APPENDIX E

Sample Size for VAMP 2011: Preliminary Analysis

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Summary of Recommendations

Single Release at Durham Ferry

- For low/medium route-specific survival (0.05 – 0.10), high detection probability at Chipps Island
- To estimate parameters: 475 for low survival; 145 for medium survival
- To detect relative effect between routes of size Δ=1.0: 790 for low survival; 410 for medium survival
- To detect relative effect between routes of size Δ=0.5: 3,510 for low survival; 1,800 for medium survival

Primary Release at Durham Ferry with Supplemental Releases in SJR and OR downstream of the OR flow split

- For low route-specific survival, high detection probability at Chipps Island
- To estimate parameters:
    - Release at Durham Ferry: 95
    - Release in San Joaquin near Lathrop: 75
    - Release in Old River near HOR: 75
- To detect relative effect between routes of size Δ=1.0:
    - Release at Durham Ferry: 97
    - Release in San Joaquin near Lathrop: 97
    - Release in Old River near HOR: 97
- To detect relative effect between routes of size Δ=0.5:
    - Release at Durham Ferry: 510
    - Release in San Joaquin near Lathrop: 510
    - Release in Old River near HOR: 510

Other Design Considerations for Sample Size

- These recommendations are based on
    - Detection probability near 100% at the receivers in both SJR and OR just downstream of the Old River flow split
    - Detection probability of 90-97% at the dual array at Chipps Island
    - Survival from Durham Ferry to Old River = 0.5
    - Route entrainment probability into SJR at Old River = 0.3 - 0.6.
- Relative effect of size Δ=1.0 means one route has twice the survival of the other (e.g., $S_A=2S_B$)
- Relative effect of size Δ=0.5 means one route has 1.5 times the survival of the other (e.g., $S_A=1.5S_B$)
- Power to detect relative effect was calculated at 70% with probability of Type I error: α=0.10.
- With supplemental releases, could use lower sample size if release fewer fish at Durham Ferry than in the supplemental releases. But releasing fewer than 75 fish at Durham Ferry is not recommended.

Introduction

The appropriate sample size for the VAMP 2011 study refers both to the number of release groups and the size of each release group. For both the 2009 and 2010 VAMP studies, numerous releases of between 30 and 135 fish each were released at Durham Ferry and elsewhere in order to obtain information on survival and route selection throughout the VAMP period while also providing enough release groups to garner sufficient statistical power for the non-physical barrier study at the head of Old River. Both 2009 and 2010 were marked by fairly stable river conditions, with low variation in river flow and water exports during the VAMP period. The stable conditions allowed data from multiple release groups to be pooled for statistical analysis in the case where sparse data prevented estimation of model parameters for individual release groups. This was particularly necessary for the 2009 study, when both river flow and smolt survival were markedly low.

In 2011, it is expected that the river environment will be more variable, with potentially sizeable changes in both river flow and water exports during the VAMP period. In a changing environment, it is inadvisable to pool data from across release groups that migrated through the system under different conditions. If it were known ahead of time when or how often changes in the river environment (particularly flow and exports) will occur, then it might be possible to plan multiple small releases with the expectation of pooling data from all release groups that migrated under one set of river conditions, if necessary. However, without knowing the schedule and degree of environmental changes ahead of time, it is impossible to plan for multiple releases during periods of unchanging conditions, and thus impossible rely on pooling data from multiple release groups. Relying on multiple small release groups presents a danger of being unable to estimate key model parameters for one or more release groups. For this reason, it is necessary to plan release groups of sufficient size to maximize the probability that all model parameters will be estimable for each release group. With a fixed total number of tags available, this means making relatively few releases of large size, rather than many small releases. The size of each release group will depend on actual model parameters and the desired degree of precision of the estimates. The number of release groups will then depend on the total number of tags available.

This rest of this document discusses the advantages and disadvantages of various release scenarios for a single release group, and for different values of the model parameters. A simplified version of the release-recapture model is used, representing only key parameters and detection sites. It is assumed that the primary goal of the study is to estimate the route selection probability at the head of Old River (ψ_A) and survival from the head of Old River to Chipps Island through the San Joaquin route (S_A) and also through the Old River route (S_B). A secondary objective is to be able to detect a relative difference between S_A and S_B of a particular size (e.g., 30% or 50%) with a desired level of statistical power and a Type I error probability (α) of either 5% or 10%. The focus is on the size of a single release group, possibly composed of both primary and supplemental releases.

Methods

Two approaches were used to determine the necessary sample size for varying conditions, represented by different values of model parameters. The first approach was a simulation exercise that identified the release size necessary to provide informative estimates of model parameters (survival and route selection probabilities) with high probability. This approach was used to plan the 2010 VAMP study, and the results from the 2010 sample size analysis remain valid. Those results have been augmented with additional simulations here. The second approach consisted of power calculations to detect a relative difference in route survival probabilities of a particular size.

Simulations – summary of methods from 2010 proposal

A simplified study design (Figure 1) was used both to simulate detection data and to generate estimates of model parameters. The model parameters estimated were: S_{RO} = survival from Durham Ferry to the head of Old River; ψ_A = probability of selecting the San Joaquin River at the Old River flow split; S_A = survival from the San Joaquin River near Lathrop (site A1) to Chipps Island, through all possible routes; S_B = survival from the first Old River receiver (site B1) to Chipps Island, through all possible routes; P_C = detection probability at the dual array at Chipps Island. Also estimated was the overall survival from Durham Ferry to Chipps Island, $S_R = S_{RO}\left(\psi_A S_A + \psi_B S_B\right)$.

Data were simulated for different release sizes and for different values of the model parameters. Method of moments estimates were computed from each simulated data set. Parameter values used to simulate the data (Table 1) were selected based on parameter estimates reported in the 2008 VAMP draft report (Holbrook et al. 2009) and estimates from the 2009 VAMP study (SJRGA 2010). For each parameter set and release size, 5000 simulations were run. Simulations reflect sampling error but not natural variability. Release sizes considered were: 95, 145, 190, 250, 475, 750, and 1000.

Table 1. Values of parameters used for data simulation in Analysis 1 to estimate survival to Chipps Island and route selection at Old River.

Parameter	Value
S_R	0.025, 0.045, 0.08, 0.14
S_{RO}	0.5, 0.9
ψ_A	0.3, 0.5
S_A	0.05, 0.10, 0.15
S_B	0.05, 0.10, 0.15
P_{A1}	0.98
P_{B1}	0.98
P_C	0.6, 0.9

The minimum release size for each parameter set was selected based on three criteria reflecting the ability to attain a point estimate of each parameter, the reasonableness of the point estimate , and the uncertainty associated with the point estimate (Table 2). See 2010 VAMP proposal for further description of the simulations analysis.

Additional analyses were performed considering the possibility of a supplemental release in the San Joaquin River near Lathrop (site A1) and another supplemental release in Old River near site B1. See 2010 VAMP proposal for further description of these analyses.

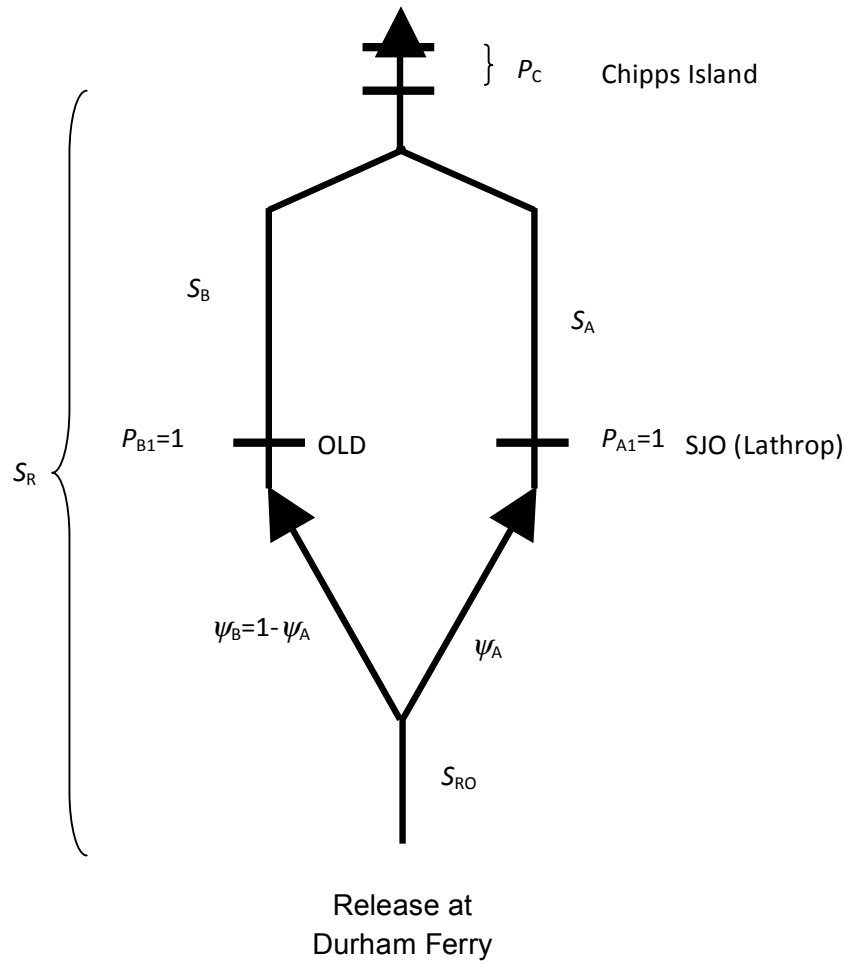

Figure 1. Schematic of model simulations and power calculations, with parameters: survival from Durham Ferry to Chipps Island (S_R), survival to Chipps Island from the head of Old River in the San Joaquin route (S_A) and in the Old River route (S_B), and the probability of remaining in the San Joaquin River at the head of Old River (ψ_A). Other parameters are survival from Durham Ferry to the head of Old River (S_{RO}), detection probabilities at site A1 (P_{A1}), site B1 (P_{B1}), and overall probability of detection on at least one receiver at Chipps Island (P_C).

Table 2. Criteria used for identification of minimum sample size necessary to estimate a model parameter, assuming 5000 simulations.

Criterion	Definition
C1	Parameter is estimable in at least 95% of simulations (4750 or more)
C2	Probability estimate is not greater than 1.1 in 95% of simulations (4750 or more)
C3	Standard error on parameter estimate is not greater than 0.10

Power Calculations – No supplemental releases

Power was calculated based on the asymptotic normal distribution of the maximum likelihood estimators of survival in both the San Joaquin and Old River routes (S_A and S_B, respectively). For a given Type I error probability (α), the probability of detecting an absolute difference between S_A and S_B of size δ is approximately

$$P(\delta) \approx \Phi\left(z_{\alpha/2} + \frac{\delta}{\sqrt{Var\left(\hat{S}_A - \hat{S}_B\right)}} \right) + \Phi\left(z_{\alpha/2} - \frac{\delta}{\sqrt{Var\left(\hat{S}_A - \hat{S}_B\right)}} \right),$$

where Φ is the cumulative distribution function of the standard normal distribution and $z_{\alpha/2}$ is the $(\alpha/2)$-th quantile of the standard normal distribution. The variance of the difference in survival estimates, $Var\left(\hat{S}_A - \hat{S}_B\right)$, can be approximated by the Delta Method (Seber 2002, pp.7-9). For a single primary release with no supplemental releases, the variance of the difference in survival estimates is (to a first-order Taylor series approximation, and ignoring covariance terms):

$$Var\left(\hat{S}_A - \hat{S}_B\right) \approx \frac{1}{RS_{RO}P_C}\left[\frac{(S_A - S_B)^2 (1 - P_C)}{\psi_A S_A + \psi_B S_B} + \xi \right],$$

where

$$\xi = \frac{S_A}{\psi_A}\left(1 + S_A P_C - 2S_{RO}\psi_A S_A P_C\right) + \frac{S_B}{\psi_B}\left(1 + S_B P_C - 2S_{RO}\psi_B S_B P_C\right)$$

and

$$\psi_B = 1 - \psi_A .$$

For a single release occasion with a primary release at Durham Ferry of size R_1, a supplemental release in the San Joaquin River (of size R_2) just downstream of the Old River flow split, and another supplemental release in Old River (of size R_3) just downstream of the Old River flow split, the variance of the difference in survival estimates is approximately:

$$
\begin{aligned}
Var\left(\hat{S}_A - \hat{S}_B\right) \approx\ & \frac{\left(S_A - S_B\right)^2 \left(1 - P_C\right)}{P_C\left[R_1 S_{RO}\left(\psi_A S_A + \psi_B S_B + R_2 S_A + R_3 S_B\right)\right]} \\
+\ & \frac{S_A}{P_C}\left[\frac{R_1 S_{RO}\psi_A\left(1 + S_A P_C\right) - 2R_1 S_{RO}^2 \psi_A^2 S_A P_C + R_2\left(1 - S_A P_C\right)}{\left(R_1 S_{RO}\psi_A + R_2\right)^2}\right] \\
+\ & \frac{S_B}{P_C}\left[\frac{R_1 S_{RO}\psi_B\left(1 + S_B P_C\right) - 2R_1 S_{RO}^2 \psi_B^2 S_B P_C + R_3\left(1 - S_B P_C\right)}{\left(R_1 S_{RO}\psi_B + R_3\right)^2}\right].
\end{aligned}
$$

For a given value of S_A and a given value of δ, the absolute difference between S_A and S_B, the value of S_B can be found by $S_B = S_A\left(1-\delta\right)$, and the relative difference between S_A and S_B is $\Delta = S_A\delta$. Thus, although power is expressed in terms of absolute differences in survival, it can be found for any desired relative difference in survival, as well.

Power to detect a relative effect (Δ) of varying sizes was calculated for eight scenarios representing a combination of low/high survival from Durham Ferry to the receivers in both rivers just downstream of the head of Old River (S_{RO}), low/medium probability of route entrainment into the San Joaquin River at the head of Old River (ψ_A), and low/high detection probability at Chipps Island (P_C) (Table 3). For each scenario, power was calculated to detect three levels of relative effect: $\Delta = 0.3$, 0.5, and 1.0. These three levels correspond to S_A being 20% higher than S_B, 50% higher than S_B, and twice as large as S_B, respectively. Values of S_A considered ranged from 0.05 to 0.8. Power was calculated for two levels of the Type I error probability: $\alpha = 0.05$ and 0.10. Power was calculated for varying release sizes, both for a single primary release at Durham Ferry (Scenarios 1 – 8) and for a Durham Ferry release coupled with two supplemental releases (Scenarios 9 – 24). Scenarios 9 – 16 used equal release sizes at Durham Ferry and the two supplemental release sites, while for Scenarios 17 – 24, the Durham Ferry release group was three times the size of the supplemental releases (Table 3).

Table 3. Scenarios used in power calculations. R_1 = size of release at Durham Ferry. R_2 = size of supplemental release in the San Joaquin River near Lathrop. R_3 = size of supplemental release in Old River just downstream of the Old River flow split.

	Scenario				
No Supplemental Releases	With Supplemental Releases				
	R_1=R_2=R_3	R_1 = 3R_2 = 3R_3	Survival from DF to head of Old River (receivers) (S_{OR})	Route entrainment probability in SJR at head of Old River (ψ_A)	Detection probability at Chipps Island (P_C)
1	9	17	0.5	0.5	0.6
2	10	18	0.5	0.5	0.9
3	11	19	0.9	0.5	0.6
4	12	20	0.9	0.5	0.9
5	13	21	0.5	0.3	0.6
6	14	22	0.5	0.3	0.9
7	15	23	0.9	0.3	0.6
8	16	24	0.9	0.3	0.9

Results

Single Release at Durham Ferry, No Supplemental Release

Simulations

Although a wide range of parameter values were considered, recommendations were based on the assumption of S_{RO} =0.5, ψ_A=0.5, P_{A1}=0.98, and P_{B1}=0.98 (Table 4). The minimum release size needed to estimate all key model parameters (S_A, S_B, ψ_A, S_R, and S_{RO}) depended on the values of survival from the head of Old River to Chipps Island through the San Joaquin River (S_A) and through the Old River route (S_B), and overall detection probability of the dual array at Chipps Island (P_C). In the case of low survival (0.05) to Chipps Island in either route, a minimum of 475 fish would need to be released at Durham Ferry to insure being able to estimate both S_A and S_B. For higher values of route-specific survival, the minimum release size necessary depended on the detection probability at Chipps Island (P_C): between 145 and 250 fish would be required at Durham Ferry if P_C =0.6, while between 95 and 145 fish would be required if P_C =0.9 (Table 4). In all cases, 95 fish were sufficient to guarantee estimation of survival from Durham Ferry to the head of Old River (S_{RO}) and the route entrainment probability at the head of Old River (ψ_A). If overall survival from Durham Ferry to Chipps Island is to be estimated without route-specific survival, then a release of 145 fish at Durham Ferry should be sufficient, unless survival through both routes and detection probability at Chipps Island are all very low.

Table 4. Minimum release size to estimate parameters S_A, S_B, ψ_A, S_{RO}, and S_R, based on simulations using a single release at Durham Ferry (no supplemental releases). Recommendations are based on the assumption of S_{RO} = 0.5, ψ_A = 0.5, P_{A1} = 0.98, and P_{B1} = 0.98.

		Minimum release size with	
Parameter	True Value	P_C=0.6	P_C=0.9
S_A	0.05	475	475
S_A	0.10	250	145
S_A	0.15	145	95
S_B	0.05	475	475
S_B	0.10	250	145
S_B	0.15	145	95

Power Calculations

Detecting a difference ("effect") in route-specific survival between the San Joaquin and Old River routes is more demanding than simply estimating the model parameters, and thus much larger sample sizes are required. In general, detecting a smaller effect (Δ), demanding a smaller Type I error probability (α), and desiring higher power all require more fish (Table 5 - Table 7; Figure A1 - Figure A8).

With route-specific survival to Chipps Island in the San Joaquin River route (S_A) equal to 0.05 and a Type I error probability of α =0.10, from 260 to nearly 1,500 fish would need to be released at Durham Ferry to detect a relative effect of Δ =1.0 (i.e., S_A=2 S_B) with approximately 70% power (Table 5). To detect an effect of only Δ=0.50 (i.e., S_A = 1.5 S_B) with 70% power, from 1,420 to 5,370 fish would be required at Durham Ferry. The range of release sizes depends on the value of survival from Durham Ferry to the head of Old River (S_{RO}), the route entrainment probability at the head of Old River (ψ_A), and the overall detection probability at the dual array at Chipps Island (P_C). Low values of any of these parameters results in nearly doubling the necessary release size (Table 5). Lower desired power values demand fewer fish (Figure A1 - Figure A8). With route-specific survival through the San Joaquin River route at 0.1, the release size necessary to detect a relative effect of Δ=1.0 with 70% power and a Type I error probability of α=0.10 ranges from 130 to 760. From 710 to 2,730 fish would be required to detect a relative error of Δ=0.5 (Table 6). With route-specific survival through the San Joaquin River route at S_A=0.15, between approximately 90 and 510 fish would be required to detect a relative effect of Δ=1.0, and between 475 and 1,850 would be required to detect a relative effect of Δ=0.5 (α=0.10, power = 0.7; Table 7).

In all cases, the only parameter that is marginally under human control is the detection probability at the dual array at Chipps Island (P_C). Low values of the detection probability (e.g., P_C=0.6) require many more fish than higher values of the detection probability (e.g., P_C=0.9). Thus, regardless of the desired power to detect an effect or the desired effect size, it is recommended that efforts be made to optimize the detection probability at Chipps Island as much as possible. Further, these power calculations were performed under the assumption of 100% detection at the first detection arrays in both the San Joaquin River and Old River just downstream of the Old River flow split (i.e., sites A1 and B1). Lower detection probabilities at these sites will lower the power to detect effects.

Table 5. Release size to detect relative effect of either Δ =0.5 or Δ =1.0 with approximately 70% power and a Type I error probability of either α=0.05 or α=1.0, for S_A=0.05, for a single primary release group with no supplemental release.

				Δ=0.5		Δ=1.0	
Scenario	S_{OR}	ψ_A	P_C	α=0.05	α=0.10	α=0.05	α=0.10
1	0.5	0.5	0.6	5,230	3,980	1,170	890
2	0.5	0.5	0.9	3,390	2,590	620	470
3	0.9	0.5	0.6	2,900	2,190	650	490
4	0.9	0.5	0.9	1,860	1,420	340	260
5	0.5	0.3	0.6	7,050	5,370	1,950	1,490
6	0.5	0.3	0.9	4,610	3,510	1,040	790
7	0.9	0.3	0.6	3,900	2,960	1,080	830
8	0.9	0.3	0.9	2,540	1,930	570	440

Table 6. Release size to detect relative effect of either Δ =0.5 or Δ =1.0 with approximately 70% power and a Type I error probability of either α=0.05 or α=1.0, for S_A=0.1, for a single primary release group with no supplemental release.

				Δ=0.5		Δ=1.0	
Scenario	S_{OR}	ψ_A	P_C	α=0.05	α=0.10	α=0.05	α=0.10
1	0.5	0.5	0.6	2,640	2,020	590	450
2	0.5	0.5	0.9	1,730	1,320	320	240
3	0.9	0.5	0.6	1,440	1,100	330	250
4	0.9	0.5	0.9	940	710	170	130
5	0.5	0.3	0.6	3,580	2,730	990	760
6	0.5	0.3	0.9	2,360	1,800	540	410
7	0.9	0.3	0.6	1,960	1,500	550	420
8	0.9	0.3	0.9	1,290	980	290	230

Table 7. Release size to detect relative effect of either Δ =0.5 or Δ =1.0 with approximately 70% power and a Type I error probability of either α=0.05 or α=1.0, for S_A=0.15, for a single primary release group with no supplemental release.

				Δ=0.5		Δ=1.0	
Scenario	S_{OR}	ψ_A	P_C	α=0.05	α=0.10	α=0.05	α=0.10
1	0.5	0.5	0.6	1,790	1,360	400	300
2	0.5	0.5	0.9	1,180	900	210	165
3	0.9	0.5	0.6	960	740	215	165
4	0.9	0.5	0.9	625	475	115	87
5	0.5	0.3	0.6	2,430	1,850	670	510
6	0.5	0.3	0.9	1,630	1,230	370	280
7	0.9	0.3	0.6	1,320	1,010	365	280
8	0.9	0.3	0.9	870	670	200	150

Release at Durham Ferry with two Supplemental Releases

Simulations

Simulation results from the sample size analysis performed for the 2010 VAMP study are summarized here. For further details, see 2010 VAMP proposal.

In general, lower detection probability at Chipps Island demanded larger release groups at Durham Ferry and also at the downstream supplemental release sites (Table 8). Under the assumption of high detection probability at Chipps Island (0.97) and fairly low survival to Chipps Island in both routes, the recommended sample sizes of the three groups are R_1 = 95 (at Durham Ferry), R_2 = 75 (in the San Joaquin near Lathrop), and R_3 = 75 (in Old River near its head). This gives a total of 245 fish released. With lower detection probability at Chipps Island (0.76), a total of 440 fish would be necessary, comparable to the number recommended for a single primary release at Durham Ferry. Using smaller release groups may require pooling data across release groups in the event of low survival or low detection. Every effort should be made to ensure that detection probability at Chipps Island is as high as possible (at least 0.75). Similarly, detection probabilities lower than 0.9 at the first receivers in the San Joaquin River or Old River just downstream of the flow split may require a larger release group at Durham Ferry.

Table 8. Parameter values used to simulated data, and minimum release size recommended at Durham Ferry (R_1), site A1 in the San Joaquin River (R_2), and site B1 in Old River (R_3) to estimate key model survival and route selection parameters. Recommendations are based on the assumption of S_{RO} = 0.5, ψ_{A1} = 0.6, P_{A3} = 0.98, and P_{B1} = 0.94.

True Values			Minimum release size at Durham Ferry (R_1) to estimate:					Minimum supplemental release size to estimate:	
S_A	S_B	P_C	S_R	S_{RO}	S_A	S_B	ψ_{A1}	S_A (R_2)	S_B (R_3)
0.1	0.06	0.76	190	95	95	250	95	100	150
0.1	0.06	0.97	95	95	95	95	95	75	75
0.1	0.06	1.00	95	95	95	95	95	25	75
0.15	0.09	0.76	190	95	95	95	95	75	150
0.15	0.09	0.97	95	95	95	95	95	25	75
0.15	0.09	1.00	95	95	95	95	95	25	25

Power Calculations

Power was calculated for two supplemental release protocols: equal weighting across all release groups (i.e., common release size across all three releases: R_1=R_1=R_3), and triple weighting for the primary release group at Durham Ferry (R_1=3R_2=3R_3).

Equal Weight across all primary and supplemental release groups: $R_1 = R_2 = R_3$

As with a single release, more fish are required to detect smaller effect sizes at higher power and with a lower Type I error probability. Using equal release sizes at Durham Ferry and the two supplemental release groups, and assuming route-specific survival in the San Joaquin River route is 0.05,

between 235 and 570 fish would be necessary to detect an effect of Δ=1.0 with approximately 70% power and a Type I error probability of α=0.10. To detect an effect of size Δ=0.5, from 1,280 to 2,390 fish would be required (Table 9). A third of those fish would be released at Durham Ferry. If route-specific survival in the San Joaquin River route is 0.15, total release sizes necessary to detect an effect of Δ=1.0 range from 75 to 185, and from 410 to 680 to detect an effect of Δ=0.5 (α=0.10, power = 0.7) (Table 10). In both cases, the largest benefits to using supplemental releases instead of a single Durham Ferry release arise when survival from Durham Ferry to the head of Old River (S_{RO}) is low (0.5). Different values of S_A and different desired power levels require different release sizes (Figure A9 - Figure A16).

Table 9. Total release size to detect relative effect of either Δ =0.5 or Δ =1.0 with approximately 70% power and a Type I error probability of either α=0.05 or α=1.0, for S_A=0.05, for a primary release at Durham Ferry of size R1, a supplemental release in the San Joaquin River just downstream of the OR flow split (size R2 = R1), and a supplemental release in Old River just downstream of the OR flow split (size R3 = R1). The number in parenthesis is R1.

				Δ=0.5		Δ=1.0	
Scenario	S_{OR}	ψ_A	P_C	α=0.05	α=0.10	α=0.05	α=0.10
1	0.5	0.5	0.6	3,050 (1,017)	2,320 (773)	685 (228)	520 (173)
2	0.5	0.5	0.9	1,950 (650)	1,480 (493)	355 (118)	270 (90)
3	0.9	0.5	0.6	2,630 (877)	2,010 (670)	590 (197)	450 (150)
4	0.9	0.5	0.9	1,700 (567)	1,280 (427)	305 (102)	235 (78)
5	0.5	0.3	0.6	3,140 (1,047)	2,390 (797)	740 (247)	570 (190)
6	0.5	0.3	0.9	2,010 (670)	1,530 (510)	385 (128)	290 (97)
7	0.9	0.3	0.6	2,780 (927)	2,120 (707)	670 (223)	510 (170)
8	0.9	0.3	0.9	1,770 (590)	1,355 (452)	350 (117)	265 (88)

Table 10. Total release size to detect relative effect of either Δ =0.5 or Δ =1.0 with approximately 70% power and a Type I error probability of either α=0.05 or α=1.0, for S_A=0.15, for a primary release at Durham Ferry of size R1, a supplemental release in the San Joaquin River just downstream of the OR flow split (size R2 = R1), and a supplemental release in Old River just downstream of the OR flow split (size R3 = R1). The number in parenthesis is R1.

				Δ=0.5		Δ=1.0	
Scenario	S_{OR}	ψ_A	P_C	α=0.05	α=0.10	α=0.05	α=0.10
1	0.5	0.5	0.6	980 (327)	750 (250)	220 (73)	170 (57)
2	0.5	0.5	0.9	615 (205)	470 (157)	110 (38)	85 (28)
3	0.9	0.5	0.6	850 (283)	650 (217)	190 (63)	145 (48)
4	0.9	0.5	0.9	540 (180)	410 (137)	100 (33)	75 (25)
5	0.5	0.3	0.6	1,005 (335)	770 (257)	240 (80)	185 (62)
6	0.5	0.3	0.9	630 (210)	480 (160)	120 (40)	90 (30)
7	0.9	0.3	0.6	890 (297)	680 (227)	215 (72)	165 (55)
8	0.9	0.3	0.9	560 (187)	430 (143)	110 (37)	85 (28)

Unequal Weights across Primary and Supplemental Release Groups: $R_1 = 3R_2 = 3R_3$

Putting more fish in the primary release at Durham Ferry (R_1) and fewer in the supplemental releases tends to require more fish overall than using an equal weighting across the three release groups (compare Table 9 and Table 11, or Table 10 and Table 12). This is because most of the parameters we wish to estimate arise downstream of the Old River flow split. With low route-specific survival (S_A=0.05), a total of from 240 to 750 fish would be required to detect relative effect of size Δ=1.0, while from 1,330 to 3,020 fish would be required to detect an effect of size Δ=0.5 (α=0.10, power=0.7; Table 11). With higher route-specific survival (S_A=0.15), between 80 and 245 fish would be required to detect a relative effect of size Δ=1.0, and between 440 and 990 fish would be required to detect an effect of size Δ=0.5 (α=0.10, power = 0.7) (Table 12). Results for other values of route-specific survival and other power levels are available in the Appendix (Figure A17 - Figure A24).

Table 11. Total release size to detect relative effect of either Δ =0.5 or Δ =1.0 with approximately 70% power and a Type I error probability of either α=0.05 or α=1.0, for S_A=0.05, for a primary release at Durham Ferry of size R1, a supplemental release in the San Joaquin River just downstream of the OR flow split (size R2 = R1/3), and a supplemental release in Old River just downstream of the OR flow split (size R3 = R1/3). The number in parenthesis is R1.

				Δ=0.5		Δ=1.0	
Scenario	S_{OR}	ψ_A	P_C	α=0.05	α=0.10	α=0.05	α=0.10
1	0.5	0.5	0.6	3,660 (2,196)	2,780 (1,668)	820 (492)	630 (378)
2	0.5	0.5	0.9	2,350 (1,410)	1,790 (1,074)	425 (255)	325 (195)
3	0.9	0.5	0.6	2,750 (1,650)	2,075 (1,245)	610 (366)	470 (282)
4	0.9	0.5	0.9	1,750 (1,050)	1,330 (798)	320 (192)	240 (144)
5	0.5	0.3	0.6	3,970 (2,382)	3,020 (1,812)	985 (591)	750 (450)
6	0.5	0.3	0.9	2,550 (1,530)	1,940 (1,164)	510 (306)	390 (234)
7	0.9	0.3	0.6	3,080 (1,848)	2,350 (1,410)	790 (474)	605 (363)
8	0.9	0.3	0.9	1,985 (1,191)	1,510 (906)	415 (249)	315 (189)

Table 12. Total release size to detect relative effect of either Δ =0.5 or Δ =1.0 with approximately 70% power and a Type I error probability of either α=0.05 or α=1.0, for S_A=0.15, for a primary release at Durham Ferry of size R1, a supplemental release in the San Joaquin River just downstream of the OR flow split (size R2 = R1/3), and a supplemental release in Old River just downstream of the OR flow split (size R3 = R1/3). The number in parenthesis is R1.

				Δ=0.5		Δ=1.0	
Scenario	S_{OR}	ψ_A	P_C	α=0.05	α=0.10	α=0.05	α=0.10
1	0.5	0.5	0.6	1,195 (717)	910 (546)	270 (162)	205 (123)
2	0.5	0.5	0.9	760 (456)	580 (348)	140 (84)	105 (63)
3	0.9	0.5	0.6	890 (534)	680 (408)	200 (120)	155 (93)
4	0.9	0.5	0.9	570 (342)	440 (264)	102 (61)	80 (48)
5	0.5	0.3	0.6	1,290 (774)	990 (594)	325 (195)	245 (147)
6	0.5	0.3	0.9	820 (492)	625 (375)	165 (99)	125 (75)
7	0.9	0.3	0.6	1,010 (606)	770 (462)	260 (156)	200 (120)
8	0.9	0.3	0.9	650 (390)	500 (300)	135 (81)	100 (60)

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San Joaquin River Group Authority (SJRGA) 2010. 2009 Annual Technical Report on Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). Prepared for the California Water Resources Control Board in compliance with D-1641.

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Appendix: Power Curves

No Supplemental Releases

Scenario 1: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.5, Low Detection Probability at Chipps Island (0.6). No supplemental release.

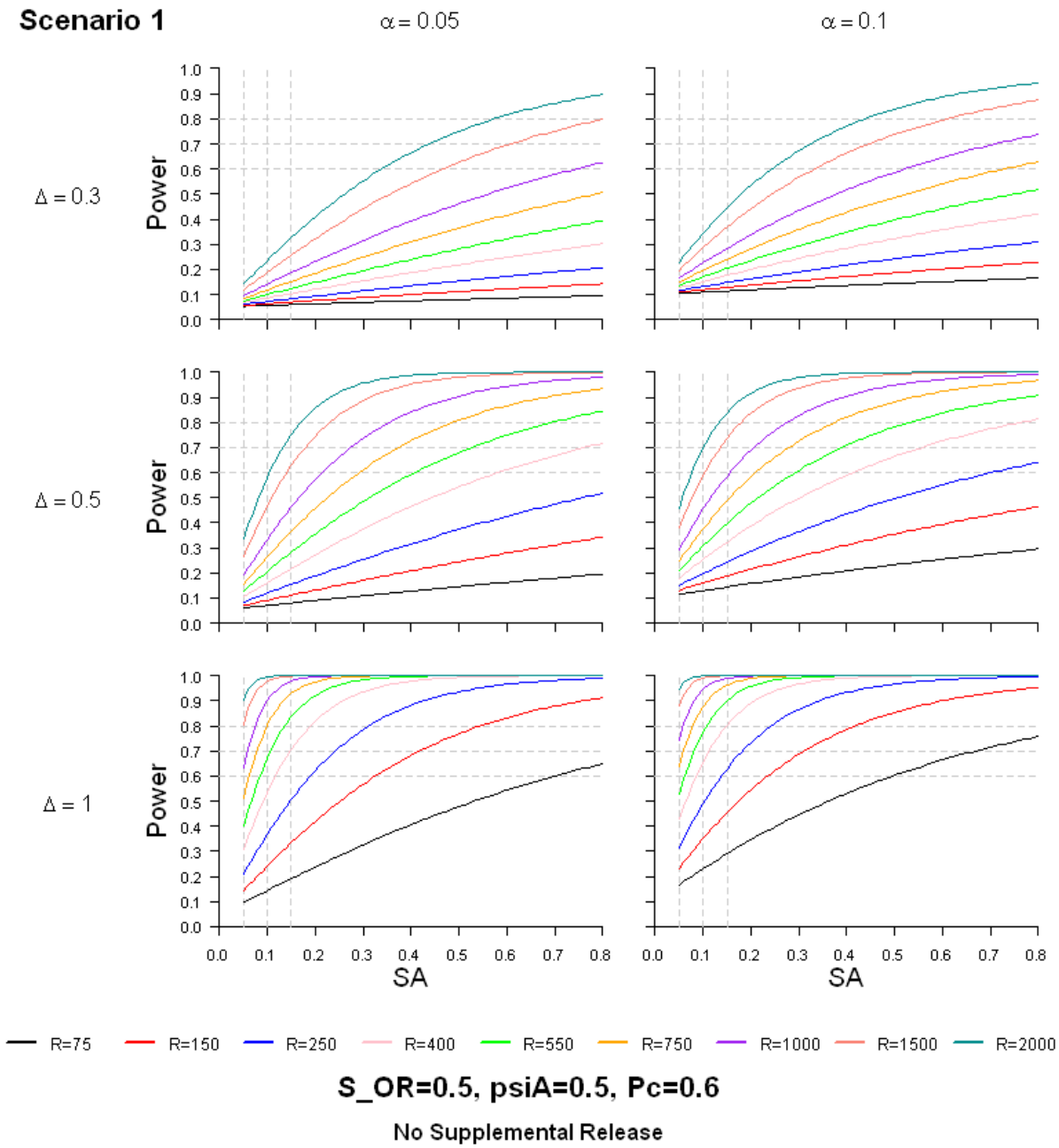

Figure A1. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Scenario 2: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.5, High Detection Probability at Chipps Island (0.9). No supplemental release.

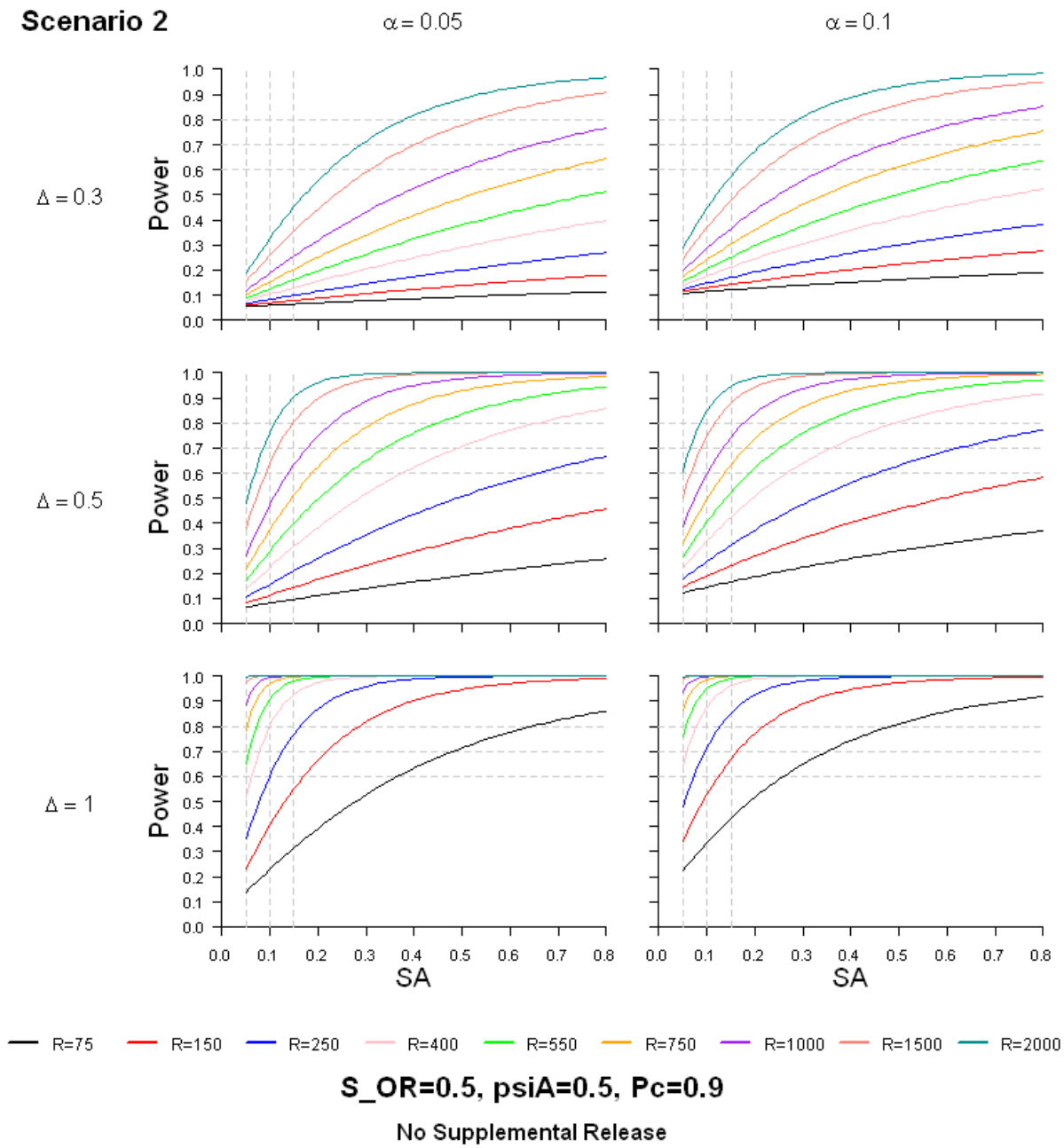

Figure A2. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Scenario 3: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.5, Low Detection Probability at Chipps Island (0.6). No supplemental release.

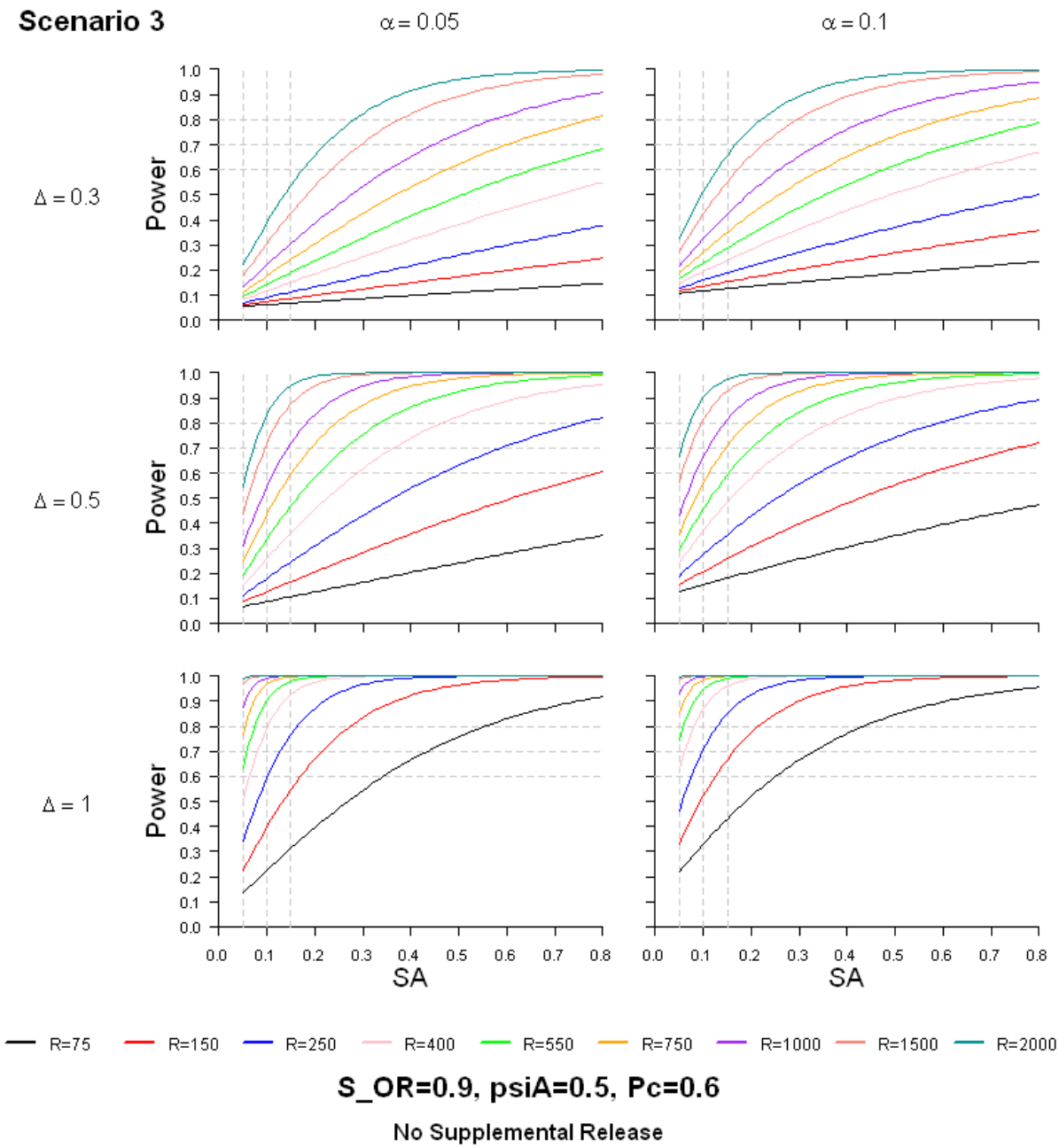

Figure A3. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Scenario 4: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.5, High Detection Probability at Chipps Island (0.9). No supplemental release.

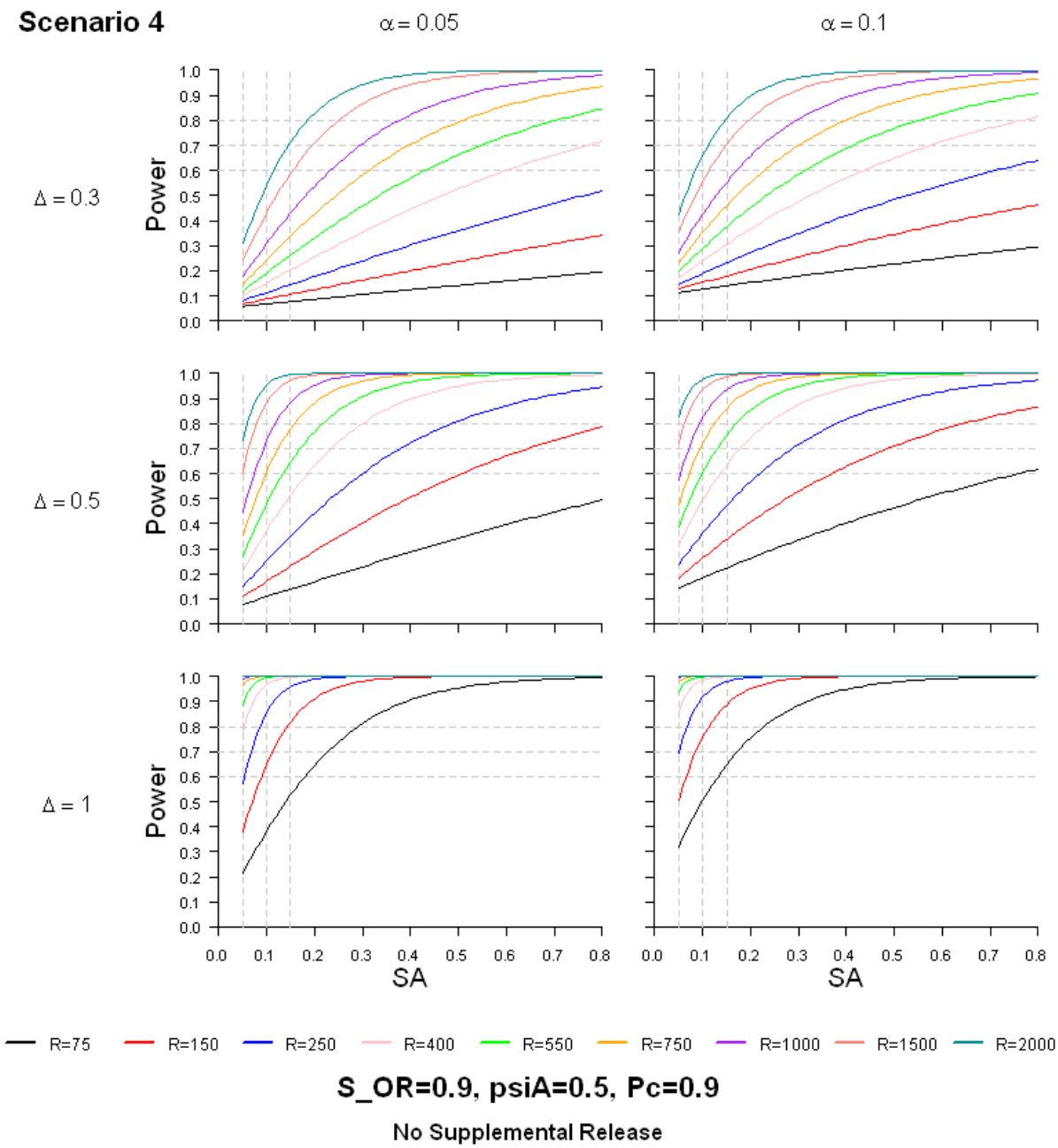

Figure A4. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Scenario 5: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.3, Low Detection Probability at Chipps Island (0.6). No supplemental release.

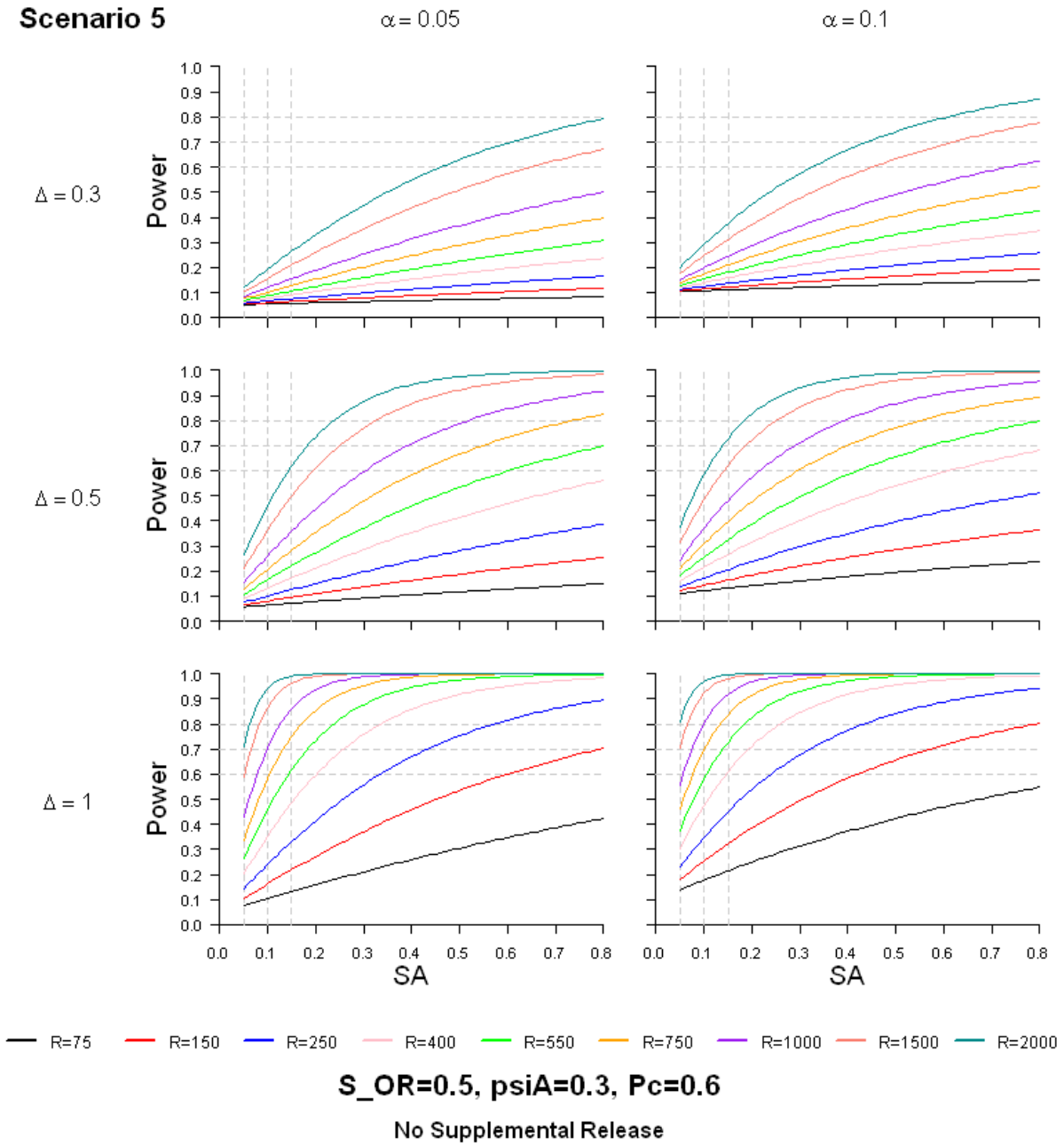

Figure A5. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Scenario 6: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.3, High Detection Probability at Chipps Island (0.9). No supplemental release.

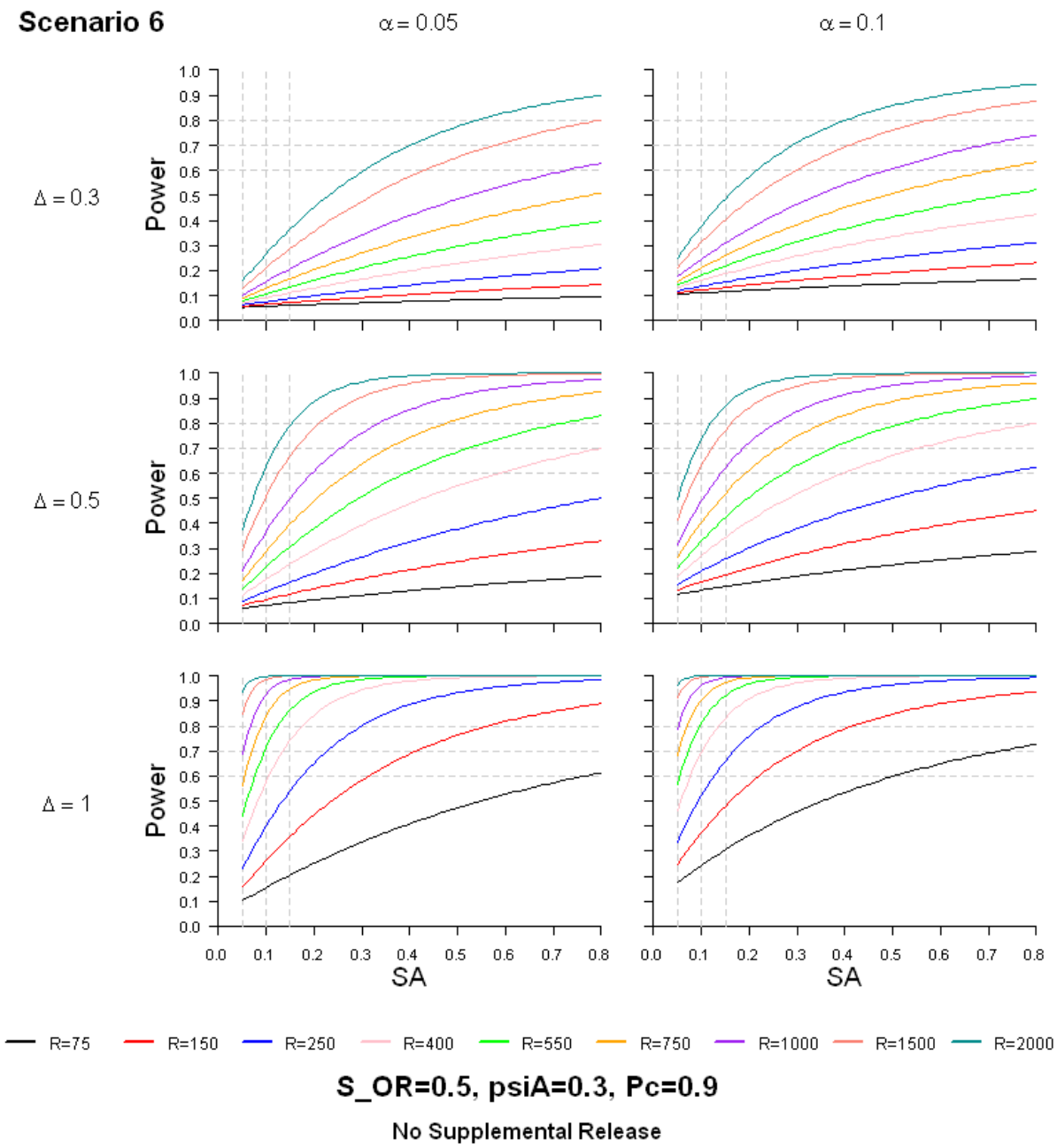

Figure A6. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Scenario 7: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.3, Low Detection Probability at Chipps Island (0.6). No supplemental release.

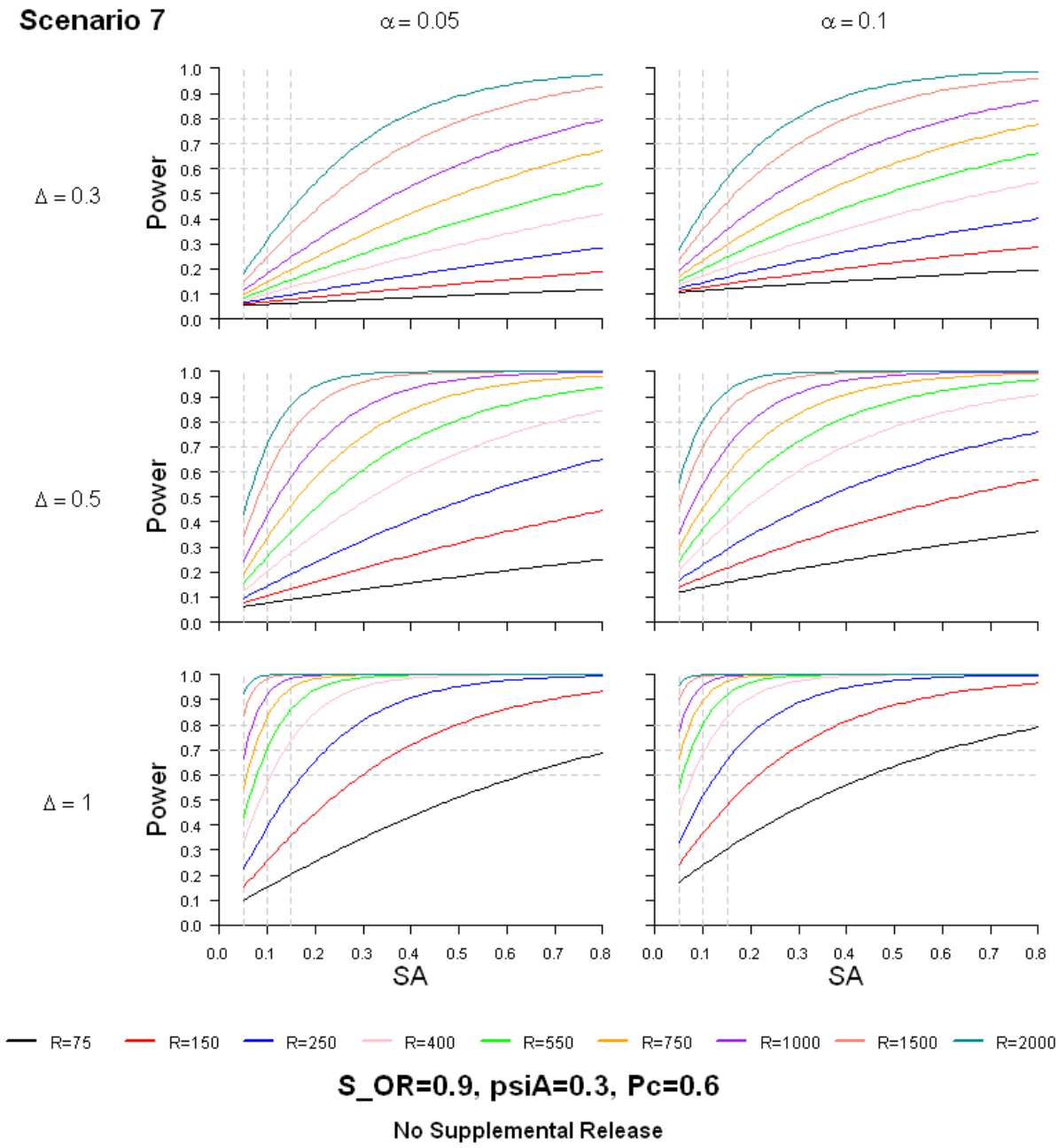

Figure A7. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Scenario 8: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.3, High Detection Probability at Chipps Island (0.9). No supplemental release.

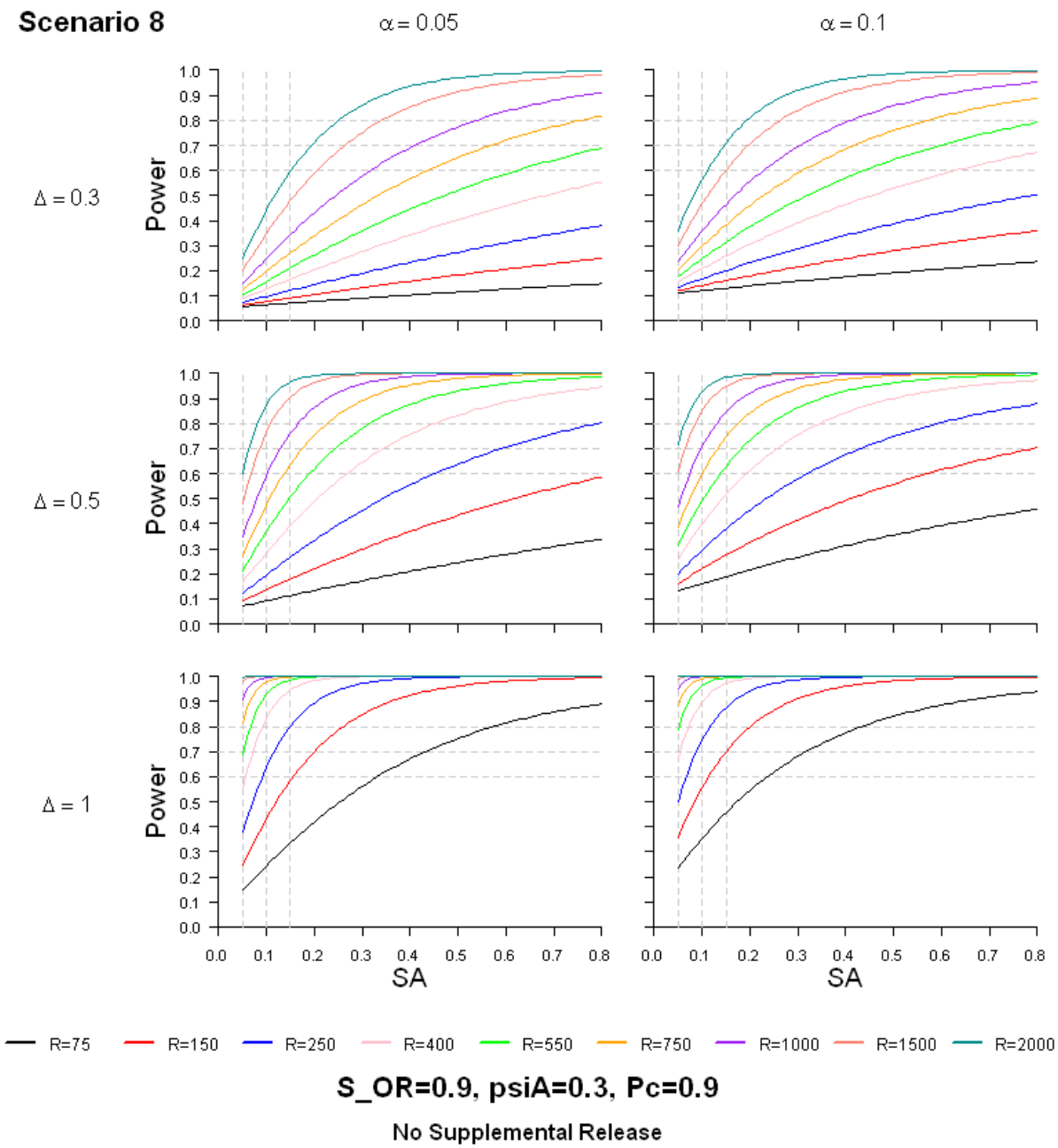

Figure A8. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. No supplemental release.

Equal Weights across Primary and Supplemental Release Groups: R1=R2=R3

Scenario 9: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.5, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (equal release sizes).

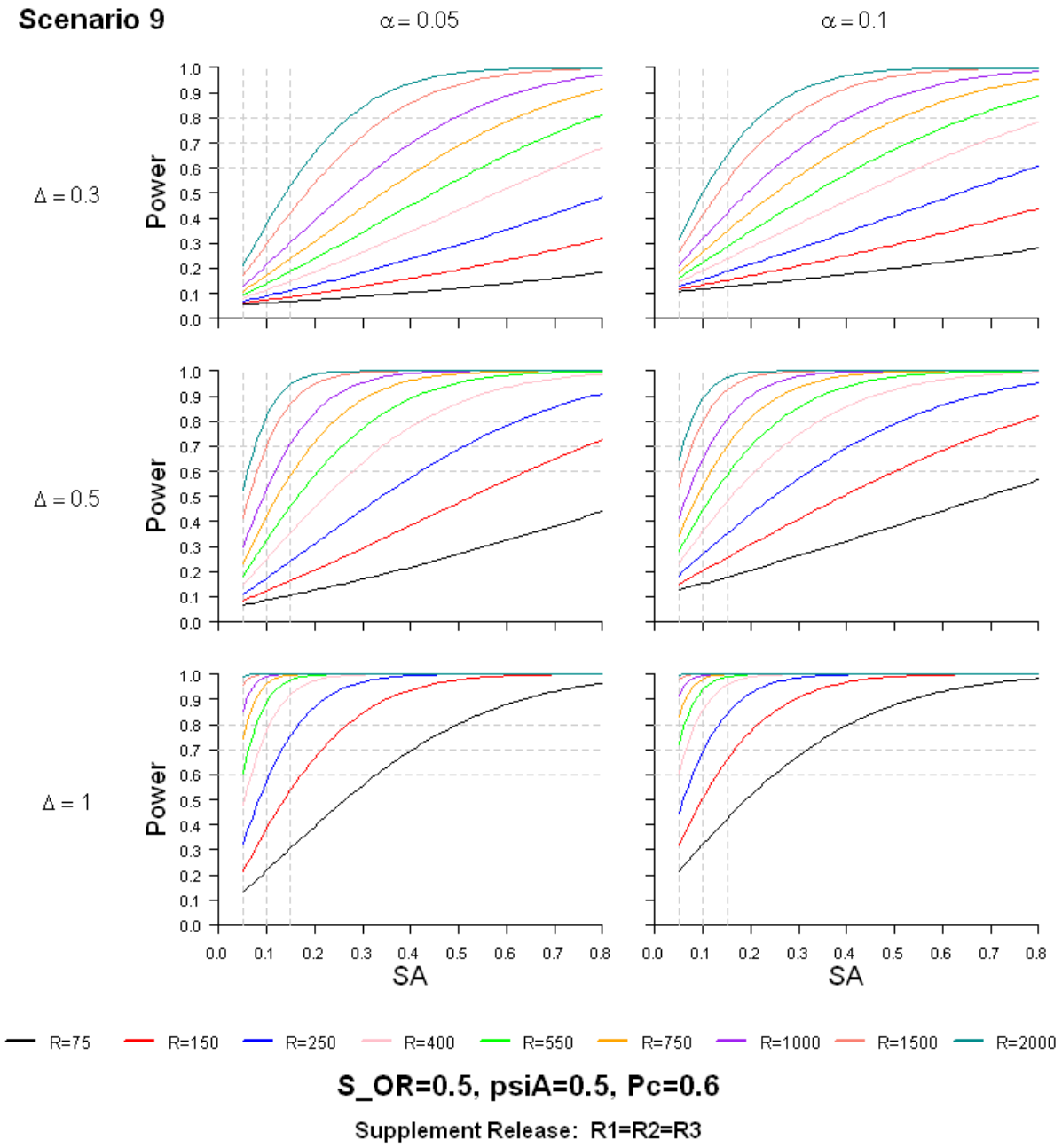

Figure A9. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Scenario 10: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.5, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (equal release sizes).

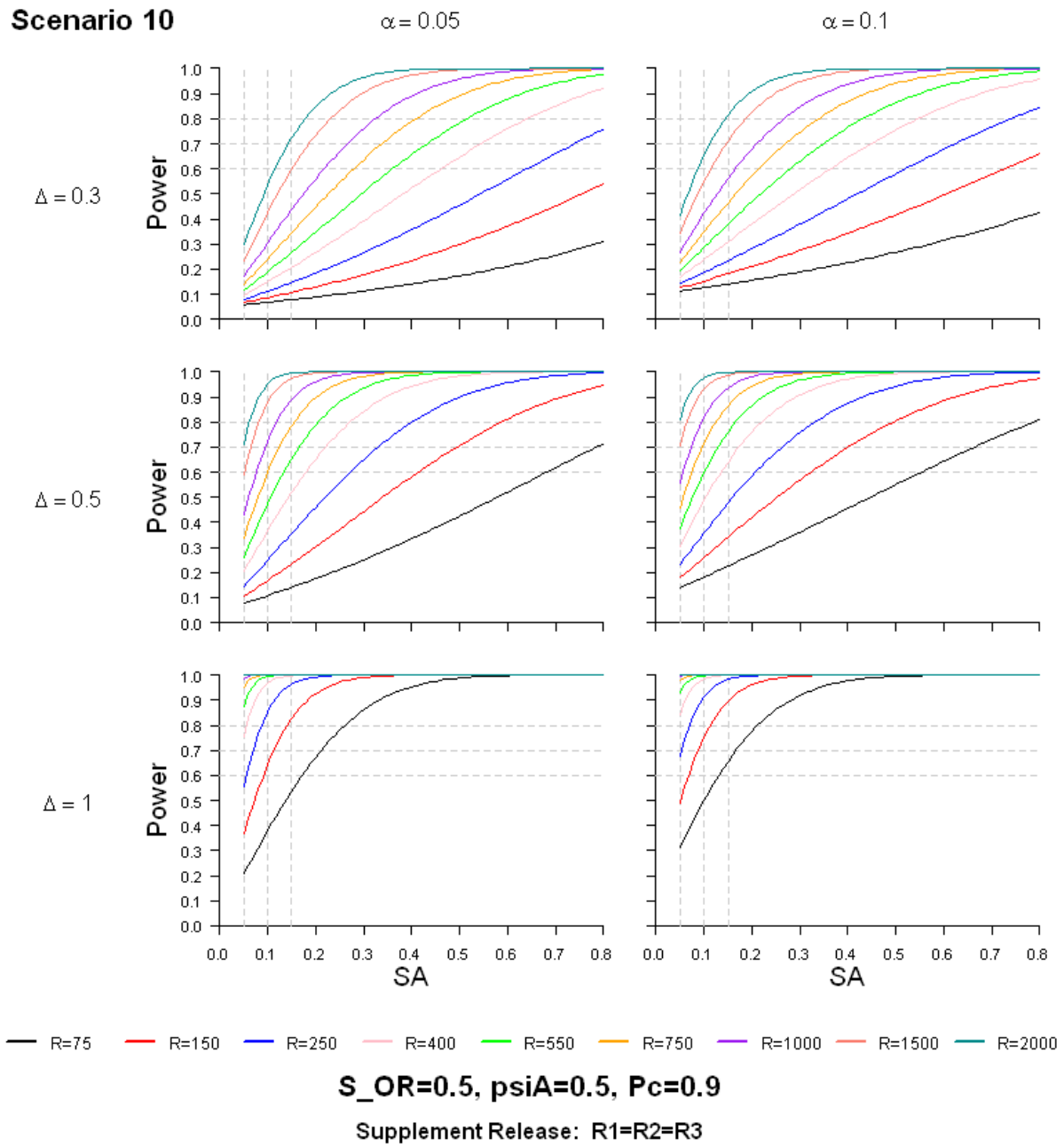

Figure A10. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Scenario 11: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.5, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (equal release sizes).

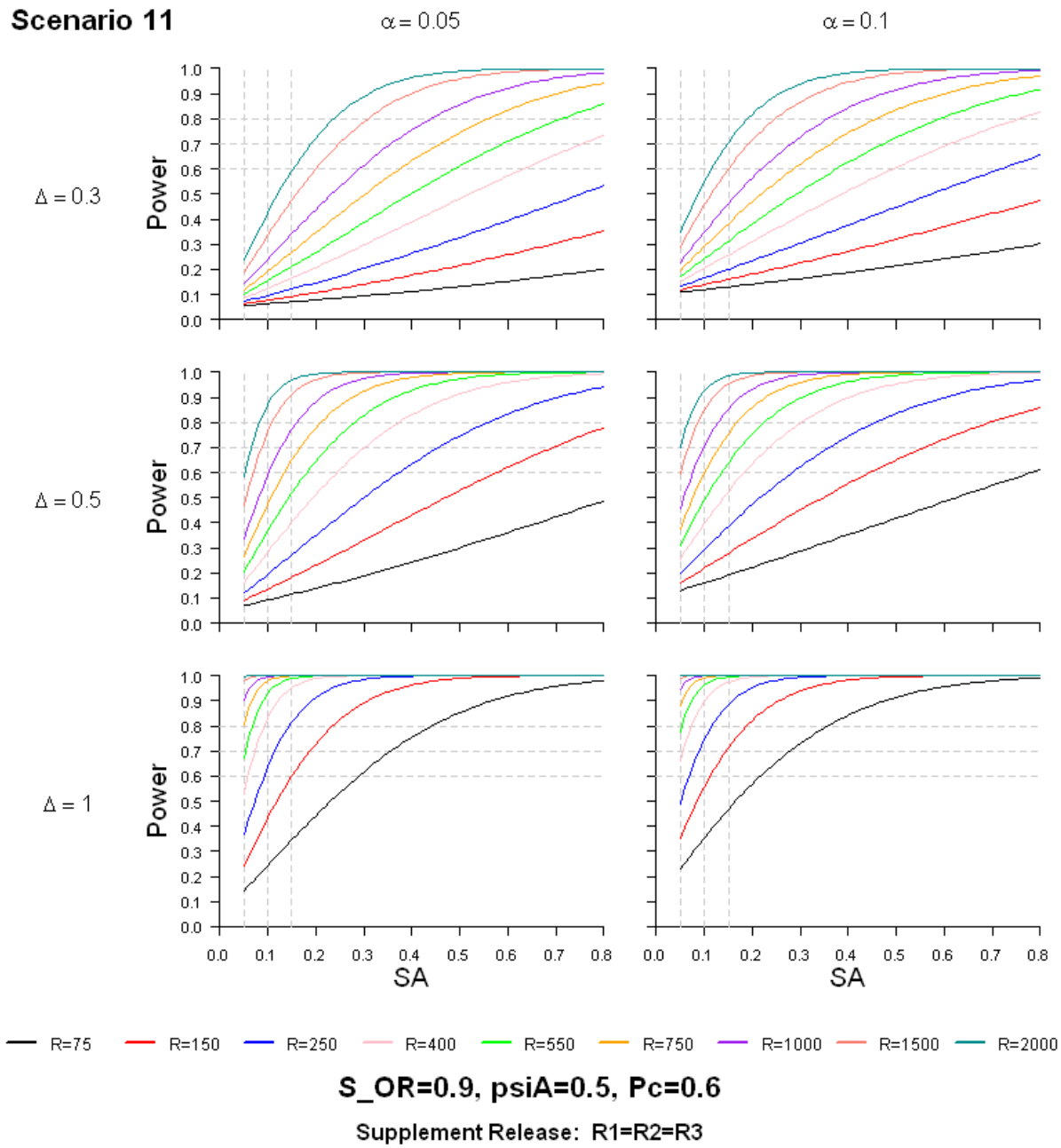

Figure A11. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Scenario 12: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.5, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (equal release sizes).

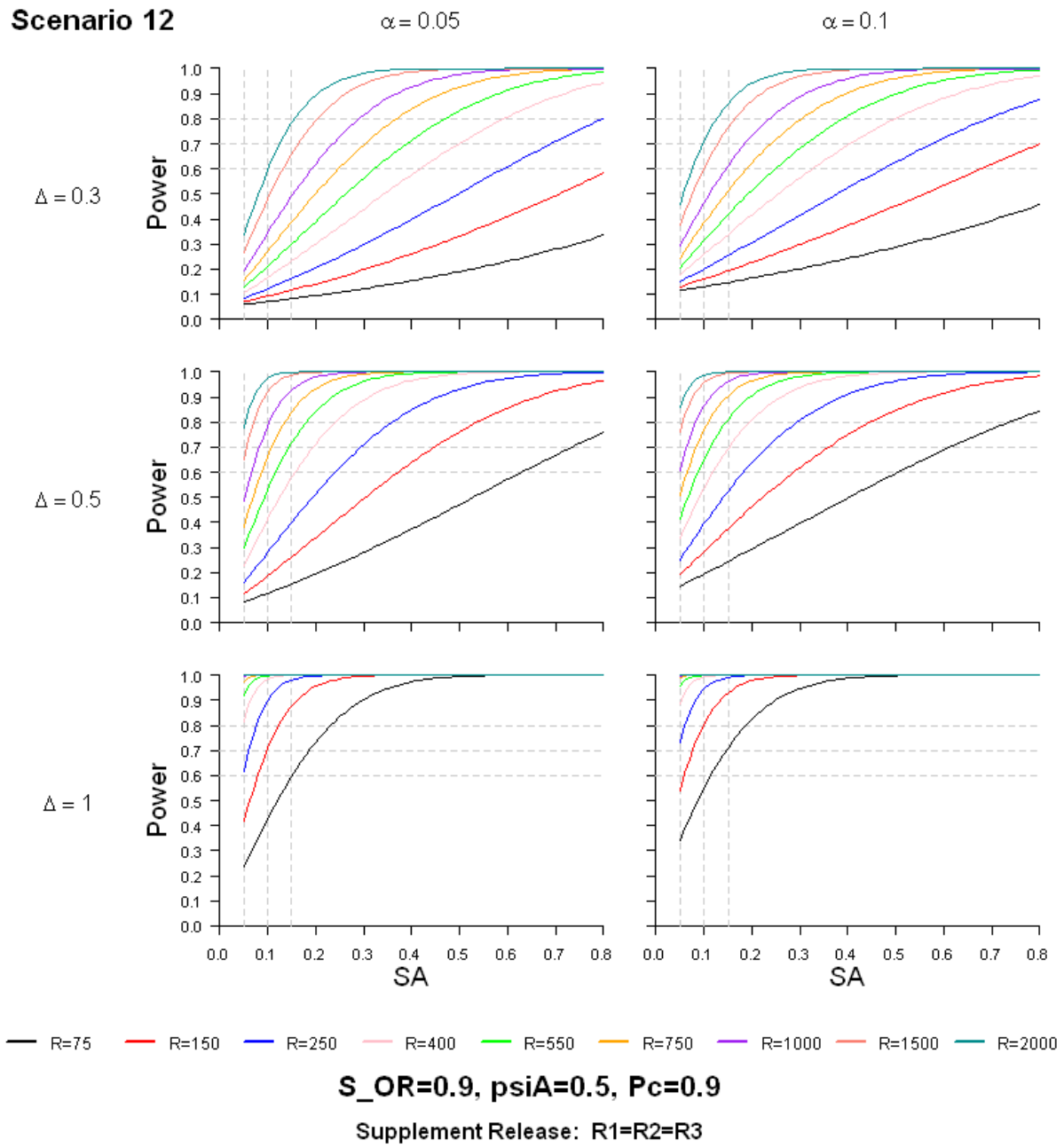

Figure A12. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Scenario 13: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.3, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (equal release sizes).

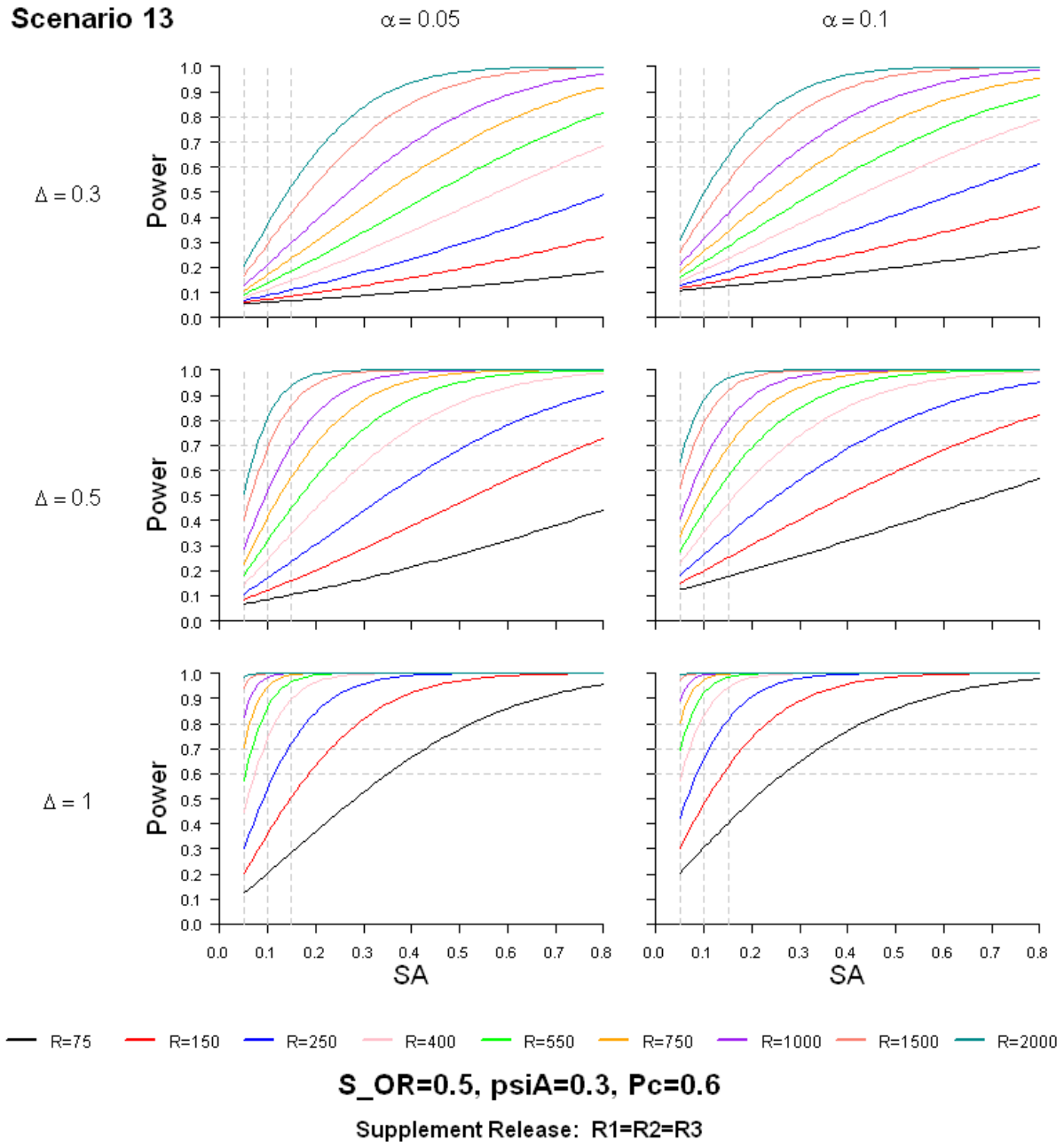

Figure A13. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Scenario 14: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.3, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (equal release sizes).

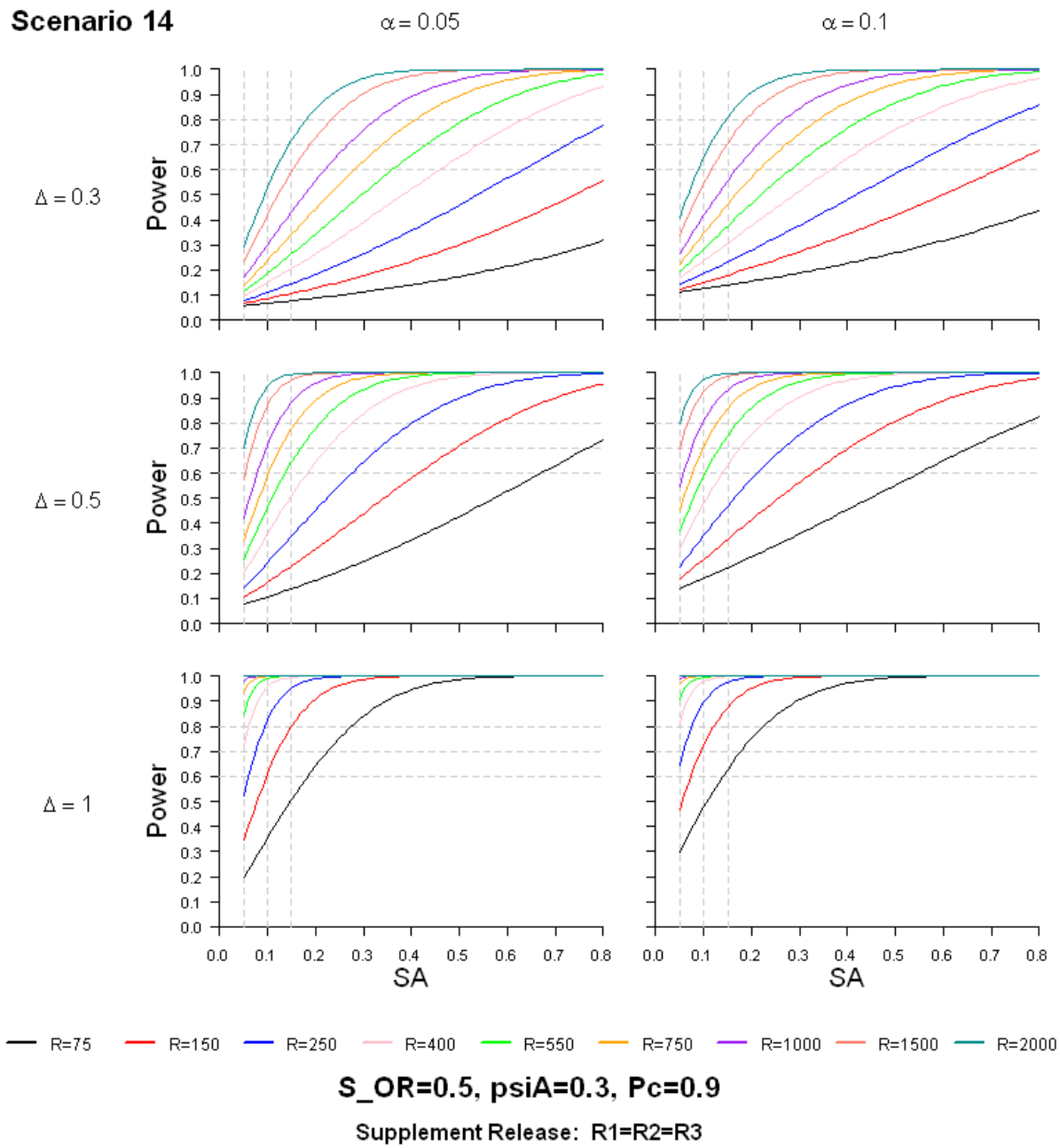

Figure A14. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Scenario 15: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.3, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (equal release sizes).

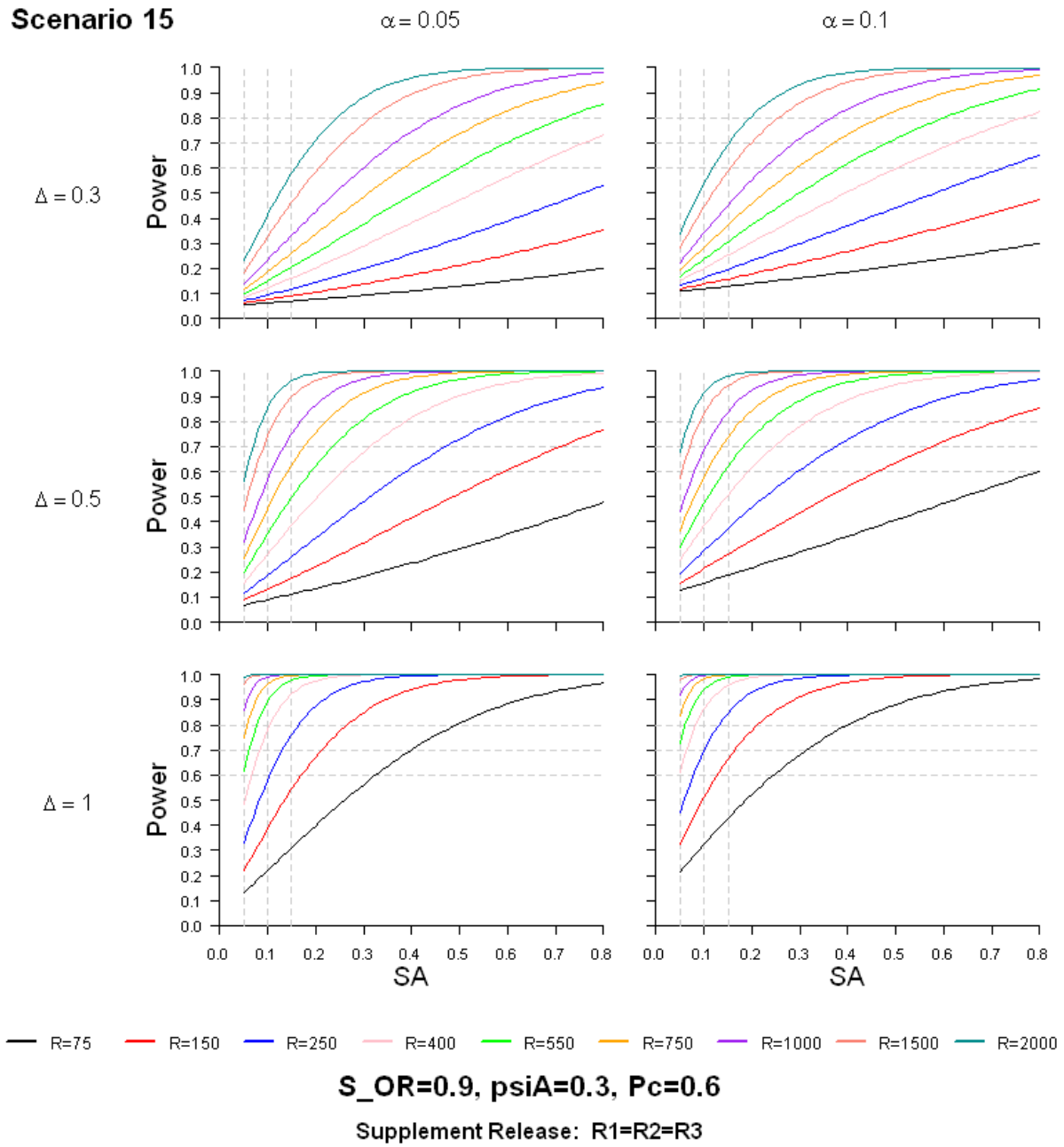

Figure A15. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Scenario 16: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.3, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (equal release sizes).

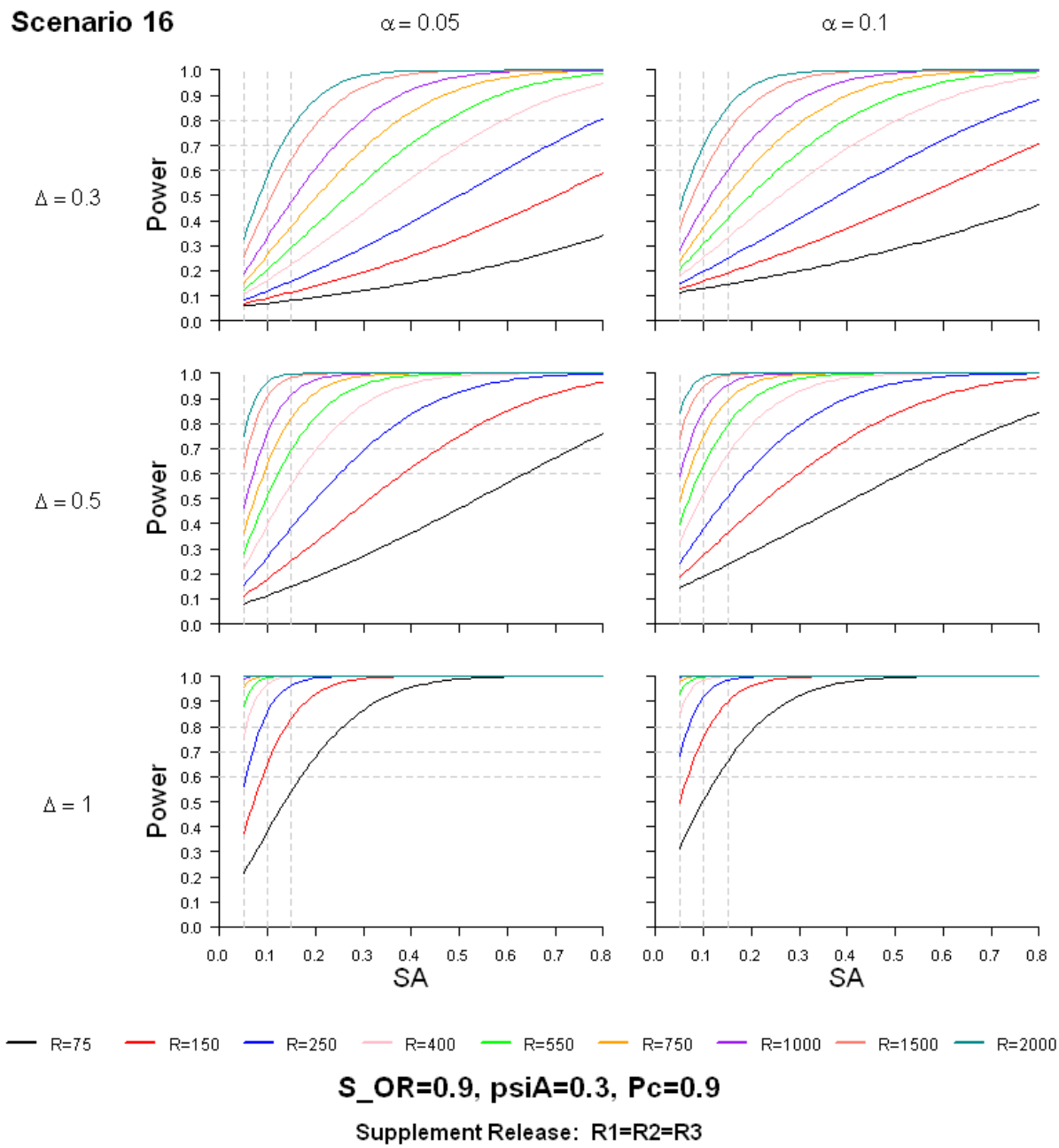

Figure A16. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=R2=R3 and R=R1+R2+R3.

Unequal Weights across Primary and Supplemental Release Groups: R1=3R2=3R3

Scenario 17: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.5, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

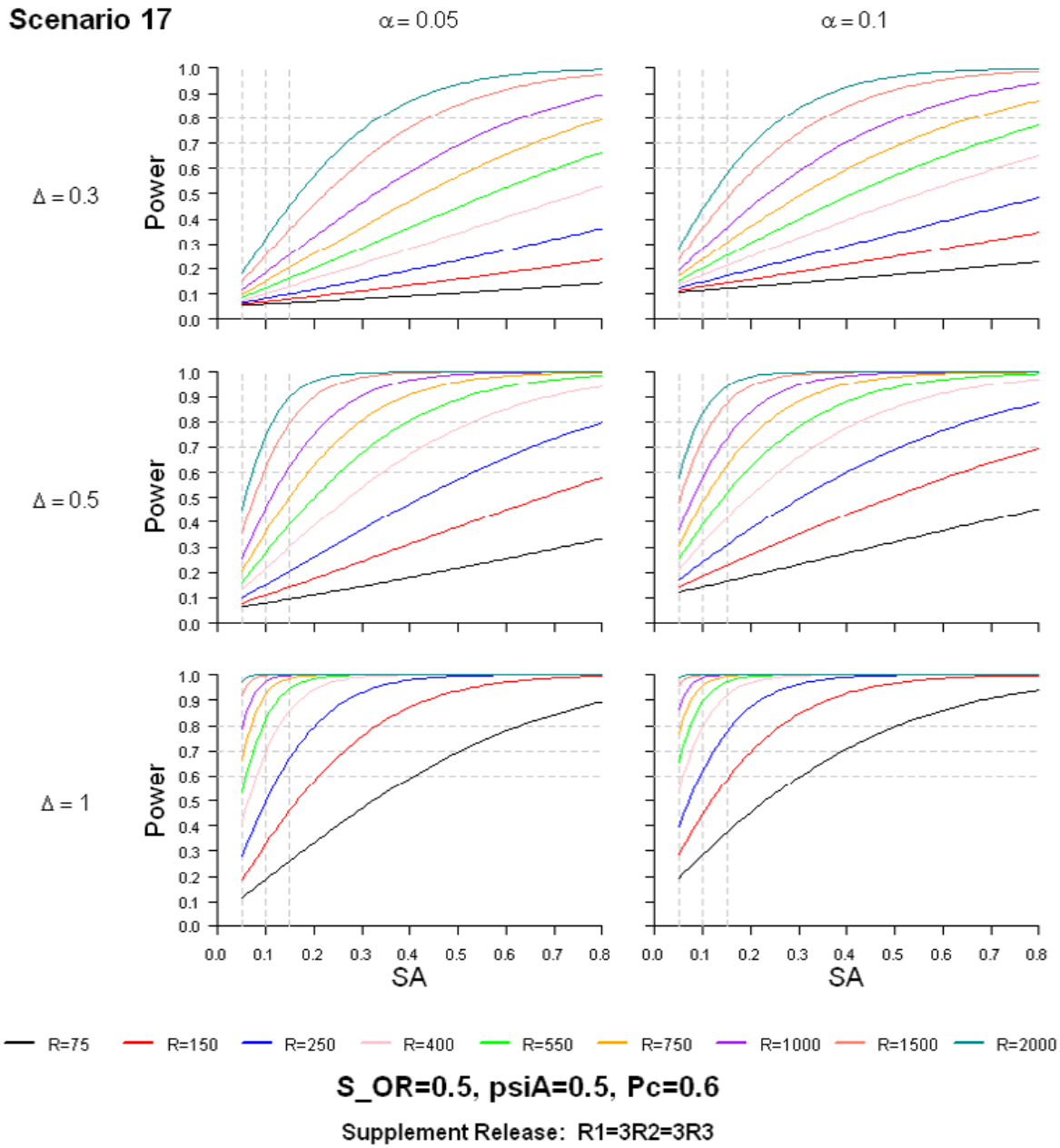

Figure A17. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.

Scenario 18: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.5, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

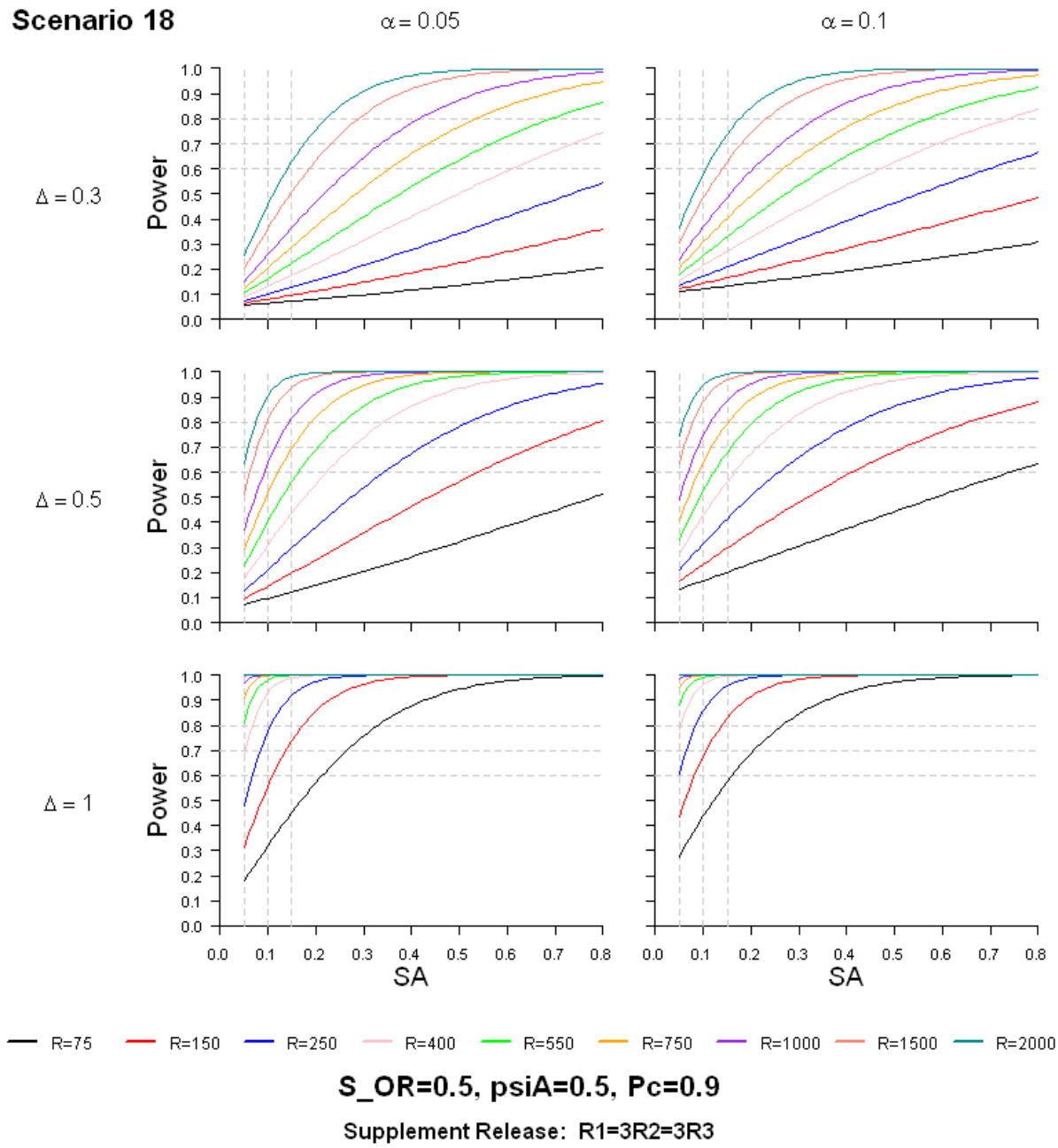

Figure A18. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.

Scenario 19: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.5, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

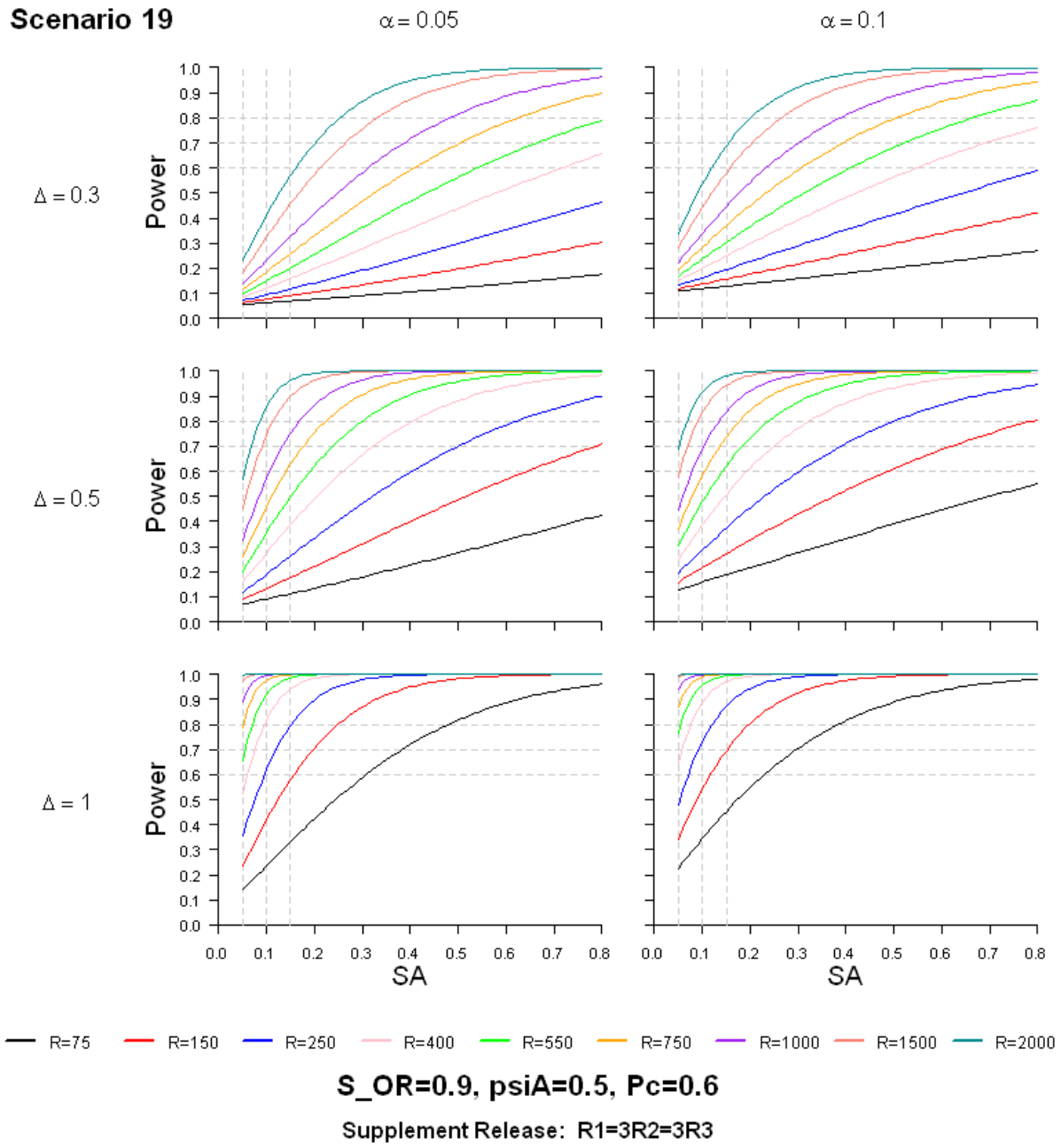

Figure A19. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.

Scenario 20: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.5, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

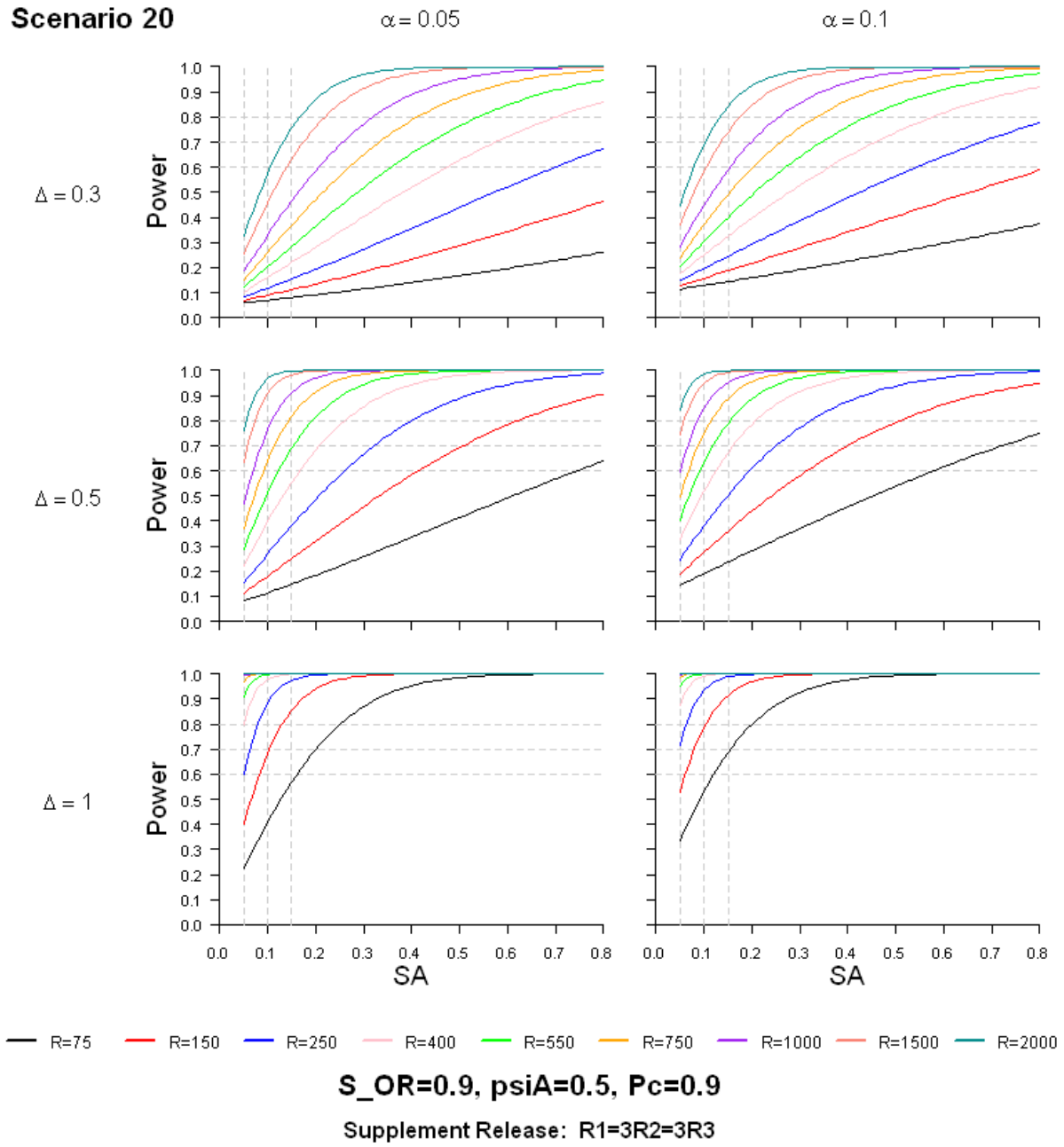

Figure A20. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.5, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.

Scenario 21: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.3, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

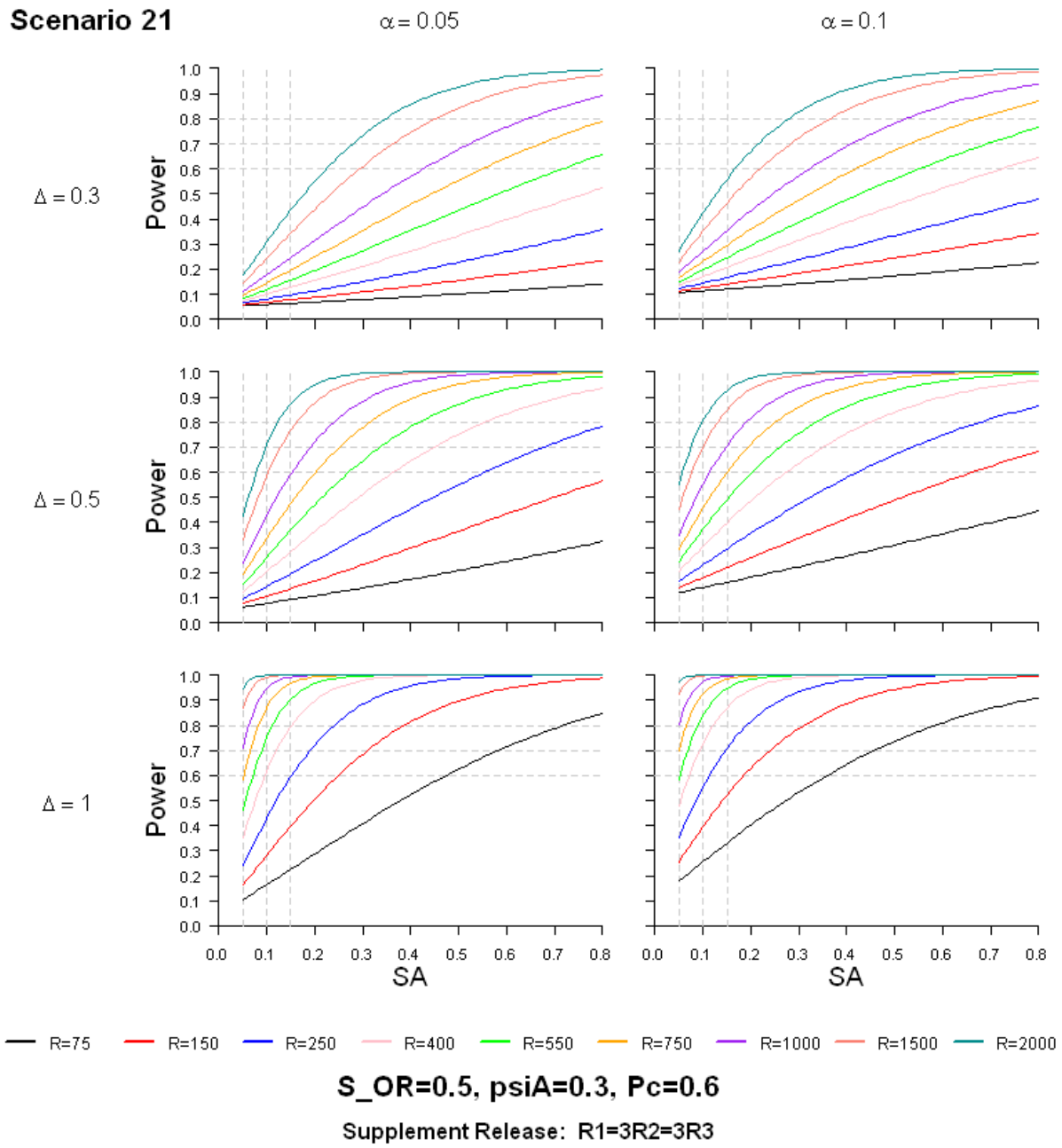

Figure A21. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.

Scenario 22: Low Survival to Old River (0.5), Route Entrainment into San Joaquin River at Old River = 0.3, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

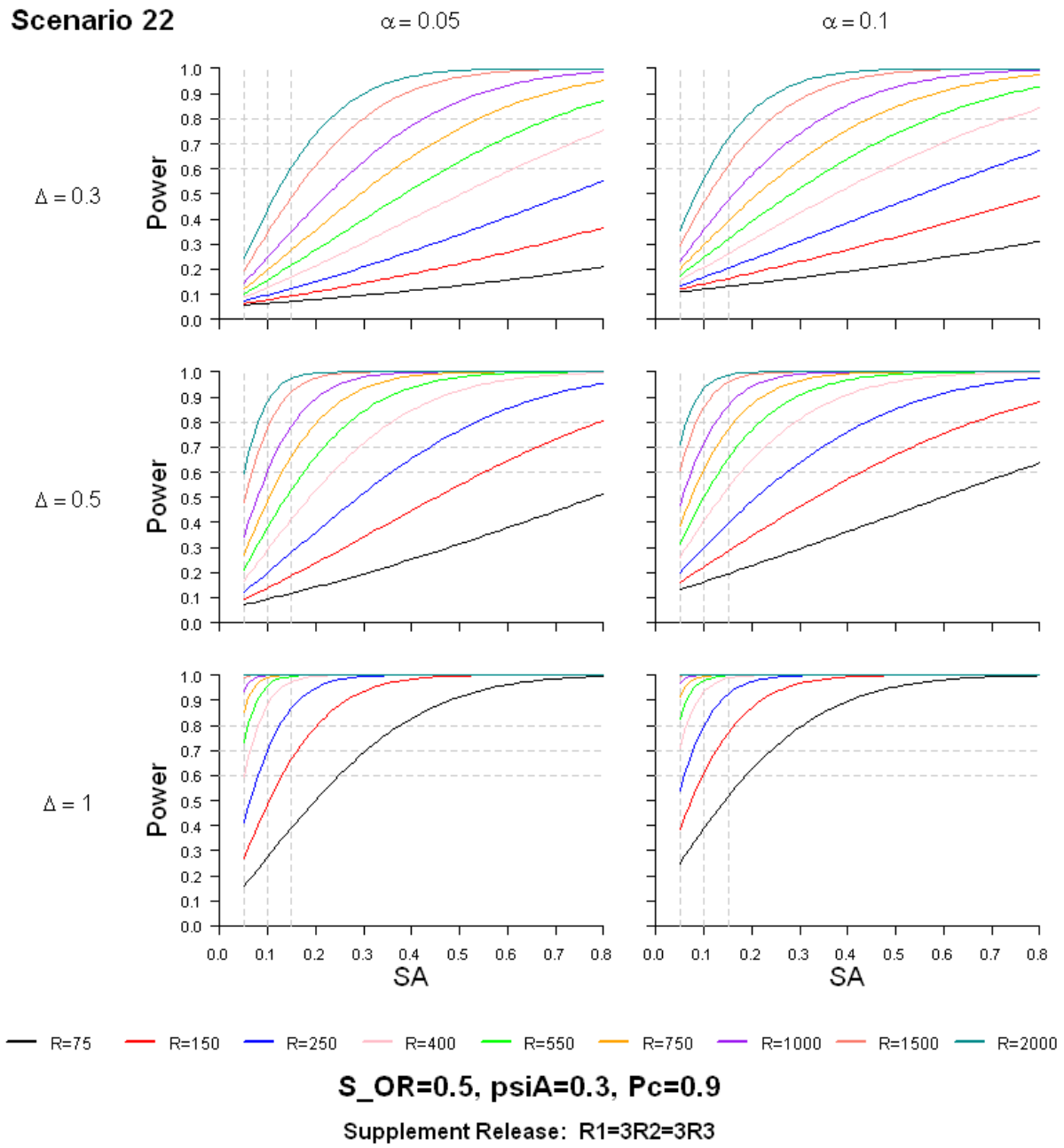

Figure A22. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.5, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.

Scenario 23: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.3, Low Detection Probability at Chipps Island (0.6). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

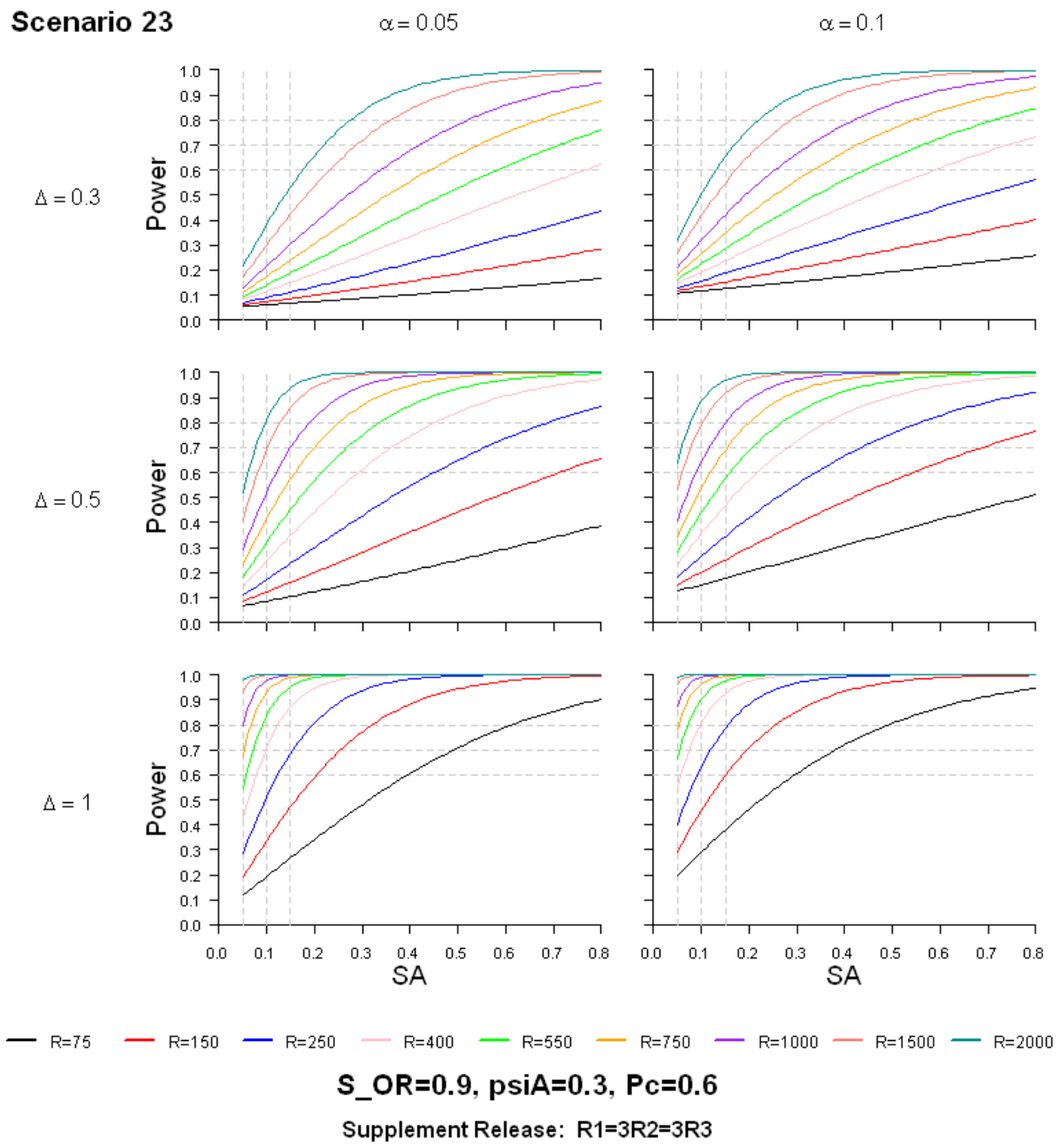

Figure A23. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.6. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.

Scenario 24: High Survival to Old River (0.9), Route Entrainment into San Joaquin River at Old River = 0.3, High Detection Probability at Chipps Island (0.9). Supplemental Release in SJR, OR (Primary release size=3 times each supplemental release size).

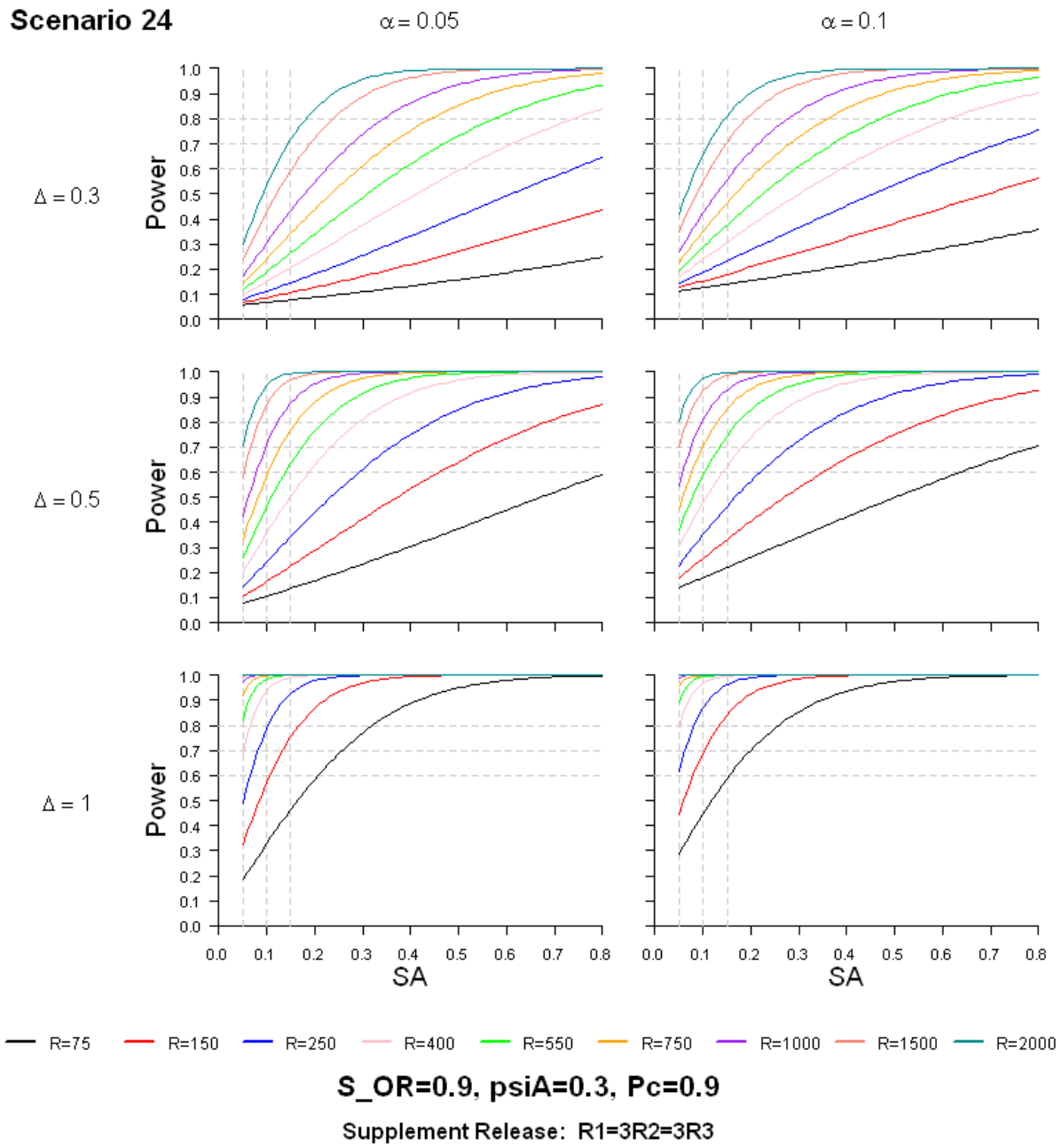

Figure A24. Power to detect relative difference of Delta between survival from the head of Old River to Chipps Island in the San Joaquin River route (SA) or in the Old River route, with a Type I error probability of alpha, and survival from Durham Ferry to the receivers just downstream of the head of Old River = 0.9, route entrainment probability into the San Joaquin River at head of Old River = 0.3, and detection probability at Chipps Island = 0.9. Detection probability at receivers in San Joaquin River and Old River just downstream of the head of Old River = 1. Primary release (R1) with supplemental releases in San Joaquin River (R2) and Old River (R3) just downstream of the Old River flow split, with R1=3R2=3R3 and R=R1+R2+R3.