish (*Champsocephalus gunnari*) are widespread on the South Georgia shelf, Antarctica, and have been fished commercially since the early 1970s. They are known to feed predominantly on krill. An index of condition which uses the ratio of the measured total mass to the estimated mass is shown to provide a good indicator of local krill density. The index is likely to be little affected by the reproductive cycle unless there is high krill availability during the months around the spawning time, and even then the effect is much less than the highest observed values. The condition index responds rapidly to changes in krill density and therefore can provide indications of short-term variations in krill availability. Condition index provides a useful proxy for krill density and is likely to be of considerable value in interpreting the results from ecosystem assessments such as that in progress under the auspices of CCAMLR.

Résumé

Le poisson des glaces (*Champsocephalus gunnari*) est une espèce courante sur le plateau de Géorgie du Sud, en Antarctique, et fait l'objet de pêche commerciale depuis le début des années 70. Il se nourrit principalement de krill. Un indice de condition reposant sur le rapport entre le poids total mesuré et le poids estimé constitue un bon indicateur de la densité locale de krill. Il est peu probable qu'il soit affecté par le cycle reproductif à moins que le krill soit particulièrement abondant les mois entourant le frai, et même dans ce cas, l'effet serait beaucoup moins important que les valeurs les plus élevées observées. L'indice de condition, du fait qu'il répond rapidement aux changements de densité du krill, donne une indication des variations à court terme de l'abondance du krill disponible. Il peut illustrer la densité du krill et devrait être des plus utiles pour interpréter les résultats des évaluations de l'écosystème en cours sous les auspices de la CCAMLR.

Резюме

Ледяная рыба (*Champsocephalus gunnari*) широко распространена на шельфе Южной Георгии (Антарктика), а коммерческий промысел этого вида велся с начала 1970-х гг. Известно, что эта рыба в основном питается крилем. Индекс физиологического состояния, использующий соотношение измеренной общей массы к оценочной массе, служит хорошим индикатором локальной плотности криля. Репродуктивный цикл сказывается на индексе только тогда, когда криля много в течение нескольких месяцев до и после нереста, но даже тогда это влияние намного меньше наивысших наблюдавшихся значений. Этот индекс быстро реагирует на изменения в плотности криля и может служить показателем краткосрочной изменчивости в наличии криля. Давая представление о плотности криля, индекс физиологического состояния может быть полезным при интерпретации результатов проводимых в рамках АНТКОМа экосистемных оценок.

Resumen

El draco rayado (*Champsocephalus gunnari*) se encuentra distribuido ampliamente en la plataforma de Georgia del Sur (Antártida), y su explotación comercial comenzó a principios de la década de los setenta. El kril es el componente principal de su dieta y se ha encontrado que el índice de condición dado por la proporción de la masa total medida con respecto a la masa estimada es un buen indicador de la densidad local de kril. El índice varía muy poco en función del ciclo reproductor, salvo que haya una gran abundancia de kril durante los meses cercanos a la época de desove, y aún así, el efecto es mucho menor que los valores máximos observados. Los cambios en la densidad de kril afectan rápidamente al índice de condición y por lo tanto éste puede indicar variaciones de la disponibilidad de kril a corto plazo. El índice de condición es un sustituto viable para la densidad de kril y tiene gran potencial en la interpretación de los resultados de las evaluaciones del ecosistema que se efectúan bajo los auspicios de la CCRVMA.

Keywords: mackerel icefish, *C. gunnari*, condition, krill, ecosystem interaction, CCAMLR

INTRODUCTION

Mackerel icefish (*Champsocephalus gunnari*) are widespread in CCAMLR Subarea 48.3 in water up to 400 m deep. Since 1970 they have been subject to a commercial fishery of varying intensity, in peak years yielding a total catch of over 100 000 tonnes (Kock, 1992). They feed predominantly on Antarctic krill (*Euphausia superba*), (Kock et al., 1994) which itself is subject to commercial fishing. Trophic interactions between icefish and krill are thus of particular interest due to the complexities of applying an ecosystem approach to management as required by the Convention for the Conservation of Antarctic Marine Living Resources.

An index of condition of *C. gunnari* derived by comparing measured mass to an estimated 'average' mass has been shown to be related to the amount of krill available to *C. gunnari* in the sampled region (Everson et al., 1997). That study used the gutted mass of fish, from a series of research vessel surveys to South Georgia, to derive the condition index. Data from commercial vessels are available for many months going back to the start of the fishery, although the sampling of such catches included the total length and total mass but not the gutted mass of fish. If a condition index using total mass can be demonstrated to provide a reliable indicator of krill availability then this information might be used to provide a much more extensive view of the status of fish and krill since the early 1970s.

The gutted mass of fish comprises the total mass of bone, body musculature, fins and spinal chord. All of these can vary but, for this study, we assume that the greatest variation is likely to be present in the mass of the body musculature. Total mass is the gutted mass plus the mass of the viscera and gonads. The mass of the viscera will vary mostly due to the amount of food contained in the stomach and energy stored as fat deposits in the body cavity (Frolkina, pers. comm.). In addition, the gonads of sexually mature fish increase in size in the months leading up to spawning, at which time they may account for 20% of the total mass (Kock, 1992; Everson et al., 1996). Arising from this, we envisage two scenarios whereby the total mass of the fish may vary as a result of changes in feeding conditions.

Good followed by poor feeding conditions. Initially the stomach contents would decrease leading to a reduction in total mass. If the poor feeding conditions continue, then there is likely to be an effect on the body fat deposits and also a reduction in the musculature.

Poor followed by good feeding conditions. Initially the stomach is likely to be empty, or nearly so, and, if the poor feeding conditions have been prolonged, the musculature will also have a below-average mass. An improvement in feeding conditions will result in an increase in stomach mass and some time later, if favourable conditions continue, total lipid and body muscle, as some of the energy is converted to structural protein.

We recognise that this is a very simplified view, however it is based on the extensive review by Love (1988) of the effects of different feeding regimes on fish that are being used in aquaculture and also information reported to us by Frolkina (pers. comm. reported in Anon., 1998). The scenarios outlined above take no account of any variation in gonad mass and are consequently only appropriate for immature fish. The gonad mass, as part of the total but not gutted mass, brings an added level of complexity that is dependent on the reproductive cycle. Thus, as the gonads approach spawning condition the total mass is likely to increase although the gutted mass may remain more or less stable.

Arising from this, we expect a condition index using total mass to respond quickly to changes in feeding status but be subject to a greater degree of variation arising from changes in stomach contents.

One using gutted mass is likely to respond with a slight time delay and have a lower variance with respect to one using total mass.

In this study we have sought to determine whether a condition index derived from total mass can provide indications of krill status in a similar manner to one using gutted mass and from it determine when good and poor feeding conditions were present in the past.

MATERIALS AND METHODS

Data were collected from the following sources:

(i) research vessel surveys by Germany, UK and the USA, details of which are given in Everson et al. (1997);

(ii) research vessel surveys by Argentinian scientists (Marschoff et al., 1994, 1995, 1996, 1997);

(iii) commercial fishing activities by Russian vessels between 1972 and 1991 (unpublished data provided by VNIRO, Moscow, collated and checked by Institut für Seefischerei, Hamburg, Germany); and

(iv) commercial fishing and research vessel data from Polish vessels from 1977 (unpublished data provided by Sea Fisheries Institute, Gdynia, Poland).

The data were divided into two groups geographically: South Georgia for hauls between 34°W and 40°W, and Shag Rocks for hauls between 40°W and 44°W. The series of data have been grouped by month, beginning in August 1972 and extending to September 1997, although not all months over that period were sampled.

Data were loaded into a central database. In some instances total length was not recorded and for those records it was estimated from the standard length using the relationship:

$L_t =$ (1.1017 * Standard Length) + 0.611
(n = 1 247, r^2 = 0.992).

This relationship was derived from all records that contained values for both the total and standard length.

The database included a measured total (W_{ti}) and gutted mass (W_{gi}) for each fish. The condition index analyses were undertaken in stages. The first part entailed determining average length-to-mass relationships using only those records for which both W_{gi} and W_{ti} had been measured. The same analytical procedures as used in Everson et al. (1997), a least-squares regression on the log-transformed L_t, W_{gi} and W_{ti}, were used. The resultant length-to-mass relationships were used to derive an estimated mass for each fish ($\hat{W}_{gi}$ and $\hat{W}_{ti}$). Two condition indices were calculated: C_g, a gutted mass condition index and C_t, a total mass condition index for each of the 'i' fish:

$$C_{gi} = \frac{W_{gi}}{\hat{W}_{gi}}$$

and

$$C_{ti} = \frac{W_{ti}}{\hat{W}_{ti}}$$

All the data for this part of the study came from research vessel surveys and consequently are restricted to nine separate months (eight as described in Everson et al. (1997) and a further survey in September 1997).

Gutted mass was not available from the datasets from the commercial fishery and for these only C_t could be determined. For this analysis a new length-to-mass relationship was calculated using data from all the sources. This much larger dataset contained a large number of fish which were measured and weighed at sea. Inconsistencies in data from smaller fish in some samples forced us to consider only those fish greater than or equal in total length to 30 cm. This group is composed of sexually mature fish (Everson et al., 1996).

Information on krill status was derived from two sources:

(i) direct estimates of krill density from acoustic surveys (Brierley et al., 1999); and

(ii) indirect estimates of krill status as indicated by species dependent on krill and monitored by the CCAMLR Ecosystem Monitoring Program (CEMP) (SC-CAMLR, 1995).

Statistical analyses were undertaken using Minitab.

RESULTS

Length-to-mass Relationships

A number of total length (L_t) to mass relationships were derived and these are summarised below.

Records from fish where both total mass and gutted mass had been measured:

males (N = 1 246):

total mass $= 0.001294\ L_t^{3.46}$ ($r^2 = 0.984$)

gutted mass $= 0.001137\ L_t^{3.46}$ ($r^2 = 0.988$)

females (N = 1 421):

total mass $= 0.001243\ L_t^{3.47}$ ($r^2 = 0.980$)

gutted mass $= 0.001256\ L_t^{3.43}$ ($r^2 = 0.986$).

Records from fish where only total mass had been measured and which were 30 cm or greater in total length:

males:

total mass $= 0.001322.L_t^{3.45}$ (N = 5 453; $r^2 = 0.896$)

females:

total mass $= 0.001003.L_t^{3.52}$ (N = 8 277; $r^2 = 0.869$).

Comparison of C_g with C_t

The results, plotted separately for male and female fish, are shown in Figure 1 and have a fairly tight distribution around the line where C_g equals C_t. The product moment correlation coefficients were 0.951 for males and 0.898 for females, both of which were significant at the 1% level.

While we would expect C_g and C_t to be correlated, a very close relationship would not be expected due to differences in response times to changes in feeding conditions. Variation between C_g and C_t can be due to a variety of additional causes such as measurement error and natural variation between individual fish, but since the trend is clearly present, we feel that the total mass condition index has similar validity to that derived from gutted mass and reported earlier (Everson et al., 1997) for providing an indicator of krill availability to icefish.

Comparison of Condition Index to Krill Density

A series of krill density estimates reported by Brierley et al., (1999) was compared with C_t obtained from fish caught in the same month as the krill survey. These are plotted in Figure 2. Under good feeding conditions icefish will eventually reach satiation, whereas when krill are scarce fish feed more on the hyperiid amphipod *Themisto gaudichaudii* and also tend to eat less overall (Kock et al., 1994). Arising from these considerations we would expect the relationship between krill density and condition index to be asymptotic, rather than linear. A least-squares regression on the log-transformed data gave the following relationship:

$$\text{Ln } C_t = -0.1182 + 0.0439^*(\text{Ln}(\textit{Krill density}))$$
($r^2 = 0.713$).

Although these conclusions are based on data from relatively few months, they do indicate a strong functional relationship between the icefish C_t and krill density. We conclude from this that condition index is following food availability with a short, of the order of a month or less, response time.

Temporal Variation in Condition Index

Relationship to Icefish Reproductive Cycle

The gonadosomatic index (GSI), the ratio of gonad mass to total mass expressed as a percentage increases, in the case of female Antarctic fish, to over 20% in the months leading up to spawning. Such an increase in gonad mass would increase the total mass and consequently C_t immediately prior to spawning. Taking a generalised nototheniid cycle described by Everson (1984) as a standard because the equivalent information is unavailable for *C. gunnari*, we estimate a theoretical condition index using GSI to estimate gonad mass. During the resting phase, because the ovary contains vitellogenous oocytes, the GSI remains at around 3.5%. The resting testis is much smaller but still accounts for around 1% of the body mass. A theoretical condition cycle would consequently be as in Table 1. From this analysis it is apparent that the gonad mass will contribute less than 5% to C_t in all except the two months prior to spawning. Depending on locality, that will mean that except for the months of March, April, May and possibly February, C_t will be little affected by the spawning cycle.

We have investigated this by plotting C_t and the results are shown in Figure 3. The spawning season in April and May (months 4 and 5) is not clearly apparent from an inspection of the monthly C_t for two reasons. Firstly, because the GSI makes only a small contribution to C_t except prior to spawning (Table 1) and, secondly, because there were relatively

Table 1: Theoretical changes in total mass condition index caused by seasonal variation in the gonadosomatic index (GSI). The calculations assume that during the resting phase, the first seven months since last spawning, the GSI is 1% for males and 3.5–4% for females.

Months Since Last Spawning	Male GSI	Male C_t	Female GSI	Female C_t
1–7	1	1.00	3.5–4	1.00
8	2	1.01	5	1.01
9	3	1.02	6	1.02
10	5	1.04	8	1.04
11	8	1.07	15	1.11
12	9	1.08	20	1.16

few samples around the spawning season. The important point here is that gonad mass appears to be having little influence on the variation in C_t through most of the year.

Annual Variation

The mean indices during the first part of the year tend to be greater than unity, an indication that more fish are actively feeding during this period than during the latter part of the winter as noted by Frolkina (pers. comm. reported in Anon., 1998).

Between-season Variation

Information from 13 731 *C. gunnari* sampled in 65 months on the South Georgia shelf and 2 160 sampled in 20 months from the Shag Rocks shelf were used in the analysis. The C_t and 95% confidence limits were plotted sequentially by month in Figure 4. The mean values fluctuate although not in an apparently regular manner.

Periods during which the C_t was significantly less than one and assumed to indicate poor feeding conditions at South Georgia and/or at Shag Rocks occurred during the following months:

South Georgia:	Shag Rocks:
Aug–Oct 72	July + Sept 72
Nov 77 + Jan 78	No sample
Nov 78	No sample
Dec 80–Jan 81	No sample
No sample (Feb 81 normal)	April + June 81
Nov 82	No sample
Nov 83–Jan 84	No sample
Nov–Dec 85	Oct–Nov 85
No sample	Jan 87
Sept 87	No sample
June 90–Jan 91	**Normal**
Jan–March 94	**Normal**
Sept 97	Sept 97

It is unfortunate that there are relatively few periods when samples were available simultaneously from both localities, but in spite of this there are several obvious inconsistencies. There are several periods, indicated in boldface type, for which the C_t is normal in one area but low in the other. There are also some instances of low C_t at both South Georgia and Shag Rocks; these are indicated by underscore in the list above. Such a difference is not unexpected because, although South Georgia and Shag Rocks are separated geographically by only a narrow region of deep water, the degree of separation means that there are likely to be different feeding regimes for *C. gunnari* (Kock et al., 1994). Of the months for which sampling is available, 40% of those on the South Georgia shelf and 35% of those on the Shag Rocks shelf had C_t significantly less than one.

Short-term Variation

Looking at the results sequentially month by month, rather than as a longer-term picture, further features emerge. A good example is around the period 1977 to 1983 plotted in Figure 5, where there is good temporal coverage. In some periods there is a sequence of values following a clear trend. Good examples of rising trends are over the periods January to May 1978 and from November 1978 to March 1979. Declining trends are seen from February to May 1977 and October 1977 to January 1978. Thus, the general trend that is apparent in Figure 3, and noted in Anon. (1998), is subject to a large degree of variation from year to year.

The evidence from Figure 2 indicates that the changes shown in Figure 5 are responses to changing krill density. When there has been a rapid change, such as between January and February and between November and December in the same year, we infer that there has been a sudden change in krill density and consequently the feeding status of icefish.

Table 2: Comparison of icefish condition indices (C_f) during the summer months with the CEMP indices for land-based species that are dependent on krill. The condition indices are the mean value for all sexually mature fish. FUSE = fur seal; GEPE = gentoo penguin; MAPE = macaroni penguin; trip = foraging trip duration; surv = pup survival; meal = meal size and S = breeding success.

Year	C_f					FUSE		GEPE		MAPE	
	Nov	Dec	Jan	Feb	Mar	Trip	Surv	Meal	S	Meal	S
76/77			1.19	1.2	1.07				1		0
77/78	0.97		0.93	1.1	1.03				-1		-1
78/79	0.89	0.97			1.15				0		0
80/81	0.98	0.96	0.98	1.08		1	1				1
81/82	1.17	1.19	1.2	1.21		1	0		-1		0
83/84	-0.84	0.93	0.93			-1	-1		0		-1
84/85			1.04	1.07		1	1	1	0	1	0
85/86	0.97	0.97	1.02			1	0	1	0	0	0
88/89		0.99	1.05			0	0	0	0	0	0
89/90			1.05			1	0	-1	0	0	1
90/91		0.88	0.92			-1	-1	-1	-1	-1	1
91/92			1.08			1	1	0	1	0	0
92/93						0	0	-1	1	0	1
93/94			0.98		0.92	-1	-1	-1	-1	-1	0
94/95					1.03	0	1	0	1	-1	0
95/96					1.03	1	1	0	1	-1	0
96/97					1.07	1	1	1	1	1	0

Comparison of Condition Index with Fur Seal and Penguin Indices

The ecosystem approach to management is central to the aims of CCAMLR. Much work has been done on the functional relationships between fur seals, macaroni and gentoo penguins monitored as part of CEMP and reported in SC-CAMLR (1997). It is beyond the scope of the present paper to consider all parameters in detail, so we focus on characteristics related directly to the diet of each of the three species. These are fur seal foraging trip duration and pup survival, gentoo and macaroni penguin meal size and breeding success, all of which are considered to have a close affinity to local krill availability (Reid et al., 1999). These parameters are considered to be integrating over the period December to March over the approximate range of 50 to 100 km from the breeding site. The foraging trip and diet parameters integrate over these same scales but in periods of two to five days, whereas pup survival and penguin breeding success are single values integrating over the whole period (SC-CAMLR, 1989, Table 4). For this analysis the CEMP indices have been scored as +1 if the mean value for the season is greater than the upper 95% confidence limit for the mean of all values, 0 if it lies within the confidence interval and -1 if it is lower than the lower 95% confidence limit. These results are summarised in Table 2.

During the 1977/78 season, breeding success, the only parameter reported at that time for both penguin species, was extremely low and this coincides with a low icefish condition index for November 1977 and January 1978. Comparing the average fur seal pup weight in 1973, a year when there were no reports of krill scarcity, to that on the same calendar date in 1978 showed that in the 1977/78 season the growth rates were running almost a month later, as shown in Figure 6. An alternative comparison is that on the same date the pups were 1.4 kg lighter despite having been born on the same calendar date (Bonner et al., 1978). The apparent return of favourable krill conditions in February and March 1978, as indicated by the icefish C_f, occurred too late or else was of insufficient magnitude to change the situation since the gentoo penguins and black-browed albatrosses had very low chick survival rates during that season. Poor feeding conditions for gentoo penguins may have persisted locally; one of the authors (K.-H. Kock) found dead penguins on the shore of Cumberland Bay, South Georgia, in March 1978. In 1978/79, when penguin breeding success was normal, the icefish C_f was low in November but close to one in December, suggesting that the penguins had not been unduly affected by poor conditions early in the season followed by more favourable feeding conditions later.

During the 1990/91 and 1993/94 seasons all CEMP parameters, with the exception of macaroni penguin breeding success, indicated poor feeding conditions. At South Georgia the icefish C_f over the same period was also low, indicating a scarcity of krill. By contrast, the icefish C_f in both these seasons at Shag Rocks was close to one. The Shag Rocks shelf is at the extreme range for macaroni penguins during the breeding season (Trathan et al., 1998) and it is therefore possible that this species could just obtain sufficient food to provision chicks by feeding at the limit of its foraging range. Such a spatial separation would require greater energy expenditure by the parent bird, a situation which could adversely affect the meal size delivered to the chick without affecting chick survival. Gentoo penguins, and to a lesser extent fur seals, are more restricted in their foraging range during the breeding season and hence are more likely to be affected by local krill scarcity.

DISCUSSION

An analysis of condition indices needs to take account of the key components that make up the index. An index based on total mass is likely to vary due to the size of the gonad, the amount of food in the stomach and the mass of the musculature.

Consideration of the reproductive cycle and its effects on the condition index led us to conclude that outside the period (possibly) from February to May gonad mass has little effect on the index. Consequently, periods when the condition index is down to 0.9 or up to 1.1 can be largely attributed to the status of the body musculature, liver size and stomach fullness. The liver mass, as noted by Everson et al. (1997), varies from around 1 to 4% of the body mass. Arising from this it is only likely to have a minor effect (less than 2%) on a total mass condition index.

The gutted mass condition index is well correlated with the total mass index, indicating that a large part of the variation is occurring due to changes in the musculature. Love (1988) has demonstrated that for cod (*Gadus morhua*) periods of starvation can lead to emaciation, although under such conditions some of the weight loss is compensated for by the uptake of water.

The results from the initial parts of this study comparing icefish condition with krill density indicates a strong relationship between the two factors as shown in Figure 2. For such a situation to be present, it is necessary that the icefish condition index responds to change at least as rapidly as the rate of change in krill density. There were no krill density estimates during 1977 and 1978, so we infer that the changes in condition index indicate changes in krill density.

CONCLUSIONS

Using the condition indices gives a much more extensive dataset that provides indications not only of long-term status, whether it has been a 'good' or 'poor' krill season, but also some insight into within-season changes. From this it is clear that 'good' and 'poor' krill status are not just seasonal categories, but need to be considered on a smaller timescale. Thus, there can be quite rapid (of the order of a month) changes in krill status within a region. In this paper we suggest that such changes have a rapid effect on icefish condition. Such rapid responses may be seen by looking at small temporal scale subsets of the CEMP data but, since these are integrating over periods which are greater than the timescale over which krill status changes, the signal as summarised in a 'seasonal mean value' can provide equivocal answers.

It has become the practice to develop combined standardised indices (CSI) of the CEMP data (SC-CAMLR, 1997). These have the advantage that they provide a graphical form that clearly indicates when there has been a 'poor' krill season. However, their utility does not go beyond this because they do not take account of the response functions of the CEMP parameters to changes in the krill status. In determining these response functions, note should also be taken of the interdependence of the different parameters. For example, penguin arrival weight, a parameter that is thought to be dependent on feeding status in winter, almost certainly has an effect on breeding success.

In developing an ecosystem assessment using these various indices it is clear that there are interdependencies which need to be considered. Investigating the way in which these different components interact and their resultant responses will provide a greater insight into understanding the system and eventually an ecosystem assessment of value in providing advice for resource management.

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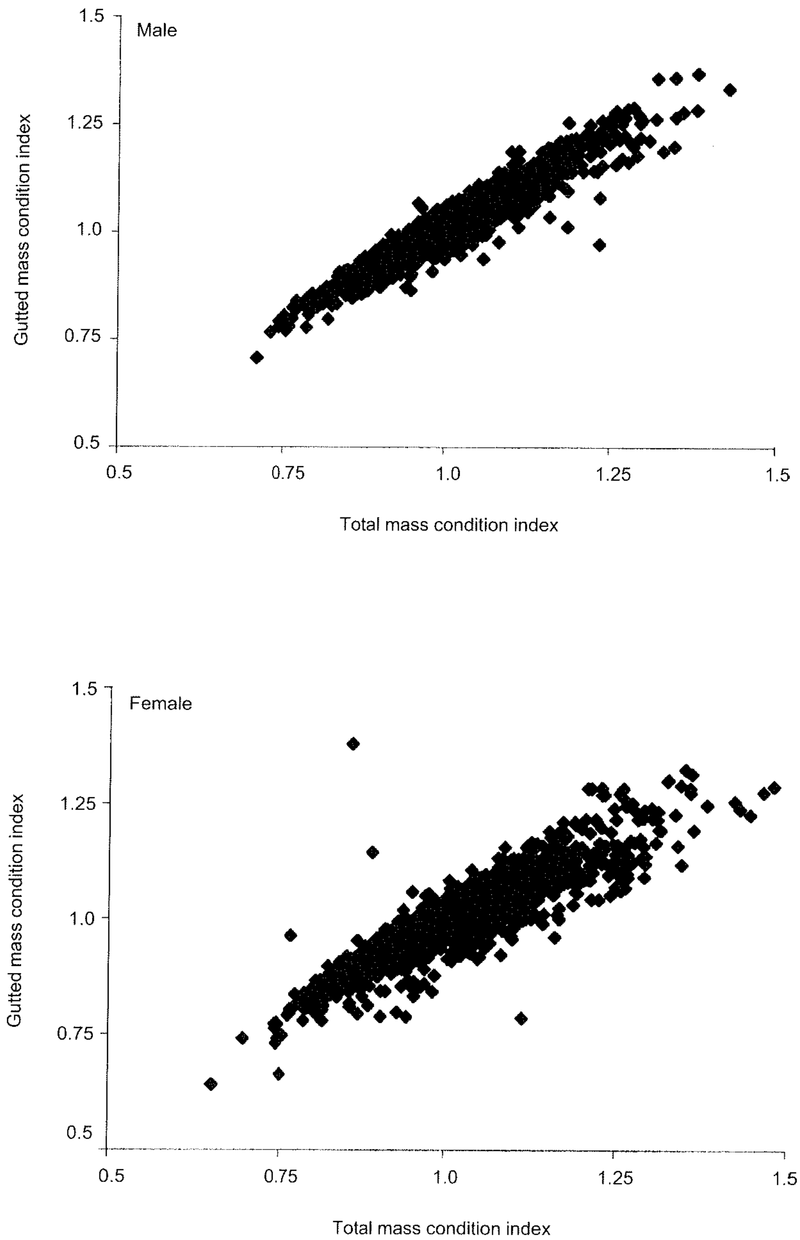


Figure 1: Scatter plot of mean monthly values for C_t plotted against the total mass.

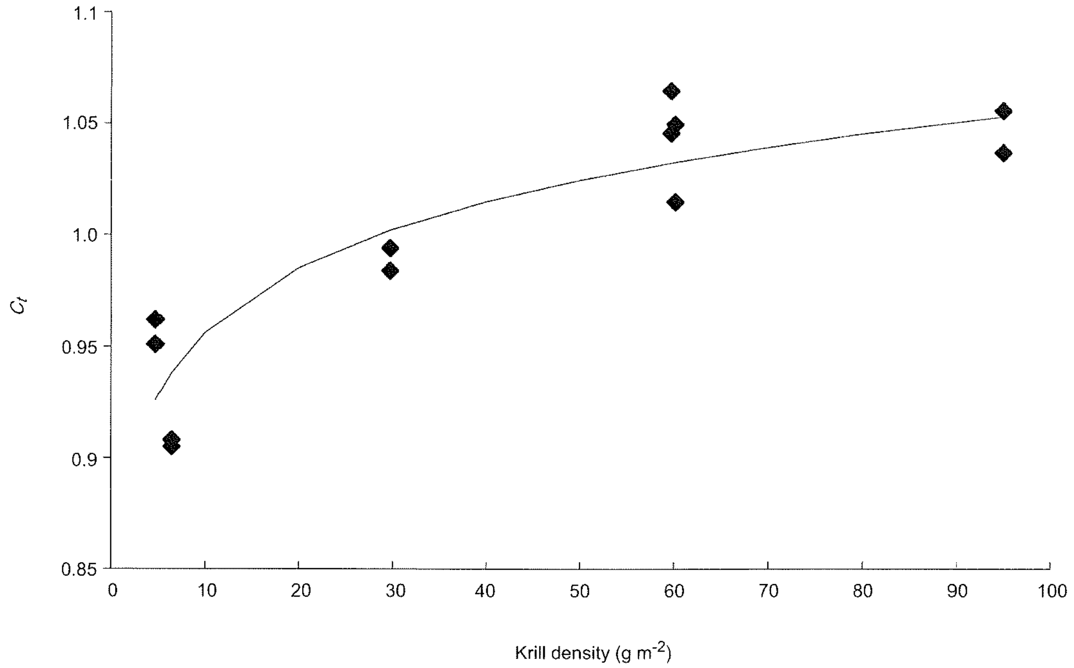


Figure 2: *Champsocephalus gunnari* C_t plotted against krill density from acoustic surveys during the same month (krill data from Brierley et al., 1999).

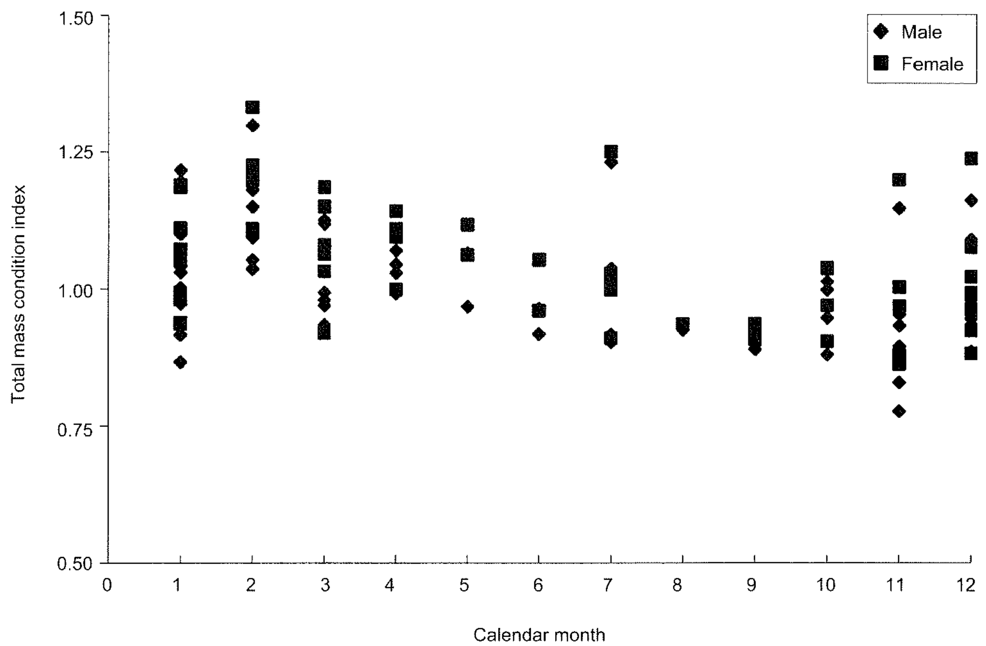
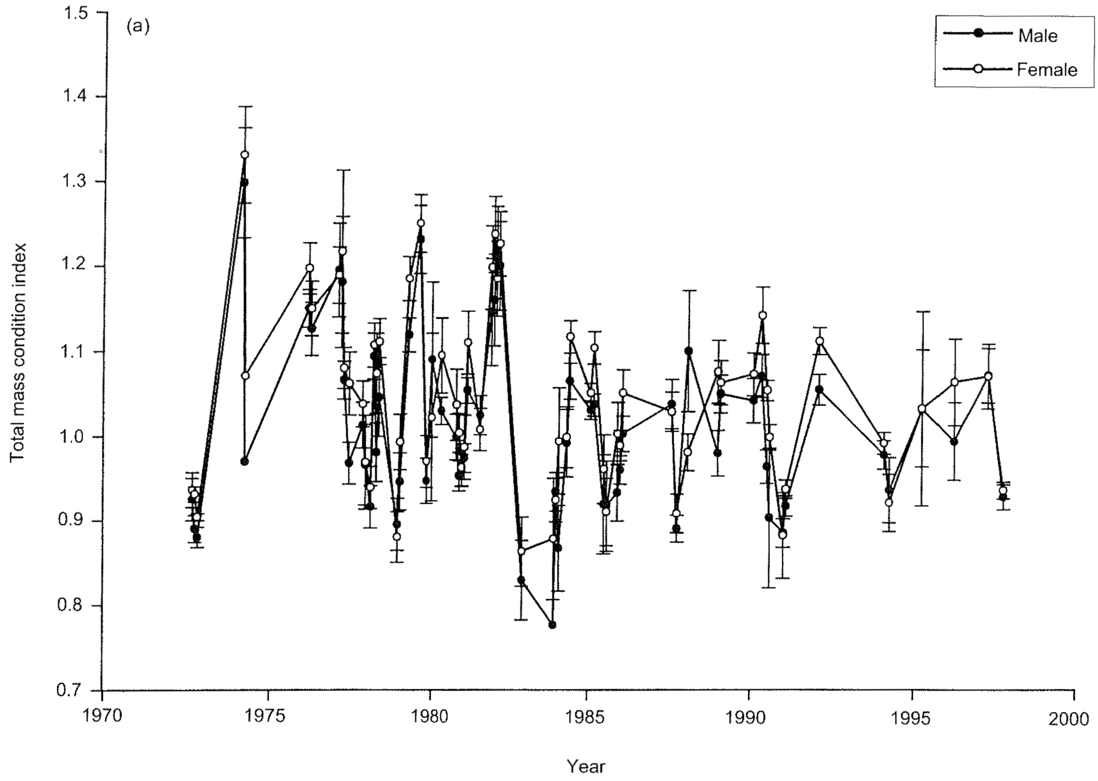


Figure 3: Mean C_t plotted by month. The normal spawning period is during April and May, months 4 and 5 respectively.



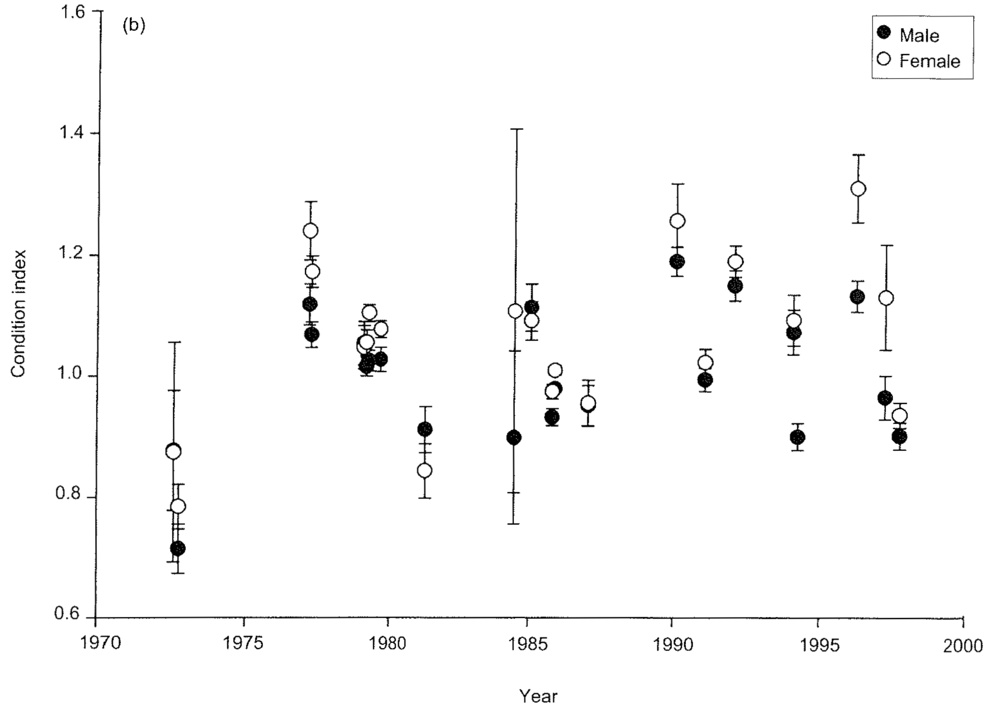


Figure 4: Monthly mean C_t and error bars (2x SE) for all the data from (a) South Georgia and (b) Shag Rocks.

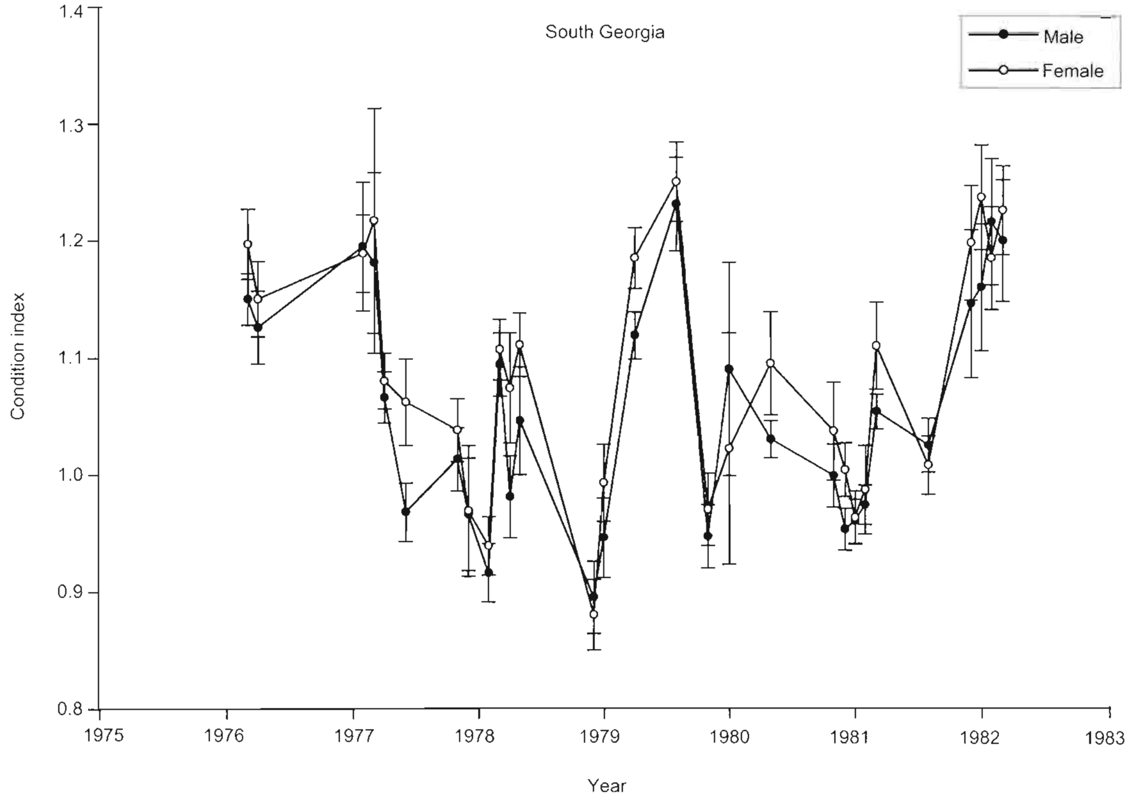


Figure 5: Plots of monthly mean C_I for the period 1975 to 1983.

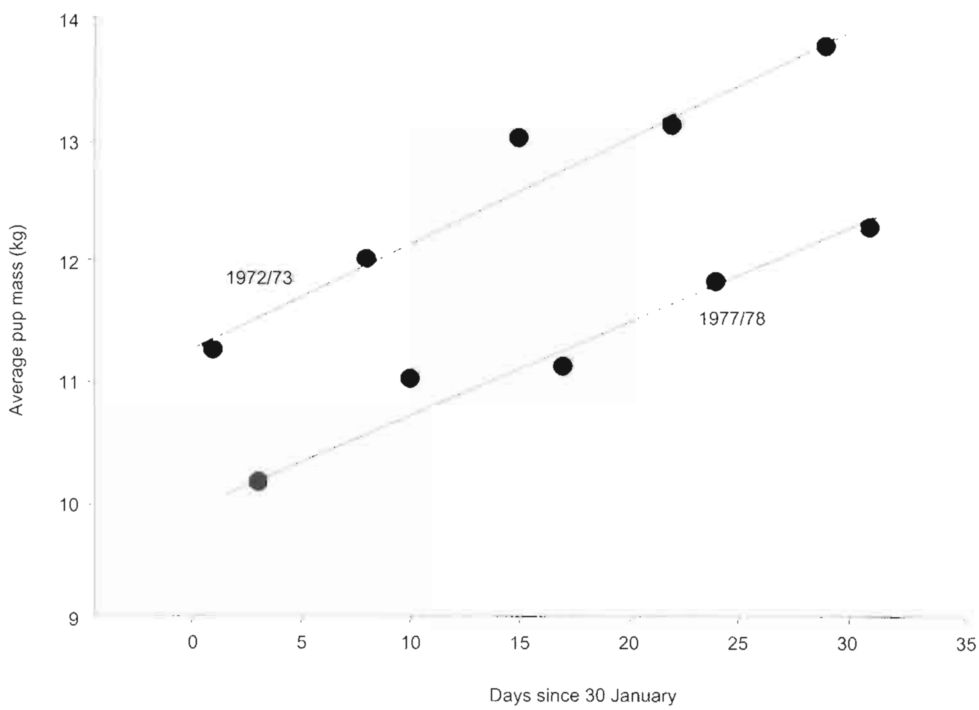


Figure 6: Fur seal pup growth during two seasons, from Bonner et al. (1978).

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