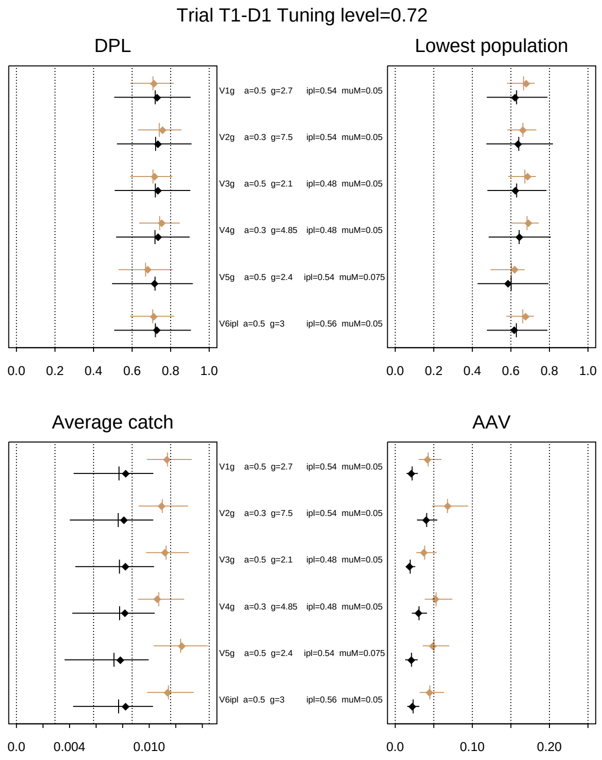
Norsk Regnesentral
NORWEGIAN COMPUTING CENTER

Variants of the Catch Limit Algorithm

Note



Note no SAMBA/11/06

Author Magne Aldrin,
Ragnar Bang Huseby
and Tore Schweder

Date April 26, 2006

NR Norsk Regnesentral
NORWEGIAN COMPUTING CENTER

The author

Magne Aldrin is chief research scientist at the Norwegian Computing Center and has a Ph.D. in statistics from the University of Oslo. Ragnar Bang Huseby is senior research scientist at the Norwegian Computing Center and has a M.Sc. in mathematics from the University of Oslo. Tore Schweder is professor in statistics at the University of Oslo and works part-time at the Norwegian Computing Center.

Norwegian Computing Center

Norsk Regnesentral (Norwegian Computing Center, NR) is a private, independent, non-profit foundation established in 1952. NR carries out contract research and development projects in the areas of information and communication technology and applied statistical modeling. The clients are a broad range of industrial, commercial and public service organizations in the national as well as the international market. Our scientific and technical capabilities are further developed in co-operation with The Research Council of Norway and key customers. The results of our projects may take the form of reports, software, prototypes, and short courses. A proof of the confidence and appreciation our clients have for us is given by the fact that most of our new contracts are signed with previous customers.

Norsk Regnesentral
Norwegian Computing Center
Postboks 114, Blindern
NO-0314 Oslo, Norway

Besøksadresse
Office address
Gaustadalléen 23
NO-0373 Oslo, Norway

Telefon · telephone
(+47) 22 85 25 00
Telefaks · telefax
(+47) 22 69 76 60

Internett · internet
www.nr.no
E-post · e-mail
nr@nr.no

Title	**Variants of the Catch Limit Algorithm**
Author	**Magne Aldrin,** `<magne.aldrin@nr.no>` **Ragnar Bang Huseby** `<ragnar.bang.huseby@nr.no>` **and Tore Schweder** `<tore.schweder@econ.uio.no>`
Date	April 26, 2006
Publication number	SAMBA/11/06

Abstract

The catch limit algorithm (CLA) is a central part of the revised management procedure (RMP) for whaling. The CLA has previously been tuned to a specified final depletion after 100 years of management, based on simulations from a population model with $MSYR^{mature}$=1%. The CLA contains several parameters, but traditionally one of these has been used as tuning parameter, whereas the others have been fixed.

Here we define a "new" tuning procedure based on simulations from a population model with $MSYR^{1+}$=1%, and where the final depletion is calculated after 300 years of management. The traditional tuning parameter can not be used for "new" tuning levels below 0.70. In this report we study the performance and robustness properties for a selection of other variants of the CLA.

Keywords	
Target group	
Availability	
Project	
Project number	
Research field	
Number of pages	38

Contents

1 Introduction

The revised management procedure RMP and its rule for setting catch quotas, the catch limit algorithm CLA, were developed around 1990. Its catch performance and robustness were tested on simulation trials based on an age- and sex-structured population dynamics model for whales. The productivity of the stock was specified in terms of its mature component through the maximum sustainable yield relative to the number of sexually mature whales $MSYR^{mature}$. All simulation trials were carried out for a period of 100 years of management.

One of the so-called base case trials (T1-D1) acts as a tuning case. Tuning means to set the parameters of the CLA to values making the median final depletion reach a specified level after a certain number of years of management, conventionally 100 years. Due to randomness in the survey part of the model, final depletion has a distribution of which its median shall reach the target. We refer to this as the "old" tuning procedure. Final depletions between 0.60 and 0.72 were typical tuning levels with this "old" tuning procedure.

The present study has been commissioned to investigate the potential for revising the RMP (IWC/56/22). Instead of measuring the productivity in terms of the sexually mature stock, we define maximum sustainable yield rate as the maximum sustainable yield relative to the total stock excluding calves, $MSYR^{1+}$. We also run the trials over more years of management in order to allow the population to come closer to equilibrium at the end of the management period. It turns out that population size in many trials increases beyond 100 years of management. We therefore run the trials for 300 years, which in most trials is sufficient to reach a reasonably stable population size.

Here we define a "new" tuning procedure based on simulations from a population model with $MSYR^{1+}$=1%, and where the final depletion is calculated after 300 years of management. The "old" tuning levels 0.60, 0.66 and 0.72 correspond to "new" tuning levels 0.72, 0.74 and 0.78, respectively.

It turns out that the traditional tuning parameter can not be used to tune the CLA to "new" tuning levels below 0.70 (Aldrin, Huseby and Schweder, 2006).

Therefore we here investigate the properties of a selection of other variants of the CLA. First the variants are tuned to "new" levels between 0.60 and 0.72 on the T1-D1 trial, then their properties are tested on a small selection of other simulation trials. The population model in these trials is based on $MSYR^{1+}$ rather than $MSYR^{mature}$. Catch performance and robustness statistics are calculated over the first 100 and over the next 200 years of management.

One of the variants of the CLA tested here has been investigated in detail by Aldrin, Huseby and Schweder (2006). The present work is meant as a supplement to that report, and more details may be found there.

In Section 2 we first review the CLA, then present the simulation trials and finally describe the tuning process. The results are given in Section 3.

2 Methods

2.1 The Catch Limit Algorithm (CLA)

The input data to the catch limit algorithm (IWC, 1999, p. 251-258.) consists of a time series of historic annual catches and a time series of absolute abundance estimates along with their standard errors and correlations on the logarithmic scale.

The internal population model of the catch limit algorithm is defined by the following dynamics

$$\begin{aligned} P_0 &= \frac{P_T}{D_T}, \\ P_{t+1} &= P_t - C_t + 1.4184\,\mu\,P_t(1-(\frac{P_t}{P_0})^2) \qquad (0 \le t < T), \end{aligned} \tag{1}$$

where

- 0 is the first year of recorded catch, and T is the current year of management (i.e. the first year of an assessment cycle). P_0 is regarded as pristine population size, and P_t is the population size in numbers at the beginning of year t,
- C_t is the catch in numbers in year t,
- $D_T = P_T/P_0$ is the ratio of the population size at the beginning of year T to the population size at the beginning of year zero, measuring stock depletion,
- μ is a parameter describing the productivity,
- the historic catch series used in assessments covers years 0 to $T-1$, and ????

The abundance estimates are assumed to be log-normally distributed with a given (estimated) information matrix for the on the log scale. The likelihood based on the abundance data is

$$\text{Likelihood}(\mu, D_T, b) \propto \exp\Big(-0.5(\mathbf{a}-\mathbf{p}-\beta\mathbf{1})' H(\mathbf{a}-\mathbf{p}-\beta\mathbf{1})\Big) \tag{2}$$

where the symbol $\propto$ means proportional to, and where

- a is the vector of logarithms of the estimates of population size by year,

- $\mathbf{p}$ is the vector of logarithms of the modelled annual population sizes for the years with population estimates, $p_t = \ln(P_t)$,
- β is the logarithm of the bias parameter, thus $b = \exp(\beta)$;
- H is the information matrix of the $\mathbf{a}$ vector. H is assumed nonsingular, and $V = H^{-1}$ is the covariance matrix of the vector $\mathbf{a}$.

The parameters μ, D_T, and b are assigned independent uniform prior distributions making their joint prior distribution uniform over the region

$$[\mu_{\min}, \mu_{\max}] \times [D_{T,\min}, D_{T,\max}] \times [b_{\min}, b_{\max}], \tag{3}$$

where $\mu_{\min}$, $\mu_{\max}$, $D_{T,\min}$, $D_{T,\max}$, $b_{\min}$, and $b_{\max}$ are chosen constants. We will use $\mu_{\min} = 0.0$, $\mu_{\max} = 0.05$ or $\mu_{\max} = 0.075$, $D_{T,\min} = 0.0$, $D_{T,\max} = 1.0$, $b_{\min} = 0.0$, and $b_{\max} = 1.6667$.

A distinctive feature of the CLA is that abundance data are strongly down-weighted to obtain desired robustness properties. In the internal model, all variances and covariances of logarithmic abundance estimates are actually multiplied by 16. The historic catch data are furthermore assumed to be accurate, without any measurement errors. The posterior density function of the parameters μ, D_T, and b is therefore

$$\text{Posterior}(\mu, D_T, b) \propto \text{Prior}(\mu, D_T, b) \cdot \text{Likelihood}(\mu, D_T, b)^s, \quad s = 1/16 \tag{4}$$

The presence of a deflation parameter $0 < s < 1$ down-weights the survey information relative to a strict Bayesian approach.

The internal catch limit is the following function of μ, D_T, and P_T:

$$L_T = \begin{cases} 0 & \text{if } D_T \le IPL \\ \gamma\mu(D_T - IPL)P_T & \text{if } D_T > IPL \end{cases} \tag{5}$$

where γ and the internal protection level IPL are control parameters.

The internal catch limit can be regarded as the catch limit in the hypothetical case of perfect knowledge of population parameters and size. However, in the Bayesian formalism, L_T is regarded as a random variable, with marginal posterior distribution obtained from the joint posterior distribution of (μ, D_T, b). The actual catch limit z is defined as a certain percentile of its distribution,

$$P(L_T < z|data) \le \alpha \le P(L_T \le z|data) \tag{6}$$

for a given value of α.

Traditionally, α has been a tuning parameter, whereas IPL has been fixed to 0.54 and γ has been fixed to 3. Here we will use IPL or γ as tuning parameters instead of α.. Furthermore, $\mu_{\max}$ has traditionally been set to 0.05, but here we will also try the value 0.075.

We use the implementation of the algorithm of the Norwegian Computing Center (Huseby and Aldrin 2006). This implementation is available from the IWC secretariat.

2.2 Variants of the CLA tested on simulation trials

Aldrin, Huseby and Schweder (2006) showed that it was impossible to achieve "new" tuning levels (with management horizon 300 years and $MSYR^{1+}$=1%) below 0.70 by varying the traditional tuning parameter α. Here we will investigate the performance of six alternative variants of the CLA, listed in Table 1. Five of these (named V1g, V2g, ..., V5g) use γ as tuning parameter, whereas the sixth (V6ipl) use IPL as tuning parameter.

First, each of these variants of the CLA is tuned on the T1-D1 case to "new" tuning levels 0.72, 0.66, 0.62 and 0.60 if possible. 50 simulations are used for each trial. Since the median final depletion based on only 50 simulations is slightly unstable, we here instead tune by making the mean final deletion equal to the specified tuning level. Not all variants are able to achieve the lowest tuning levels 0.62 and 0.60. Then the performance of these variants of the CLA and tuning level are tested on a few other simulation trials (Table 2).

These simulation trials are carried out using the FORTRAN program MANTST which is available from the IWC secretariat. Our version of MANTST is based on version 11 (received from the IWC secretariat in January 2005), but modified by Andre Punt to allow for projections more than 100 year. The trials are based on an age- and sex-structured population dynamics model for whales with density-dependent fertility. Two parameters are varied systematically from trial to trial:

- The initial population size in year 0, relative to the carrying capacity K, is either $0.99K$, $0.60K$, $0.30K$ or $0.05K$.
- The maximum sustainable yield rate ($MSYR^{1+}$) in terms of the total stock, excluding calves, is either 1% or 4%.

3 Results

We investigate the performance properties of the six variants of the CLA, with up to four different tuning levels for each variant.

All population and catch quantities reported are scaled by the carrying capacity K in year 0. For each trial and for each variant of the CLA, four main quantities

Name	α	γ	IPL	μ_{max}
V1g	0.5	tuning par.	0.54	0.05
V2g	0.3	tuning par.	0.54	0.05
V3g	0.5	tuning par.	0.48	0.05
V4g	0.3	tuning par.	0.48	0.05
V5g	0.5	tuning par.	0.54	0.075
V6ipl	0.5	3	tuning par.	0.05

Table 1. Tested variants of the CLA.

Trial name	Initial size	$MSYR^{1+}$ (%)	Description
T1-D1	0.99	1	Base case
T1-D4	0.99	1	Base case
T1-R1	0.30	1	Base case
T1-R4	0.30	4	Base case
T1-S1	0.60	1	Base case
T4-X1	0.05	1	Initial depletion = $0.05K$

Table 2. Trials performed.

are calculated based on the first 100 and the next 200 years of each single simulation:

- Final depletion (DPL) at the end of the period in question.
- Lowest population over the period.
- Average catch.
- Average annual catch variation (AAV), defined as $ave|C_t - C_{t-1}|/ave(C_t)$, where C_t is the catch in year t and ave means average over the period in question.

For each of these quantities, the following summary statistics are calculated based on the 100 or 400 simulations:

- The median.
- The mean.
- The 5% and 95% values. The 5%-values are calculated as the 5th lowest value if they are based on 100 simulations or the 20th lowest if they are based on 400 simulations, according to the description in IWC (1992, p. 317-318). The 95% values are similarly calculated as the 96th or 381st value.

The results from each trial sand tuning level separately are shown in the four panels of Figures 1 to 24. In each panel of the figures, the results are given pairwise for each variant of the CLA, with the results for the first 100 years at the top and for the next 200 years below. The various summary statistics are symbolised by:

- The median is shown as a diamond.
- The mean is shown as a short vertical line segment.
- The 90% interval between the 5% and 95% values is shown as a horizontal line segment.

The variants V2g and V5g are not able to achieve the “new” tuning levels 0.62 or 0.60, whereas the variants V1g and V4g are not able to achieve the “new” tuning level 0.60. It is not possible to choose an over all best variant. However, if we look at trial T1-R4 for “new” tuning level 0.66, the V2g and V4g, both with $\alpha = 0.3$ are too conservative, resulting in final depletion close to 1. On this trial, the variant V5g, with $\mu_{max} = 0.075$ performs best, but on trial T1-S1 for the same “new” tuning level 0.66, it seems to allow too high catches, resulting in significantly lower population than the other variants. The remaining three variants (V1g, V3g and V6g) performs rather similar on most trials for “new” tuning levels 0.72 and 0.66. We have chosen the V1g variant as the one we investigate in much more detail in Aldrin, Huseby and Schweder (2006).

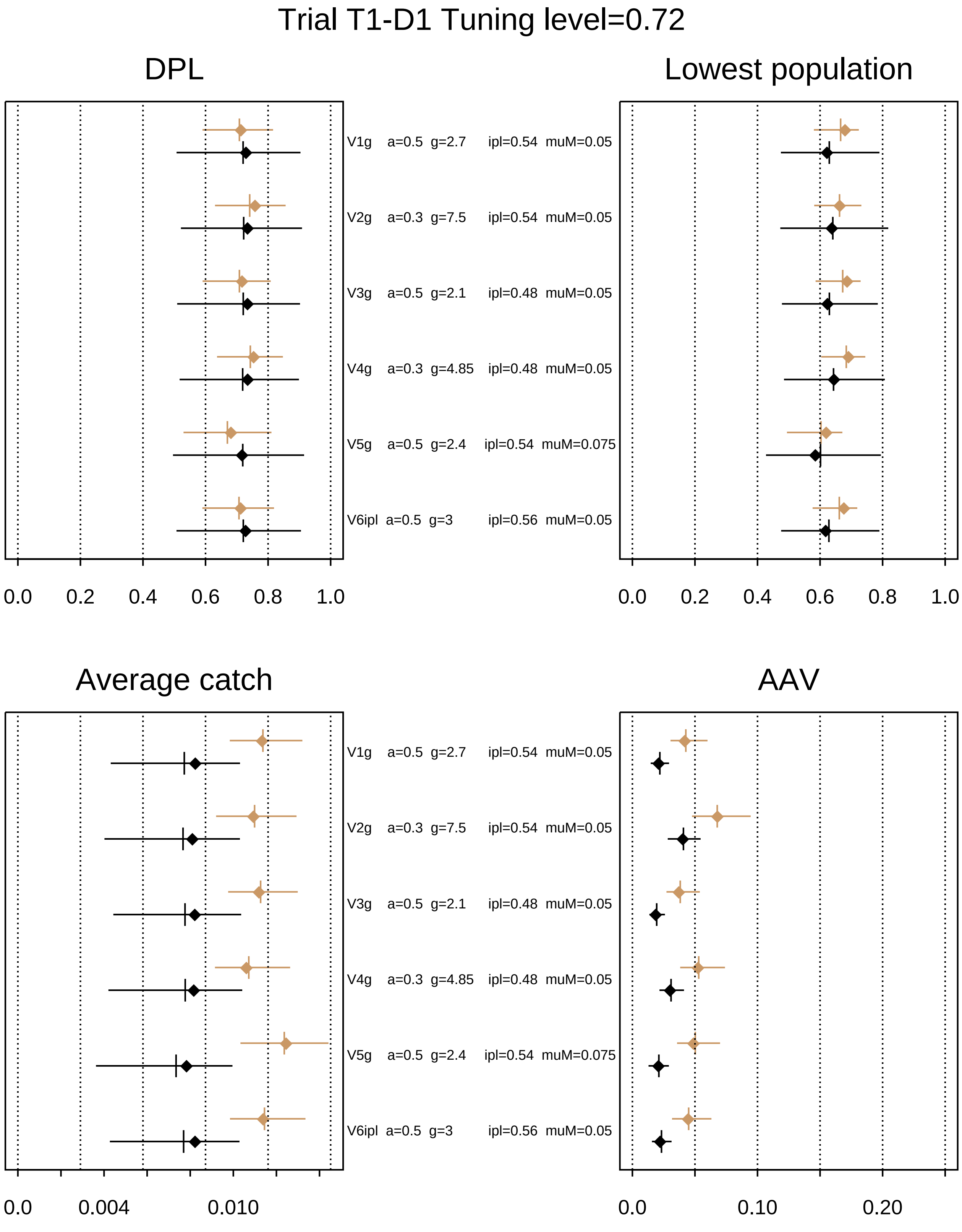


Figure 1. Trial T1-D1, base case, tuning level 0.72.

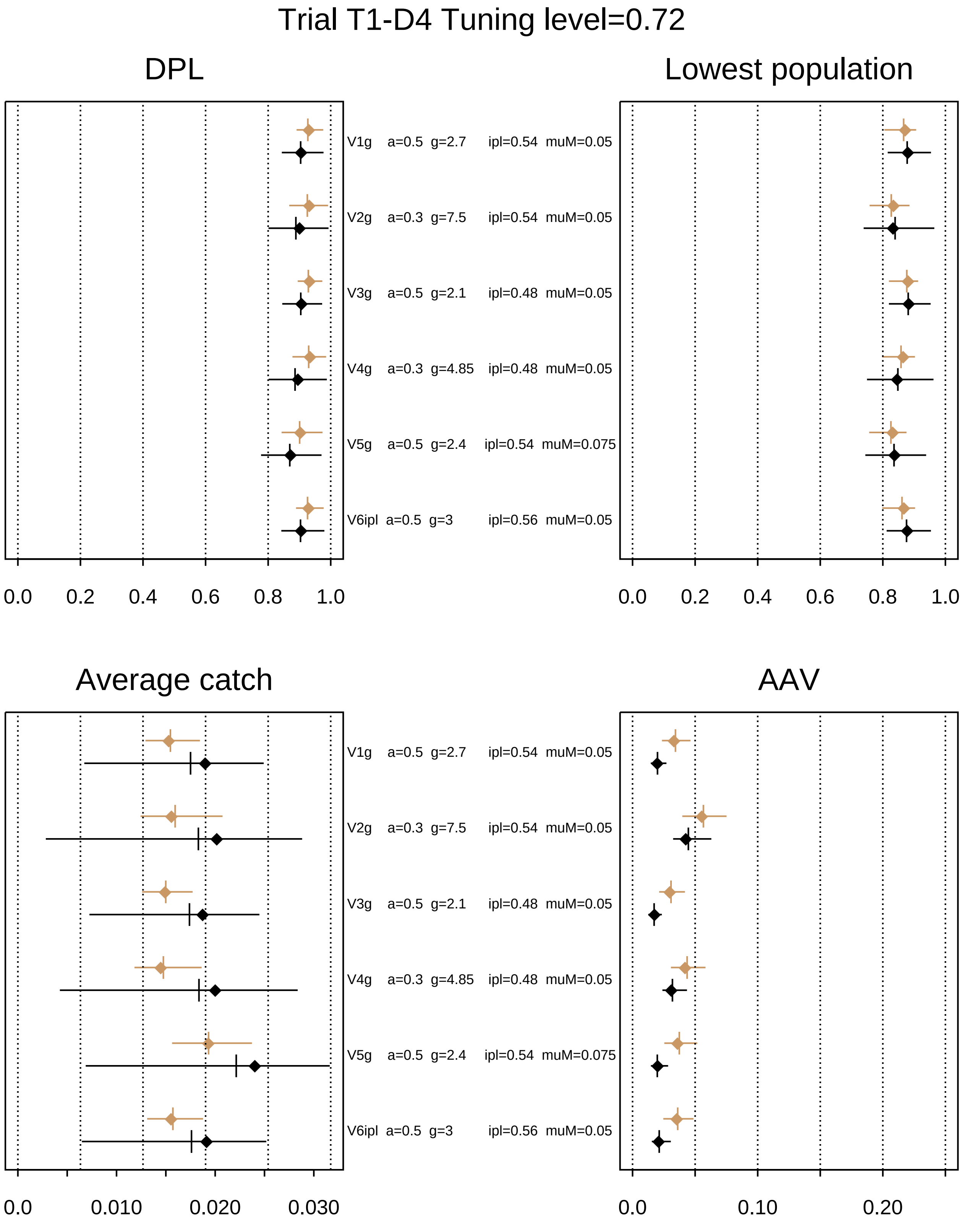


Figure 2. Trial T1-D4, base case, tuning level 0.72.

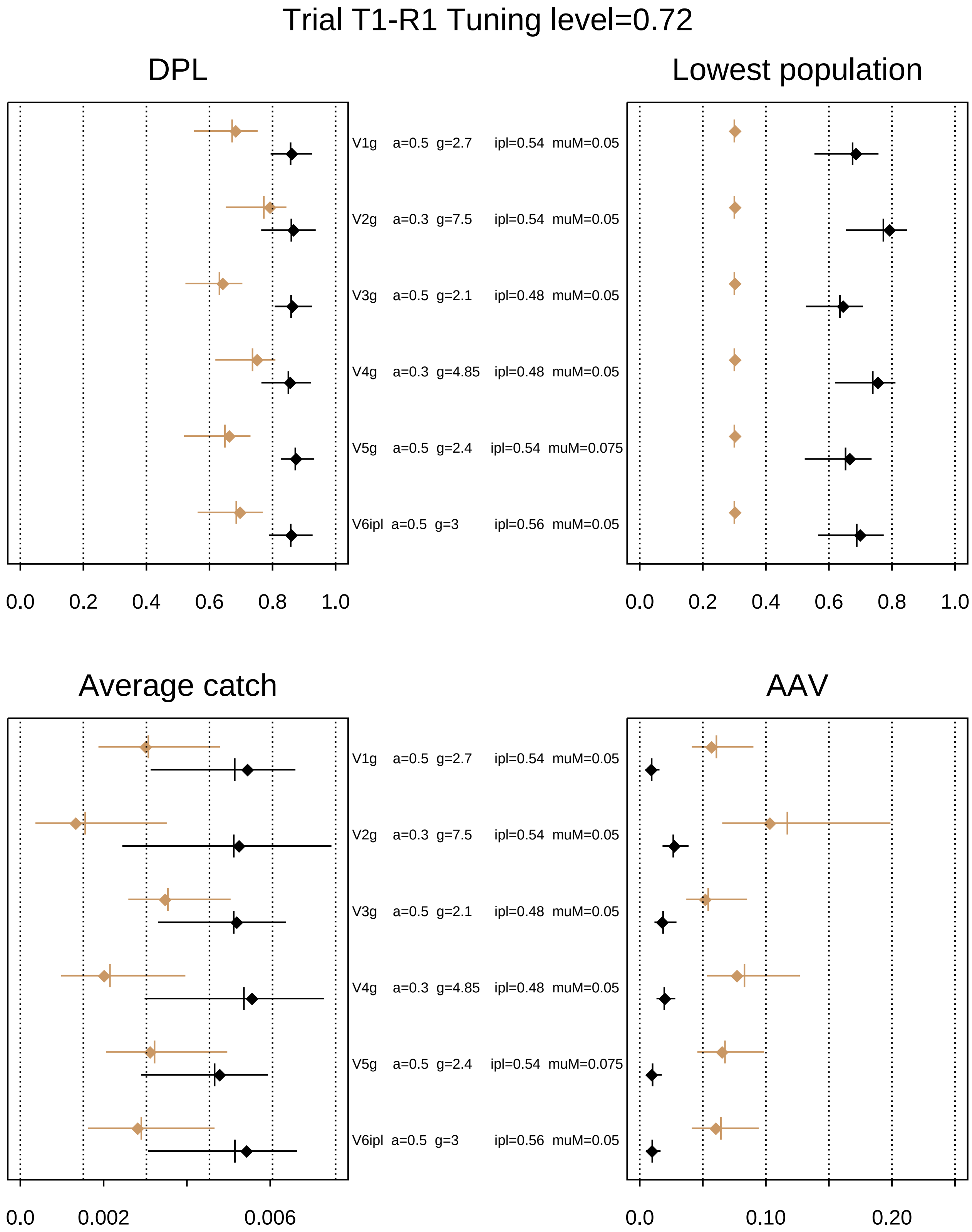


Figure 3. Trial T1-R1, base case, tuning level 0.72.

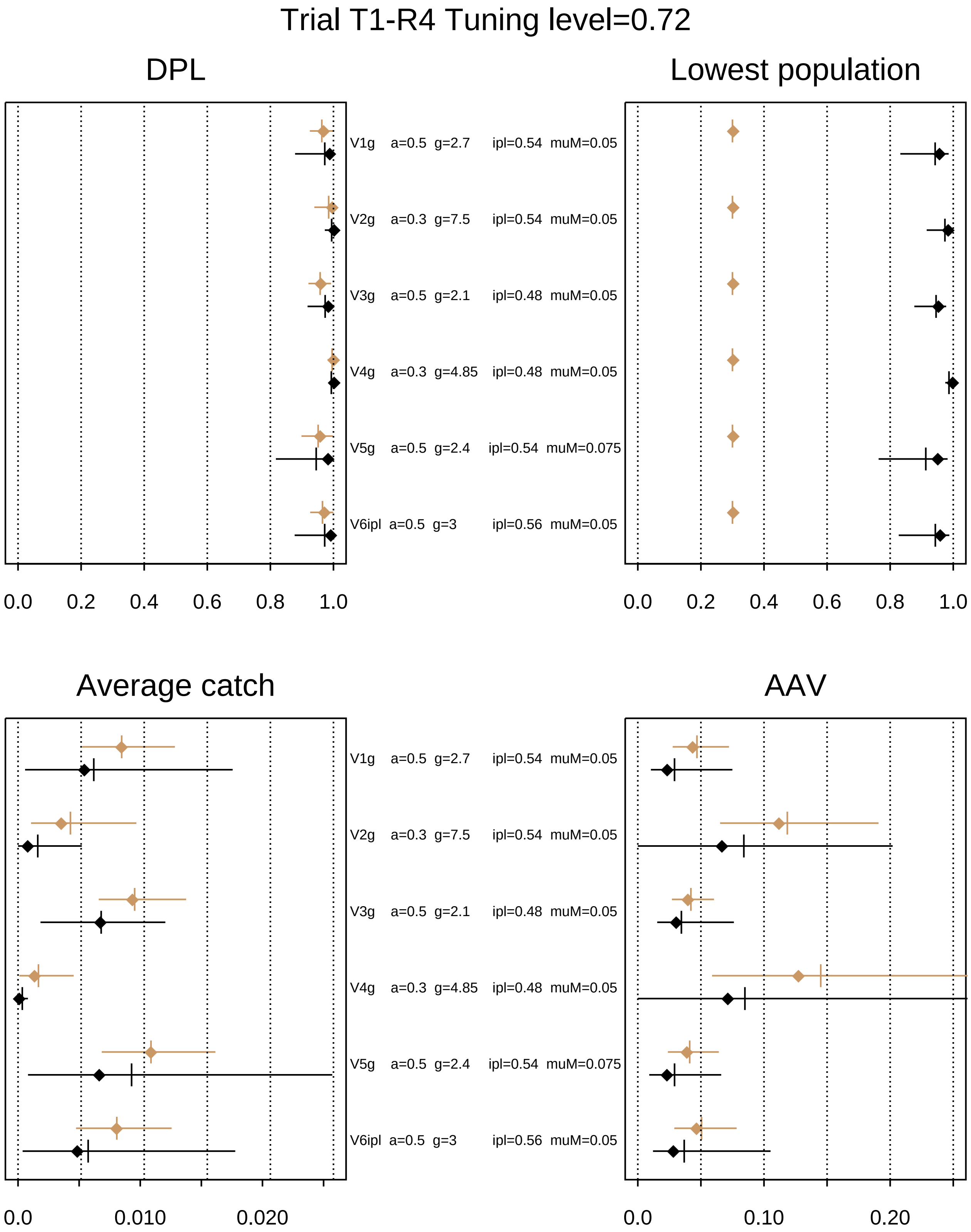


Figure 4. Trial T1-R4, base case, tuning level 0.72.

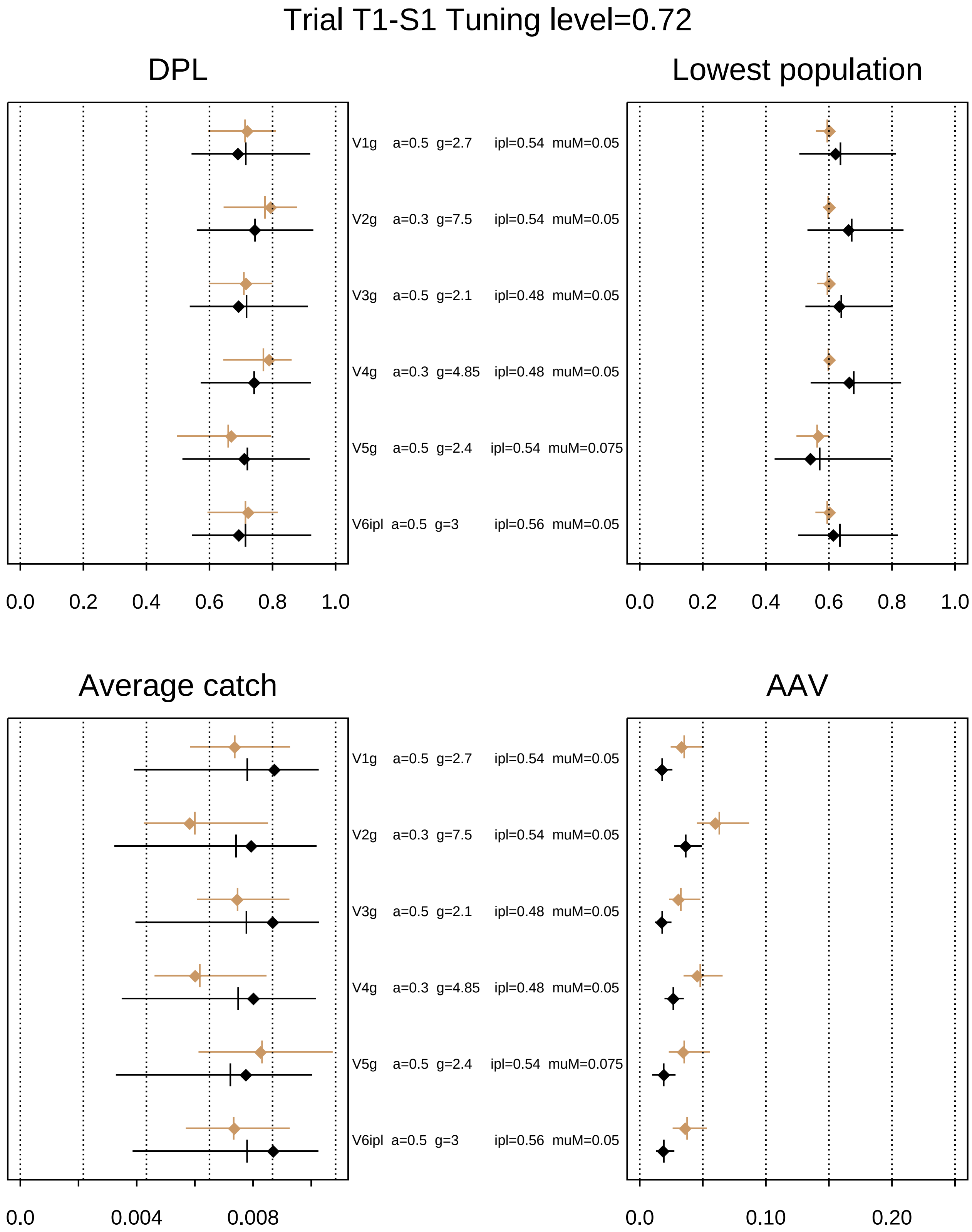


Figure 5. Trial T1-S1, base case, tuning level 0.72.

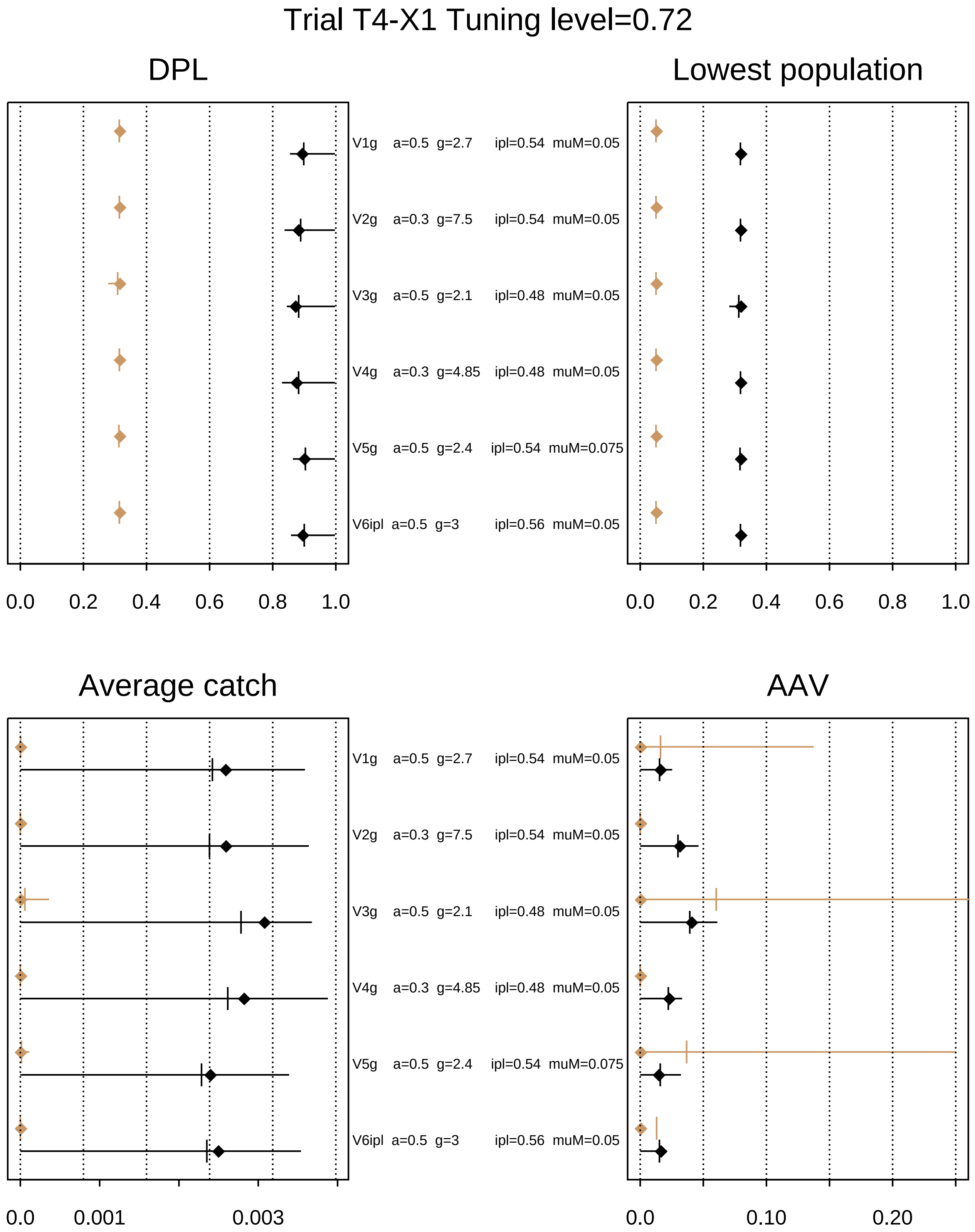


Figure 6. Trial T4-X1, base case, tuning level 0.72.

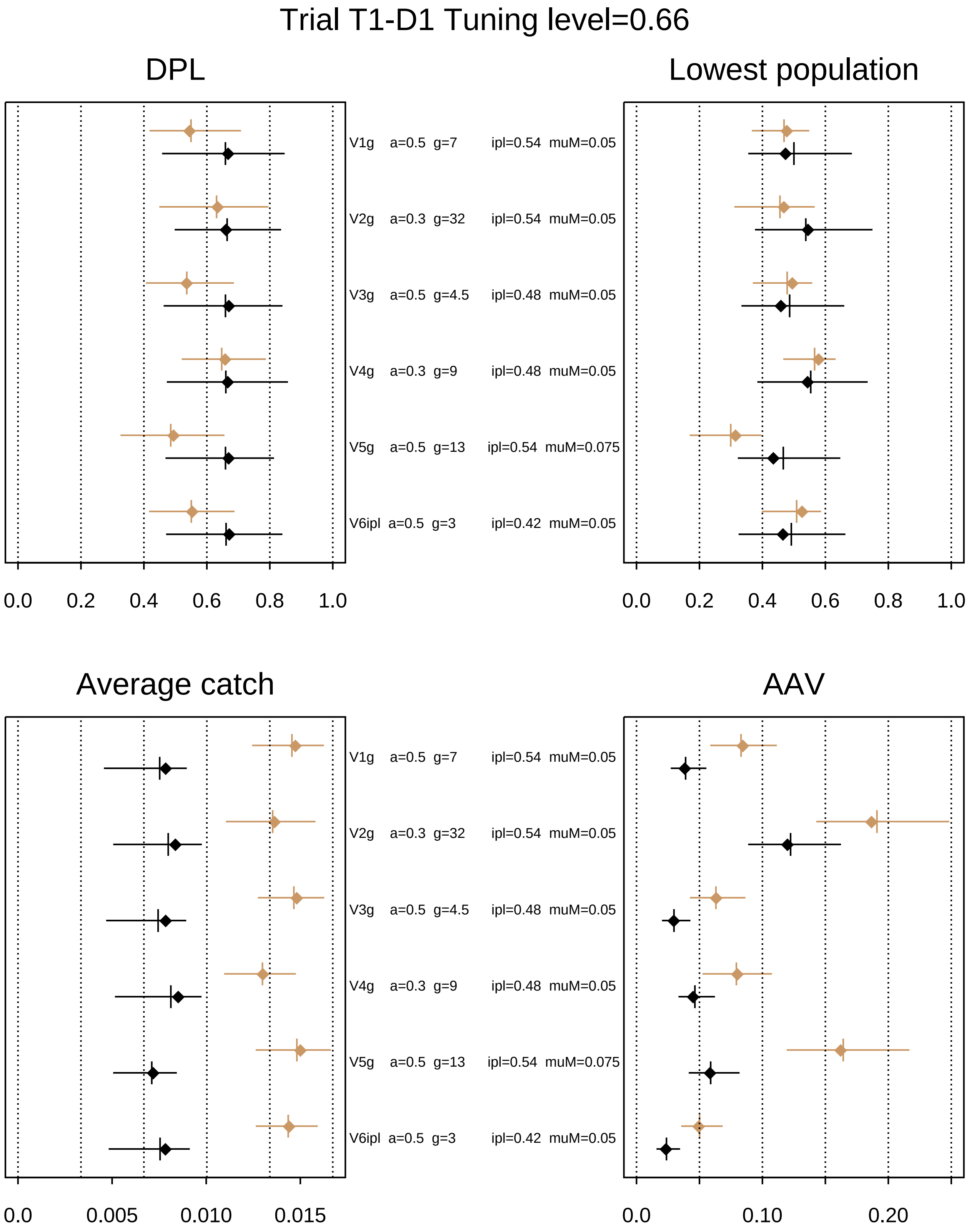


Figure 7. Trial T1-D1, base case, tuning level 0.66.

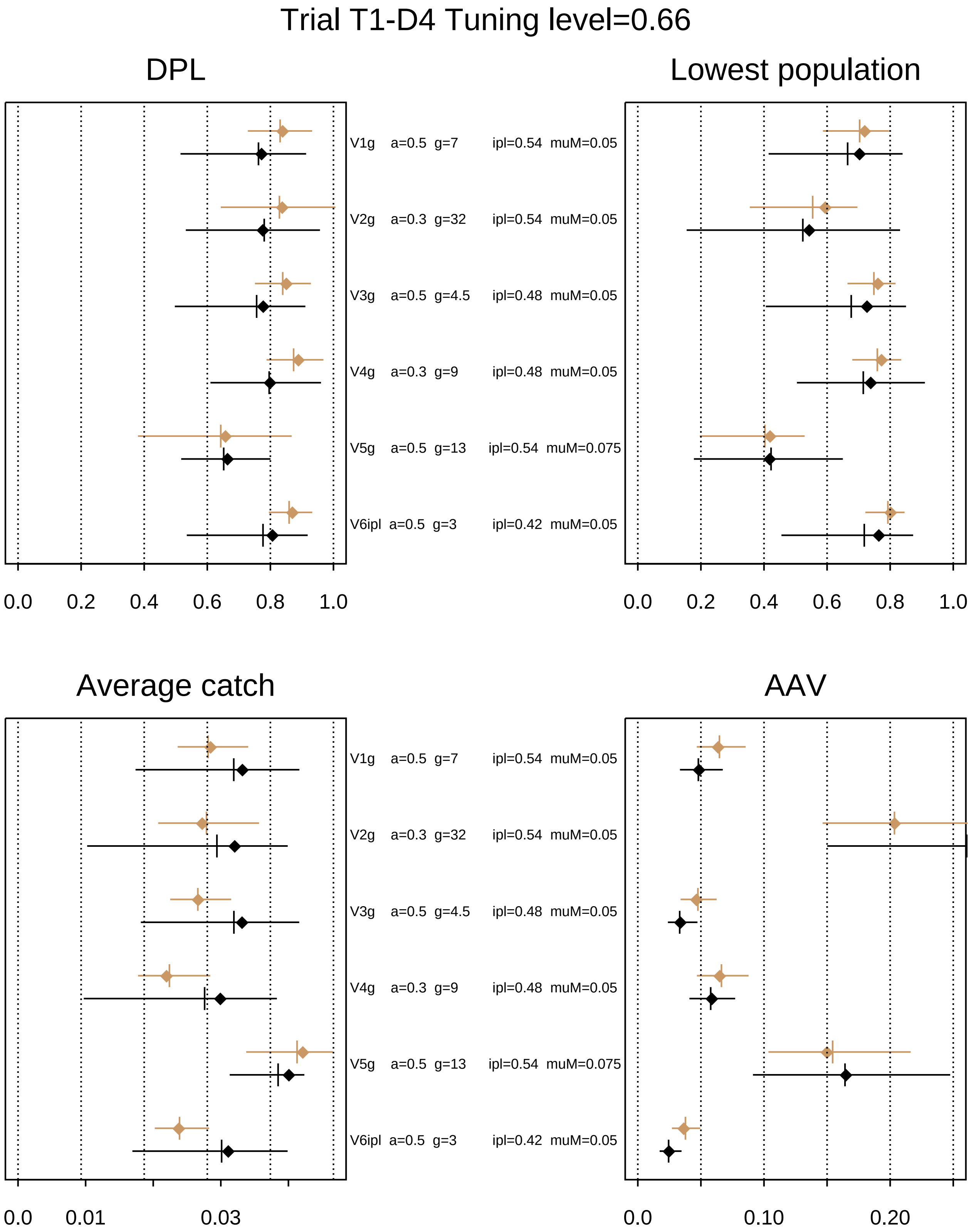


Figure 8. Trial T1-D4, base case, tuning level 0.66.

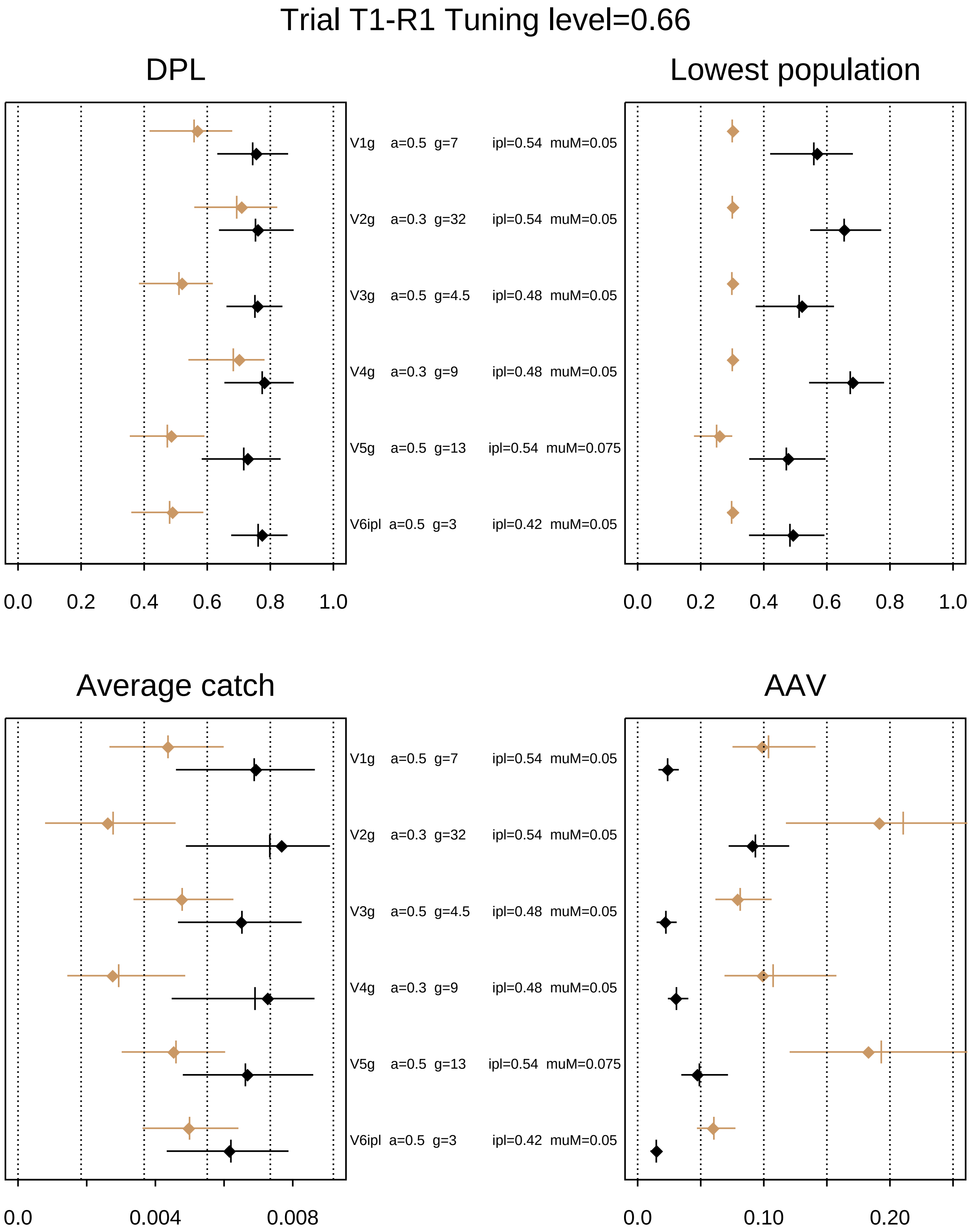


Figure 9. Trial T1-R1, base case, tuning level 0.66.

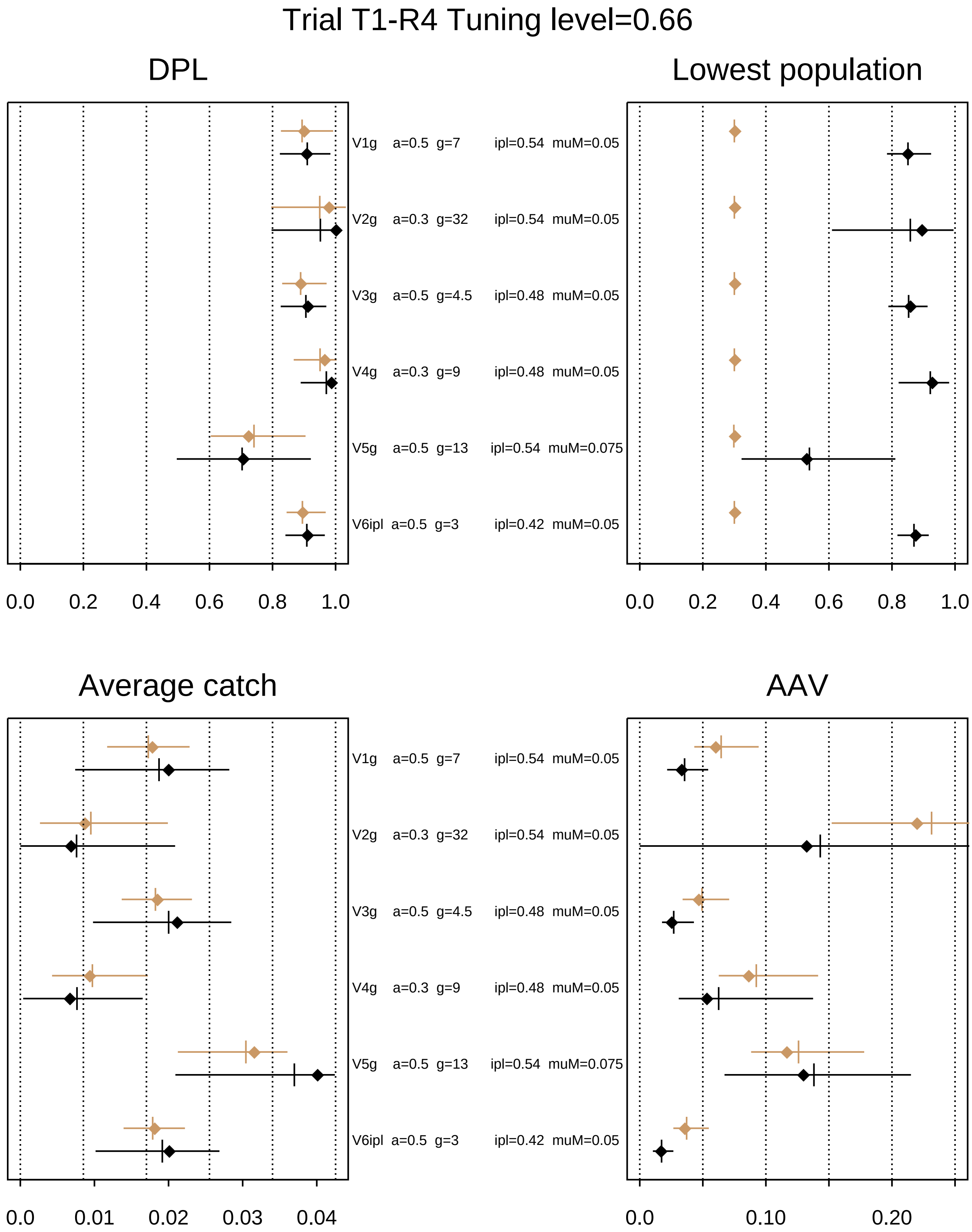


Figure 10. Trial T1-R4, base case, tuning level 0.66.

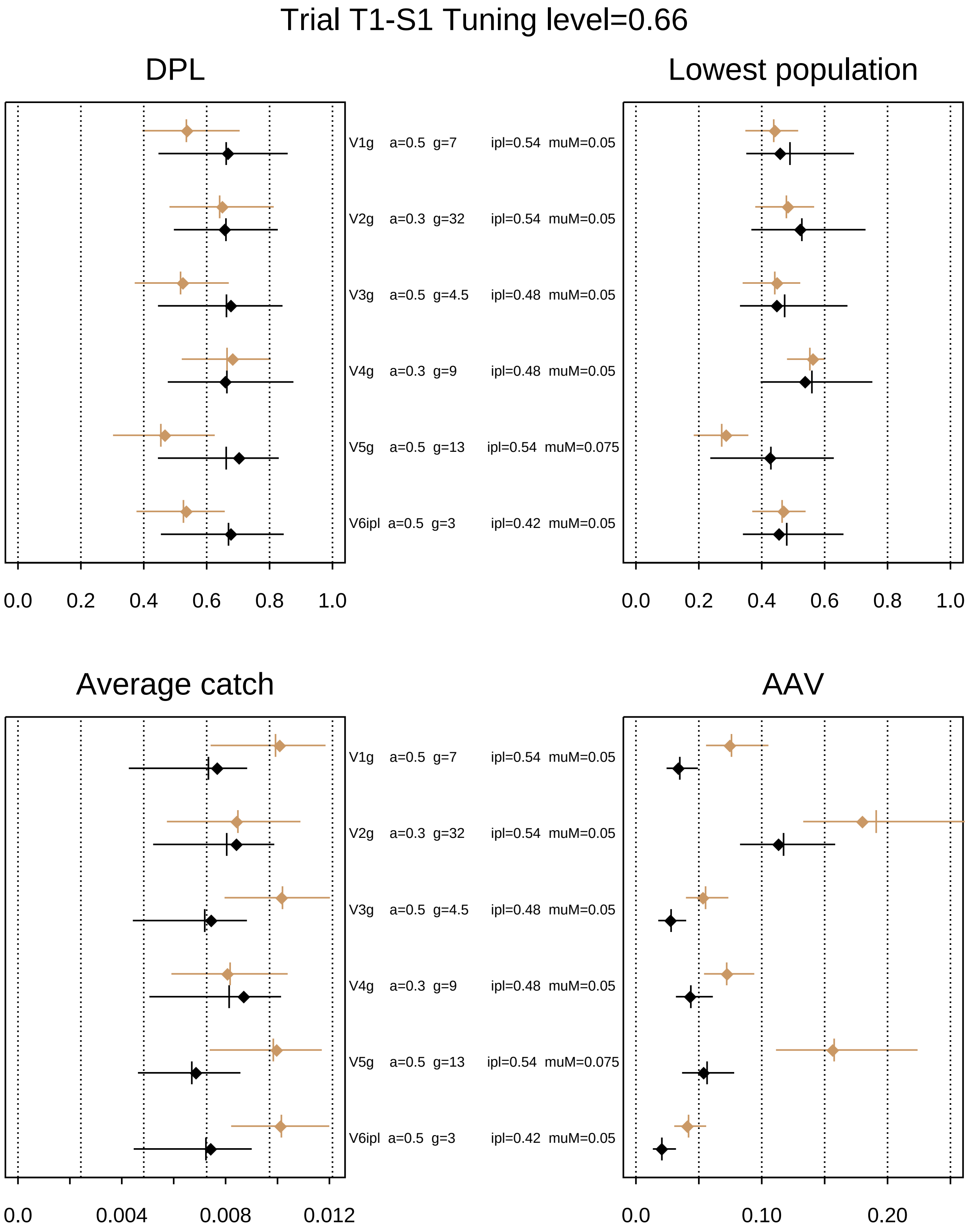


Figure 11. Trial T1-S1, base case, tuning level 0.66.

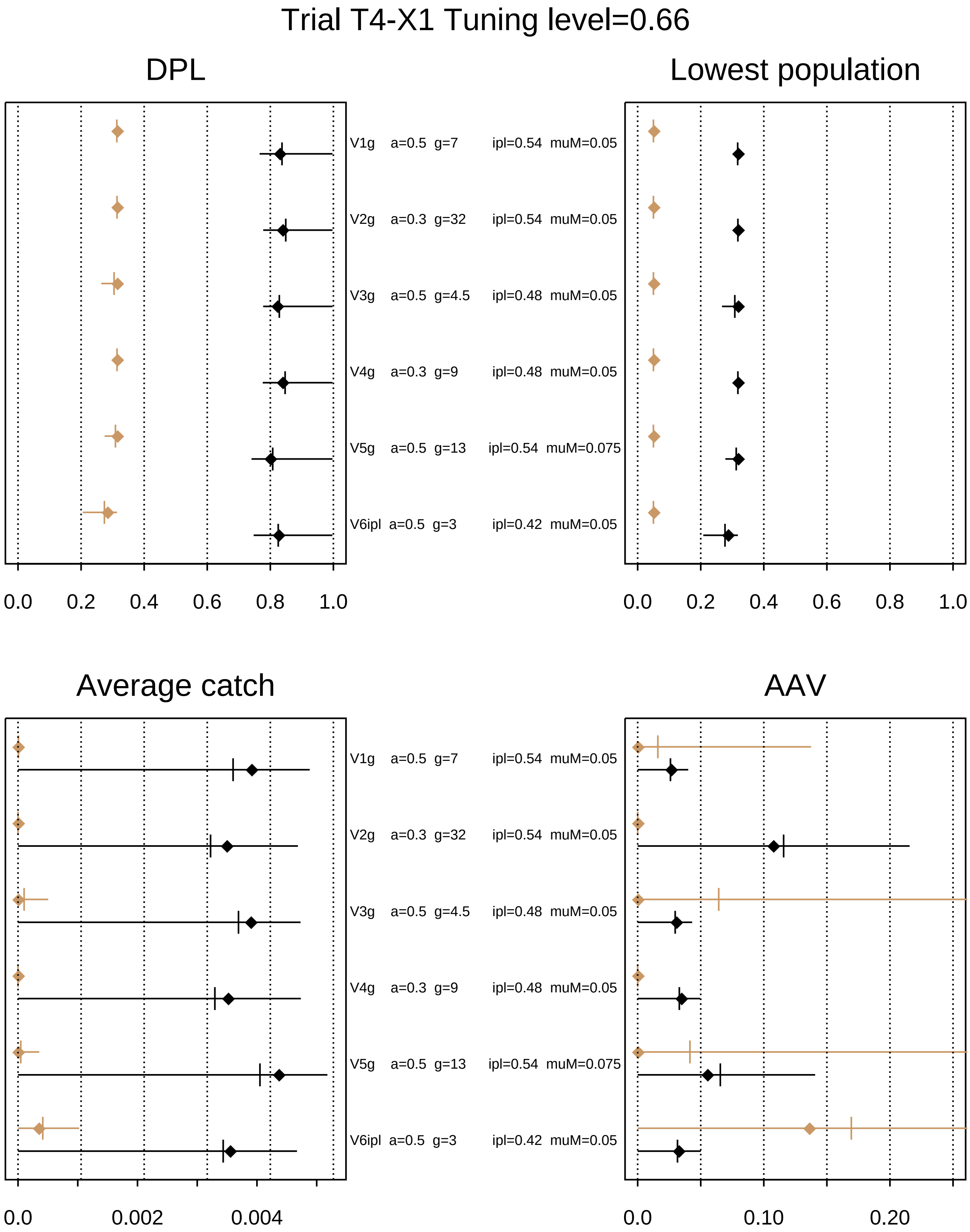


Figure 12. Trial T4-X1, base case, tuning level 0.66.

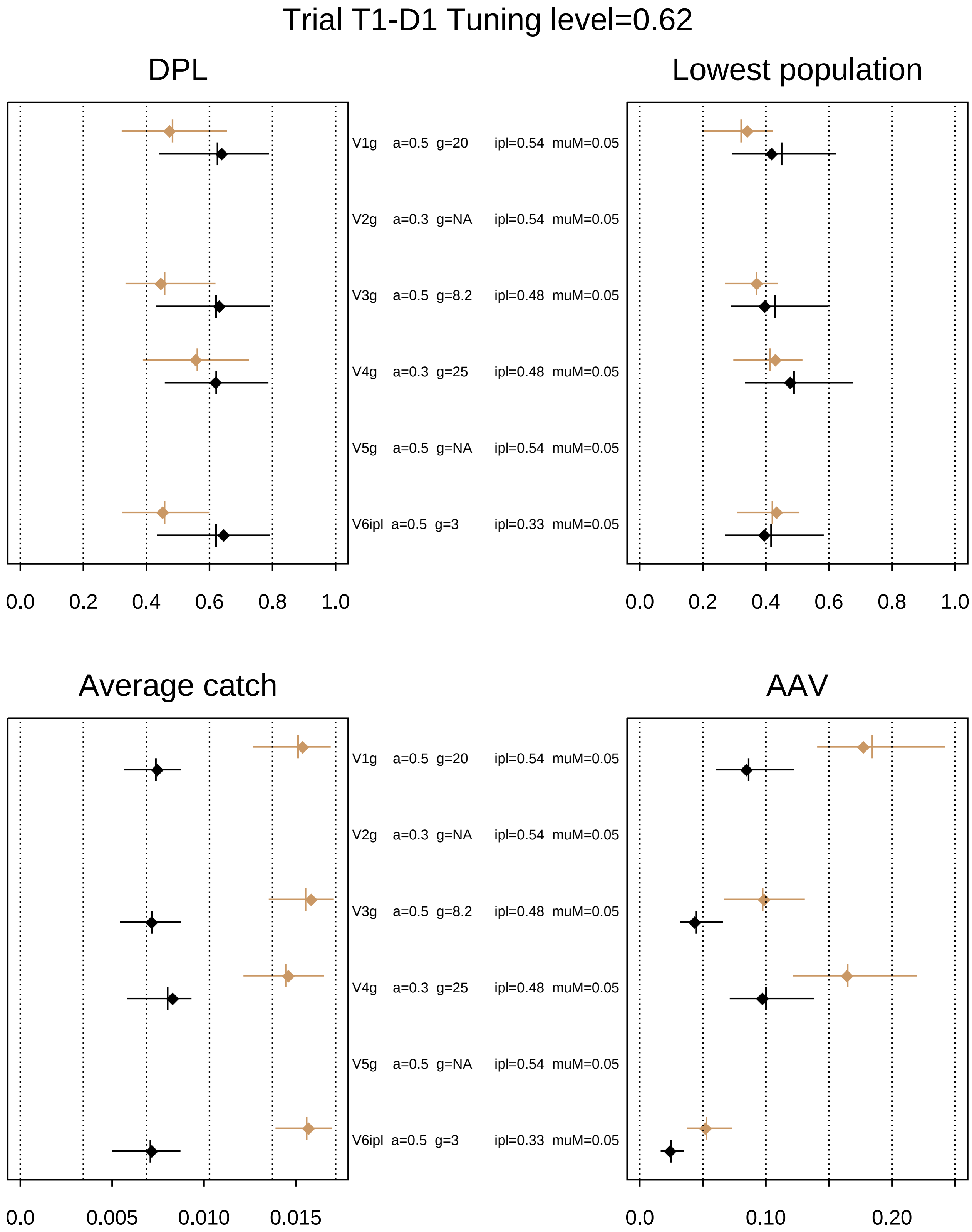


Figure 13. Trial T1-D1, base case, tuning level 0.62.

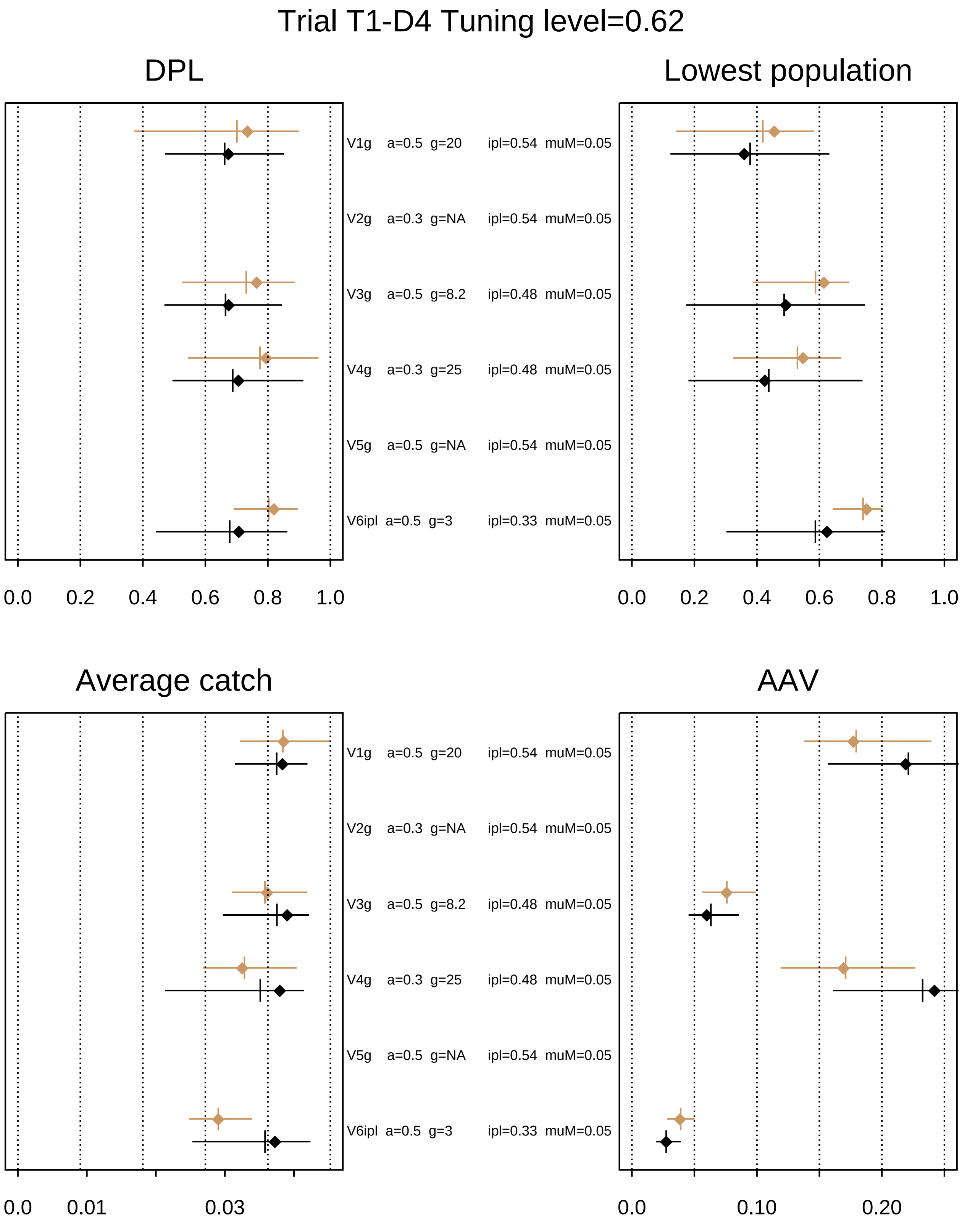


Figure 14. Trial T1-D4, base case, tuning level 0.62.

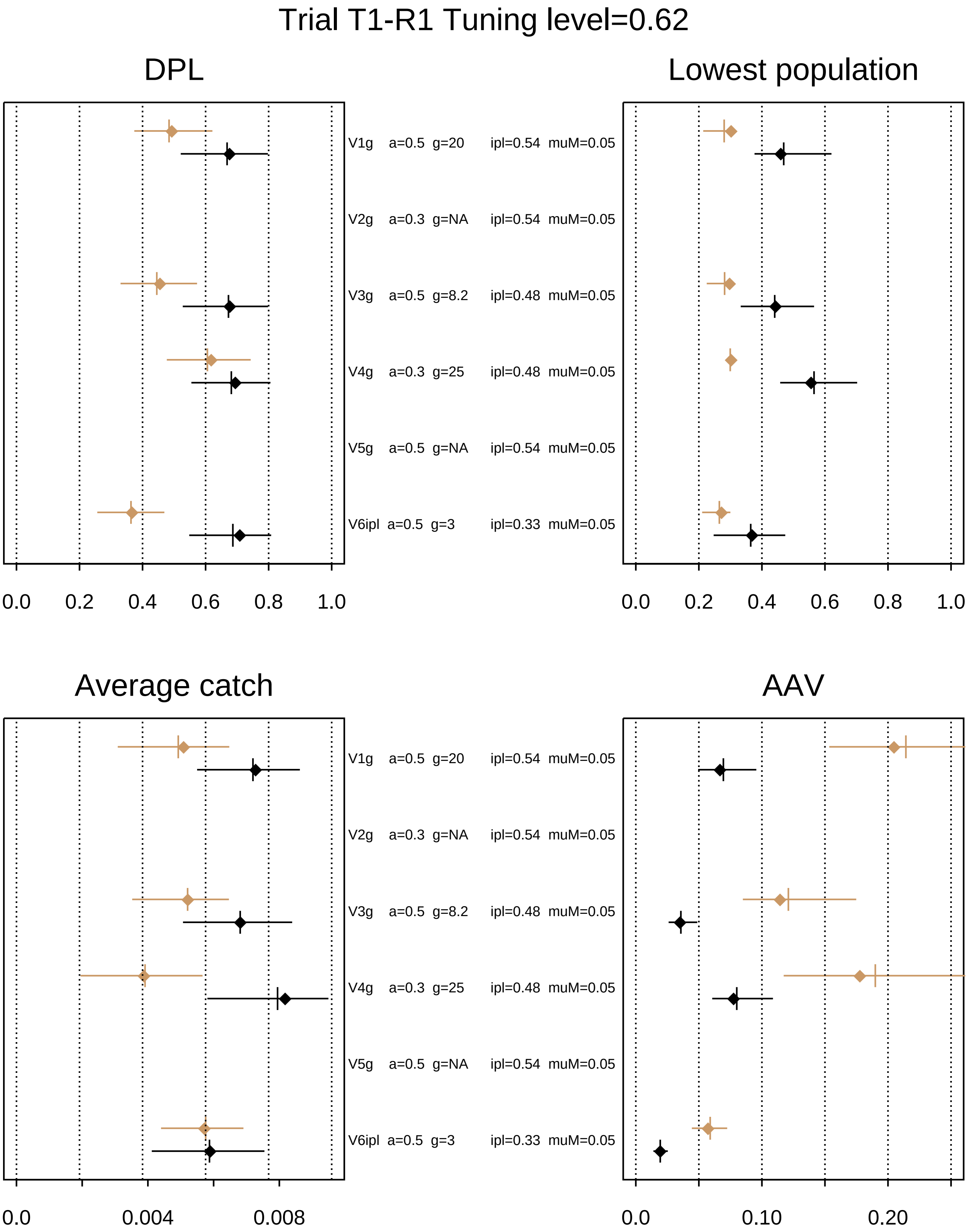


Figure 15. Trial T1-R1, base case, tuning level 0.62.

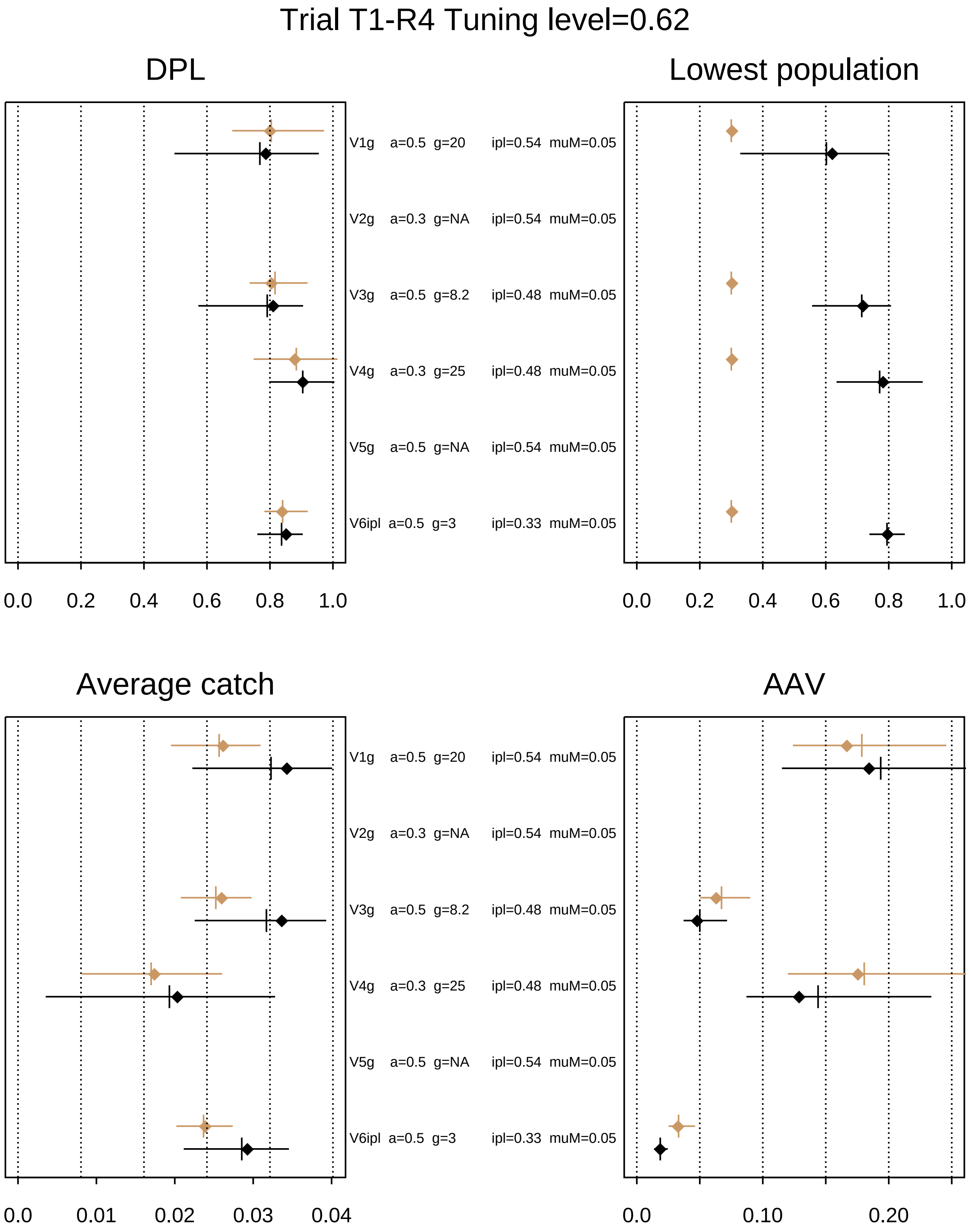


Figure 16. Trial T1-R4, base case, tuning level 0.62.

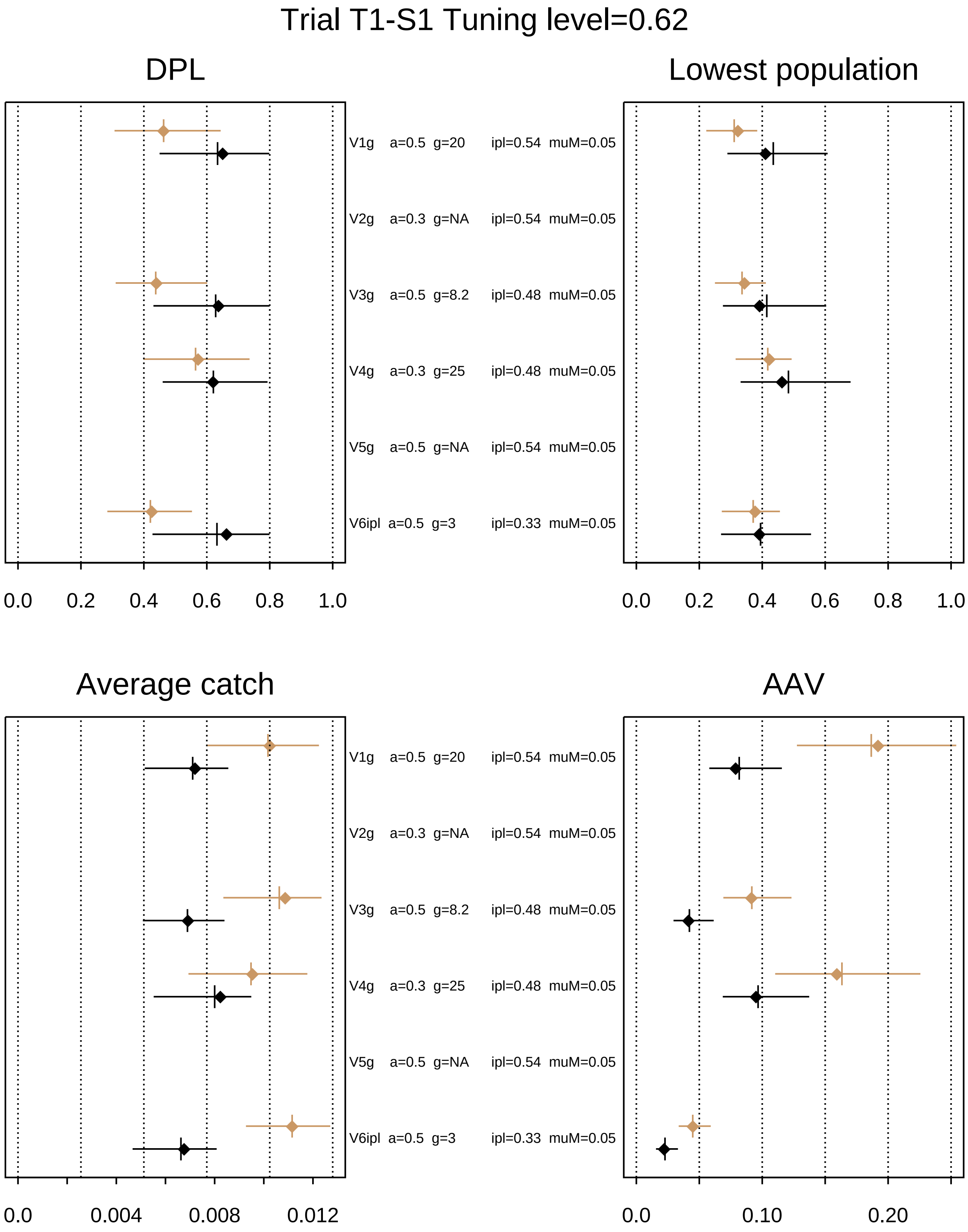


Figure 17. Trial T1-S1, base case, tuning level 0.62.

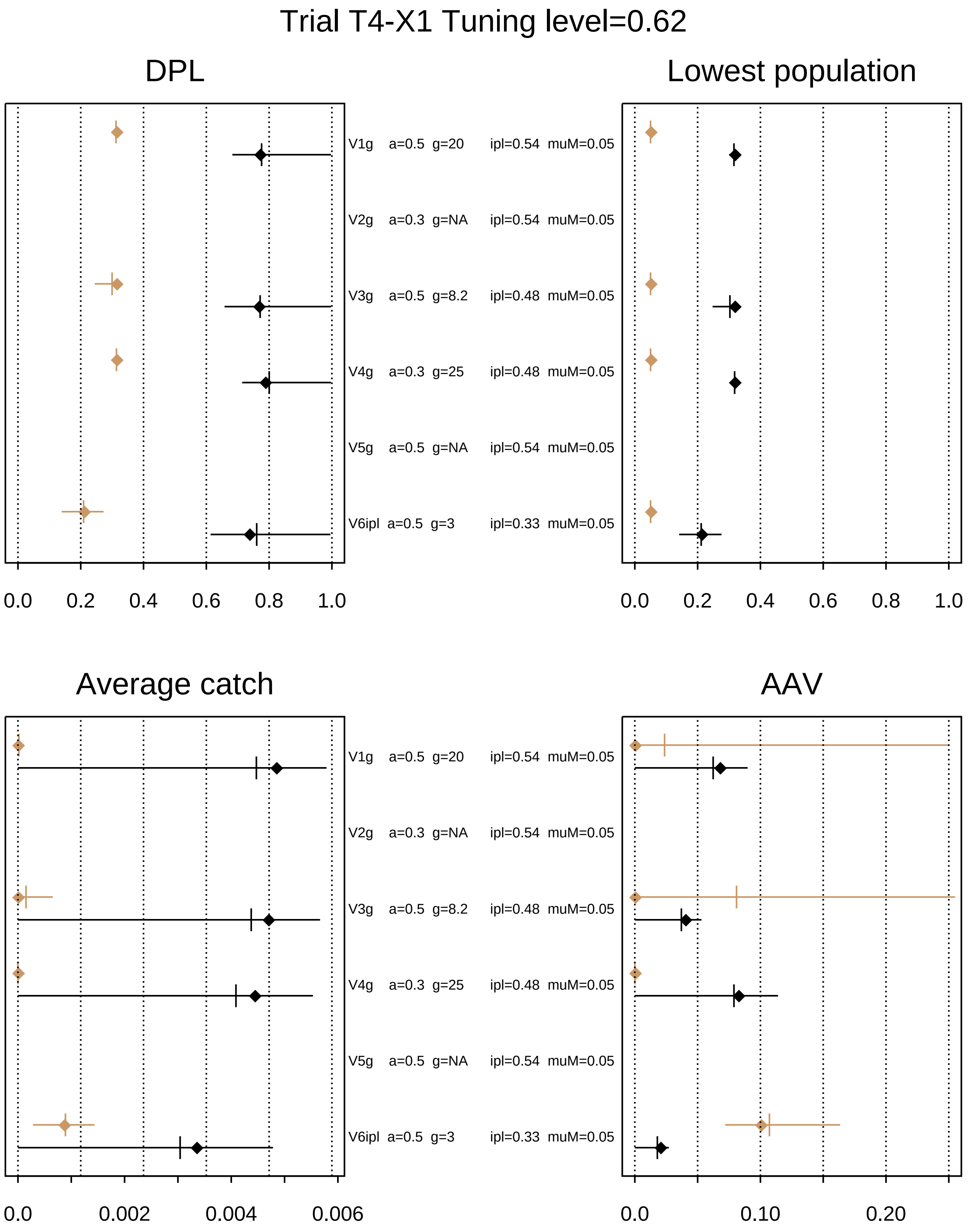


Figure 18. Trial T4-X1, base case, tuning level 0.62.

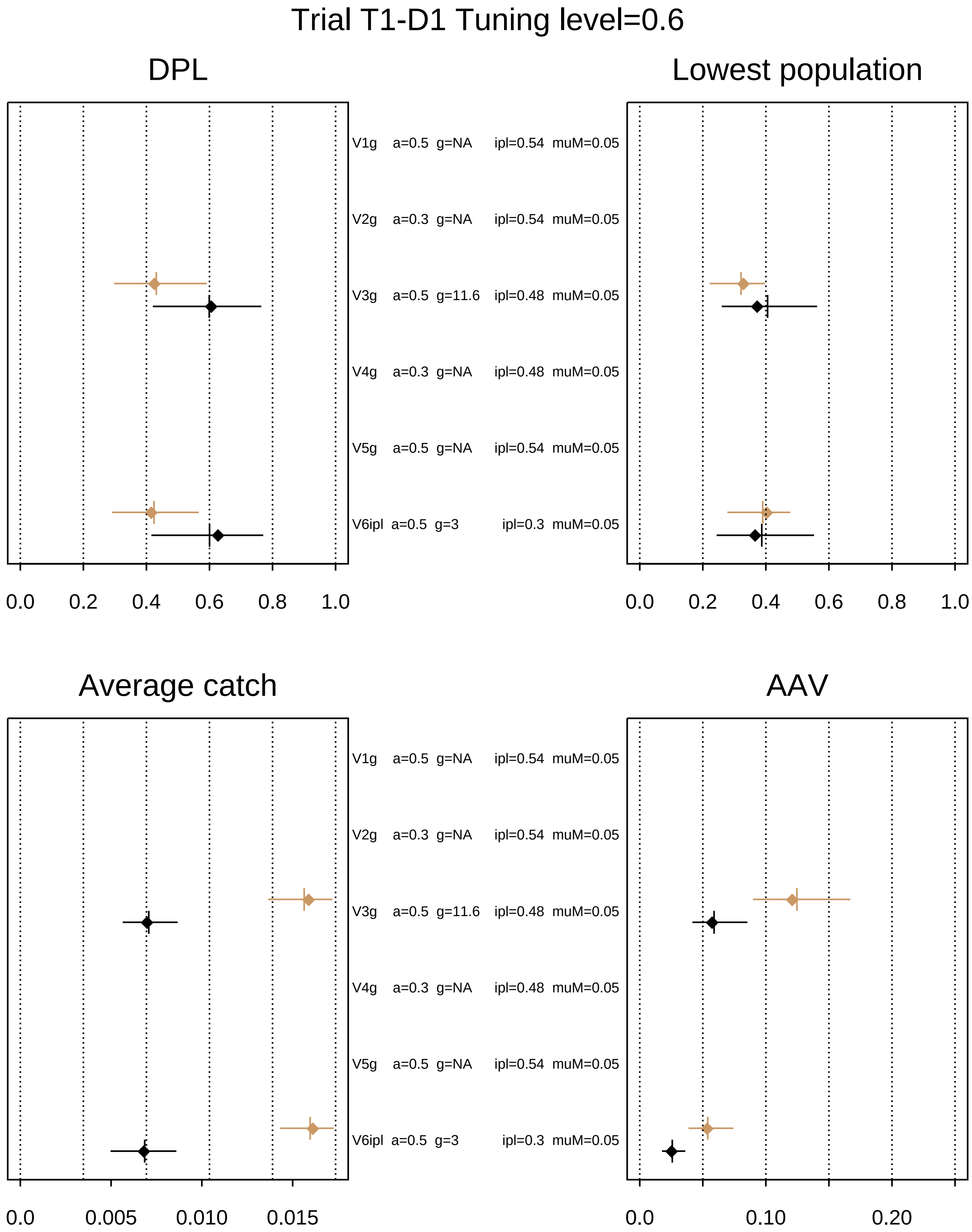


Figure 19. Trial T1-D1, base case, tuning level 0.60.

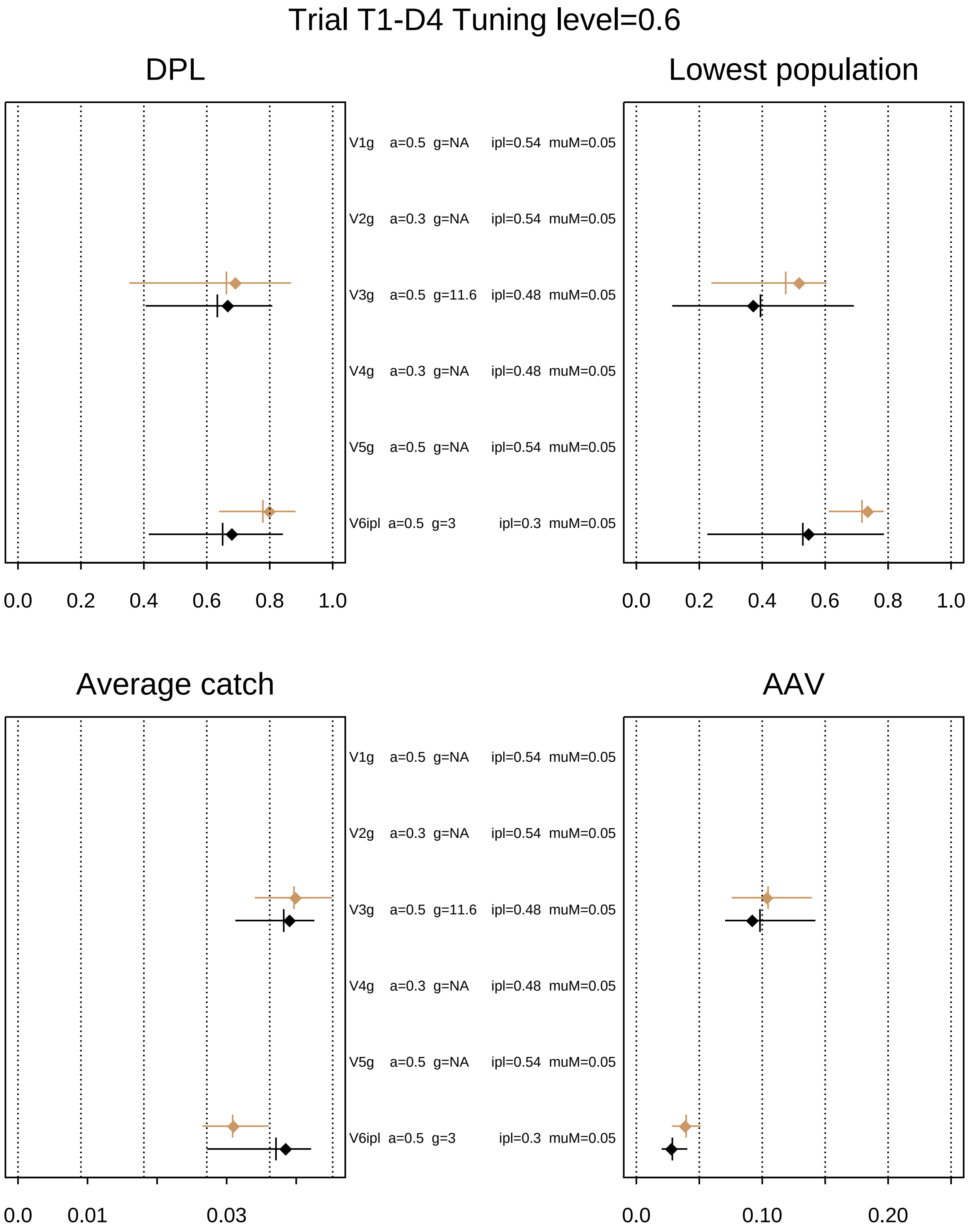


Figure 20. Trial T1-D4, base case, tuning level 0.60.

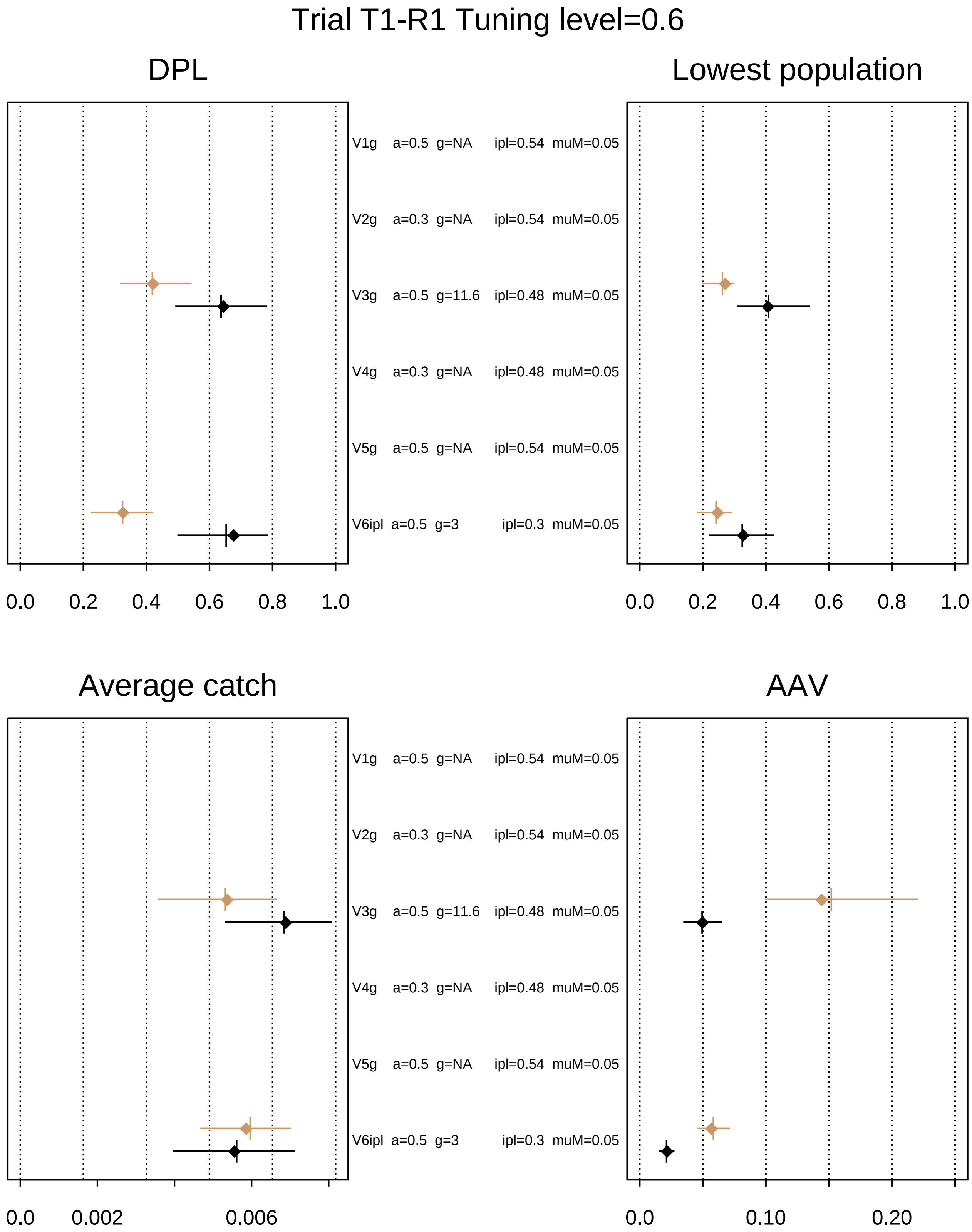


Figure 21. Trial T1-R1, base case, tuning level 0.60.

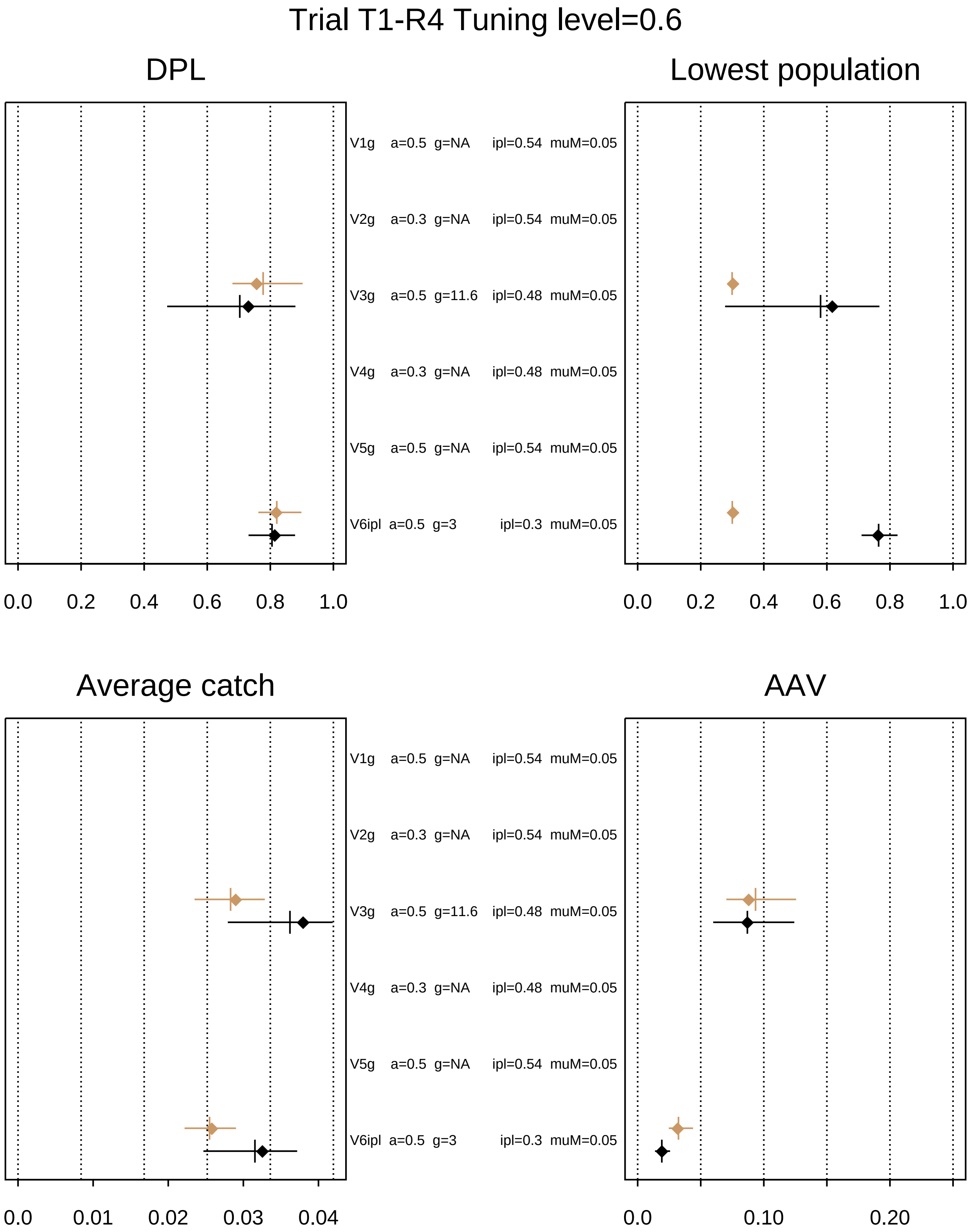


Figure 22. Trial T1-R4, base case, tuning level 0.60.

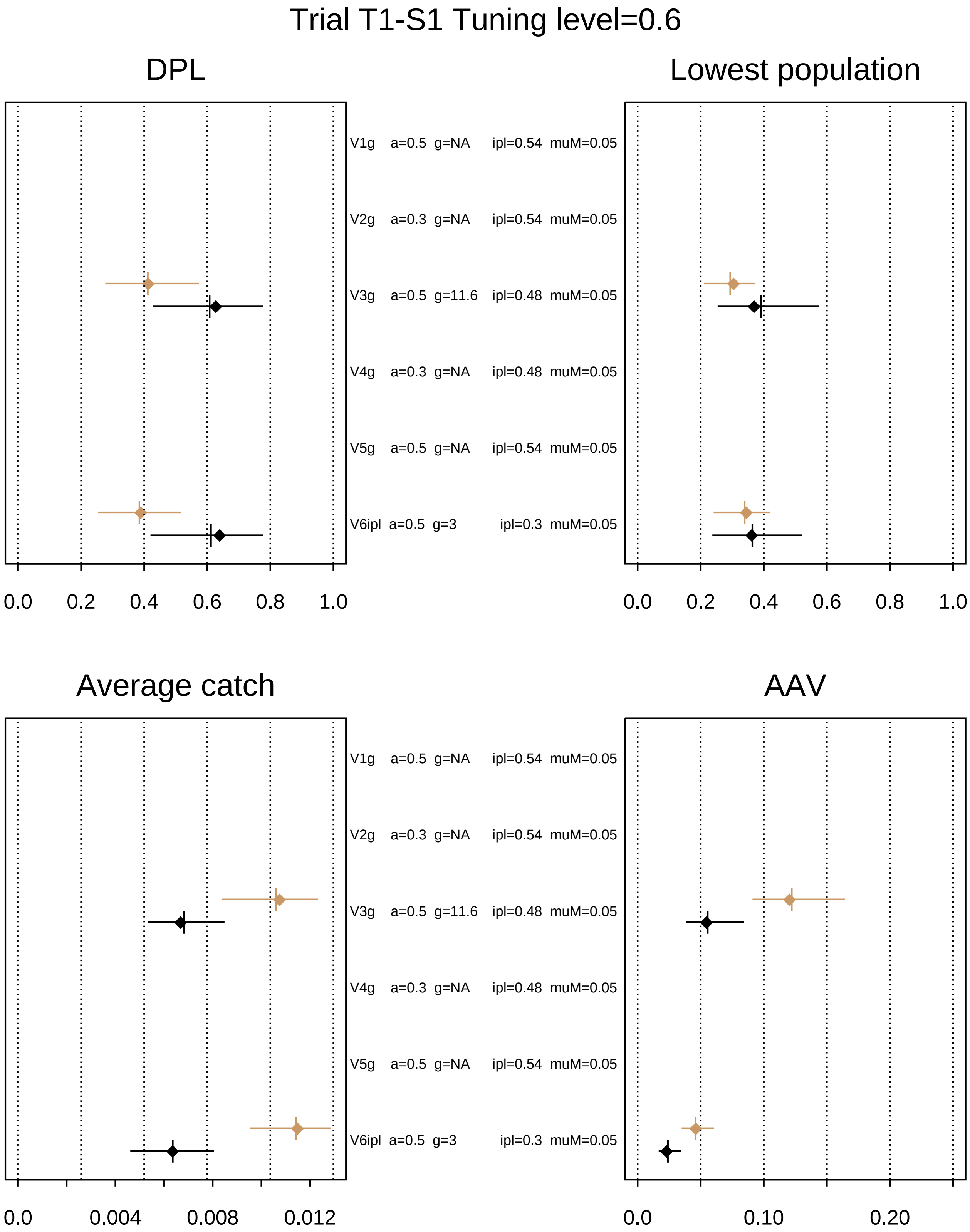


Figure 23. Trial T1-S1, base case, tuning level 0.60.

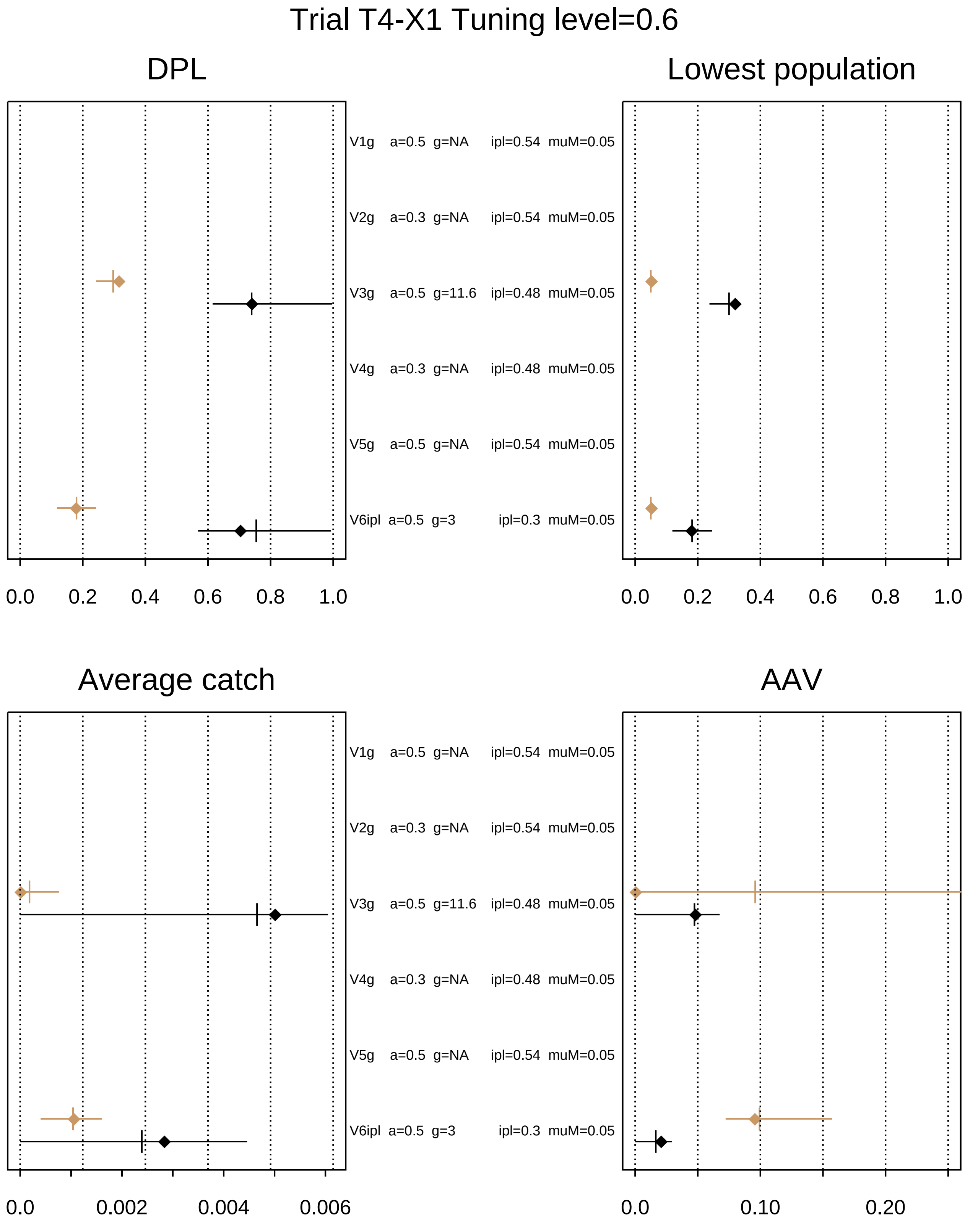


Figure 24. Trial T4-X1, base case, tuning level 0.60.

Acknowledgements

The authors are grateful to Andre Punt, Doug Butterworth and Lars Walløe for good help when designing this study and when presenting its results. We also thank Andre Punt for modifying the MANTST program, version 11, to allow for projections more than 100 years.

This work has been funded by the Norwegian Ministry of Fisheries and Coastal Affairs and the Norwegian Research Council by the project 169046/S40.

References

Aldrin, M., Huseby, R.B. and Schweder, T. (2006). Simulation trials for a re-tuned Catch Limit Algorithm. NR-note SAMBA/10/06, Norwegian Computing Center.

Huseby, R.B. and Aldrin, M (2006). Updated documentation of a Fortran 77 subroutine implementing the catch limit algorithm - Version January 2006. NR-note SAMBA/06/06, Norwegian Computing Center.

IWC (1992). Rep. Int. Whal. Commn 42.

IWC (1999). J. Cetacean Res. Manage. 1 (Suppl.)