

Appendix 4A Incidental sonar

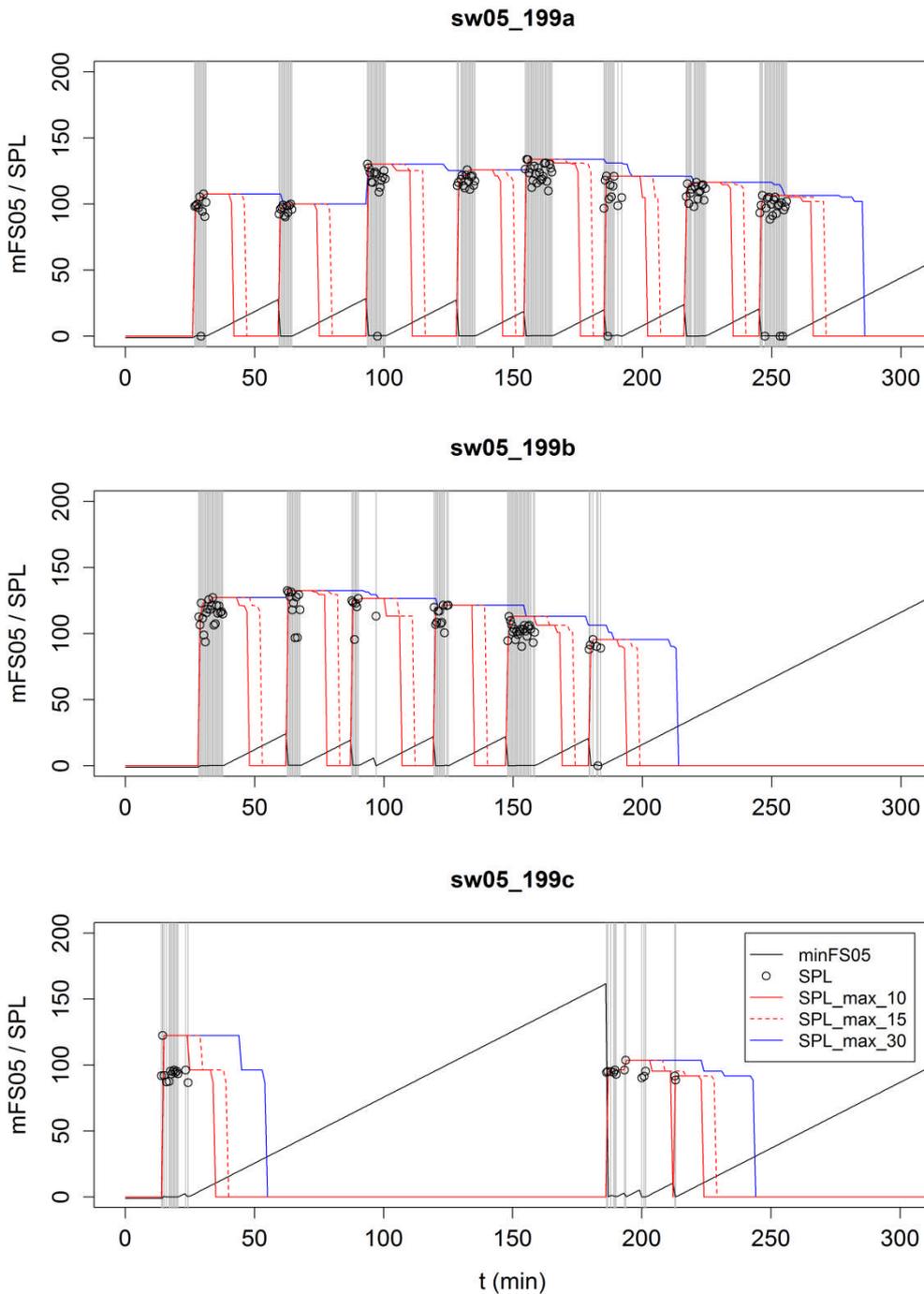


Figure 4A.1 Covariates used to describe incidental sonar exposures in 2005

Grey vertical lines show timing of detected sonar pings. Black circles show  $SPL_{90\%rms}$  re  $1\mu Pa$ , values at zero show detections that could not be estimated a received level due to masking. Times (x-axis) are given as minutes from tag deployment time for each whale.

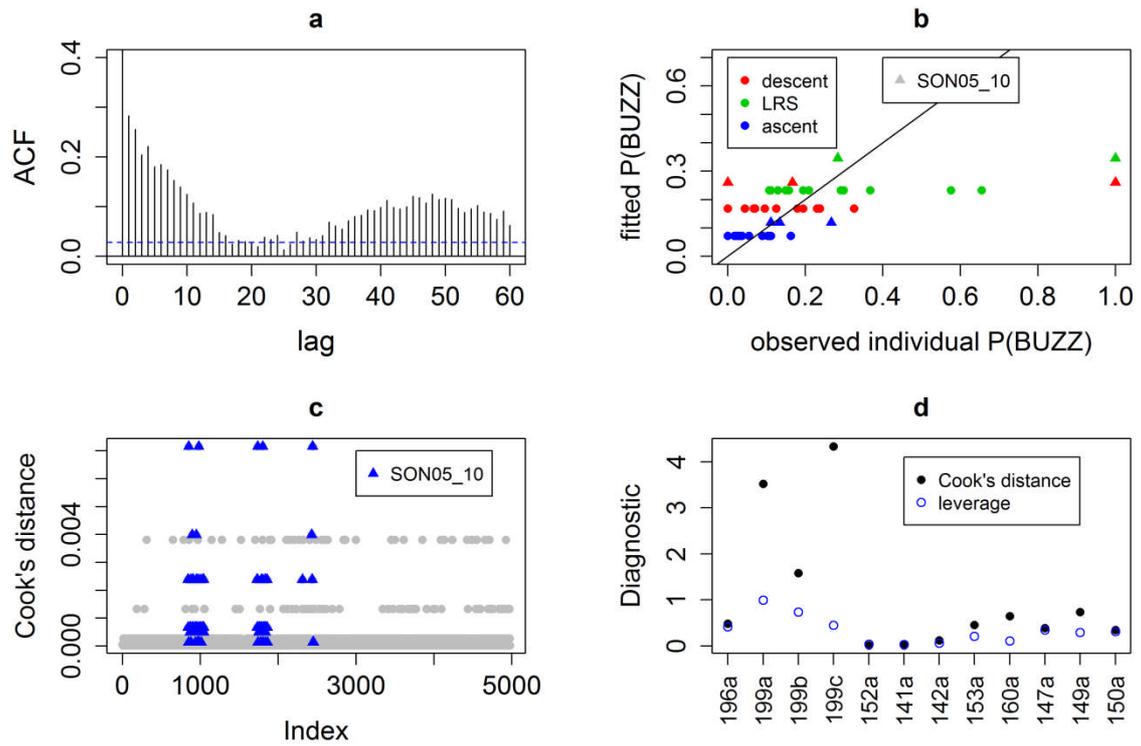


Figure 4A.2 Diagnostic plots for the binomial GEE for probability of buzzing

a) autocorrelation function for raw residuals; b) Observed vs. fitted mean probability of buzzing in each state (colour-coded) during *SON05\_10* (triangles) vs. other (solid circles); c) Cook's distance, data during *SON05\_10* (blue triangles) vs. other (grey circles) shown; d) Cook's distance and leverage diagnostics for each individual.

## Appendix 4B Experimental exposures

Table 4B.1 AIC model selection for for state, buzz and ODBA.

Response	Model	Candidate covariates	AIC	ΔAIC
State during	base model	<i>prevState + whale</i>	5911.4	0.0
	candidates	<i>SON05_w</i>	5911.4	0.0
		<i>BoatPass</i>	5910.7	-0.7
		<i>#BoatPass</i>	5914.0	2.6
		<i>OrcaPB</i>	5911.8	0.5
		<i>MFAS</i>	5906.4	-4.9
		<i>MFAS:maxSEL</i>	5906.9	-4.4
		<i>LFAS</i>	5867.9	-43.5
		<i>LFAS:maxSEL</i>	5868.3	-43.1
		<i>maxSEL</i>	5892.7	-18.6
	<i>OrcaS</i>	5910.2	-1.1	
retained	<i>LFAS + OrcaS</i>	5849.4	-62.0	
sound metric	<i>LFAS:maxSL + OrcaS</i>	5849.1	-62.2	
State post	base model	<i>prevState + whale + LFAS + OrcaS</i>	7534.1	0.0
	candidates	<i>SON05_w</i>	7524.9	-9.2
		<i>BoatPass</i>	7506.4	-27.7
		<i>#BoatPass</i>	7531.6	-2.5
		<i>OrcaPB</i>	7534.8	0.7
		<i>MFAS</i>	7536.6	2.5
		<i>MFAS:maxSEL</i>	7536.8	2.8
		<i>LFAS</i>	7534.1	0.0
		<i>LFAS:maxSEL</i>	7540.7	6.6
		<i>maxSEL</i>	7536.6	2.6
	<i>OrcaS</i>	7534.1	0.0	
retained	<i>LFAS_8 + OrcaS_19 + minFromOrcaS2</i>	7480.8	-53.2	
Buzz during	base model	<i>state + whale</i>	4255.4	0.0
	candidates	<i>SON05_w</i>	4255.4	0.0
		<i>BoatPass</i>	4244.7	-10.7
		<i>#BoatPass</i>	4244.9	-10.5
		<i>OrcaPB</i>	4253.8	-1.6
		<i>MFAS</i>	4256.6	1.2
		<i>MFAS:maxSEL</i>	4256.6	1.2
		<i>LFAS</i>	4233.6	-21.8
		<i>LFAS:maxSEL</i>	4233.5	-21.9
		<i>maxSEL</i>	4248.2	-7.2
	<i>OrcaS</i>	4254.5	-0.9	
retained	<i>BoatPass + MFAS + OrcaPB</i>	4226.4	-29.1	
sound metric	<i>BoatPass + MFAS:maxSELcum + OrcaPB</i>	4226.4	-29.0	

Buzz post	base model	<i>BoatPass + MFAS + OrcaPB</i>	5063.9	0.0
	candidates	<i>minFromBoatPass</i>	5065.5	1.7
		<i>minFromBoatPass2</i>	5065.6	1.7
		<i>minFromMFAS</i>	5061.5	-2.4
		<i>minFromMFAS2</i>	5063.7	-0.1
	retained	<i>minFromMFAS + minFromBoatPass2</i>	5058.6	-5.3
ODBA during	base model	<i>state + whale</i>	54550.7	0.0
	candidates	<i>SON05_w</i>	54550.7	0.0
		<i>BoatPass</i>	54552.6	2.0
		<i>#BoatPass</i>	54550.1	-0.6
		<i>OrcaPB</i>	54552.7	2.0
		<i>MFAS</i>	54552.6	2.0
		<i>MFAS:maxSEL</i>	54552.7	2.0
		<i>LFAS</i>	54549.3	-1.4
		<i>LFAS:maxSEL</i>	54549.0	-1.7
		<i>maxSEL</i>	54550.1	-0.5
		<i>OrcaS</i>	54552.7	2.0
		<i>#BoatPass + MFAS + LFAS</i>	54530.9	-19.8
	retained	<i>#BoatPass + MFAS:maxSL + LFAS</i>	54531.4	-19.2
	sound metric	<i>#BoatPass + MFAS + LFAS:maxRL</i>	54530.9	-19.8
ODBA post	base model	<i>#BoatPass + MFAS + LFAS</i>	67979.8	0.0
	candidates	<i>MFAS_13</i>	67971.5	-8.3
		<i>minFromBoatPass</i>	67981.0	1.3
		<i>minFromBoatPass2</i>	67981.2	1.5
		<i>minFromMFAS</i>	67981.7	1.9
		<i>minFromMFAS2</i>	67981.6	1.9
		<i>minFromLFAS</i>	67978.1	-1.7
		<i>minFromLFAS2</i>	67979.5	-0.3
		<i>minFromOrcaS</i>	67981.6	1.8
		<i>minFromOrcaS2</i>	67981.0	1.2
	retained	<i>#BoatPass + MFAS_13 + LFAS + minFromLFAS</i>	67969.7	-10.0

Base model: all covariates included a-priori in during exposure and post-exposure selection. Candidates: univariate explanatory variables added to the base model. Retained: combination of candidates retained in AIC selection. Sound metric: if sonar covariates were retained, the lowest AIC sound metric model.  $\Delta$ AIC values are model AICs subtracted from each base model.

Table 4B.2 Coefficient estimates from the best multinomial model for state

Parameters	State 2		State 3		State 4		State 5		State 6	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
(Intercept)	-2.82	0.20	-26.83	8.51	-17.18	103.03	-5.89	0.55	-3.34	0.24
prevState 2	19.19	51.05	42.16	42.54	26.92	51.99	16.63	51.06	15.25	51.05
prevState 3	3.88	0.46	33.12	8.52	20.01	103.03	5.68	0.76	3.84	0.50
prevState 4	-2.92	1.01	24.31	8.51	18.10	103.03	1.29	0.85	-0.92	0.48
prevState 5	-7.25	57.79	26.41	8.53	16.75	103.03	9.82	0.61	4.28	0.47
prevState 6	2.87	0.23	25.53	8.52	15.06	103.03	5.27	0.51	3.86	0.20
sw05_199a	0.68	0.30	0.46	0.33	0.37	0.32	-8.81	64.75	-0.55	0.56
sw05_199b	0.62	0.30	-0.05	0.33	0.57	0.31	0.48	0.60	-0.19	0.46
sw05_199c	0.15	0.34	-0.63	0.38	0.72	0.34	1.24	0.48	0.48	0.37
sw08_152a	1.00	0.39	0.35	0.43	0.60	0.40	-10.37	150.52	0.84	0.45
sw09_141a	-0.11	0.30	-0.35	0.32	0.25	0.31	0.77	0.43	1.76	0.28
sw09_142a	0.18	0.29	-0.16	0.32	0.38	0.30	0.70	0.47	0.69	0.31
sw09_153a	0.83	0.36	0.62	0.39	0.30	0.37	-10.56	200.42	-0.22	0.63
sw09_160a	1.07	0.28	0.52	0.31	0.80	0.29	-9.36	73.58	-0.56	0.45
sw10_147a	0.12	0.28	-0.39	0.30	0.57	0.28	0.66	0.47	0.09	0.34
sw10_149a	0.70	0.29	0.11	0.32	0.60	0.30	-1.87	1.35	0.28	0.38
sw10_150a	0.79	0.29	-0.11	0.33	0.86	0.30	-0.83	1.00	-0.82	0.55
LFAS_8	-0.64	0.38	-0.97	0.43	0.00	0.37	0.03	0.56	1.88	0.31
OrcaS_19	-0.33	0.47	-0.79	0.53	-0.21	0.53	-0.77	0.77	1.65	0.39

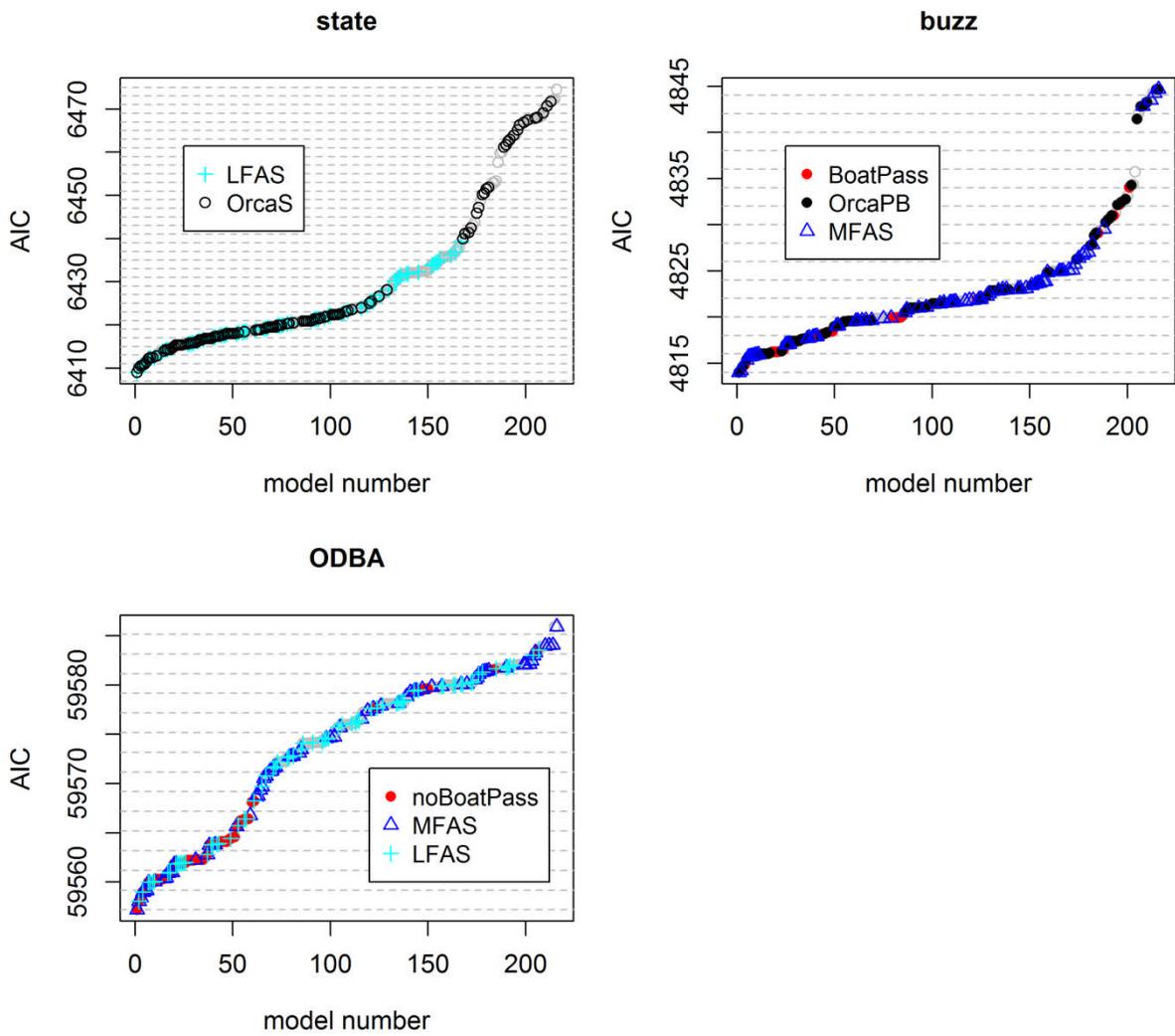


Figure 4B.1 AIC:s for all explored during-exposure effects for each response variable

Symbols show models that include the covariates retained in the selection. Horizontal lines show AIC differences of 2 units.

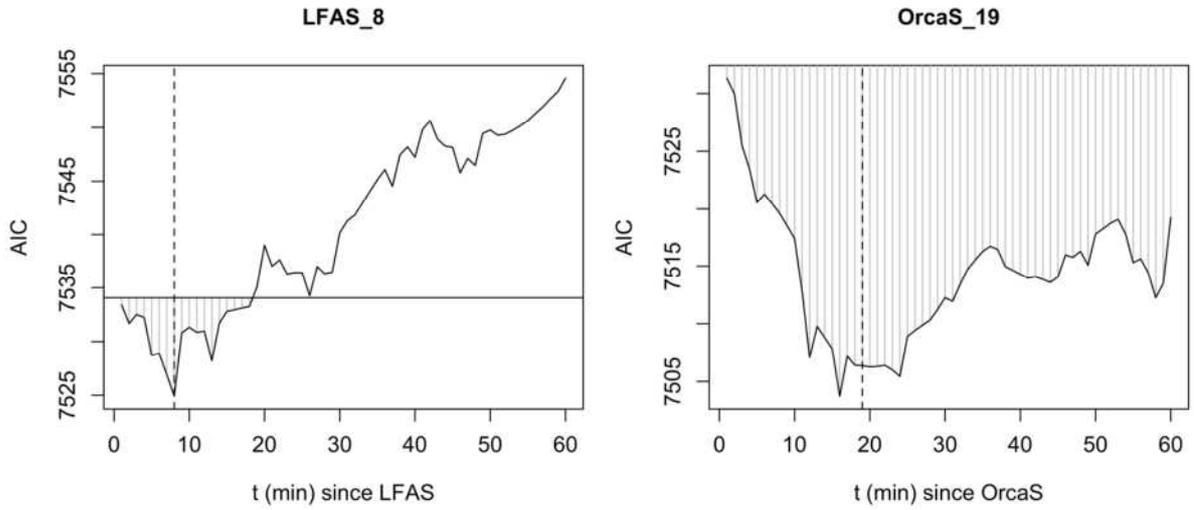


Figure 4B.2. a AIC window length selection for effort

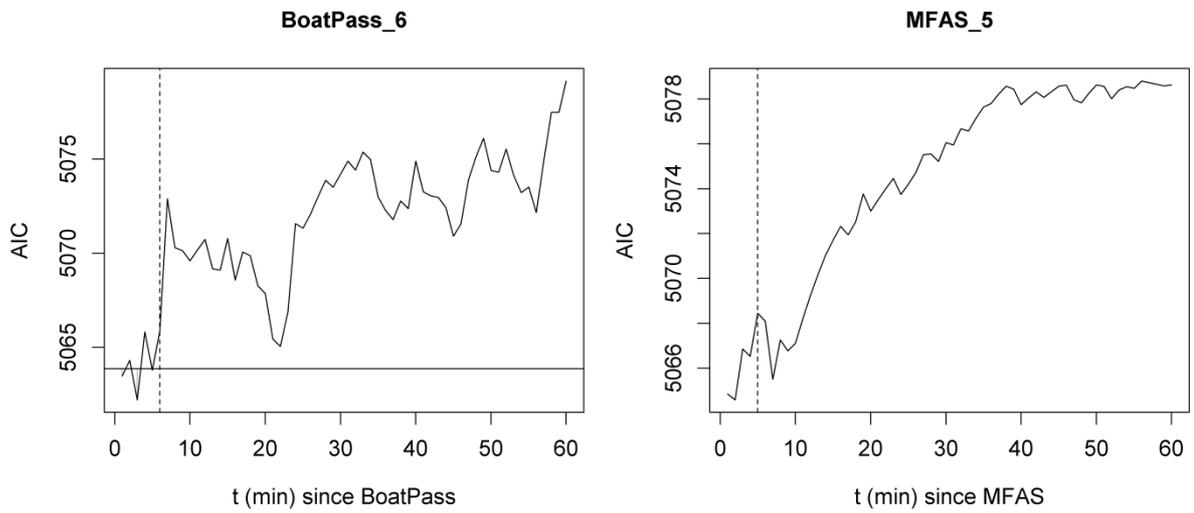


Figure 4B.2. b AIC window length selection for buzzing

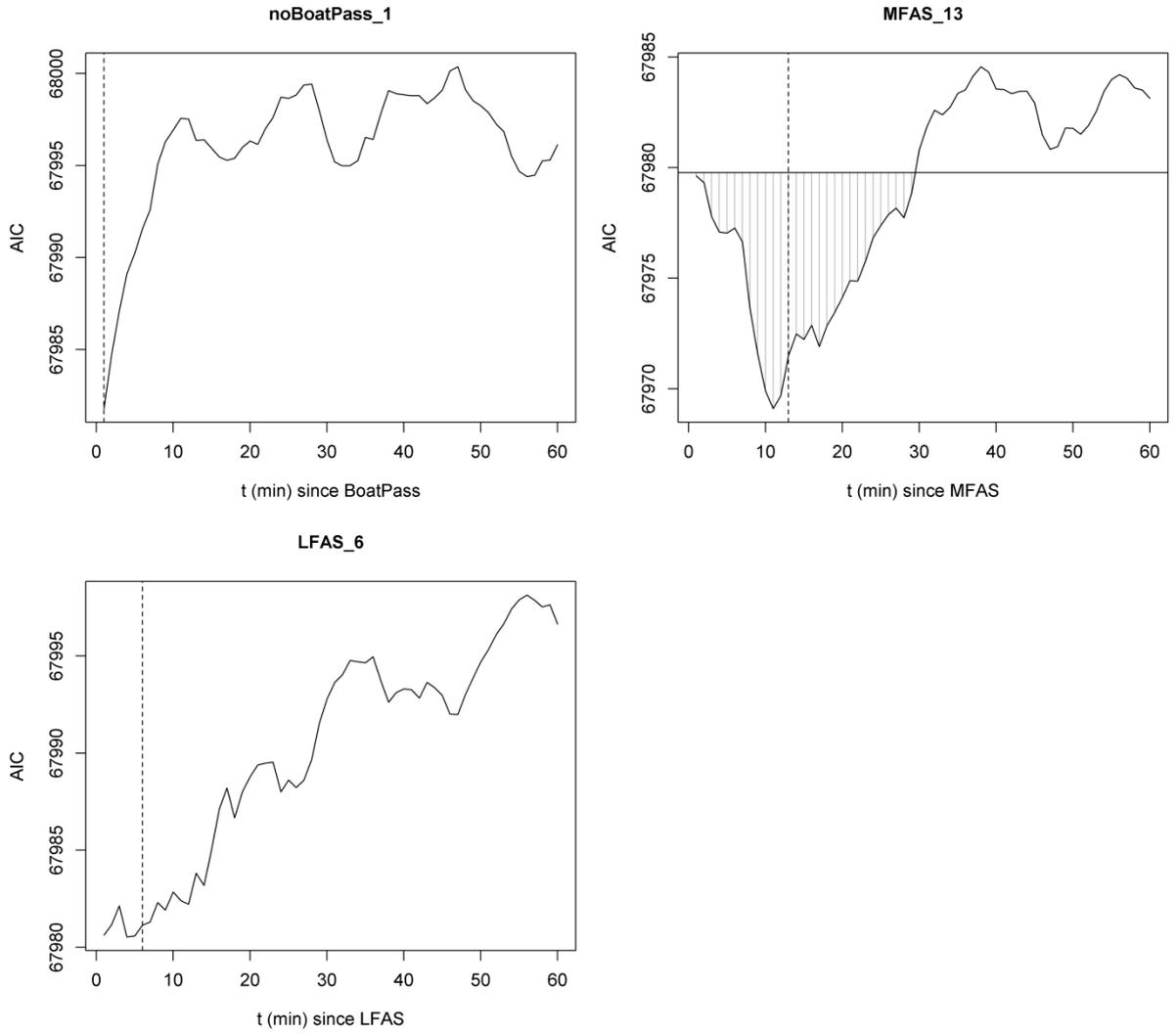


Figure 4B.2. c AIC window length selection for ODBA

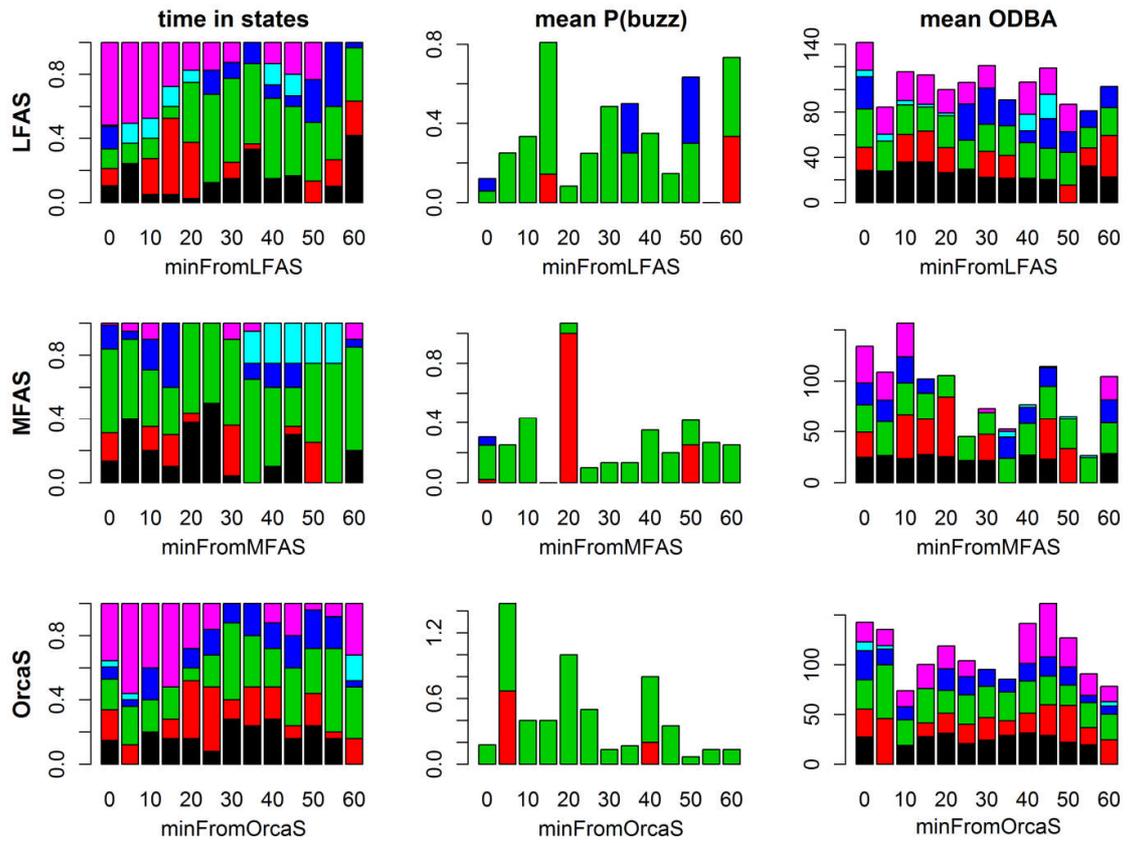


Figure 4B.2. d Time, buzz and ODBA budgets as a function of time since exposure

Time budget (left), probability of buzzing (% of bins, centre) and ODBA (right) averaged across individuals for each state as a function of time since LFAS (6 exposures on 4 tags), MFAS (4 exposures on 4 tags) and *OrcaS* (5 exposures on 5 tags). Data were binned at every 5 minutes post-exposure; first bar (t=0 min) shows data from during exposure.

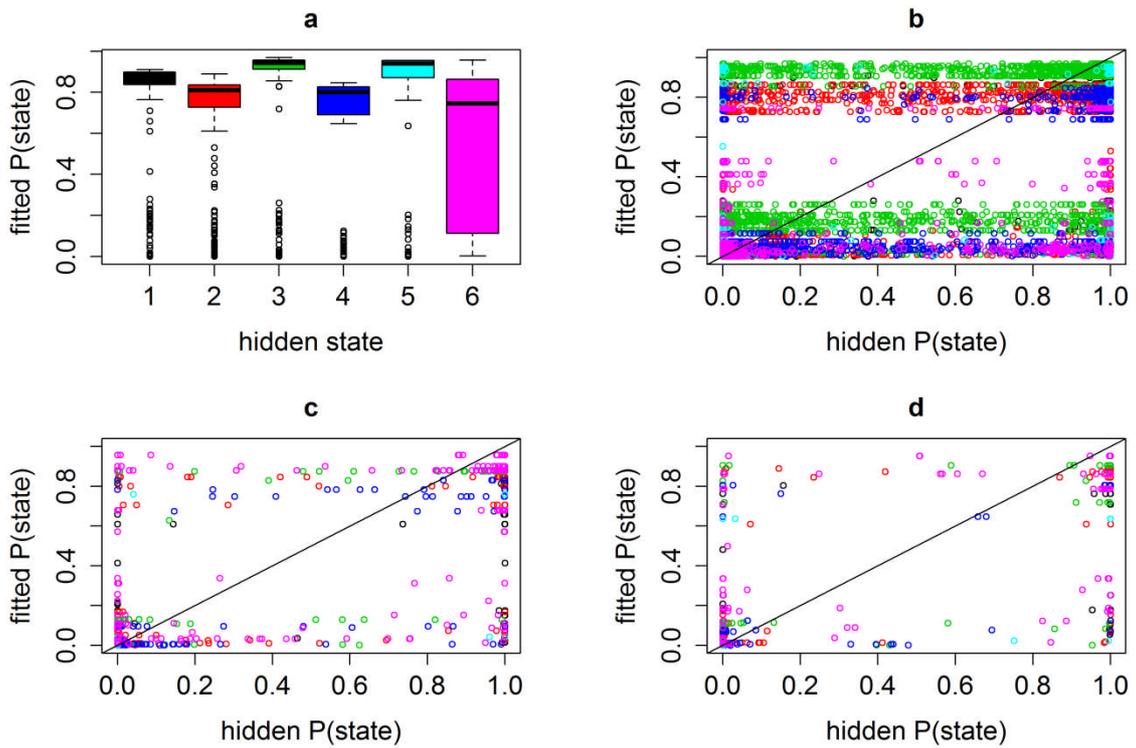


Figure 4B.3 Fitted values for the multinomial model ( $state \sim prevState + whale + LFAS\_8 + LFAS\_19$ ).

a) fitted probabilities for each hidden state (i.e. observed state vs. fitted probability in the multinomial model); c-e) fitted probabilities by the multinomial model as a function of the posterior probability of each state; Figure c) shows data for time periods other than LFAS\_8 and OrcaS\_19, d) shows data for LFAS\_8 and e) shows data for OrcaS\_19.

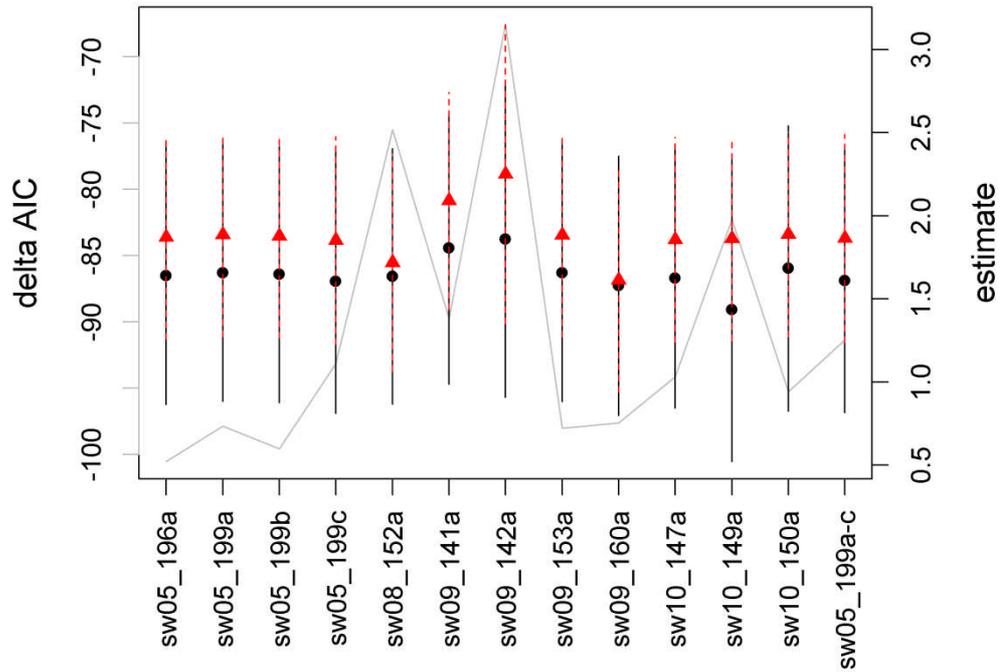


Figure 4B.4 Individual influence on AIC model selection for state and coefficient estimates

The base model ( $state \sim prevState + whale$ ) and the best multinomial model ( $state \sim prevState + whale + LFAS\_8 + LFAS\_19$ ) were re-fitted to the data by excluding each individual at a time. The AIC difference of the two models is shown as a grey line (left y-axis). Coefficient estimates ( $\pm 2 \cdot SE$ ) for *LFAS\_8* (red triangles) and *OrcaS* (black circles) are shown for each model.

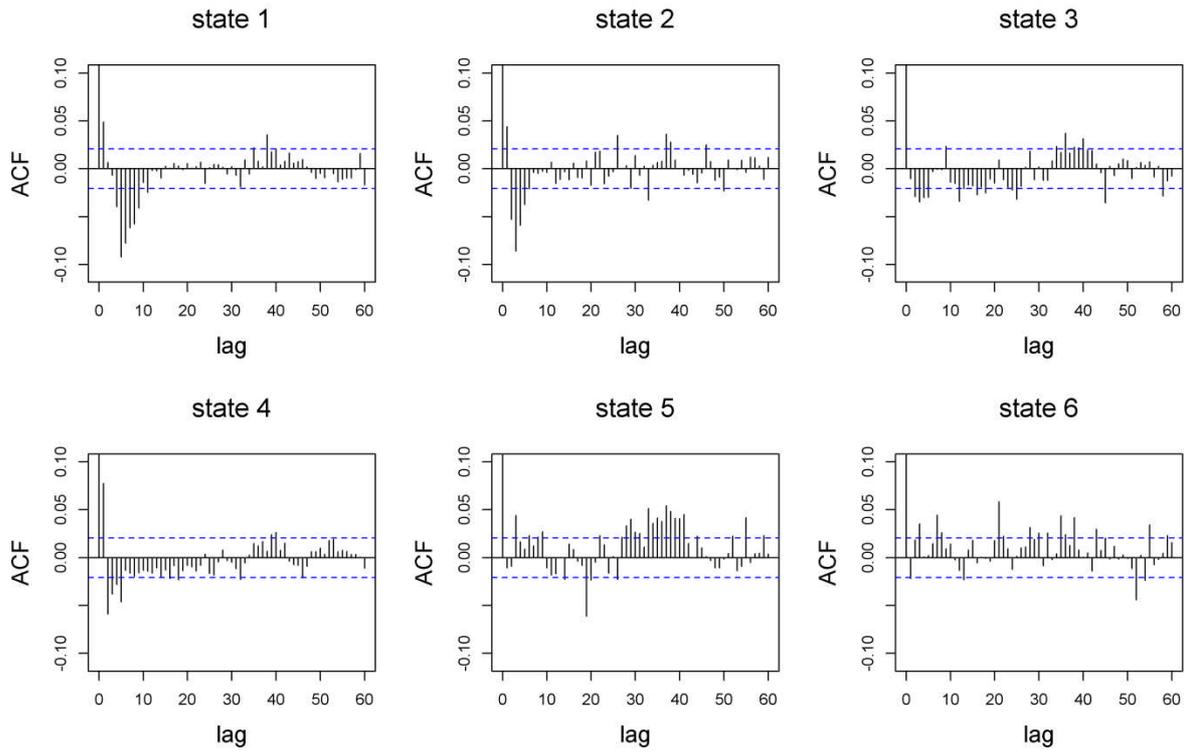


Figure 4B.5 Autocorrelation (y-axis) as a function of lag (x-axis) for the state-specific residuals of the best multinomial model ( $state \sim prevState + whale + LFAS\_8 + OrcaS\_19$ ).

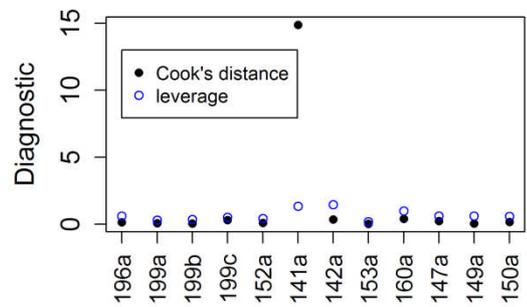
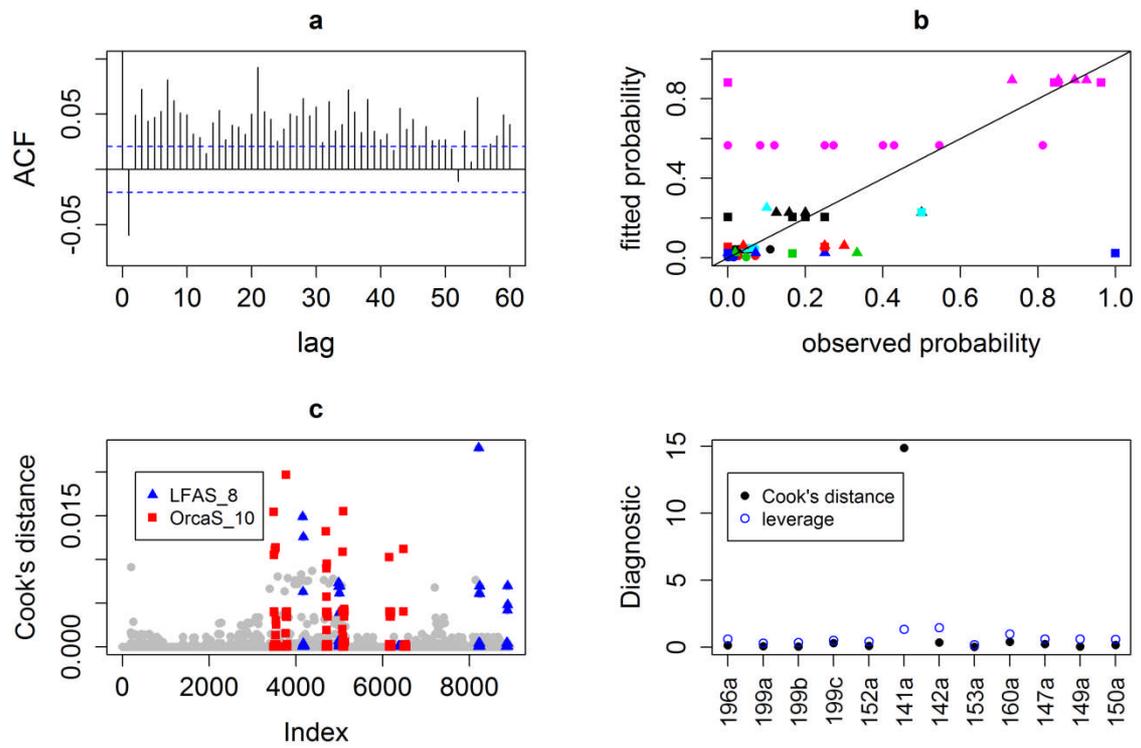


Figure 4B.6 Diagnostic plots for the binomial GEE model for silent active state

a) autocorrelation function for raw residuals; b) Observed vs. fitted mean probability of state 6 given previous state (colour-coded) within each individual during baseline (circles) and exposure (LFAS\_8: triangles, OrcaS\_19: squares); c) Cook's distance, data during exposures (colour-coded symbols) vs. other (grey) shown; d) Cook's distance and leverage diagnostics for each individual.

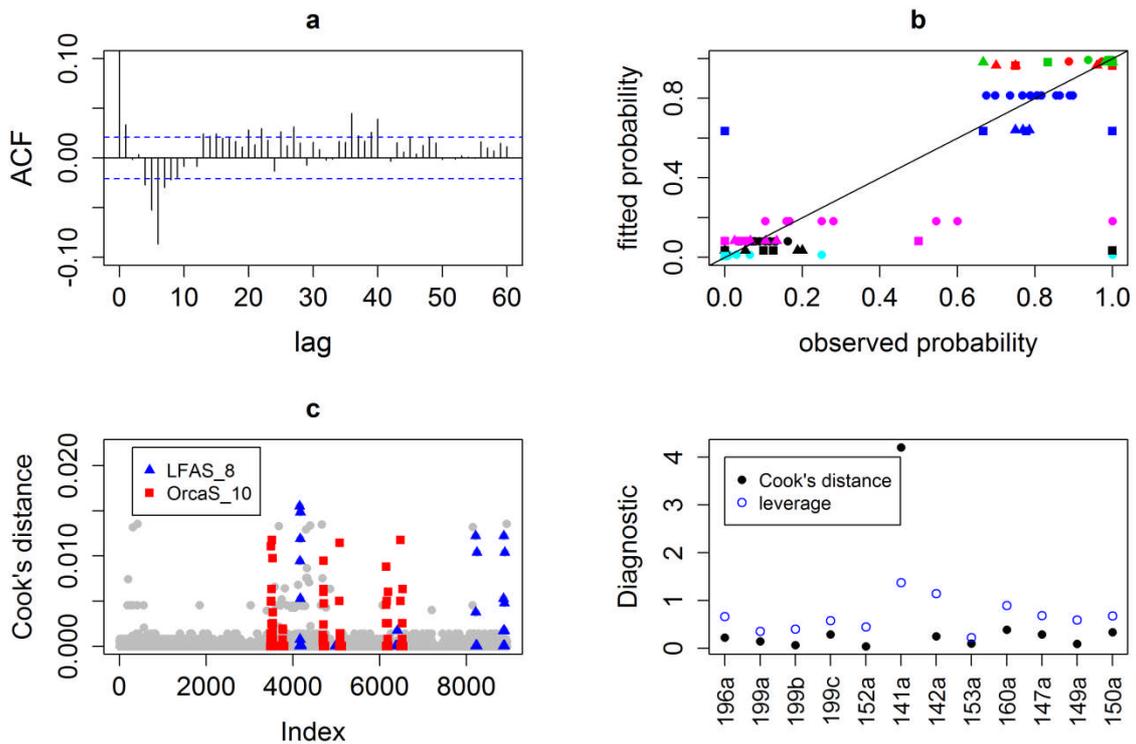


Figure 4B.7 Diagnostic plots for the binomial GEE model for foraging state (descent, layer-restricted search, or ascent)

a) autocorrelation function for raw residuals; b) Observed vs. fitted mean probability of state 6 given previous state (colour-coded) within each individual during baseline (circles) and exposure (LFAS\_8: triangles, OrcaS\_19: squares); c) Cook's distance, data during exposures (colour-coded symbols) vs. other (grey) shown; d) Cook's distance and leverage diagnostics for each individual.

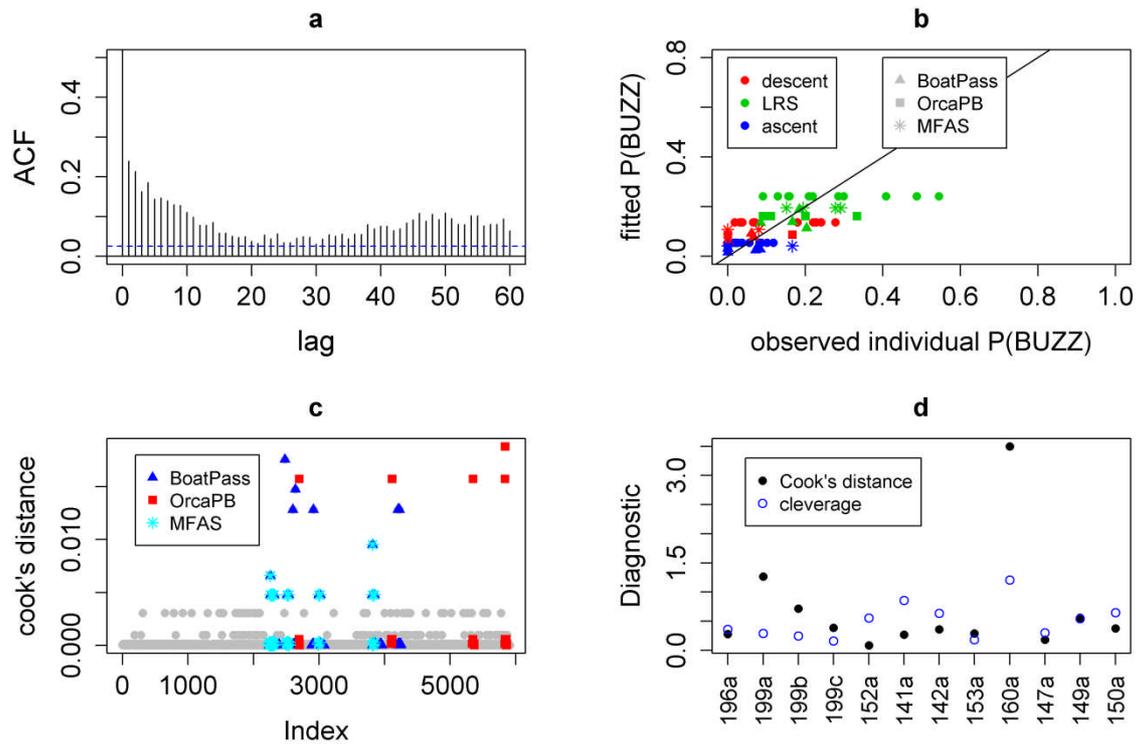


Figure 4B.8 Diagnostic plots for the binomial GEE model for buzz

a) autocorrelation function for raw residuals (only positive correlation was detected); b) Observed vs fitted mean probability of buzzing in each state (colour-coded) during exposures vs. other (symbols); c) Cook's distance, data during exposures (colour-coded symbols) vs. other (grey) shown; d) Cook's distance and leverage diagnostics for each individual.

#### *Appendix 4C Effects on overall time budget (based on Markov model)*

The multinomial model assumed that the probability of state was only dependent on previous step, and subsequently a geometric distribution for the distribution of state durations. In other words, the model did not account for any changes in state durations that could not be explained by 1st order Markov state transitions alone. To diagnose that the assumption did not compromise robust detection of effects, predicted budgets from the multinomial model were compared with observed time budgets. The multinomial Markov model  $state \sim prevState + whale + LFAS\_8 + OrcaS\_19$  was re-fitted to the baseline and exposure data ( $LFAS\_8 + OrcaS\_19$ ). The estimated coefficients (Table 4C.1) were used to predict state transitions for each whale (n=9) and for each baseline and exposure condition. To estimate the respective state budgets, the transition matrices were multiplied until a stationary distribution was reached for each row. The resulting predicted state budgets appeared a relatively good fit to the observed state budgets for each individual, both during baseline and the observed exposures (Fig 4C.1). Averaging across individuals, time spent in foraging states was predicted to decrease by 53.6% during *LFAS* (+8 min post-exposure) and by 33.3 % during *OrcaS* (+19min post-exposure) compared to baseline. Time spent in layer-restricted search state was predicted to decrease the most.

A second diagnosis for the Markov assumption was done by including time spent in previous state as a covariate in the model. To allow for different level of decay in the instantaneous probability of staying in each state, the covariate *prevStateTime* was allowed to interact with *prevState* (Fig. 4C.3). *prevStateTime* improved the model 153.4 AIC units, suggesting that longer-term processes were important to explain state transitions. However, the two models fitted the same states for 98.3% of pre-exposure data, 100% during *LFAS\_8*, and 97.9% during *OrcaS\_19*, suggesting that inclusion of *prevStateTime* would contribute relatively little to overall time budgets.

Table 4C.1 Multinomial model coefficients

Parameters	State 2		State 3		State 4		State 5		State 6	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Intercept	-2.75	0.20	-15.80	91.66	-32.79	4.00	-6.00	0.75	-3.29	0.25
prevState 2	28.50	23.91	40.67	67.75	52.56	19.94	-8.19	0.00	24.63	23.92
prevState 3	4.63	0.75	22.67	91.67	36.30	4.04	7.25	1.10	3.75	0.85
prevState 4	-2.45	1.02	13.24	91.66	33.59	4.00	1.58	1.26	-0.64	0.53
prevState 5	-9.49	253.09	16.03	91.67	31.63	4.08	9.63	0.92	4.30	0.67
prevState 6	2.83	0.30	14.07	91.67	30.62	4.01	5.51	0.79	3.69	0.26
sw08_152a	0.69	0.54	0.08	0.61	0.24	0.57	-12.76	333.52	0.69	0.57
sw09_141a	-0.55	0.48	-0.23	0.54	0.22	0.51	-1.38	0.89	1.96	0.36
sw09_142a	0.06	0.49	-0.04	0.53	0.04	0.50	-0.41	1.17	0.38	0.47
sw09_153a	0.83	0.35	0.62	0.39	0.30	0.36	-11.57	277.35	-0.18	0.63
sw09_160a	1.39	0.41	0.94	0.45	0.46	0.41	-9.67	67.48	-0.33	0.57
sw10_147a	0.15	0.27	-0.37	0.30	0.60	0.28	0.70	0.43	0.07	0.34
sw10_149a	0.71	0.30	0.10	0.33	0.52	0.30	-1.96	1.27	0.37	0.39
sw10_150a	0.80	0.30	-0.10	0.33	0.85	0.30	-14.02	0.00	-0.71	0.56
LFAS_8	-0.69	0.46	-1.20	0.52	0.41	0.44	1.06	1.19	1.97	0.41
OrcaS_19	-0.32	0.48	-1.01	0.57	-0.03	0.55	0.30	1.24	1.69	0.41

Multinomial model coefficients for  $state \sim prevState + whale + LFAS\_8 + OrcaS\_19$  fitted to baseline data (pre-exposure baseline and baseline whales that were not exposed to incidental sonar) and the two exposures alone (LFA signal playback + 8 min post-exposure; killer whale signal playback + 19 min post-exposure).

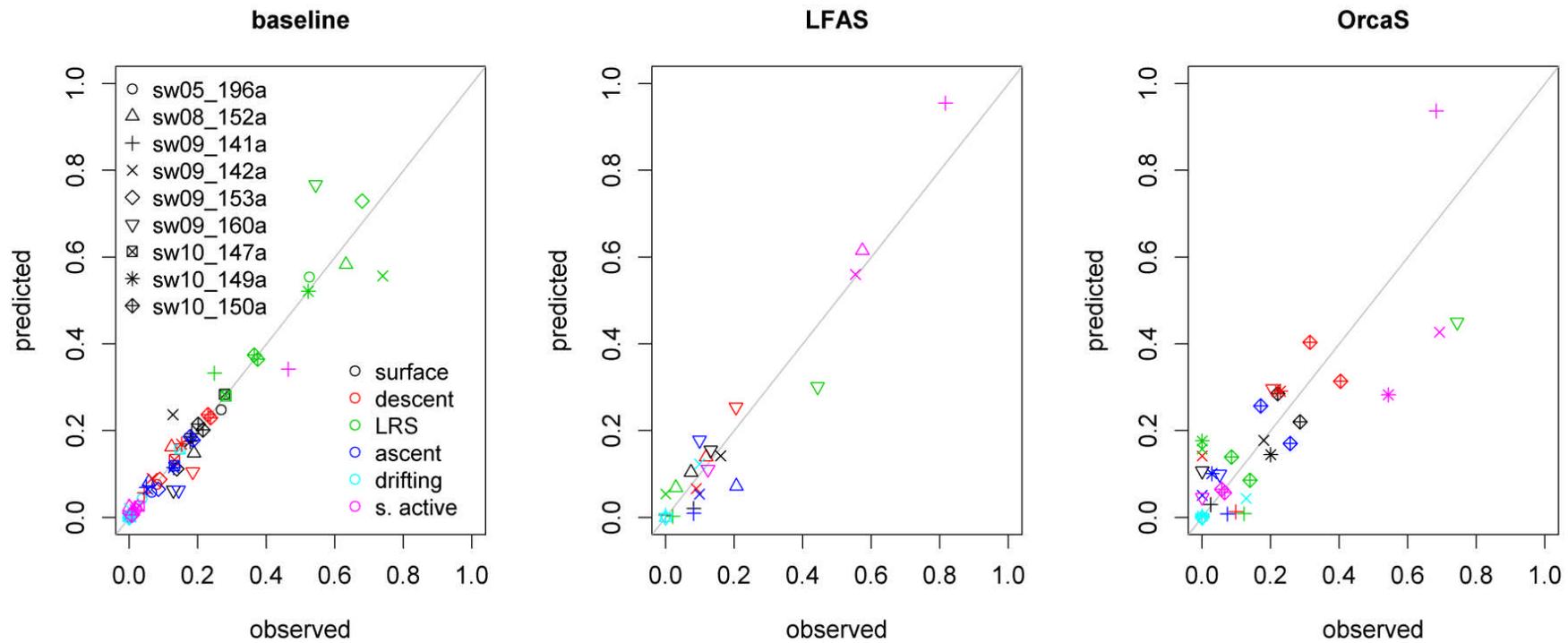


Fig. 4C.1 Predicted state budgets as a function of observed budgets

Predictions state budgets are given left: baseline, middle: LFAS + 8 min post-exposure and right: OrcaS + 19 min post-exposure. State predictions were based on multinomial model  $state \sim prevState + whale + LFAS\_8 + OrcaS\_19$  coefficients that were used to predict individual state transition matrices in baseline and each exposure condition. To estimate the respective state budgets, the transition matrices were multiplied until a stationary distribution was reached.

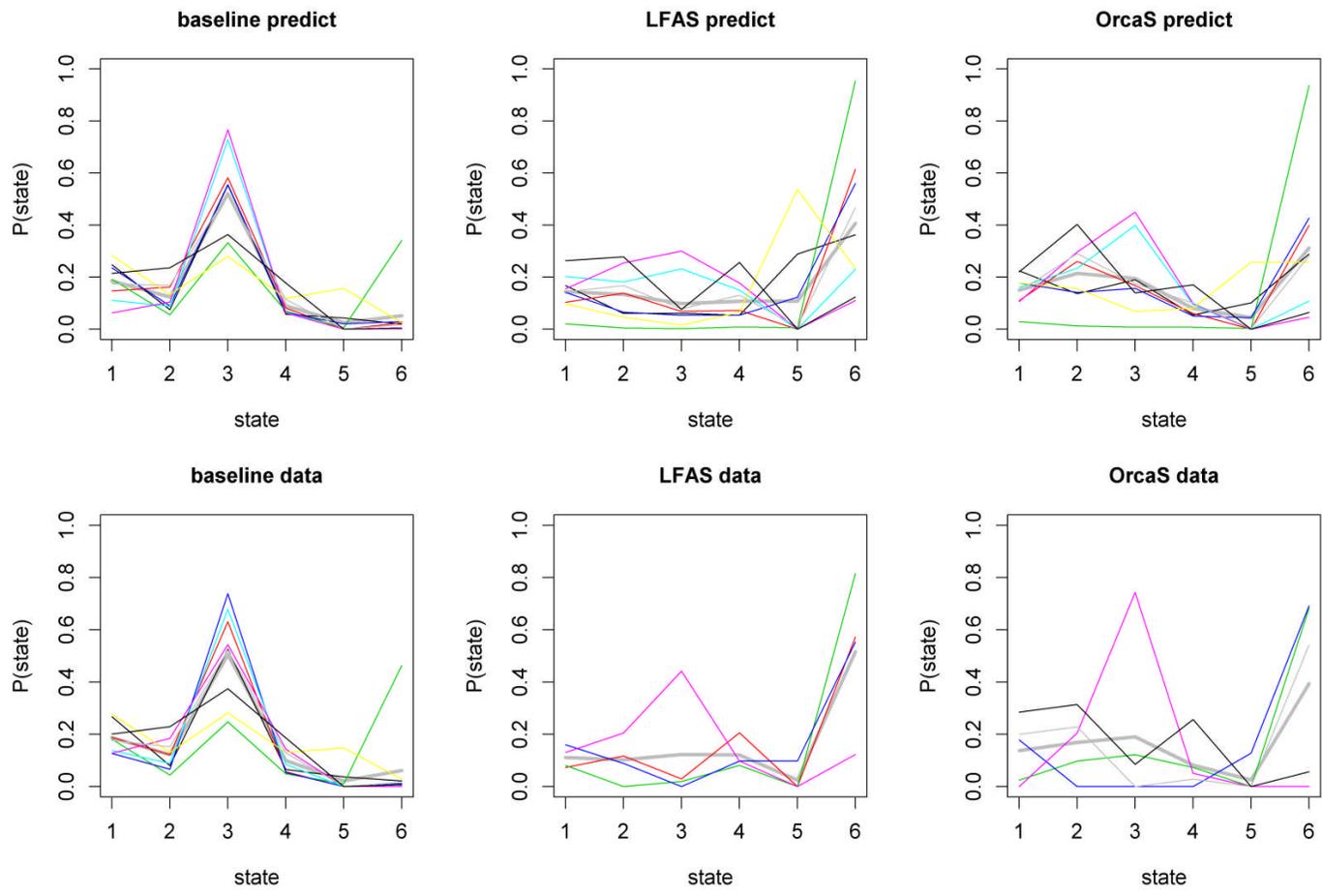
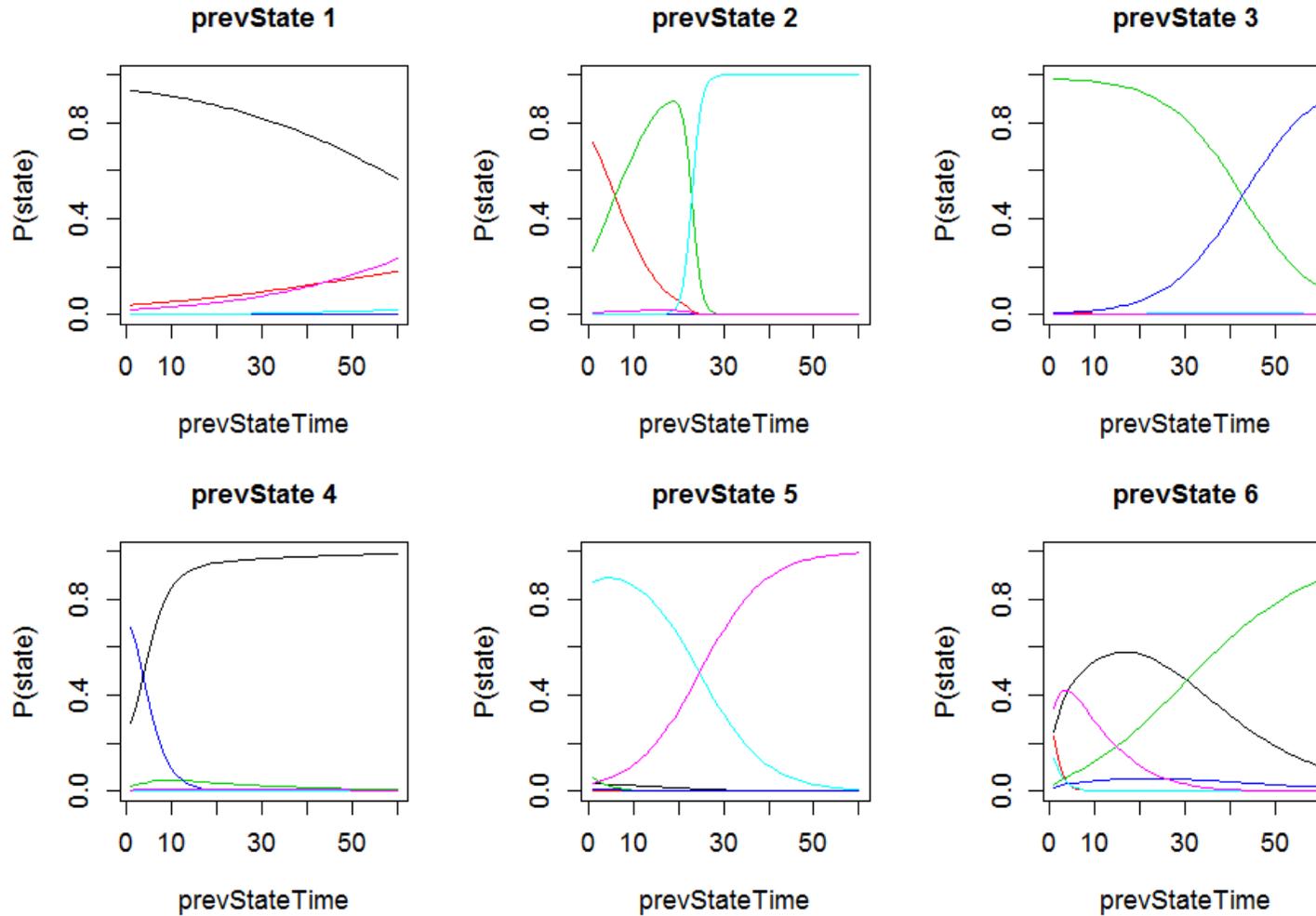


Fig. 4C.2 Predicted and observed state budgets for each individual

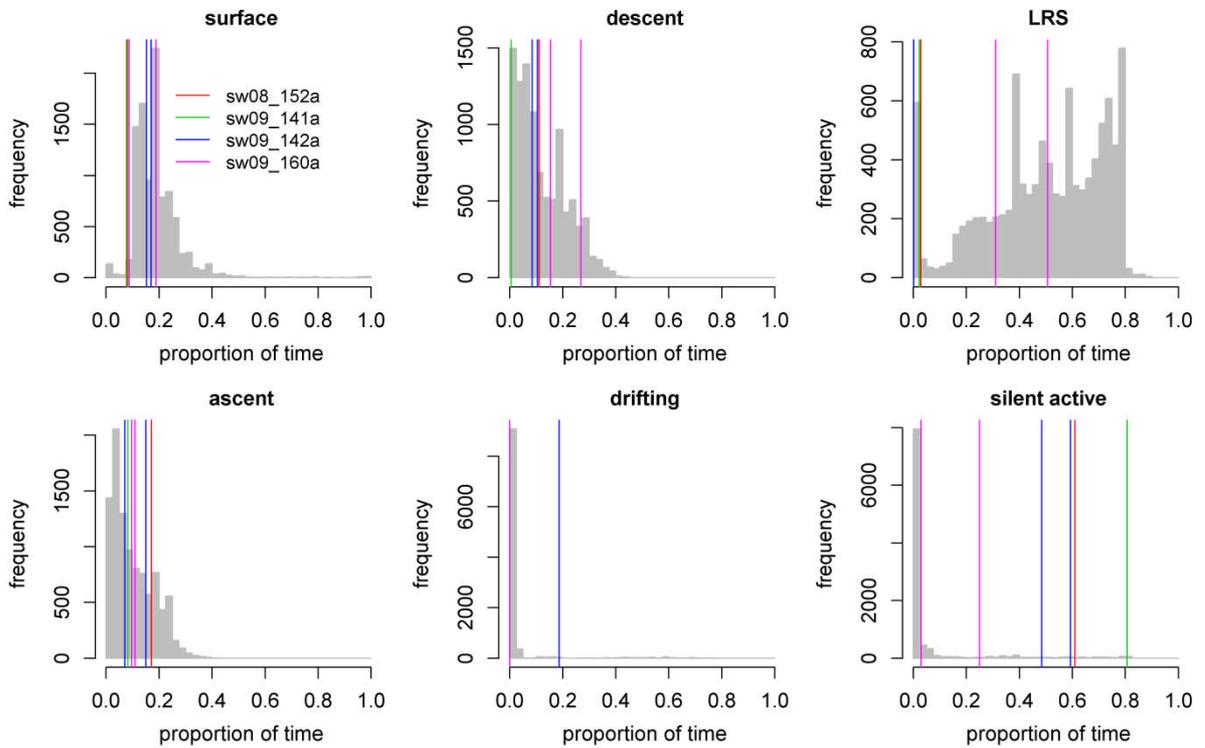
Top: predicted, bottom: observed state budgets for each individual (colour-coded line) in baseline and exposure conditions (LFAS + 8 min post-exposure and OrcaS + 19 min post-exposure). Individual average is shown as thick grey line.



*Fig. 4C.3 Interaction between time spent in previous state and instantaneous transition probability*

Predicted instantaneous probability of staying in each state (y-axis), given previous state (prevState) as a function of time spent in previous state. Values were predicted for whale sw09\_196 and assuming baseline.

*Appendix 4D Effects on overall time budget (based on randomisation)*



*Figure 4D.1 Randomisation of time budgets for each state*

Proportion of time spent in each state during LFAS\_8 exposures (vertical lines) overlaid with distribution of proportions in each state for randomly drawn pseudo-exposures (target duration 45 min).

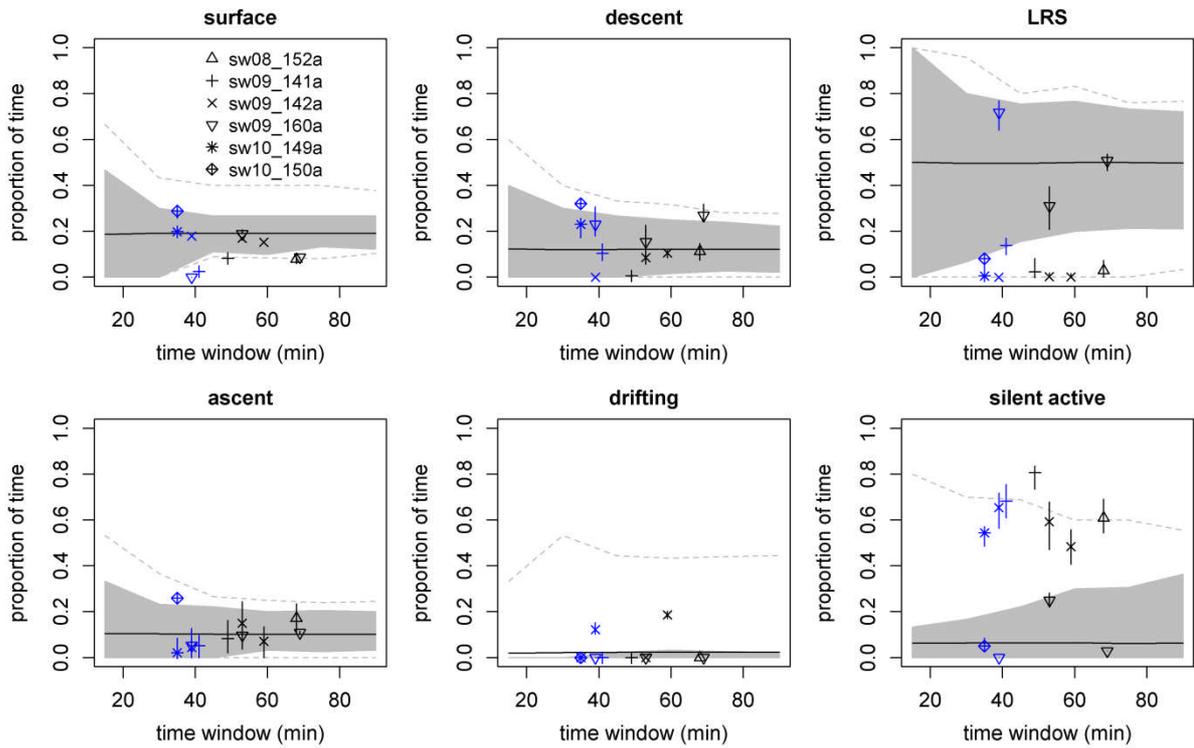


Figure 4D.2 a

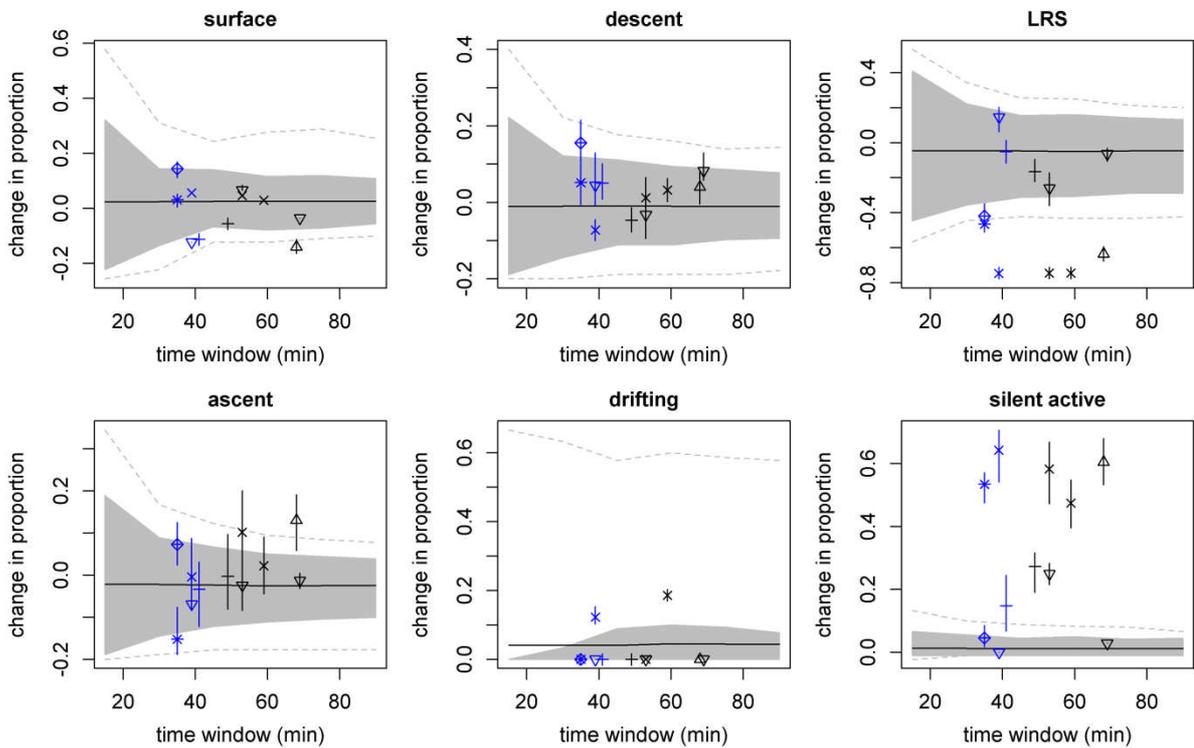


Figure 4D.2 b

*Figure 4D.2 Randomisations of baseline data as a function target duration*

Two randomisations of baseline data were used to quantify a) how unusual the time budget of each experiment was given baseline variability in time budgets across tag records, and b) how much exposure budgets changed from pre-exposure baseline, given baseline changes across tag records. For the respective randomisations, Figure a) shows proportion of time spent in each state during actual and pseudo exposures and Figure b) shows differences in proportion of time spent in each state between pre-exposure baseline and exposures. Mean and 95% quantile of resampled data from actual exposures (black symbols: *LFA5\_8*, blue symbols: *Orca5\_19*) are overlaid with mean (black horizontal line line), 80 % quantile (shaded grey area) and 95% quantile (dashed grey line) of resampled data from pseudo-exposures, as a function of pseudo-exposure target duration (min).

*Appendix 4E Effects on overall energetic budget (based on GEE estimates)*

*Table 4E.1 GEE model estimates for presence/absence of buzz (~Binomial) and ODBA (~Gamma) excluding state effects ('overall'), and only including state effects ('base')*

Model	Estimate	SE	95% CI		Z	p-value
<b>Buzz overall</b>						
Intercept	-1.94	0.12	-2.18	-1.70	-15.71	0.000
LFAS_8	-1.40	0.62	-2.63	-0.18	-2.25	0.025
OrcaS_19	-0.38	0.61	-1.56	0.81	-0.62	0.534
<b>Buzz base</b>						
Ascent (intercept)	-3.02	0.30	-3.60	-2.43	-10.14	0.000
descent	1.14	0.52	0.12	2.15	2.19	0.028
LRS	1.75	0.38	1.01	2.49	4.65	0.000
<b>ODBA overall</b>						
Intercept	25.03	0.57	23.92	26.15	43.91	0.000
LFAS_8	-2.00	2.09	-6.09	2.09	-0.96	0.337
OrcaS_19	-2.11	1.16	-4.38	0.16	-1.82	0.068
<b>ODBA base</b>						
Silent active (intercept)	25.00	0.76	23.52	26.48	33.05	0.000
Surface	-3.94	0.82	-5.54	-2.34	-4.82	0.000
Descent	0.15	1.69	-3.16	3.46	0.09	0.930
LRS	4.61	1.43	1.82	7.41	3.23	0.001
Ascent	-5.47	1.65	-8.71	-2.23	-3.31	0.001
Drifting	-17.96	3.29	-24.40	-11.52	-5.46	0.000

Data for 'base' models included pre-exposure baseline data and baseline whales that were not exposed to incidental sonar. 'overall' models also included data from the two exposures (LFA signal playback + 8 min post-exposure; killer whale playback + 19 min post-exposure).

Table 4E.2 Observed buzz presence and mean ODBA during pre-exposure baseline data

Tag id	Buzz presence (% bins)			mean ODBA					
	descent	LRS	ascent	surface	descent	LRS	ascent	drift	silent active
sw08_152a	0.0	19.4	0.0	19.8	26.6	26.9	19.9	7.0	25.0
sw09_141a	12.5	11.1	11.1	28.2	29.7	25.3	28.2	18.3	24.5
sw09_142a	0.0	10.7	11.1	18.6	25.7	26.1	20.0	7.0	26.3
sw09_160a	19.4	57.5	10.7	21.5	18.8	30.0	21.2	7.0	25.0
sw10_149a	4.3	14.9	10.3	17.7	21.7	28.3	23.6	20.6	25.1
sw10_150a	23.7	29.1	3.0	19.6	29.1	37.5	17.4	7.0	27.9

Time spent buzzing (% of 1-min bins) in foraging states, and mean ODBA in each state in pre-exposure baseline that was used to predict the energetic proxies during exposures. Drifting state or silent active were not always observed in pre-exposure baseline, and overall baseline average was used instead (red).