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Estimates of predation and residual mortality for the Flemish Cap cod

by

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ABSTRACT

The current 3M cod stock assessment assumes that natural mortality is the same for all ages and constant over time. As part of the EU project SC03 "*Support to a robust model assessment, benchmark and development of a management strategy evaluation for cod in nafo division 3M*", different approaches to set total natural mortality by age and year have been tested. One of these approaches is using the matrix of natural mortality at age estimated with the multispecies model GadCap. These values of mortality at age are the result of predation mortality (M_{pred}) and a residual mortality (M_{resid}). In this document different approaches to estimate the residual natural mortality are explored. An Mresid of 0.35 is finally decided, and it is used to re-optimize the GadCap model parameters. A final matrix of total natural mortality (M_{pred} + M_{resid}) was produced to be used in the 3M cod benchmark.

INTRODUCTION

Currently, the assessment of the 3M cod is conducted assuming a constant natural mortality M overtime, the same for all ages. This M constant value is estimated during the fit of the XSA Bayesian model used to conduct the stock assessment. However, it has been discussed during the NAFO Scientific Council (SC) that the estimated values (last accepted value M=0.19) is too low and it seems not to agree with the biological characteristics (high growth rate) and age structure of this stock (shorter than in other cod stocks in the Northwest Atlantic).

The multispecies model GadCap (Pérez-Rodríguez et al. 2017) indicates that cannibalism in cod is a very important driver determining the survivorship or juvenile stages, especially when high recruitment events are coincident with high numbers of large individuals in the stock. The available cod stomach content analysis suggest that this occurred recently, over the period 2010-2014, when the highest recruitment events since 1988 were observed, combined with a high abundance of very large individuals. This above normal abundance of large individuals was the result of high survivorship of cohorts 2005-2008 due to a moratoria of more than 10 years (Pérez-Rodríguez et al. 2017), in combination with above normal growth rates (Pérez-Rodríguez et al. 2013). This increased cannibalism was captured and expressed in terms of higher predation mortality by the multispecies model GadCap.

One of the recommendations of the Workshop that took place in Vigo in March of 2017 (NAFO, 2017) was to estimate M outside the stock assessment model, and that the benchmark process should further explore this issue and would selected a preferred option between a number of candidates possibilities (see the different options tested in González-Costas and González-Troncoso (2018)). It was decided that one of the candidate options, to be tested during the benchmark, would be the matrix of estimated total M by age and year (residual mortality (M_{resid}) plus predation mortality (M_{pred})) result of the up-to-date best gadget multispecies model GadCap result of the work developed in a parallel European Union Specific Contract, the SC05 ("Multispecies Fisheries Assessment for NAFO").

A direct output of GadCap model is the estimation of M_{pred}, that is estimated as result of the diet composition, consumption estimate, predator-prey length relationship, number of predators and number of prey. However, the M_{resid} is still a portion of remaining M that has to be provided to the model as fixed values. Estimating M internally during model optimization is extremely difficult, and often impossible, due to the interaction of M with the optimization of recruitment, growth and fishing catchability at age. For this reason, M_{resid} has to be estimated externally using an alternative option.

In this work different methods to estimate the Mresid based in the catch curve, the longevity and the loglikelihood methods are explored. Finally, a matrix with values of total M (M_{pred} and M_{resid}) is provided as result of optimizing the up-to-date best version of GadCap (model version GadCap_87) with the selected value of $M_{resid.}$

MATERIAL & METHODS

Gadget is a process-based model that allows the user to include several biological and ecological features into the model: one or more species each of which may be split into multiple components, multiple areas with migration between areas, predation between and within species, growth, maturation, reproduction and recruitment, as well as multiple commercial and survey fleets taking catches from the populations (Begley 2005, Begley and Howell 2004). The model is age and length structured, allowing length data to be used directly and for processes such as fishing selectivity and predation to be modelled on a length basis. The model is freely available and fully described at http://www.hafro.is/gadget/index.html. In this work the version 2.2.00 was employed. The structure of the multispecies model GadCap (Gadget multispecies model for the Flemish Cap) has been updated and improved over the basic framework presented in Pérez-Rodríguez et al., 2016 (Figure 1), where the main features were:

- Cod, redfish and shrimp were split in different sub-stocks based on sex, maturity state and diet composition.
- Immature and mature cod prey on immature cod, redfish and shrimp, whereas redfish prey on immature redfish and shrimp.
- Two fleets target cod (gillnetters and trawlers), one trawl fleet on redfish, and one trawl fleet on shrimp, which also catches redfish as by-catch, especially in years 1993 and 1994.

The project SC05 "Multispecies Fisheries Assessment for NAFO" is developed within the Framework Contract EASME/EMFF/2016/008 for the Provision of Scientific Advice for Fisheries Beyond EU Waters. The purpose of this specific study is to provide with a comprehensive overview (from the economic and ecological perspective) on how multispecies assessments would fit into the scientific and decision-making processes within NAFO and develop specific analyses and techniques on a case study, the Flemish Cap, that result in potential practical implementations for the multispecies approach. Finally, future steps and research activities to progress in the implementation of the multispecies assessment in the Flemish Cap, and extensively in the area NAFO will be identified. Within the task 2 an updated version of the multispecies model GadCap (Pérez-Rodríguez et al, 2016) has been produced, by:

- Extending the time period covered and used for model parameters fit to 1988-2016. Commercial fishing and survey data has been updated to cover this whole period:
  - Length distributions in commercial and survey fleets by season
  - Survey indices
  - Diet composition
  - Catch by season
  - Prey abundance estimates:
    - survey data for demersal and pelagic fishes, Anarhichas, Micthophiids.

        - CPR data: copepods, hyperiids, chaetognats, euphausiids.
    - Bottom water temperature
    - Review of trophic related parameters for the new period: suitability, prey-predator length relation.
    - Improvement in length-weight relationships
- A new longline fleet has been introduced for cod.
- The fit of cod growth curves have been improved to improve the fitting to the observed size distribution during the survey.
- Fitting to maturity ogives in cod has been improved to produce a better estimate of SSB and a more reliable estimate of cannibalism consumption.
- Improvement of growth models in redfish to better fit the survey size distributions.
- Introduction of survey indexes of abundance at age for cod and redfish in the model fitting.
- Use of catchdistribution loglikelihood component with mean weight at age

Once the GadCap model was updated, improved and newly optimized, the M_{resid} element was tackled. Three different approaches were used to estimate the M_{resid}:

1.- Catch curve methods
2.- Longevity method
3.- Loglikelihood score selection.

Different catch curve methods were applied: Chapman-Robson, Chapman-Robson corrected, Heincke, Linear Regression, Poisson model, Random intercept Poisson and Weighted Linear Regression (Millar 2014, Smith et al. 2012). The R package Fishmethods[1] was used to estimate the average Z over the group of selected ages. The criteria presented in Smith et al. (2012) were used to select the range of ages to be considered in the analysis, and the cohorts finally included in the study were selected based in the level of fishing effort and predation that those cohorts experienced.

The longevity method to estimate M_{resid} is presented in Hewitt and Hoenig (2005). This method is based in the assumption that the average M at age value is that one that allows that 1.5% of the individuals recruited in a cohort reach to the age defined as maximum longevity. For the Flemish Cap cod it was selected that this age is 12 years, based in the knowledge that the longevity in the Flemish Cap cod is shorter than in other cod stocks in the Northwest Atlantic. The range of cohorts from 1998 to 2002, when cannibalism and fishing was considered negligible, was selected to estimate the Z (Mresid for these cohorts) that would bring the percentage of the individuals at the beginning of the time series to the 1.5%.

The last selected method was the loglikelihood score selection. Different values of M_{resid} (constant for all ages) were tested in the models GadCap_87, and parameters were re-optimized. The M_{resid} that led to the lower Likelihood score was selected.

Based in the results of these methods, a final M_{resid} was selected and introduced in the model GadCap_87 as a fixed over time for all ages. Next the model GadCap_87 was re-optimized, and the total natural mortality (M_{resid}+M_{pred}) was estimated by age and year. This values would be finally provided to be used during the 3M cod benchmark held in Lisbon from 9th to 13th April.

RESULTS and DISCUSSION

The updated database and the changes introduced in different elements of the models resulted in an improved version with better fit to survey size distribution, abundance indexes and maturity ogives. The results and diagnostics are presented in a different working document (NAFO, 2018).

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[1] https://github.com/cran/fishmethods/tree/master/R

The criteria presented in Smith et al. (2012) were used to select the range of ages to be considered in the catch curve metods. The application of these criteria resulted in an age range from 4 to 8. The range of cohort selected to estimate the M_{resid} was from 1996 to 2002 based in the fact that for this cohorts, the fishing mortality at ages 4 to 8 was negligible due to the directed cod fishing moratoria, and cannibalism predation mortality was not relevant, based in the information available for the diet composition. Hence, it may be assumed that the estimated average Z mortality with these catch curve methods for the range of ages 4-8 and cohorts 1996-2002 is representative of the M_{resid}.

The logarithm of the EU survey abundance by age is presented in Figure 2. The application of the different methods indicated in previous section produced very diverse and a wide range of Z values (figure 3). The average Z for the cohort groups of (1996-2002) produced values that ranged from 0.4 to 1.29 (table 1).

For the longevity method to estimate M_{resid} it was selected that the maximum longevity of the Flemish Cap cod is age 12, based in the knowledge that the longevity in the Flemish Cap cod is shorter than in other cod stocks in the Northwest Atlantic. The range of cohorts from 1998 to 2002, when cannibalism and fishing was considered negligible, was selected to estimate the Z (Mresid for these cohorts) that would bring the percentage of the individuals at the beginning of the time series to the 1.5%. The resulting Mresid with this method was 0.35.

The last selected method was the loglikelihood score selection. Different values of M_{resid} (constant for all ages) were tested in the models GadCap_87, and parameters were re-optimized. The M_{resid} that led to the lower Likelihood score was selected. Based in this method the M_{resid} is 0.4.

Based in the results of these methods, a final M_{resid} was selected and introduced in the model GadCap_87 as a fixed over time for all ages. The seleted Mresid for a final optimization of GadCap and provision of a matrix of M (M_{resid} + M_{pred}) was 0.35. This matrix is presented in table 3.

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FIGURES

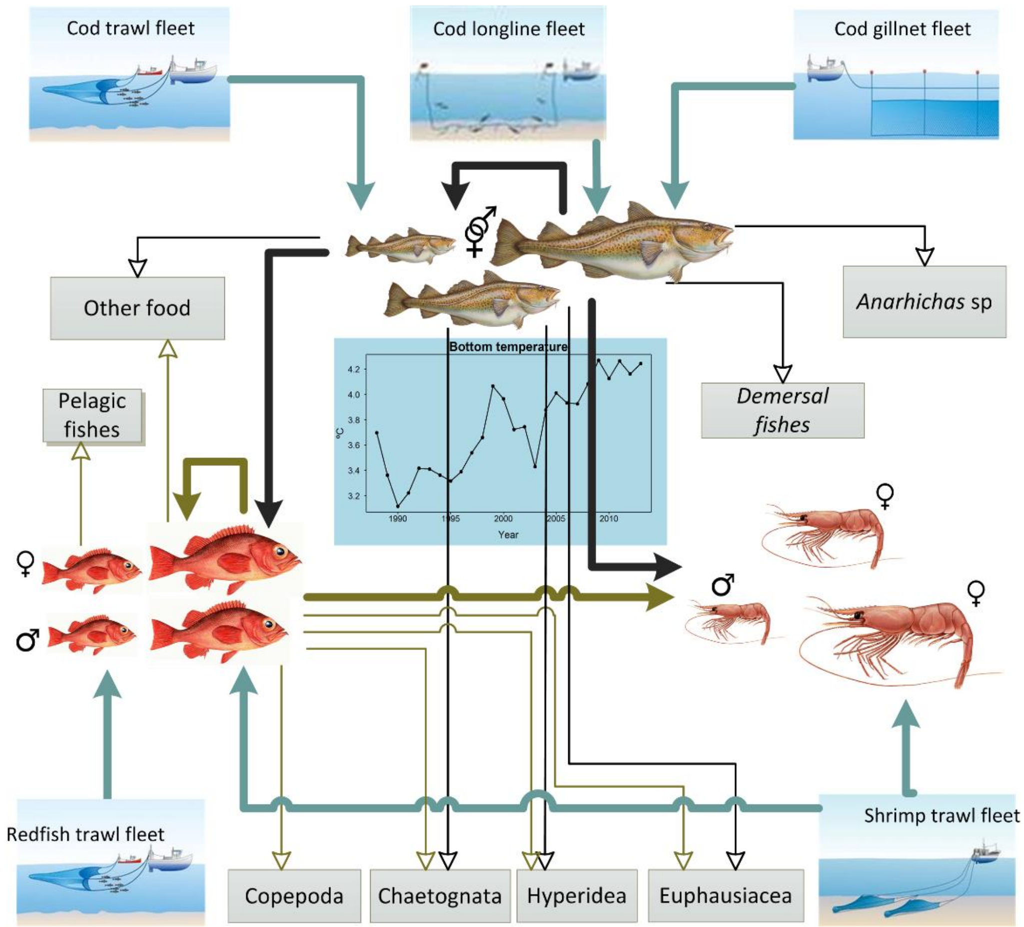

Fig. 1. Trophic interactions and commercial fleets modelled in GadCap Pérez-Rodríguez et al. (2017). Cod, redfish and shrimp are fully dynamically modelled, whereas species/prey groups in dark grey text boxes are incorporated as time series or constant values.

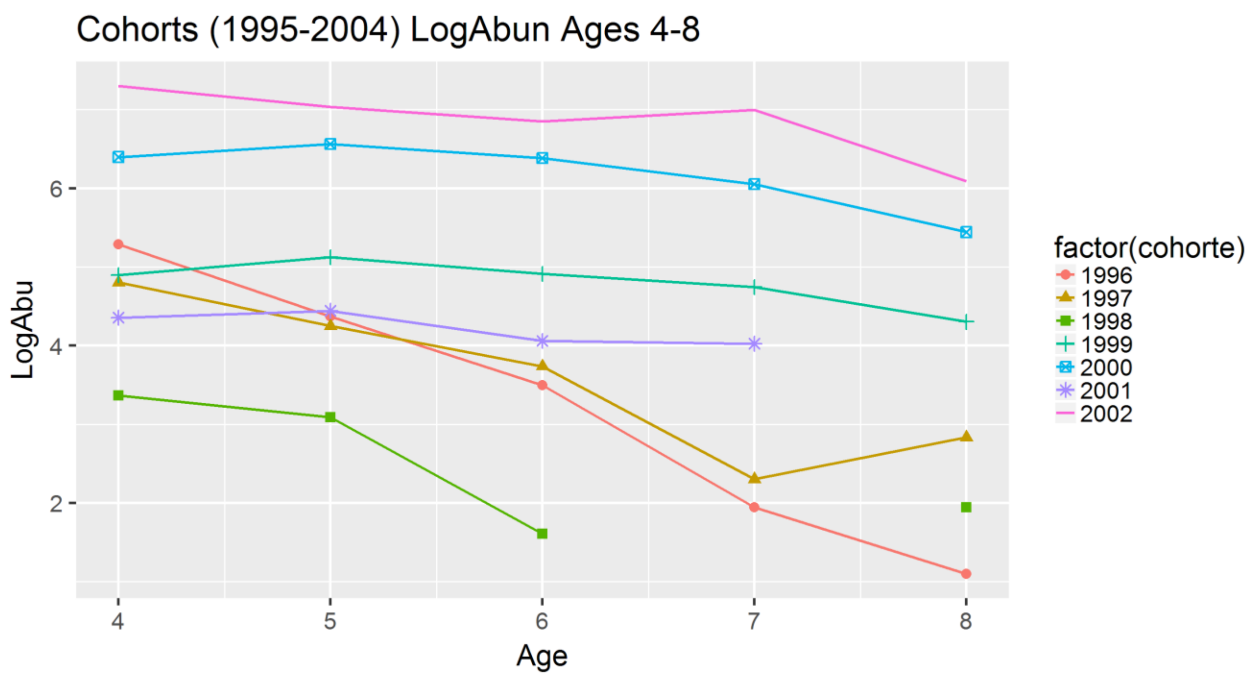

Fig.2. Logarithm of the abundance at age estimated during the EU Flemish Cap survey for the different cohorts used in the catch curve analysis and for the range of ages 4 to 8.

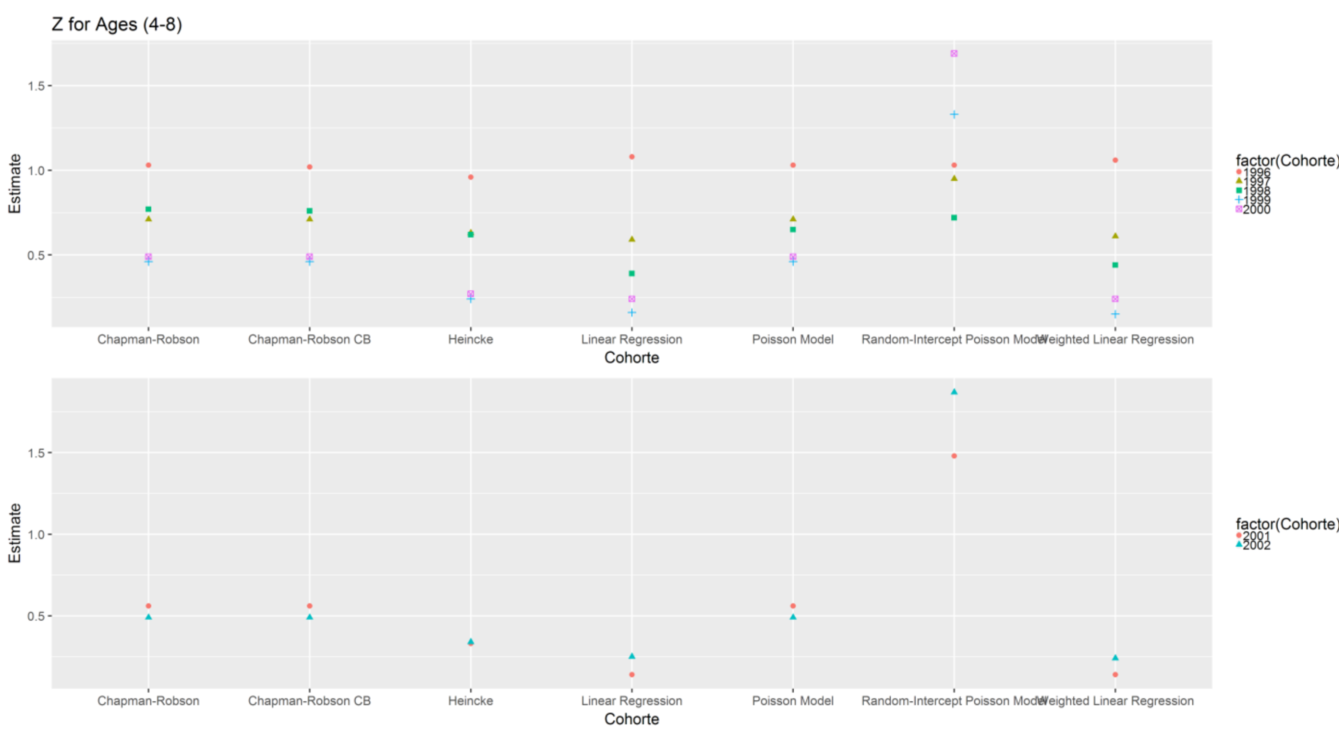

Fig. 3. Z estimate using the different catch curve methods implemented with the R package Fishmethods for cohorts 1996-2002 and range of ages 4 to 8.

Fig. 4. Loglikelihood score resulting of applying different values of M_{resid} by age and year during the optimization of GadCap.

TABLES

Table 1. Average Z for the group of cohorts 1996-2002 estimated using the different catch curve methods for the group of ages 4 to 8.

Catch curve method	Average Z
Chapman-Robson	0.644285714
Chapman-Robson CB	0.641428571
Heincke	0.484285714
Linear Regression	0.407142857
Poisson Model	0.627142857
Random-Intercept Poisson Model	1.295714286
Weighted Linear Regression	0.411428571

Table 2. Percentage of the recruited number of individuals at age 1 that reach age 12 (maximum longevity)

cohort	M_0.175	M_0.20	M_0.25	M_0.30	M_0.35	M_0.40	M_0.45	M_0.50
1996	9.57	7.5	4.56	2.69	1.59	0.93	0.54	0.31
1997	11.48	8.74	5.1	2.92	1.69	0.98	0.56	0.32
1998	11.24	8.58	4.98	2.86	1.64	0.95	0.55	0.31
1999	8.14	6.21	3.6	2.07	1.17	0.67	0.39	0.22
2000	6.5	4.93	2.85	1.62	0.9	0.51	0.29	0.16
2001	4.71	3.57	2.04	1.14	0.63	0.35	0.19	0.1
2002	2.61	1.96	1.12	0.6	0.31	0.17	0.09	0.04
Average	7.75	5.92714	3.46429	1.98571	1.13286	0.65143	0.37286	0.20857

Table 3. Total M ($M_{resid} + M_{pred}$) estimated with the model GadCap once M_{resid} is fixed as 0.35 for all ages and years.

age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1	0.766	1.125	0.91	0.455	0.479	0.406	0.41	0.471	0.392	0.373
2	0.397	0.842	0.656	0.41	0.374	0.389	0.395	0.419	0.385	0.362
3	0.358	0.388	0.581	0.367	0.355	0.355	0.36	0.357	0.362	0.358
4	0.352	0.356	0.368	0.361	0.352	0.351	0.351	0.351	0.351	0.353
5	0.35	0.351	0.353	0.351	0.351	0.35	0.35	0.35	0.35	0.35
6	0.35	0.35	0.351	0.35	0.35	0.35	0.35	0.35	0.35	0.35
7	NA	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
8	0.35	NA	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
9	0.35	0.35	NA	0.35	0.35	0.35	0.35	0.35	0.35	0.35
10	0.35	0.35	NA	NA	0.35	0.35	0.35	0.35	0.35	0.35
11	0.35	0.35	0.35	NA	NA	0.35	0.35	0.35	0.35	0.35
12	0.35	0.35	0.35	0.35	0.35	NA	0.35	0.35	0.35	0.35

age	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	0.362	0.367	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
2	0.359	0.363	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
3	0.351	0.353	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
4	0.351	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
5	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
6	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
7	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
8	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
9	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
11	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
12	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35

age	2008	2009	2010	2011	2012	2013	2014	2015	2016
1	0.35	0.35	0.876	0.822	0.581	0.592	1.441	1.425	0.809
2	0.35	0.35	0.692	0.683	0.622	0.656	0.693	0.894	0.789
3	0.35	0.35	0.412	0.457	0.506	0.497	0.517	0.48	0.527
4	0.35	0.35	0.365	0.37	0.392	0.403	0.384	0.415	0.392
5	0.35	0.35	0.352	0.354	0.356	0.363	0.361	0.364	0.373
6	0.35	0.35	0.35	0.351	0.352	0.353	0.353	0.356	0.356
7	0.35	0.35	0.35	0.35	0.35	0.351	0.351	0.352	0.352
8	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
9	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
11	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
12	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35