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Why Does Not the Shrimp Stock in the Barents Sea Respond on Predation by Cod?

by

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Abstract

The lack of correlation between changes in the shrimp stock and the cod consumption has been the reason why several assessment models including the predator has failed when applied on the Barents Sea shrimp stock. We modify the current Norwegian procedure to calculate cod consumption of shrimp in the Barents Sea, and explore how this affects the cod consumption estimate. The mean consumption is reduced with almost 30% with the new approach. In some years the reduction in estimated shrimp consumption is around 70%.

We point out the reason for over estimation in the old model, then justify why the new consumption estimates are better. The new consumption estimates do not result in a better cod-shrimp response. The cod was introduced as predator in the assessment model of shrimp in the Barents Sea, but the model is more robust when excluding the cod (Hvingel, 2006). This is because the shrimp stock does not respond on still high cod consumption, not even if a time lag is introduced.

Introduction

Stock assessment of shrimp (*Pandalus borealis*) is problematic because of the vast distribution, lack of direct methods for aging the shrimp and high variation in natural mortality due to predation (Jakobsson and Stefánsson, 1998). In a meta-analysis Worm and Myers (2003) found evidence that shrimp populations are regulated by cod predation. This seem to work well for the Greenland stock (Hvingel and Kingsley, 2006) and the Icelandic shrimp stock (Skuladottir). In the Barents Sea, cod is the main predator on shrimp, and the predation from other predators is probably negligible (Bogstad *et al*., 2000). Therefore, it has been considered important to take cod predation into account also when managing the Barents Sea shrimp stock (Anon., 2003, ICES).

A mean annual consumption of shrimp by cod in the Barents Sea is estimated to 280 000 tons (1984-2004, Bogstad and Mehl, 1997; ICES, 2006). The average annual shrimp catch since 1985 is close to 55 000 t. Within fishery management there has traditionally been an understanding that fishing mortality does not represent an important factor for the development of the shrimp stock. According to the Norwegian Fishing Vessel Owners' Association this is the main argument against the introduction of a TAC (Standal, 2003).

In the 1980s the estimated biomass of shrimp consumed by cod followed the index for the shrimp biomass and the cod's shrimp consumption seemed to be regulated by availability of shrimp (Fig. 1). However, when the shrimp stock started to decrease in 1991 the estimated cod consumption continued to rise. In 1994 the estimated consumption of shrimp by cod was 518 000 t and still the shrimp stock started to increase and increased until 1998 although the annual cod consumption was 335 000 t in this period (1995-1998). The annual shrimp catch has never exceeded the estimated consumption and in the 1990s the commercial shrimp catch has been between 6% and 43% of the cod consumption of shrimp. The exploitation rate seems to have a more obvious effect on changes in the shrimp stock than does the relative consumption by cod. The lack of correlation between changes in the shrimp stock and the cod consumption has been the reason why several assessment models including the predator has failed when applied on the Barents Sea shrimp stock.

This paper will study the reasons for why the shrimp stock does not seem to respond on the predation by:

A) Evaluating the shrimp index.

The swept area index for shrimp may not represent the whole stock. The index is estimated for the areas with the depth of 200-600 m. Shrimp is also present, though in lower densities, in vast areas of the Barents Sea shallower than 200 m.

B) Evaluating the consumption estimation.

At least five factors can lead to bias of cod consumption, and introduce annual variation caused by sampling and estimation procedures (Johannesen and Aschan, 2005):

1) Cod might feed in the trawl.
2) Stomach content data are pooled before they are entered in the consumption model and this is corrected for by a constant factor that might be too low (Dos Santos and Jobling, 1995; Bogstad and Mehl, 1997).
3) Variation in cod stomach sampling strategy from year to year, due to variable survey and sampling coverage.
4) The input temperatures used in the consumption model are too high or not representative of the ambient temperature of the cod.
5) The stomach evacuation model used in consumption estimation (dos Santos and Jobling, 1995) needs knowledge about initial meal size, which is unknown in natural conditions, and has to be approximated by the total stomach content which assumes continuous feeding

Preliminary analysis on stomach data, studying the relationship between towing time, cod size, shrimp content in stomachs and digestion stage of eaten shrimp, was inconclusive to whether to what extent cod feed on shrimp in the trawl in surveys in the Barents Sea (Johannesen and Aschan, 2005). However, there is relatively few shrimp that are recorded as newly eaten in the cod stomachs (digestion stage 1: 2-8% per year, on average 4%), so that the problem should be of limited magnitude. There is also no direct way to quantify this potential problem given the data at hand. We modify the current Norwegian procedure to calculate cod consumption of shrimp in the Barents Sea to account for points 2-4 above, and explore how this affects the cod consumption estimate.

We point out the reason for over estimation in the old model, then justify why the new consumption estimates are better. If the new estimates are unbiased they will be implemented in the shrimp assessment.

Material and Methods

The shrimp survey

Shrimp catches have not been registered systematically on the surveys conducted by the Institute of Marine Research. The exception was the shrimp cruise that was conducted annually 1982-2004. However, this time series was interrupted and replaced by a new series using the joint ecosystem survey jointly conducted in autumn by the Institute of Marine Research, Norway (IMR) and the Knipovich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia (PINRO). There has not been any inter calibration between the shrimp survey and the ecosystem survey. The sampling effort in areas with high shrimp abundance and variation has been reduced but the coverage is extended to areas shallower than 200 m. The spatial expansion of the survey to the east may have influence on the shrimp index.

The stomach database and cod consumption estimation

The joint IMR-PINRO stomach content database currently holds information about more than 200 000 cod stomachs gathered from the Barents Sea and Lofoten area from 1984 until present (Yagarina and Mehl, 1996). The base holds information on the cod (length, weight, age, its place and time of capture) and weight and type of prey in the stomach.

About one third of the data in the base stems from the Norwegian winter survey, now run in cooperation with PINRO. This survey has covered the South-Central Barents Sea since 1981 and stomach sampling was initiated in 1984. From 1993 the survey was expanded north and eastwards, to allow a better coverage of younger cod. The survey area has been the same since then (Fig. 4, Jakobsen *et al*., 1997; Anon., 2005a). However, survey data is lacking from the Russian Economic Zone in 1997 and 1998 because Norwegian vessels were not allowed entrance. The survey covers most of the feeding areas for cod in the Barents Sea, even if the survey area may vary due to ice coverage.

Other Russian and Norwegian cruises, and Russian commercial vessels have sampled cod stomachs, but these surveys have a more limited and less consistent coverage over the years, giving a large year annual variation. From 2003 on, the joint IMR-PINRO ecosystem survey conducted in autumn has covered most of the Barents Sea and gathered cod stomach samples (Anon., 2005b).

Based on the cod stomach data, consumption estimates of the main prey are calculated each year (e.g. ICES, 2006). The procedure is described in Bogstad and Mehl (1997), but a brief description will also be given here. Bogstad and Mehl (1997) used the stomach evacuation model developed by dos Santos and Jobling (1995) derived from data from a laboratory experiment by the same authors. The stomach evacuation model is given by:

$$R == \ln 2 e^{\gamma T} W^{\delta} S_i / \alpha_i S_0^{\beta}$$

where **R** is consumption of an individual cod in grams per hour
T is the temperature on the environment of the cod
$\mathbf{S_i}$ is the stomach content of prey i in grams
$\mathbf{S_0}$ is the initial meal size in grams
W is the weight of the cod in grams, and
α, β, γ and δ are coefficients.

Bogstad and Mehl (1997) calculated consumption by age groups (1-11+), for three sub areas in the Barents Sea (Fig. 3), and for the first and second half of the year. Average shrimp content ($\mathbf{S_i}$) and total stomach content (for $\mathbf{S_0}$), together with VPA data on weight at age for cod (**W**) and temperature data taken standard position within each sub area and half year taken from oceanographic models based on CTD data from surveys (**T**).

The total consumption for each age class, each half year is calculated by weighting the individual consumption of each age class by the distribution of the age class in the sub area. The distribution of the age class by sub area is taken from the winter survey and from summer surveys for the second half year. Finally, total consumption by year is calculated as the sum of consumption over age groups and half years.

Stomach contents that are at higher taxonomic level than species, but might contain shrimp (e.g. undetermined stomach content, *Crustacea, Pandalidae*, *Pandalus sp.*) are re-classified according to the proportion in which they are found in the stomachs by age group, area and half year.

When pooling data and calculating average values of the input parameters into the model, a positive bias is introduced (dos Santos and Jobling, 1995). This bias is found to be variable and on average 35%. In the annual consumption estimates given by ICES each year this bias is corrected by a constant factor.

We modified the consumption procedure described above, to account for the following problems: 1) pooling of and averaging input data 2) variable spatial and temporal sampling coverage and effort from year to year, 3) crude input temperature resolution, and 4) using total stomach content for the unknown parameter $\mathbf{S_0}$, which implies continuous feeding. We only used data from 1993 on, because the winter survey has had a good coverage since.

1) *Pooling of data*

The bias introduced by pooling data might vary according to the statistical distribution of the data. It is possible to calculate consumption at the individual level using the data in the stomach database. We calculated individual consumption by age group, sub area and half year at the individual level, using the same input temperatures and cod weight data and overall approach as by the Arctic Fisheries Working Group (ICES, 2005).

2) *Variable sampling effort*

Stomach sampling has been quite consistent during the winter survey since 1993, and this survey has covered most of the cod stock. By calculating consumption only based on stomach data from the winter survey, we exclude year to year variation caused by variable sampling in space and time.

3) *Ambient temperature*

The temperatures used in the consumption model are annually taken from standard positions. Temperature has a large influence on the estimated consumption. An increase of 1°C in the input temperature leads to 15% increase in consumption (Gjøsæter and Bogstad, 2001). We calculated consumption at each station using temperature registered at the bottom adjacent to the haul. The stomach sampling is length stratified, with 1 cod stomach sample per each 5 cm length group (2 per 5 cm length group prior to 1996). We then estimated consumption per length group by weighting each station with the number of cod caught in the length group. Calculating individual consumption by age then requires an age length key. Age-length keys calculated for seven main areas were used. The total consumption is calculated by weighing average for main area by the distribution of each age class in the main area, multiplying with VPA and summing all age classes. Stomach content classified at a higher level than species that might contain shrimp (see above) where reclassified according to year, length group and main area specific proportions.

4) *The problem of initial meal size and alternative gastric evacuation models*

Dos Santos and Jobling (1995) did laboratory experiments on cod using prey species and temperatures relevant for the Barents Sea. Temming and Anderson (1994) and Hermann and Temming (2003) fitted another gastric evacuation model to the data. This model does not include the unknown parameter initial meal size, and estimates different coefficients for temperature, stomach content of prey and cod weight. We applied this alternative model with the procedure described in 3) Ambient temperature.

Results

Shrimp index

We used the stomach database and calculated the average shrimp content per stomach adjusted for cod size for 20 by 20 nautical mile grid cells. We summed all grid cells inside and outside the shrimp survey area and found that the amount of shrimp content outside the shrimp area is about the same as the amount inside the shrimp area (Fig. 3). This indicates that the shrimp survey covered approximately 50% of the Barents Sea shrimp stock.

The shrimp assessment based on data from the ecosystem survey and catch and effort data both indicate an increase in the shrimp biomass since 2005 (Hvingel, 2006; Hvingel and Aschan, 2006).

Cod consumption

The different approaches overall reduced the shrimp consumption estimated. Not pooling the data, reduced the estimate by on average 10%, not pooling the data and including only the winter survey data reduced the estimate on average by 16%, using ambient temperatures data reduced the estimate with 23 and 16 % for the dos Santos and Jobling (1995) estimation procedure and Temming and Hermannd (2003) procedure, respectively. However, there is high variation in the difference from year to year, and hence, the pattern of temporal fluctuation between the estimates is quite large (Table 1).

The dos Santos and Jobling (1995) and Temming and Hermannd (2003) give somewhat different estimates (Table 2). On average, the estimates provided by Temming and Hermannd (2003) are higher. Also, there are some differences in temporal variability in the differences between the two approaches. The differences are particularly large in 1993 and 1994. It seems like the total stomach content was high in these years, particularly in 1993. The capelin abundance was very high in autumn 1992, and the capelin content was high in stomachs in 1993 (Gjøsæter and Bogstad, 2001). Which of the two models is most correct under these circumstances is difficult to judge.

Both the dos Santos and Jobling (1995) and Temming and Hermannd (2003) models with ambient temperatures, winter survey data only and no pooling of data were significantly positively correlated with the shrimp index (Table 2). The shrimp index explained 44% of the variation in total cod consumption. The Bogstad and Mehl (1997) approach had no correlation with the shrimp index (Table 2).

The Bogstad and Mehl (1997) approach, and the approaches with ambient temperature, winter survey data only and no pooling of data, also give different age specific estimates for consumption (Fig. 4). When not pooling data, using winter survey data only and ambient temperature with weighing each haul with the number in each length group in the haul, the consumption of ages 1 and 2 is greatly reduced. Using dos Santos and Jobling (1995) or Temming and Hermannd (2003) is unimportant for the age specific consumption.

Discussion

Suggestions on further studies should be conducted to answer if cod is feeding on shrimp in the trawl.

Fisheries management has underestimated the consequences of massive capacity increase by combining new technology with open fishery on this non-regulated stock. The ICES ACFM has advised since 2005 that a quota TAC should be used as regulatory tool. Other arguments have been that it is considered impossible to fish the shrimp stock to extinction and that a TAC would have to be shared with Russia as the shrimp in the Barents Sea is considered to be one population).

It is a general understanding by scientist that an assessment model for shrimp should include the main predator cod. However, in the Barents Sea the shrimp stock does not seem to respond on the predation by cod but on the shrimp fishery. Thereby it is not possible to produce a good responsive model for shrimp and the predator with data available. The new consumption estimates do net result in a better cod-shrimp response. The cod was introduced as predator in the assessment model of shrimp in the Barents Sea, but the model is more robust when excluding the cod (Hvingel, 2006). This is because the shrimp stock does not respond on still high cod consumption, not even if a time lag is introduced.

References

Anon. 2003. ICES, Report Arctic Fisheries Working Group, Sect. 9.

Anon. 2005. Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea in August-October 2005 (vol.1). IMR/PINRO Joint Report Series, No. 3/2005. ISSN 1502-8828, 99 p.

Bogstad, B., and H. Gjøsæter. 2001. Predation by cod (*Gadus morhua*) on capelin (*Mallotus villosus*) in the Barents Sea: implications for the capelin stock assessment. *Fish. Res*., **53**: 197-209.

Bogstad, B., T. Haug, and S. Mehl. 2000. Who eats whom in the Barents Sea? NAMMCO Scientific Publications 2: 98-119.

Bogstad, B., and S. Mehl. 1997. Interactions between Atlantic cod (*Gadus morhua*) and its prey species in the Barents Sea. *In*: Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Pp. 591-615. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks.

Dos Santos, J., And M. Jobling. 1995. Test of food consumption model for the Atlantic cod. *ICES J. Mar. Sci*., **52**: 209-219.

Hvingel, C., and M. Kingsley. 2006. A framework to model shrimp (*Pandalus borealis*) stock dynamics and quantify risk associated with alternative management options, using Bayesian methods. *ICES J. Mar. Sci*., **6**: 68-82.

ICES. 2005. Report of the Arctic Fisheries Working Group. *ICES C.M. Doc*., No. 2005/ACFM: 28, p. 378-407.

Jakobsen, T., K. Korsbrekke, S., and O. Nakken. 1997. Norwegian combined acoustic and bottom trawl surveys for demersal fish in the Barents Sea during winter *ICES C.M. Doc.*, No. 1997/Y:17, 26 p.

Jakobsson J. and Stefánsson, G. 1998. Rational harvesting of the cod-capelin-shrimp complex in the Icelandic marine ecosystem. *Fish. Res.*, **37**: 7-22.

Johannesen, E., and M. Aschan. 2005. How much shrimp does the cod really eat? – five years later. Scientific paper, NAFO Science Committee No. 05/35, 12 p.

Mehl, S., and N. A. Yaragina. 1992. Methods and results in the joint PINRO-IMR stomach sampling program. *In*: Interrelations between fish populations in the Barents Sea. Proceedings of the Fifth PINRO-IMR Symposium, 12-16 August 1991, Murmansk, pp. 5-16. Ed. by B. Bogstad, and S. Tjelmeland. Institute of Marine Research, Bergen, 238 p.

Michalsen , K., G. Ottersen, and O. Nakken. 1998. Growth of North-East Arctic cod (*Gadus morhua* L.) in relation to ambient temperature. *ICES J. Mar. Sci.*, **55**: 863-877.

Ottersen, G., K. Michalsen, and O. Nakken. 1998. Ambient temperature and distribution of North-East Arctic cod. *ICES J. Mar. Sci.*, **55**: 67-85.

Skuladottir.

Standal, D. 2003. Fishing the last frontier - Controversies in the regulations of shrimp trawling in the high Arctic. *Marine Policy*, **27**: 375-388.

Temming, A., and J.-P. Hermann. 2003. Gastric evacuation in cod prey-specific evacuation rates for use in North Sea, Baltic Sea and Barents Sea multi-species models. *Fish. Res.*, **63**: 21-41.

Worm, B., and R.A. Myers. 2003. Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. *Ecology*, **84**: 162-173.

Table 1. The percentage difference between the shrimp consumption estimates given by the Bogstad and Mehl (1997) approach and the approaches estimating consumption at the individual level without pooling. The approach A includes all stomach data, approach B uses stomach data from winter survey only, whereas the approaches C and D uses different gastric evacuation models, but uses ambient temperatures (see methods).

YEAR	A: All data	B. Winter only	C: Winter only Ambient temperature	D. Winter only Ambient temperature Temming and Herman
1993	-14	-62	-72	-56
1994	7	-61	-56	-43
1995	-27	-19	-51	-42
1996	-4	-44	-37	-30
1997	-23	-12	-11	1
1998	-20	-5	6	13
1999	-22	65	74	74
2000	-9	-42	-39	-32
2001	-26	-15	-43	-41
2002	0	0	-19	-20
2003	8	5	-21	-5
2004	6	4	20	29

Table 2. Estimates of shrimp consumption according to stomach evacuation model and estimation procedures.

Stomach evacuation model	Dos Santos and Jobling (1995)	Dos Santos and Jobling (1995)	Temming and Hermannd (2003)
Year	Bogstad and Mehl (1997) ICES (2005)	Winter survey only No pooling Ambient temperature	Winter survey only No pooling Ambient temperature
1993	315	89	140
1994	518	228	296
1995	363	179	210
1996	341	213	239
1997	311	276	312
1998	326	346	368
1999	256	447	446
2000	461	279	312
2001	284	163	167
2002	232	188	185
2003	226	179	214
2004	244	220	229
Average	**323**	**234**	**260**
Correlation with shrimp index (n = 12)	$P = 0.79$, $r = -0.12$	$P = 0.02$, $r = 0.66$	$P = 0.02$; $r = 0.66$

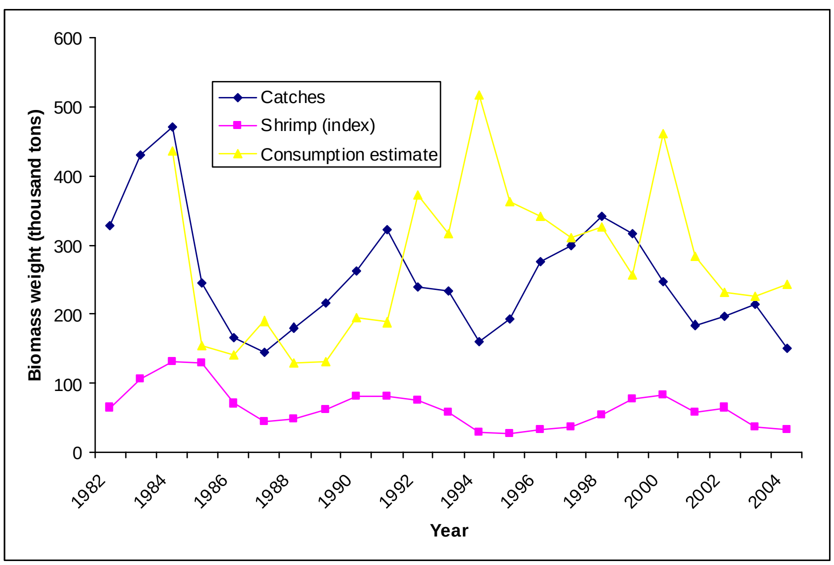

Fig. 1. Catches, estimated consumption (ICES, 2005) and shrimp index in thousand tons plotted against year.

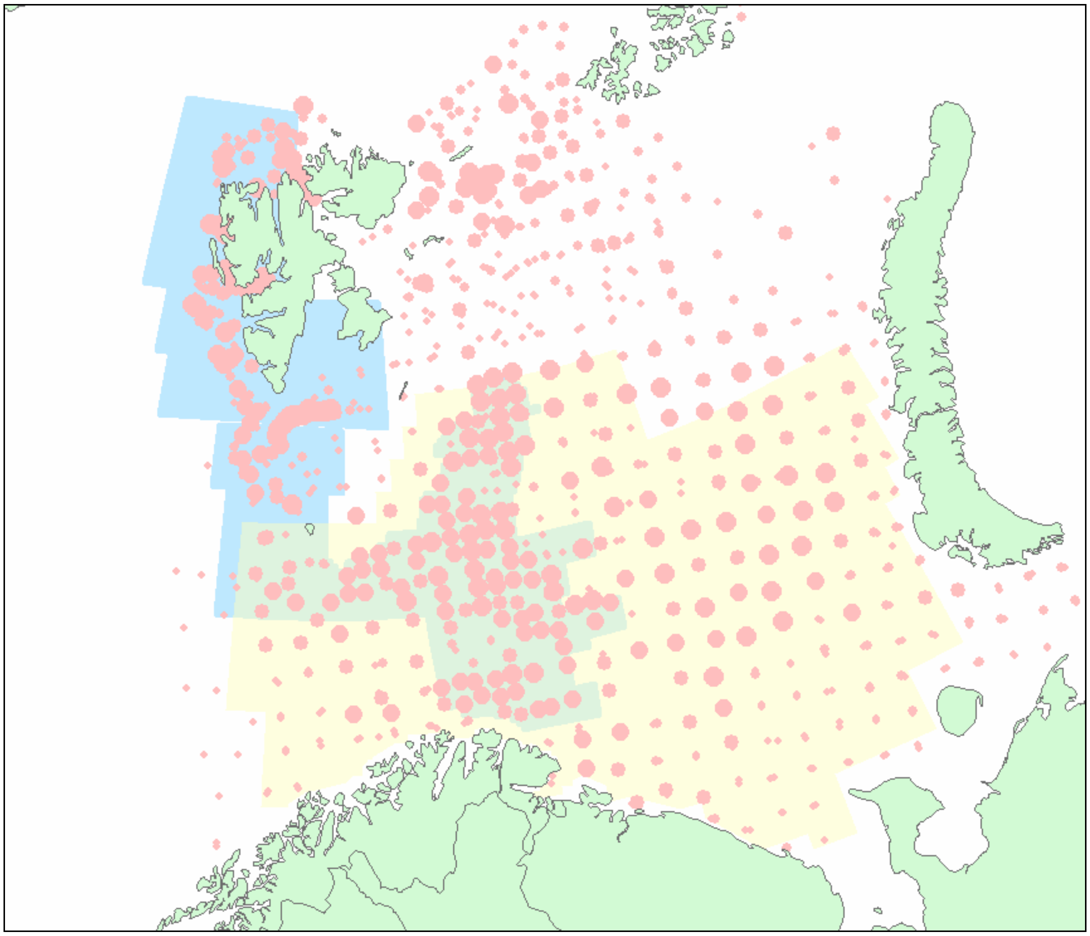

Fig. 2. Shrimp catches at the Joint IMR–PINRO ecosystem survey in autumn 2005 is shown in pink. Shrimp catches (in kg) is proportional to the size of the dots. The outline of the shrimp survey area and the winter survey area are shown in blue and yellow, respectively.

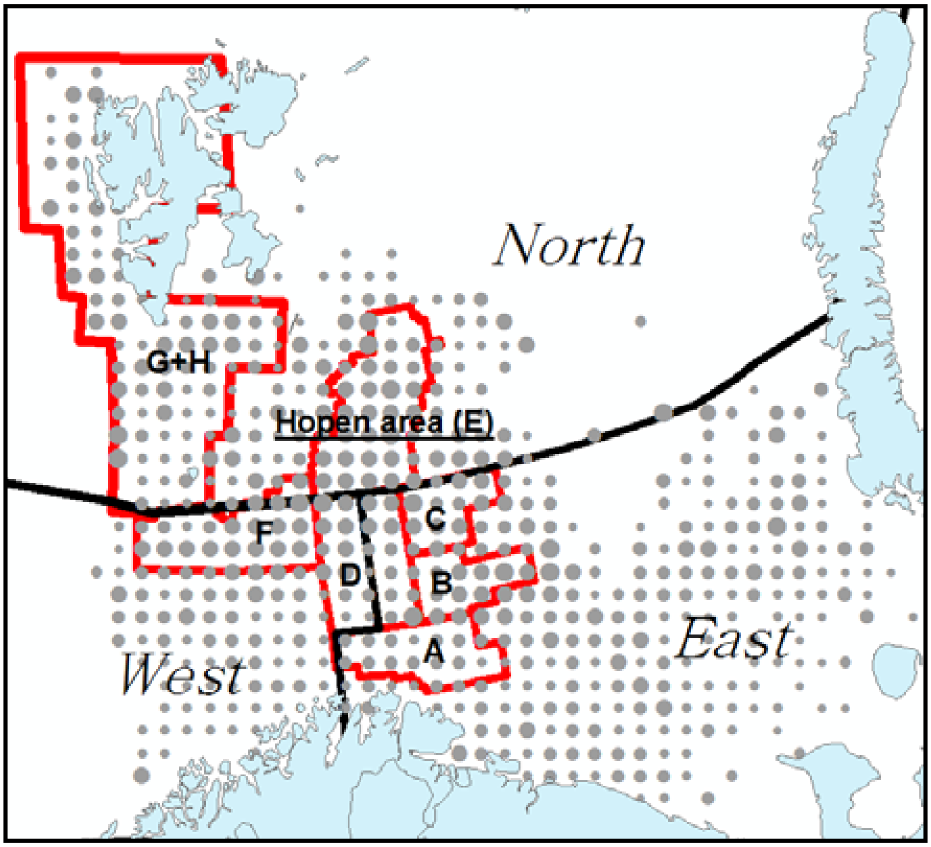

Fig. 3. Average shrimp content in cod stomachs adjusted for cod length for 20 by 20 nautical mile grid cells is shown in grey. The size dots are proportional to the shrimp content. All data from the joint IMR PINRO stomach data based are include. The shrimp survey area with sub areas A-H are shown in red. The black lines shows the borders of the sub areas used in the shrimp consumption estimation approach by Bogstad and Mehl, 1997.

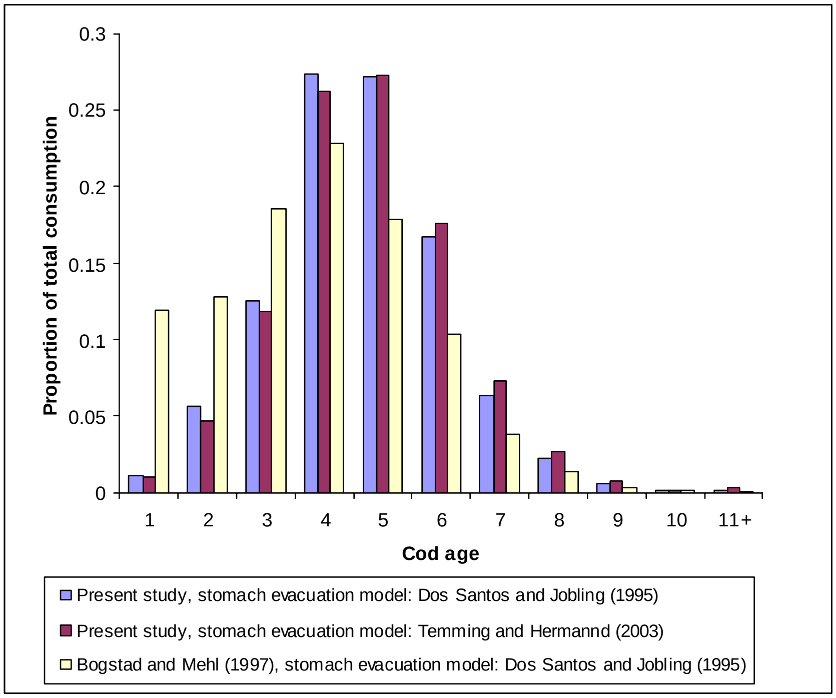

Fig. 4. Proportion of total shrimp consumption by age of cod given by the Bogstad and Mehl approach and two approaches described in the present paper. The age specific estimates area based on average from 1993-2004.