WD 20 to AFWG 2006

Cod Consume Capelin

Edda Johannesen, Geir Odd Johansen, Bjarte Bogstad, Sigbjørn Mehl, Sigurd Tjelmeland,
IMR, Bergen, Norway
and
Andrey Dolgov, PINRO, Murmansk

1. Introduction

In this WD we describe and compare four methods for estimating capelin consumption by cod in the Barents Sea. These methods are described in Johansen et al. (2004) and Johansen and Ulltang (2005), Dolgov (1998), Bogstad and Mehl (1997) and Tjelmeland (WD 2000), and are hereby called the *Johansen*, *Dolgov*, *Bogstad & Mehl* and *Tjelmeland* approach respectively. Estimates from the *Dolgov* and *Bogstad & Mehl* approaches are presented for main prey species in the AFWG report. Estimates of consumption from the *Bogstad & Mehl* approach is used in XSA for cod and haddock. Estimates of capelin consumption by cod estimated with the Tjelmeland approach is implemented in the capelin assessment tool Bifrost, and used in capelin assessment every year.

Capelin consumption by cod is input in models used in the project: “Optimal long-term harvest in the Barents Sea ecosystem.” This WD is meant as an aid to evaluate the different consumption estimate methods mentioned above. We start by describing the different methods. We then provide estimates for capelin consumption by individual cod for the 1st quarter in the period 1984-2004, by cod age groups. We focus on the 1st quarter because this quarter has the most consistent sampling throughout the time series (see appendix). The other quarters requires extrapolation in time and space, and this give rise to intractable / subjective handling of the data. We then do a correlation analysis of the relationship between capelin consumption by cod and capelin abundance and cod stock size. These abundance estimates are both used in the models for “Optimal long-term harvest in the Barents Sea ecosystem”.

2. Description of the methods

2. 1 Gastric evacuation models

All four methods use stomach evacuation models derived from laboratory experiments performed by dos Santos and Jobling (1992, 1995).

Bogstad& Mehl and *Dolgov*

Consumption per cod per time unit is calculated by pooling stomach data by cod age and according to the temporal and spatial resolution described in 2.3. Stomach content data is combined with temperature data and cod weight data in a gastric evacuation model.

The gastric evacuation model parameterised by dos Santos and Jobling (1995) is used. Here R, consumption of each species (i, g) per hour is:

$$R=\ln 2 e^{AT} W^{C} S_i / R_i' \, S_0^{D} \quad (1)$$

Input parameters are cod weight (W, kg), temperature (T, °C), initial meal size (S_0, g), stomach content of a particular prey species ($S_{i,}$, g) with coefficients R_i that vary by prey type (*i*), and the temperature coefficient A, the body weight coefficient C, and the initial meal size coefficient D.

In natural situations, initial meal size is unknown. *Bogstad & Mehl* and *Dolgov* approximate initial meal size with the total stomach content (S) multiplied by a correction factor k, so that S_0= kS. This assumes continuous feeding. k is derived in the following way: In experiments by dos Santos and Jobling (1995), the consumption model was tested by feeding cod for a 2-week period and comparing the consumption calculated using equation (1) with the observed consumption. When this was done using multiple prey species, it was found that the consumption was overestimated by 35 % if the stomachs were pooled and 20 % if the stomachs were not pooled. *Bogstad & Mehl* and *Dolgov* use pooled data (see above), and the Bogstad & Mehl and *Dolgov* methods thus uses a correction factor k=1.78 (see above, D=0.52, $1.78^{0.52}$=1.35).

Tjelmeland

A different model of gastric evacuation fitted to the same data as above is used (Temming and Andersen 1994). The gastric evacuation model is fitted to each cod individually. This model is similar to the model in Eq. (1) but excludes initial meal size, and includes a coefficient B on stomach content of prey *i* (S_i^B):

$$R=\ln 2 e^{AT} W^{C} S_i^{B} / R_i \quad (2)$$

In this method the uncertainty in the consumption calculations is essential since the results are used in a stochastic simulator (Bifrost). To account for the uncertainty in the evacuation model a file of replicate parameters are made by resampling from the original data, each time estimating new parameters.

Johansen

The model in Eq. (2) is integrated and rearranged to get the digestion time of fish prey:

$$t= (S_i^{(1-B)} - U_i^{(1-B)})/ - R_i (1\text{-}B)\, e^{AT} W^{C(1-B)} \quad (3)$$

where U_i is the weight of the prey, in this case capelin, when ingested, found by regression of body weight against body length from survey data on capelin. The *Johansen* approach thus relies on length measurements of capelin from cod stomach samples and assumes that the length is not altered in the digestion process and that there is consistency in the recording of a prey as length measurable or not.

The *Johansen* approach calculates the number of capelin in 1 cm length groups consumed per time unit by dividing the number of length measured capelin recorded per stomach with t_{max},where t_{max} is the time it takes from ingestion of the capelin until the capelin is no longer length measurable. t_{max} is dependent on temperature and capelin length. The approach by

Johansen et al. is thus treating each cod stomach individually when calculating number of capelin consumed per time unit. Johansen and Ulltang (2005) have calculated $t_{max, T4}$ for 1 cm length groups of capelin at 4°C (table 1) from eq. 3. $t_{max,T}$ at other temperatures can be found from the relationship:

$$t_{max,T} = t_{max, T4} \exp(AT_4)/\exp(AT) \quad (4)$$

Table 1. Length group of capelin, number of observations, and time from ingestion until capelin is no longer length measurable (t_{max}) at 4ºC. (From Johansen and Ulltang 2005, based on data from 1992-97).

capelin length (cm)	n	$t_{max, T4}$ (h)
<7	53	2.690
7-8	53	4.652
8-9	107	5.803
9-10	224	7.062
10-11	414	8.427
11-12	602	9.895
12-13	1094	11.465
13-14	927	13.134
14-15	857	14.900
15-16	613	16.762
16-17	314	18.718
17-18	198	20.767
>18	40	25.140

2.2 Input parameters

2.2.1 Stomach content

All four methods compared use yearly input data from the joint PINRO-IMR stomach sampling programme initiated in 1984. Data from this database is summarised in the appendix. The data is sampled at Norwegian surveys, Russian surveys and Russian commercial boats. The stomach data is quantitative data and weight of stomach content per cod stomach according to prey species is recorded.

Up to 20% of stomach content consists of unclassified or partly classified fish and undetermined stomach content (see appendix). Some of this might be capelin that was too digested to be recognized, and should therefore be included in the capelin content in stomachs. The four methods have different approaches to this problem.

Bogstad & Mehl and Dolgov

For each age group, and according to the temporal and spatial resolution used, the weight of each prey species and size group was adjusted by distributing the unidentified component of the diet proportionally among the various identified components, taking into account the level of identification (as in Anon. 1984)

Johansen

In this method there is no need to include un-classified stomach content since the method only uses stomachs where capelin can be length measured to calculate consumption rate, and combines this with the proportion of cod with length measured capelin. This is one of the advantages of this method.

Tjelmeland

The unidentified stomach content is distributed on capelin, cod and other food according to the station specific proportion of these food items in the diet.

2.2.2. Input temperatures

Bogstad & Mehl and *Dolgov*

Climatological data (Ottersen and Ådlandsvik 1993) is adjusted by yearly variation in the Kola section (Tereshchenko 1996 and PINRO, pers, comm.) to get temperature according to the spatial and temporal resolution used. The following positions and depths were used to represent each area: I (West): 7200N, 2400E, 260m, II (East); 7130N, 3500E, 180m, III (North): 7430N, 2200E, 150m. *Dolgov* uses the arithmetic mean of same temperatures from the three areas mentioned above.

Johansen and *Tjelmeland*
Johansen et al. (2004) and Johansen and Ulltang (2005) used strata-specific temperatures derived from a Temperature Atlas. In the present paper, we use station specific temperatures. These temperatures are taken from the IMR data base TINDOR. The same temperature data is used by *Tjelmeland.* The temperature used for each trawl station is the temperature at the nearest CTD station at the appropriate depth. If a temperature station is not found in the surrounding box, the same box in an adjacent year is used, and the temperature scaled with the difference in the Kola section data. If no station is found in adjacent years, stations in the same box are selected from other years, working progressively outwards. If still no temperature station is found, the surrounding box is doubled and the procedure starts again. A statistical analysis of the temperature data is made to estimate the uncertainty as function of distance in space and time between the CTD station used and the trawl station. The Russian CTD data have as yet not been available, which increases the uncertainty. The size of the surrounding box is 5 minutes (both for latitude and longitude) in each direction.

2.2.3. Cod weight

Bogstad & Mehl and *Dolgov*
Weight at age at the beginning of the year is taken from the AFWG report. The weights are adjusted to the time periods used by assuming linear growth.

Tjelmeland
The weight of each individual cod is used as input into the gastric evacuation model.

Johansen

When calculating t_{max} according to capelin length group (Table 1), the median weight of cod with length measurable capelin of the particular capelin length group was used.

2.3 Spatial and temporal resolution used in the different methods

2.3.1. Temporal resolution

Bogstad & Mehl use two half years as temporal resolution, *Tjelmeland* and *Dolgov* use quarter and *Johansen* use five periods per year.

The temporal resolution applies to the input data used. Furthermore, it applies to the VPA data used. To calculate total consumption, individual consumption by age is multiplied with number at age from VPA. The number at age in the mid point of each time period is calculated by adjusting VPA at the beginning of the year with fishing and natural mortality.

2.3.2. Spatial resolution

Dolgov has no spatial resolution, e.g. uses one area. *Bogstad & Mehl* use three areas (Bogstad and Mehl 1997). *Tjelmeland* uses MULTSPEC areas, e.g. seven areas. *Johansen* uses strata as the spatial unit. Two different strata systems are used: Norwegian winter survey strata system from 1^{st} Jan to 31^{th} of May, and for 1^{st} of June to 31. December, a strata system for the Norwegian demersal survey in autumn is used.

The spatial resolution applies to the input data used, and also as a weighting factor when the average of the total consumption of the Barents Sea is calculated. The average individual consumption for the whole Barents Sea is calculated by weighting the area specific average consumption estimates by age with the proportion of each age group of cod in each area. These proportions are derived from the Norwegian winter survey and the Norwegian demersal survey in autumn.

3. Consumption estimates for the first quarter 1984-2004.

Individual consumption by age and year for the four methods in the first quarter is given in Table 2 a-d. To get total consumption, individual consumption by age is multiplied with VPA data (Table 3) that has been adjusted by multiplying number at age with 1-proportion mature (Table 4). VPA data from the AFWG (2005) report is given in Table 3. This VPA is then adjusted for the proportion of mature cod (i.e. cod assumed to be in the Lofoten area spawning or doing spawning migrations and not feeding in the 1^{st} quarter) (Table 4). NB! *Dolgov* normally does not adjust for the proportion of mature cod.

Total consumption by year and method is shown in Figure 1. Dividing each yearly estimate for the *Tjelmeland*, *Johansen* and *Bogstad & Mehl* method, with the estimates from the *Dolgov* method, reveals that the other estimates are below the estimates by *Dolgov*; the *Tjelmeland* estimates are on average 55% of the *Dolgov* estimates (1984–2004) and the *Johansen* estimates are on average 53% of the *Dolgov* estimates (1993-2004). The *Bogstad & Mehl* estimates were on average 89% (1984 –2004) of the *Dolgov* estimates, but the differences would be greater if the VPA had not been adjusted for mature fish, because individual consumption estimated for old fish by the *Dolgov* method is higher than the estimates by the *Bogstad* method in many years (Table 2).

The difference in consumption estimates for the *Johansen* method when weighing by the number at age in the stratum is quite similar to the un-weighted estimates (Figure 1).

Average total consumption by age for the years 1993 to 2004 is shown in Figure 2. Average consumption by age was highest for 3-5 year old cod.

Table 2a. Individual consumption (kg capelin consumed per cod per Quarter 1st Quarter=90 days) calculated by the *Dolgov* method,

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15
1984	0.002	0.053	0.184	0.364	0.656	1.075	0.631	2.742	3.684	4.712	5.224	6.175	7.231	7.231	7.231
1985	0	0.032	0.471	0.999	1.319	2.153	2.818	3.631	4.648	6.271	8.497	6.861	8.236	8.236	8.236
1986	0	0.024	0.120	0.276	0.593	1.163	1.887	2.731	3.204	3.528	5.084	5.195	6.304	6.304	6.304
1987	0	0.009	0.042	0.058	0.004	0.022	0	0	0	0	0	0	0	0	0
1988	0	0.014	0.100	0.207	0.147	0.076	0.014	0	2.095	5.687	3.239	3.255	0.945	0.945	0.945
1989	0	0	0.110	0.252	0.418	0.613	1.027	0.597	2.460	3.209	3.414	4.022	0.847	0.847	0.847
1990	0.002	0.115	0.453	0.715	0.688	1.067	1.702	1.926	0.085	0.125	0.144	0.176	0.211	0.211	0.211
1991	0.007	0.190	0.798	1.731	2.512	3.555	4.150	4.962	5.714	8.654	7.618	8.866	11.117	11.117	11.117
1992	0.001	0.122	0.479	0.822	0.762	1.095	1.360	1.842	0.912	2.135	2.677	2.430	2.969	2.969	2.969
1993	0.001	0.067	0.324	0.929	1.726	2.231	2.750	2.771	3.027	3.750	4.778	4.884	5.669	5.669	5.669
1994	0	0.033	0.106	0.199	0.385	0.550	0.921	0.011	0.013	0.015	0.016	0.021	0.024	0.024	0.024
1995	0.001	0.013	0.102	0.171	0.295	0.459	0.302	0.128	0.071	0.088	0.096	0.105	0.120	0.120	0.120
1996	0	0.016	0.077	0.126	0.266	0.568	0.441	0.994	0.474	1.063	1.110	1.159	1.321	1.321	1.321
1997	0	0.006	0.099	0.164	0.311	0.713	0.831	2.160	3.078	0.331	0.410	0.395	0.522	0.522	0.522
1998	0.001	0.008	0.102	0.214	0.197	0.282	0.392	0.769	0.447	0.691	0.770	0.742	0.918	0.918	0.918
1999	0.001	0.012	0.088	0.325	0.681	0.973	1.152	1.090	1.079	1.511	1.614	1.666	2.036	2.036	2.036
2000	0	0.029	0.154	0.497	0.740	1.111	0.674	2.056	0.835	0.635	0.780	0.903	1.117	1.117	1.117
2001	0.004	0.026	0.228	0.456	0.921	2.603	2.090	3.312	3.150	4.319	5.239	5.192	6.623	6.623	6.623
2002	0.004	0.035	0.205	0.627	1.005	1.367	2.117	2.387	2.599	3.683	3.765	4.076	4.764	4.764	4.764
2003	0	0.042	0.203	0.468	0.894	1.182	1.738	2.451	2.972	3.963	6.053	4.640	5.423	5.423	5.423
2004	0	0.028	0.131	0.292	0.752	1.080	1.317	2.319	4.265	6.779	10.355	7.937	9.277	9.277	9.277

Table 2b. Individual consumption (kg capelin consumed per cod per Quarter 1st Quarter=90 days) calculated by the *Bogstad &Mehl* method. NB! this is the individual consumption by cod for first half year divided by two.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
1984	0.014	0.089	0.217	0.413	0.702	0.864	1.478	1.565	1.688	1.809	1.874
1985	0.005	0.088	0.398	0.714	1.170	1.962	2.705	2.918	3.087	3.359	3.384
1986	0	0.060	0.141	0.272	0.465	0.394	1.313	1.437	1.511	1.570	1.650
1987	0	0.010	0.041	0.087	0.027	0.015	0	0	0	0	0
1988	0.004	0.017	0.079	0.120	0.067	0.231	0.093	0.103	0.117	0.127	0.125
1989	0	0.046	0.135	0.232	0.362	0.507	0.556	0.628	0.705	0.761	0.782
1990	0.041	0.135	0.269	0.451	0.611	0.767	1.015	1.123	1.228	1.321	1.403
1991	0.047	0.206	0.567	1.055	1.362	1.651	1.811	1.968	2.180	2.411	2.342
1992	0.007	0.180	0.493	0.748	0.700	0.822	1.138	1.190	1.082	1.174	1.178
1993	0	0.091	0.333	0.757	1.283	1.678	2.452	2.471	2.595	2.728	2.205
1994	0	0.056	0.112	0.179	0.323	0.541	0.578	0.606	0.641	0.662	0.674
1995	0.001	0.021	0.126	0.125	0.165	0.188	0.093	0.063	0.069	0.073	0.075
1996	0	0.019	0.048	0.073	0.132	0.236	0.213	0.228	0.152	0.158	0.163
1997	0.003	0.010	0.143	0.134	0.225	0.311	0.398	0.875	1.041	1.114	1.081
1998	0.001	0.019	0.130	0.226	0.145	0.265	0.318	0.685	0.174	0.186	0.189
1999	0	0.025	0.091	0.346	0.546	0.678	0.718	1.024	0.420	0.466	0.472
2000	0	0.047	0.193	0.371	0.539	0.688	0.588	1.059	0.420	0.448	0.464
2001	0.007	0.035	0.228	0.364	0.490	0.689	1.089	1.540	1.194	1.284	1.337
2002	0.006	0.067	0.215	0.456	0.623	0.793	0.966	0.927	0.382	0.422	0.416
2003	0	0.101	0.245	0.416	0.668	0.985	1.390	1.067	1.341	1.429	1.584
2004	0	0.046	0.165	0.257	0.437	0.659	0.903	1.457	2.449	2.628	2.736

Table 2c. Individual consumption (kg capelin consumed per cod per Quarter 1st Quarter=90 days) calculated by the *Johansen* method. The *Johansen* method is only applied to data from 1993 on, because it relies on a consistent method in measuring prey.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
1993	0	0.007	0.327	1.296	2.104	2.833	2.983	0.438	4.295	3.373	0
1994	0	0.030	0.157	0.281	0.242	0.179	0.069	0	0	0	0
1995	0.003	0.036	0.199	0.086	0.093	0.200	0.064	0	0	0.193	0
1996	0	0	0.008	0.038	0.077	0.097	0.178	0.315	0	0.180	0
1997	0	0.003	0.030	0.009	0.116	0.356	0.118	0.566	0.834	0	0
1998	0.002	0.016	0.028	0.068	0.138	0.029	0.050	0.277	0	0	0
1999	0	0.001	0.050	0.362	0.261	0.207	0.143	0	0	0	0
2000	0	0.018	0.074	0.167	0.147	0.318	0.013	0.513	0.166	0	0
2001	0	0.003	0.251	0.504	0.414	0.441	0.529	0.707	0	0	0
2002	0	0.007	0.140	0.368	0.396	0.413	0.759	1.417	0	0	0
2003	0	0.001	0.078	0.161	0.522	0.419	0.370	0.664	0.939	0	0
2004	0	0.004	0.011	0.029	0.087	0.155	0.170	0.227	0.245	0.784	0

Table 2d. Individual consumption (kg capelin consumed per cod per Quarter 1st Quarter=90 days) calculated by the *Tjelmeland* method.

	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age10+
1984	0.006	0.046	0.11	0.178	0.877	1.05	0.396	3.941	0	0
1985	0	0.029	0.323	0.66	0.561	0.561	1.558	1.874	1.523	0
1986	0	0.023	0.059	0.101	0.182	0.234	0.183	0.012	0	0
1987	0	0.004	0.018	0.02	0.003	0	0	0	0	0
1988	0	0.003	0.019	0.06	0.042	0.015	0.027	0	0	0
1989	0.005	0.008	0.05	0.1	0.177	0.142	0.228	0.104	0	0
1990	0	0.038	0.245	0.407	0.366	0.518	0.445	0.529	0	0
1991	0.012	0.136	0.719	1.351	2.06	2.806	2.829	3.37	3.551	0
1992	0	0.072	0.325	0.493	0.375	0.465	0.637	0.966	0.323	0
1993	0.007	0.056	0.261	0.723	1.183	1.664	1.927	2.679	3.249	1.127
1994	0	0.018	0.072	0.148	0.26	0.36	0.545	0.338	0.188	0.36
1995	0	0.002	0.042	0.093	0.224	0.328	0.264	0.294	0.097	0.346
1996	0	0.005	0.019	0.058	0.096	0.224	0.266	0.384	0	0.481
1997	0.001	0.006	0.07	0.089	0.216	0.314	0.395	0.799	0.875	0
1998	0	0.009	0.048	0.11	0.099	0.116	0.128	0.379	0.209	0
1999	0	0.003	0.031	0.166	0.279	0.395	0.403	0.347	0.081	0
2000	0.044	0.065	0.218	0.365	0.647	0.897	0.625	1.961	0.248	0
2001	0	0.007	0.075	0.224	0.387	0.423	0.647	0.162	0.05	0.285
2002	0	0.011	0.107	0.422	0.52	0.669	0.971	1.016	0.421	0.069
2003	0	0.035	0.132	0.263	0.448	0.476	1.068	1.16	1.219	0
2004	0	0.004	0.041	0.121	0.287	0.3	0.534	0.639	1.803	5.111

Table 3. Number at age January 1st each year taken from VPA table Arctic WG report 2005.

	1,	2,	3,	4,	5,	6,	7,	8,	9,	10,	11,	12,	+gp
1984	211668	67034	40282	12865.85	6438.64	3286.47	1084.6	130.4	9.23	0	0	0	0
1985	137711	135540	52873	32007.69	8918	3025.28	936.9	97.2	12.72	21.4	0	0	0
1986	175524	78735	104745	38990.85	20542.68	4460.67	993.11	196.04	72.96	12	0	0	0
1987	49254	56314	28885	73430.28	25276.47	9153.66	1737.06	361.8	93	17.25	0	0	0
1988	82176	23815	20658	20685.84	45904.95	8955.22	1684.01	221.54	0	0	0	0	0
1989	81895	30099	17464	15882	14459.95	22398.3	3553.57	319.92	26.85	0	0	0	0
1990	151888	53994	24594	13699.62	10864.2	7545.29	6285.72	554.53	48.58	1.42	0	0	0
1991	173229	112958	41657	19164.48	10007.24	5894.64	2172.45	1621.46	40.74	0	0	0	0
1992	305491	127988	72240.33	3153.12	13512.4	4118.82	1215.5	232.33	165.9	0	0	0	0
1993	2429610	157005	90697	55650.84	21984.69	7058.8	1482	208.8	44.76	28.7	0	0	0
1994	936482	153097	82117	67930.83	37968.29	9369.28	2085.6	335.54	31.35	6.27	12.1	0	0
1995	2009727	137948	66759	54520	42715.83	16669.6	2280.76	345.28	26.95	5.96	0	0	0
1996	2778264	254466	44402	31391	32254.74	19841.62	4231.32	342.55	8.46	0	0	0	0
1997	1929795	310648	72723	22739	17708.6	15354.44	5613.08	796.32	34.8	8.15	2.7	0	0
1998	672105	129124	85124	41997.78	13242.24	6784.56	3967.6	808.74	73.71	2.98	0	0	0
1999	311315	109993	57415	47890	24207.48	6046.2	1731.4	562.38	155.28	0	0	0	0
2000	349714	86458	62928	41495	29871.32	9064.38	965.52	195.5	22.74	0	0	0	0
2001	414937	65803	54963	47332.89	28250.15	11387.64	2200.38	241.5	6.74	0	1.92	0	0
2002	126652	120924	43213	41955.21	32187.12	11143.8	2521.2	311.78	7.66	0	0	0	0
2003	594618	57736	54777	31314	28160.28	13760.45	3378.876	371.349	56.94	0	0	0	0
2004	532236	91717	37454	41791.74	21539.44	11829.56	3199.881	510.26	26.166	6.786	0	0	0

Table 4. Percentage Mature by age from Arctic WG report 2005.

	3	4	5	6	7	8	9	10	11	12+gp	
1984	0	0.05	0.18	0.31	0.56	0.9	0.99	1	1	1	1
1985	0	0.01	0.09	0.36	0.55	0.85	0.96	0.9	1	1	1
1986	0	0.05	0.08	0.19	0.53	0.71	0.62	0.9	1	1	1
1987	0	0.01	0.07	0.18	0.22	0.46	0.5	0.75	1	1	1
1988	0	0.02	0.05	0.33	0.53	0.62	1	1	1	1	1
1989	0	0	0.05	0.18	0.41	0.69	0.85	1	1	1	1
1990	0	0.01	0.05	0.21	0.58	0.77	0.86	0.98	1	1	1
1991	0	0.04	0.06	0.28	0.65	0.83	0.97	1	1	1	1
1992	0.01	0.01	0.12	0.43	0.75	0.93	0.97	1	1	1	1
1993	0	0.03	0.09	0.3	0.61	0.91	0.97	0.99	1	1	1
1994	0	0.01	0.11	0.33	0.6	0.81	0.97	0.99	0.99	1	1
1995	0	0	0.07	0.33	0.62	0.74	0.95	0.98	1	1	1
1996	0	0	0.02	0.26	0.63	0.83	0.98	1	1	1	1
1997	0	0	0.02	0.14	0.56	0.82	0.95	0.95	0.95	1	1
1998	0	0.01	0.04	0.19	0.44	0.82	0.93	0.98	1	1	1
1999	0	0	0.01	0.1	0.45	0.79	0.88	1	1	1	1
2000	0	0	0.06	0.22	0.64	0.83	0.97	1	1	1	1
2001	0	0.01	0.05	0.34	0.58	0.77	0.98	1	0.97	1	1
2002	0	0.01	0.08	0.4	0.7	0.86	0.98	1	1	1	1
2003	0	0	0.101	0.365	0.628	0.879	0.927	1	1	1	1
2004	0	0.006	0.093	0.403	0.717	0.876	0.979	0.982	1	1	1

Figure 1. Capelin consumed (thousand tons) by cod 1st quarter 1984-2004.

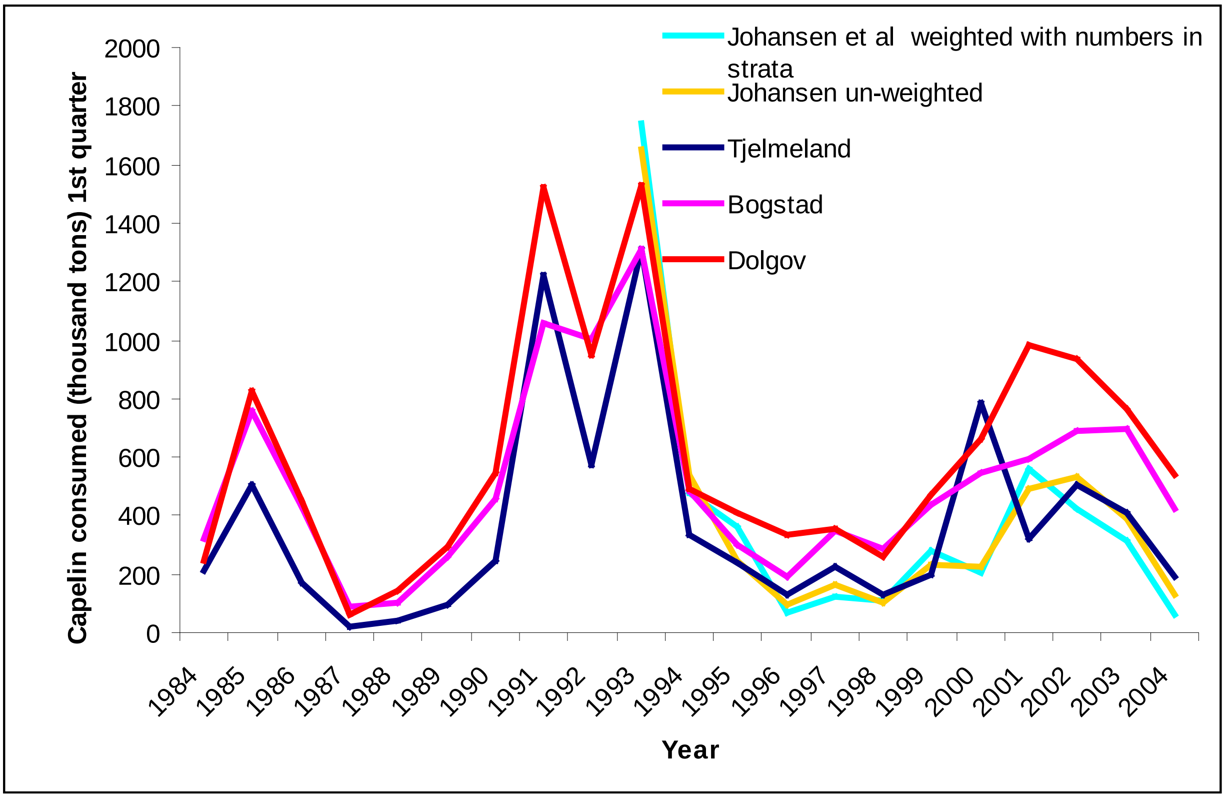
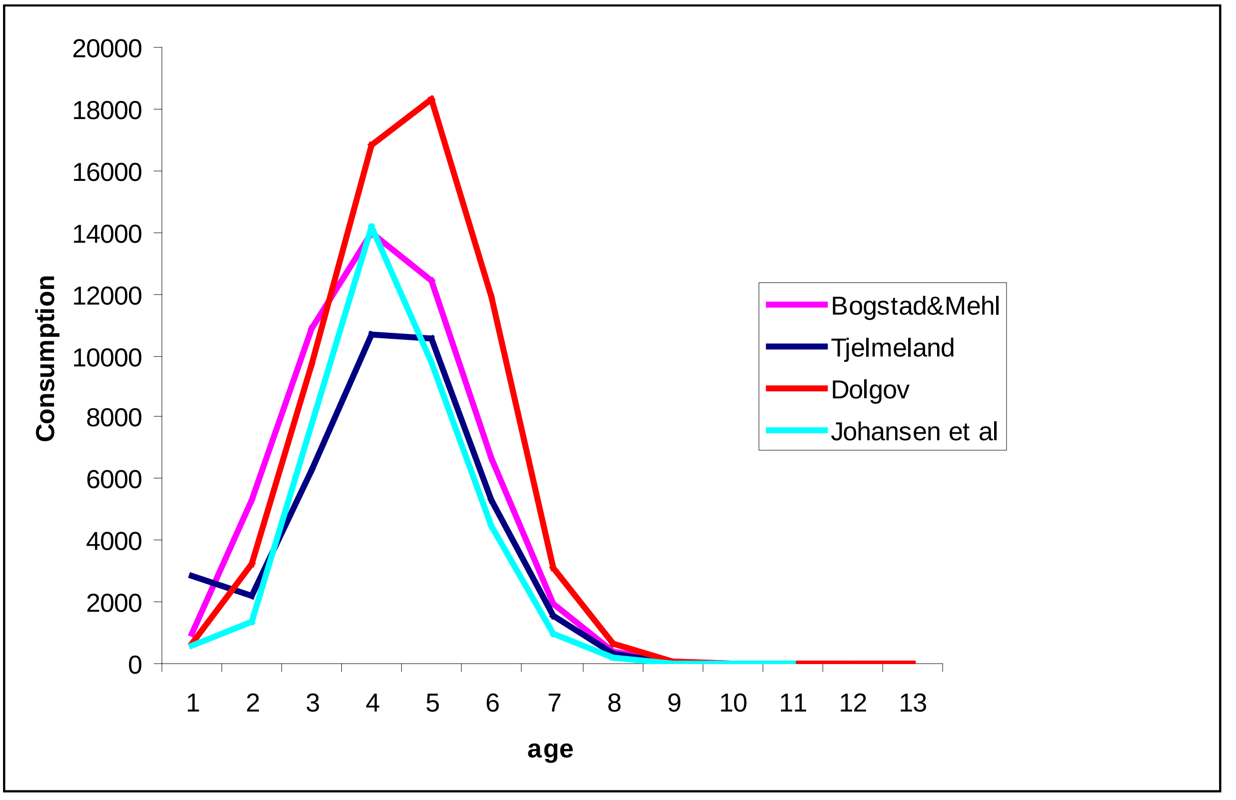


Figure 2. Capelin consumed (100 tons) by cod 1993-2004 by age and method.



4. Correlation between consumption estimates, capelin abundance and cod abundance.

Individual consumption averaged for ages 3-6 years were regressed against cod biomass and capelin abundance in year y-1. The results for the four methods are summarised in Table 6.

Table 6. Individual consumption (average 3-6 years) correlated against cod and capelin abundance. Significant correlations at the 5% level are noted with*.

1984-1992	Tjelmeland	Dolgov	Bogstad	Johansen
Capelin	0.671*	0.659*	0.728*	
Cod	0.399	0.433	0.361	
1993-2004				
Capelin	0.815*	0.942*	0.857*	0.752*
Cod	0.412	0.259	0.369	0.601*

The correlation between capelin abundance and capelin consumption was positive and significant. Interestingly, there was a positive correlation between cod abundance and capelin consumption that was significant for the *Johansen* method.

5. Conclusion

The different approaches give quite different results. The differences between *Dolgov* and *Bogstad & Mehl* are smallest, but yet surprising. These two methods only differ in spatial resolution, and this should not be sufficient for resulting in differences of the magnitude found here (Dolgov WD 1998). In the present paper, data for 2nd quarter is also included in the *Bogstad & Mehl* estimates, but due to the limited sampling in the second quarter this should not be able to explain the difference between the *Dolgov* and *Bogstad & Mehl* estimates. This need, however, to be checked, together with other possible explanations.

The *Johansen* and *Tjelmeland* approaches provide estimates well below the ones by *Bogstad* and *Dolgov*. They are similar both in using gastric evacuation models derived by Temming and Andersen (1994), and by calculating individual consumption for each cod separately, using station specific temperatures when available. The weighting according to strata specific number at age, did not seem to be that important for the overall level of total consumption (Figure 1). There also seems to be a systematic tendency for the difference between *Tjelmeland* and *Dolgov*/*Bogstad & Mehl* approaches to be greater at low capelin abundance.

The approaches have their own weaknesses and strength. Calculating individual consumption at the individual level seem intuitively appealing, and makes it unnecessary to use the scaling factor of 1.78, which is an approximation assuming average conditions only met under certain circumstances. However, calculating individual consumption at the individual level impose problems with redistributing undetermined stomach content at the individual level, when using the *Tjelmeland* approach. This problem is avoided when using the *Johansen* approach. The *Johansen* approach, however, requires consistent routines for length measuring of prey. It can be seen from the appendix that this is not likely to be the case. Between years differences in length measurement practises, will create artificial year-to-year variation in consumption. Calculating consumption at the individual level also allows testing for the effect of weighting with area specific proportion of cod at different spatial resolution when calculating average individual consumption.

The approaches could only be properly evaluated by modelling the feeding process of cod with respect to capelin and cod abundance, distribution and spatial overlap (e.g. Tjelmeland WD 2000), thus creating simulated stomach data under specified conditions and known individual consumption rates and then estimating consumption by the different approaches. There is also a need to evaluate total consumption of cod based on energetic and productivity approaches (Dommasnes et al. in prep.)

There has been a large sampling effort of cod stomachs in the Barents Sea. The effort has however, been most consistent for the 1st quarter, so the consumption and year-to-year dynamics at other times of the year is less known. This is particularly true for the 2nd quarter. Consequently, despite the large effort, there is still a lack of knowledge on year-to-year variation and seasonal dynamics in cod feeding. Some of this lack could be mediated by modelling, but to fully understand the trophic interactions between cod and key prey in the Barents Sea there is still a need for more field observations. These observations and corresponding analyses should particularly be targeted towards understanding the seasonal migrations of cod and its prey, as well as the feeding behaviour of cod.

References

Anon. 1984. Report of the meeting of the coordinators of the Stomach sampling Project 1981. ICES C. M. 1984/G:37.

Bogstad, B., and Mehl, S. 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. Alaska Sea Grant College Program Report No. 97-01. University of Alaska, Fairbanks. Pp. 591-615.

Dolgov, A. 1998. Commercial prey consumption by cod and other fish predators. WD to AFWG.

Dos Santos, J., and Jobling, M. 1992. A model to describe gastric evacuation in cod (*Gadus morhua* L.) for natural prey. ICES Journal of Marine Science 49: 145-154.

Dos Santos, J., and Jobling, M. 1995. Test of food consumption model for the Atlantic cod. ICES Journal of Marine Science 52: 209-219.

Johansen, G. O., Bogstad, B., Mehl, S., and Ulltang, Ø. 2004. Consumption of juvenile herring (*Clupea harengus*) by cod (*Gadus morhua*) in the Barents Sea: a new approach to estimating consumption in piscivorous fish. Canadian Journal of Fisheries and Aquatic Science 61: 343-359.

Johansen, G. O., and Ulltang, Ø. 2005. Estimates of cod's consumption of capelin and herring related to prey density, stock overlap and physical factors. Pp. 268-287 in Development of Structurally Detailed Statistically Testable Models of Marine Populations, QLK5-CT1999-01609. Final Report 1 January 2000- 31 August 2004. Marine Research Institute Report no. 118, Marine Research Institute, Reykjavik, Iceland.

Mehl, S. 1989. The North-East Arctic cod stocks consumption of commercially exploited prey species in 1984-1986. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 188: 185-205.

Mehl, S. 1991. The Northeast Arctic cod stock's place in the Barents Sea ecosystem in the 1980s. Pp. 525-534 in Sakshaug, E., Hopkins, C.E.E. & Øritsland, N.A. (eds.): Proceedings from the Pro Mare Symposium on Polar Marine Ecology, Trondheim, 12-16 May 1990. Polar Research 10.

Ottersen, G., and Ådlandsvik, B. 1993. Climatological temperature and salinity fields for the Nordic Seas. Report No. 8/1993, Division of Marine Environment, Institute of Marine Research, Bergen, Norway. 121 pp.

Temming, A., and Andersen, N. G. 1994. Modeling gastric evacuation without meal size as a variable: a model applicable for the estimation of daily ration of cod (*Gadus morhua* L.) in the field. ICES Journal of Marine Science 51: 429-438.

Tereshchenko, V. V. 1996. Seasonal and year-to-year variations of temperature and salinity along the Kola meridian transect. ICES C. M. 1996/C:11, 24 pp.

Tjelmeland, S. 2000. Stomach evacuation rates in the field: a Barents Sea study. WD NPBW WG.

Appendix. Overview over cod stomach sampling effort

Feeding behaviour of cod vary by season and life-stage. North East Arctic (NEA) Cod spawn in March-April in the Lofoten area. Larvae drift into the Barents Sea with Atlantic water masses during spring/summer and the 0-group settle in autumn. One-two year old cod tend to remain in the areas where they have settle. As they grow larger (from about 3 years), they start their feeding migrations. Seasonal migration and diet can differ between cod that have settled in different areas (A. Aglen pers. comm.). A large component of the immature cod stock follow the capelin spawning migration towards the coast in February/March (Mehl 1989, 1991), and may also follow feeding immature capelin towards the Polar front area in summer/autumn. When cod mature (from age 6-7), they start spawning migration from the Barents Sea in January towards the Lofoten area, where they spawn in March/April. They then return to the Barents Sea and may follow feeding immature capelin up to the Polar front area in summer/autumn, depending on the capelin stock size and distribution of alternative prey. However, there are large annual (e.g. Orlova et al 2005) as well as individual (Michalsen, in prep.) variation in the pattern described above. Because cod feeding behaviour varies by age, season and area, our perception of cod diet and consumption vary with when and where stomach have been sampled, and the age groups sampled. In the following we will describe the effort in the PINRO-IMR stomach sampling programme by quarter, area, year and cod size/age. The joint PINRO-IMR stomach content database currently holds data from 216756 cod (Table 1).

Table 1. Number of stomachs and stations in the joint PINRO-IMR stomach content database.

	Number of stomachs			Number of stations		
year	Norway	Russia	Sum	Norway	Russia	Sum
1984	3729	0	3729	120	0	120
1985	4124	0	4124	123	0	123
1986	3963	2079	6042	141	83	224
1987	4465	1476	5941	136	37	173
1988	3742	1946	5688	132	71	203
1989	5422	2866	8288	163	117	280
1990	5529	2959	8488	169	107	276
1991	6006	890	6896	156	45	201
1992	4713	497	5210	207	29	236
1993	5865	1727	7592	208	101	309
1994	4610	2939	7549	223	130	353
1995	5149	5487	10636	252	269	521
1996	5863	6344	12207	389	260	649
1997	4021	8072	12093	241	309	550
1998	4946	10832	15778	308	485	793
1999	4452	8592	13044	406	344	750
2000	5428	11577	17005	431	559	990
2001	4637	12148	16785	453	568	1021
2002	4537	11992	16529	452	669	1121
2003	4955	8240	13195	404	513	917
2004*	5677	3380	9057	489	228	717
2005*	4918	5962	10880	531	384	915

*: Not all Russian data for 2004 and 2005 have yet been included.

Stomach data has been collected on Norwegian and Russian surveys and on Russian commercial fishing boats. In the following, Russian stations with towing time >1.5 hours is assumed to be from commercial vessels. Both commercial and survey vessels have used demersal trawls, Norwegian vessels have used pelagic trawls on some surveys. The number of Norwegian stomach samples has been relatively stable over the time series but the number of stations for which stomach samples have been taken has increased (Tab. 1). There has been fewer cod stomachs sampled per station (Fig. 1), with 5 cod stomachs per 5 cm length group analysed per haul 1984-1991, 2 from1992-1995, and from 1996, 1 (Jakobsen et al 1997, Bogstad and Pennington 1995). The Russian effort has been more variable (Tab.1), but with time there has been fewer cod per station for Russian scientific surveys as well (Fig. 1).

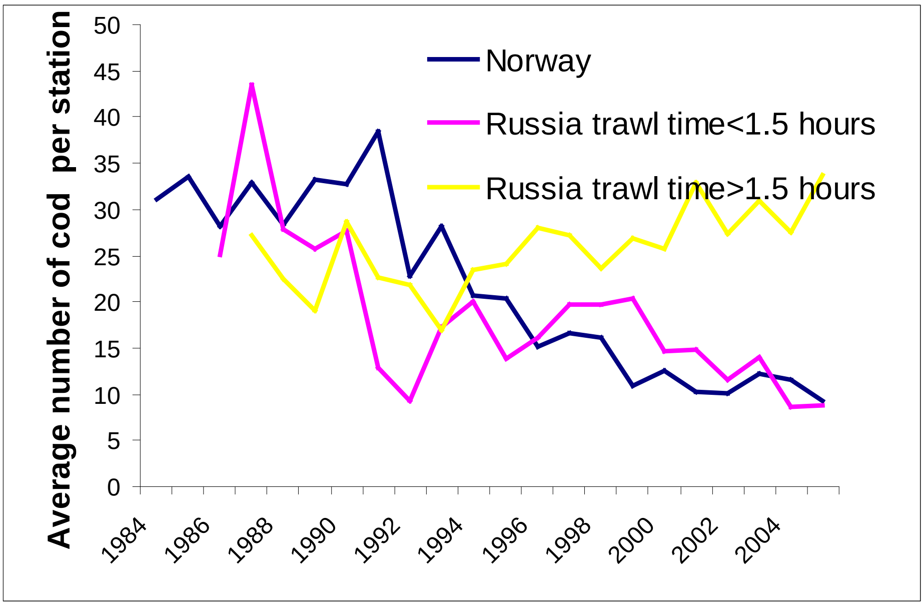


Fig. 1. Mean number of cod sampled per station by year, nation and trawling time

Size and age distribution of cod in the PINRO-IMR database

The size and age distribution as measured by average length of cod with stomach samples varies with year, quarter, nation and trawling time (Figs. 2 and 3). This variability reflects both the year-to-year variation in year-class strength and thus age distribution in the stock, gear selectivity and the relative sampling effort in areas with different age distribution of cod. Before about 1990 the average age and size was smaller compared to the latter part of the time series for both Norwegian and Russian scientific surveys and Russian commercial vessels (Figure 2 and 3), probably reflecting the dominance of the 1983 year class of cod in the catches. After this period, from about 1992, the average size and age of cod in the database for Russian commercial vessels and in Norwegian surveys has been relatively stable. There has been a decline in average size and age from Russian surveys in 1992-2005 (Figure 2).

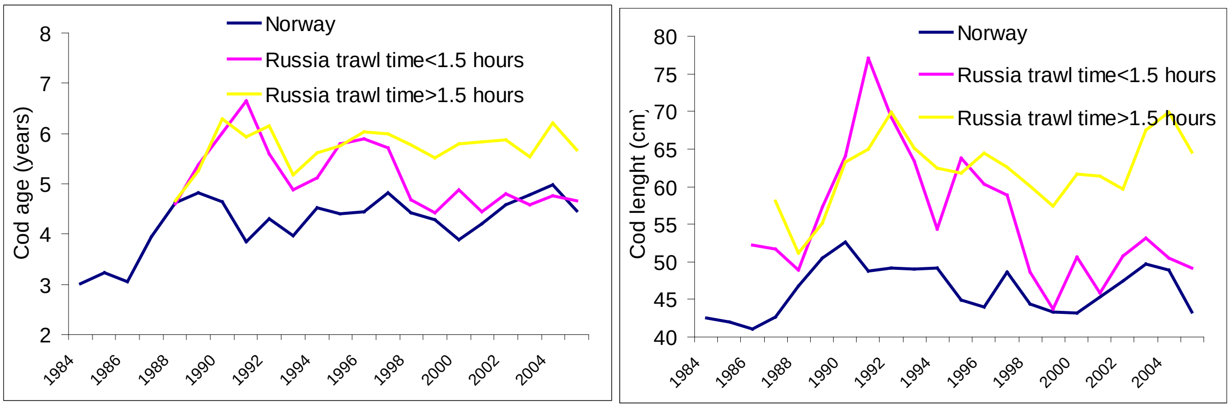


Figure 2. Mean length and age of cod with stomach samples by year, nation and tow time.

The age and size distribution by quarter from 1993 until present is shown in Fig. 3. Age and size has a wider distribution and a lower average value in the 1st and 3rd Quarter, compared to the 2nd Quarter. The distribution in the 4th Quarter is bimodal, because both survey and commercial data is important in this quarter (below).

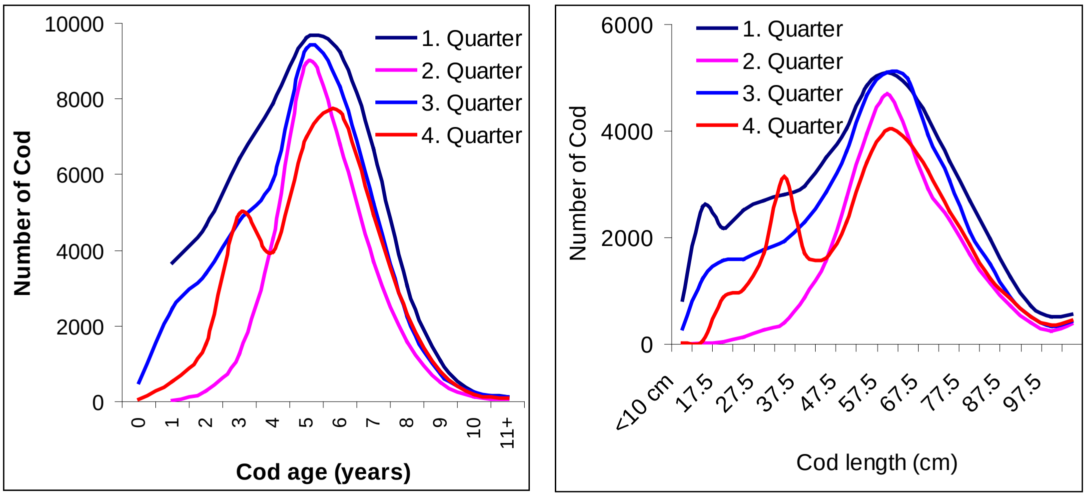


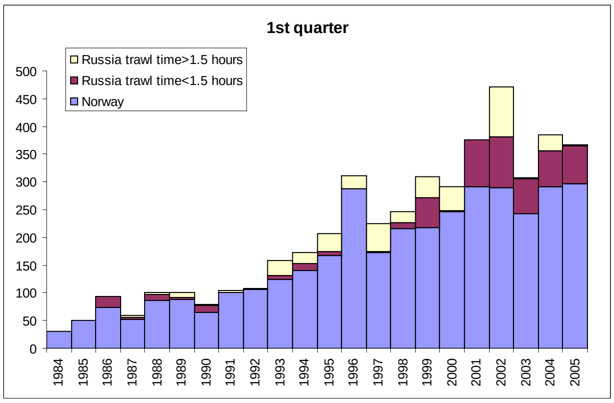
Figure 3. Age and size distribution of cod with stomach samples by Quarter 1993-2005.

Sampling effort by year and quarter

The sampling effort differs between quarters (Figures 4ab and 5).

The first quarter has had the best and most consistent sampling effort. Stomachs from the 1st quarter have mainly been sampled on the Norwegian combined acoustic and bottom trawl survey for demersal fish in the Barents Sea during winter (Jakobsen et al. 1997), run in February since 1981 (Fig. 4a). The area covered by this survey has expanded east and north in 1993 (Jakobsen et al. 1997). Overall, about one third of the trawl stations in the database are from this survey.

In the 2nd quarter, the coverage has been poor, but samples have been taken on the “Lofoten cruise” (Korsbrekke 1997), run in March-April since 1985. However, there is no capelin in the Lofoten area, so the samples taken there do not help us to calculate the consumption of capelin by cod in the second quarter. Some years stomach sampling has been conducted on the Norwegian shrimp survey (Aschan and Sunnanå 1997), but the effort has overall been low and variable on this cruise. The last ten years or so, most of the sampling in the 2nd quarter has been on Russian commercial vessels (Fig 4a).



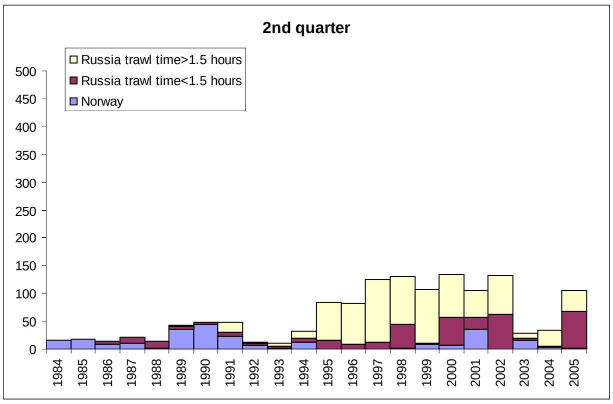
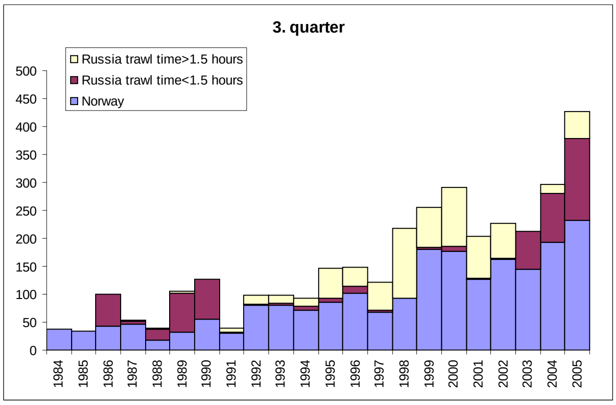


Figure 4 a. Sampling effort (number of stations) by year, nation and trawling time, 1st and 2nd Quarters.

Data from the 3rd Quarter has mainly been collected on the Norwegian survey for demersal fish in the Svalbard area (initiated in 1981), which from 1995 was extended to the Barents Sea area. The spatial extent and effort of this cruise has varied from year to year since 1996, but has from 2003 on, covered the whole of the Barents Sea, and it is now run as a joint Norwegian/Russian Ecosystem survey (Anon. 2004).

Data from the fourth quarter is mainly from the Russian survey for demersal fish (Lepesevich and Shevelev 1997) with stomachs sampled annually in October-December since 1986. Stomachs samples from the last two years collected on this cruise have not year been entered into the stomach database.



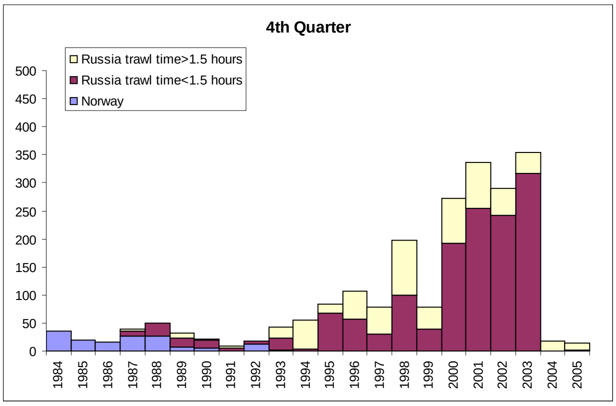


Figure 4 b. Sampling effort (number of stations) by year, nation and trawling time, 3rd and 4th Quarters.

Figure 5. Stations with stomach samples by year and quarter 1984-2005. Blue represent Norwegian stations, red Russian stations with trawling time less than 1.5 h, and black Russian stations with trawling time more than 1.5 h. Note that not all Russian data for 2004 and 2005 have yet been included.

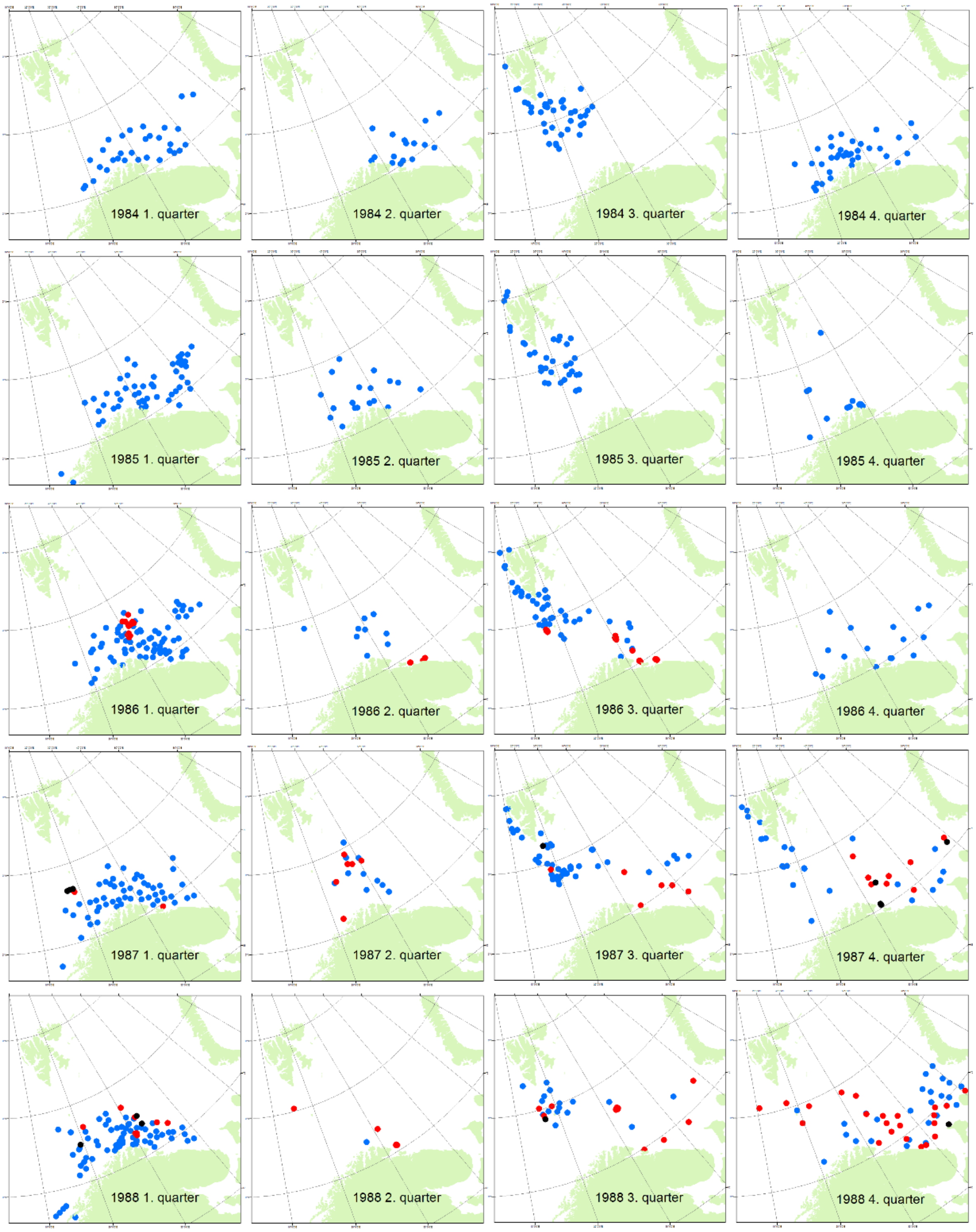
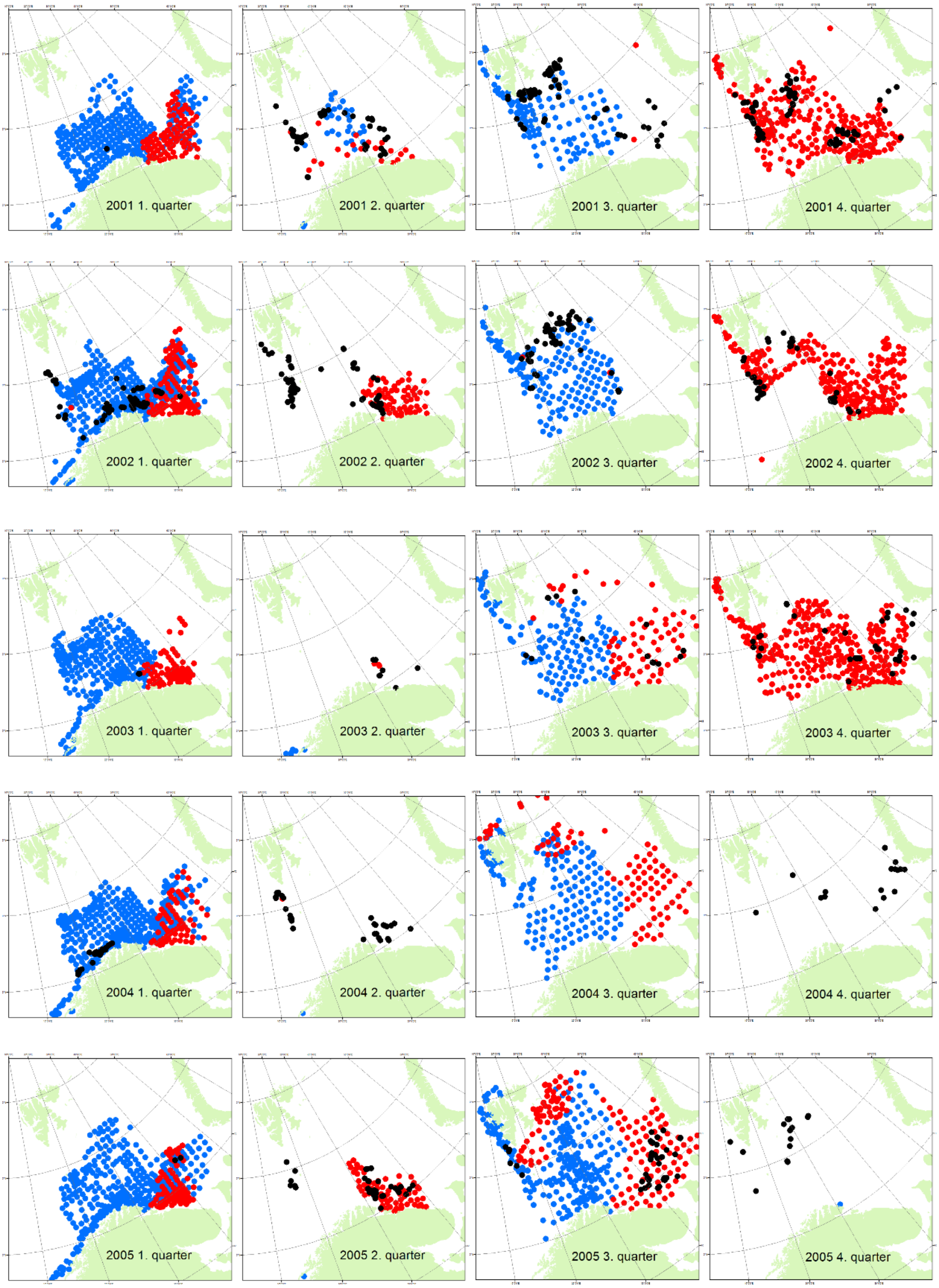


Fig. 5 cont

Fig. 5 cont

Figure 5 cont.



Proportion length measured prey and undetermined stomach content

The proportion of undetermined and unclassified fish material varies from year to year and can constitute over 20% of the stomach content in some years (Figure 6). Including or excluding this material can thus influence the magnitude of the capelin consumption estimate.

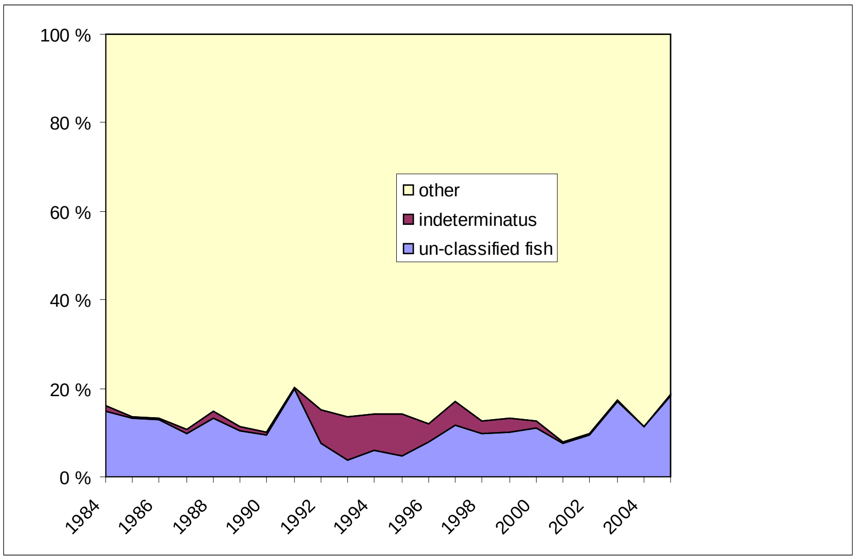


Figure 6. Proportion of unclassified material in cod stomachs by year.

Length measurements of consumed capelin are relevant for the Johansen method of estimating capelin consumption, and are needed when calculating age-specific mortality of capelin from the consumption estimates. Also, the Bogstad and Dolgov methods calculate capelin consumption distributed by 5cm length groups. The proportion of length-measured capelin out of total amount of capelin recorded in the stomachs has varied somewhat from year to year (Figure 7), and has shown a declining trend, especially in the Russian material. However, the Russian data for 2003-2005 are under revision, and this revision will increase the proportion of length measured capelin in those years. The proportion of length measured capelin was calculated as the proportion of P lines on the ‘nydump’- format (exchange format between PINRO and IMR from 2003 onwards, also used in data analysis at IMR) with capelin as prey which contained length-measured capelin.

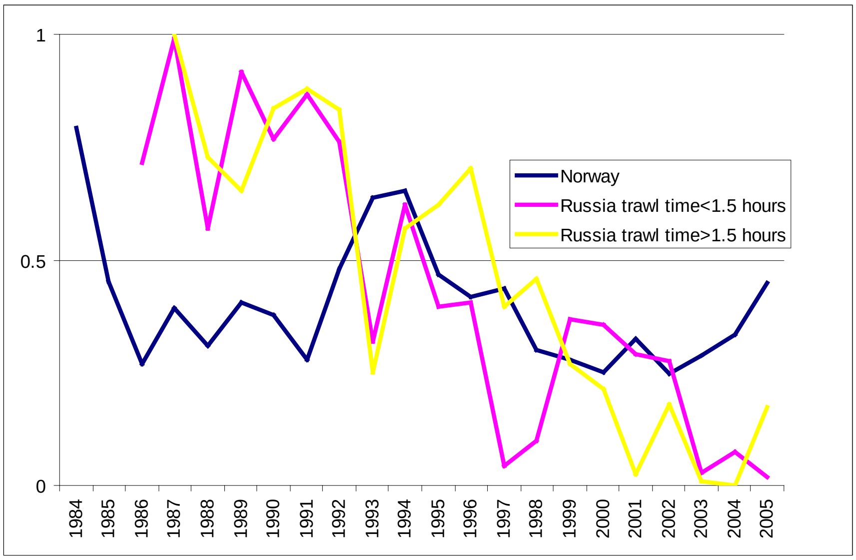


Figure 7. Proportion of length-measured capelin out of all capelin recorded in cod stomachs by year, nation and trawling time.