Using duck proxies and surface water to inform hunting arrangements

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Introduction

Based on literature, practices elsewhere, and earlier recommendations, duck harvest management for Victoria should contain indices that inform on (i) breeding conditions in Victoria, (ii) breeding conditions throughout SE Australia, (iii) current or recent duck population size in Victoria, and (iv) duck population size throughout SE Australia.

Following a protocol outlined in *Relationships among duck population indices and abiotic drivers to guide annual duck harvest management* by Klaassen and Kingsford (2021) we calculate five indices reflecting the above elements i-iv. Three of these indices, reflecting breeding condition elements i and ii, use availability of water in the landscape (LANDSAT satellite imagery) across up to 4 regions in SE Australia over 1-3 year intervals. The models underlying these three indices are updated annually making use of the latest data.

After a presentation of the water data in section 2, the three updated models are presented in sections 3-5.

In section 6, we compare the indices with actual hunting regulations between 1991-2021 and briefly evaluate their use in advising on future annual hunting arrangement.

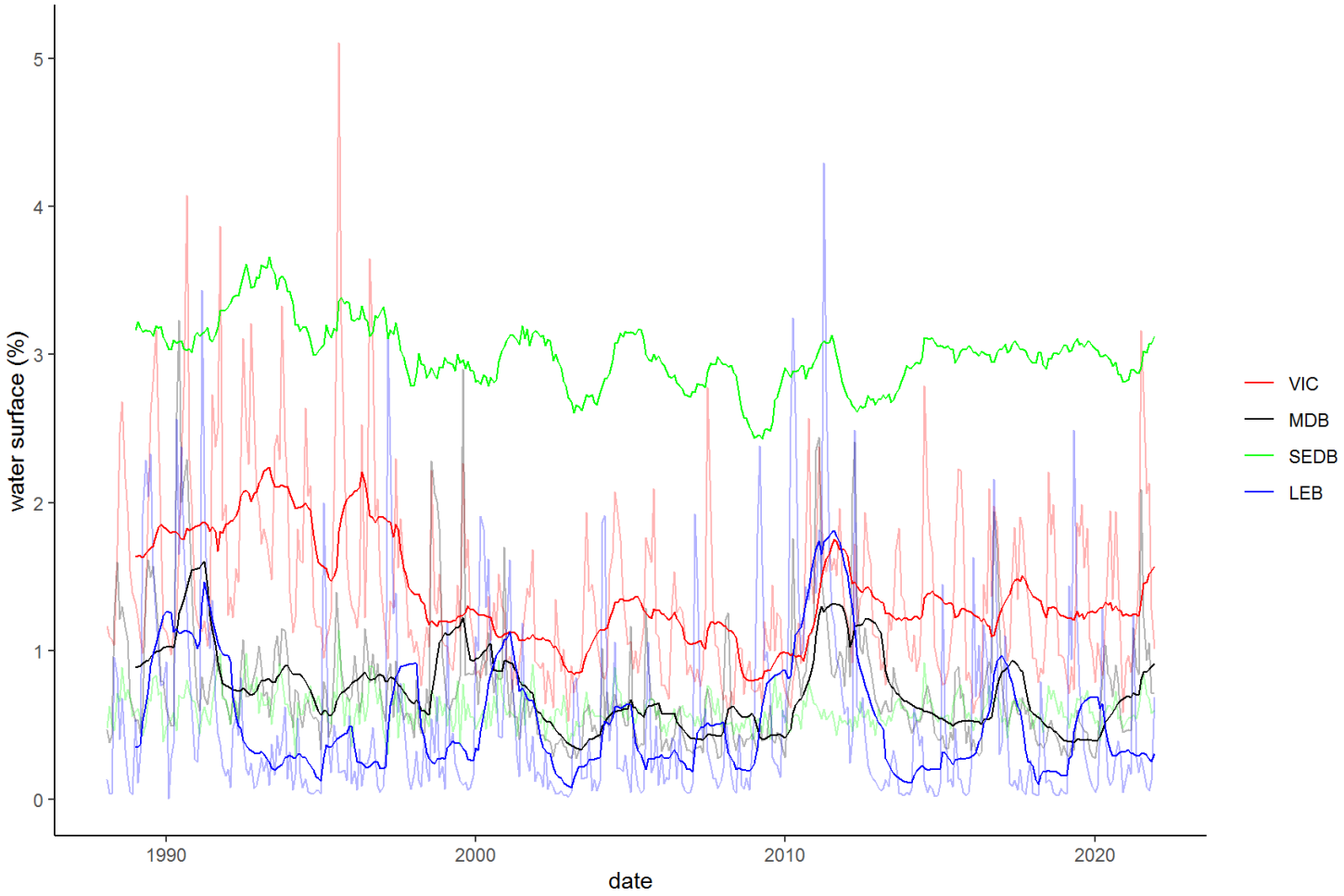
Finally, in section 7, a proposed hunting arrangement for 2022 is proposed.

Water surface area across SE Australia

The monthly maximum water surface area in the landscape calculated from LANDSAT imagery using the https://docs.dea.ga.gov.au/setup/Sandbox/sandbox.html tool were kindly obtained by Roxane Francis (UNSW) for

- Victoria (VIC)
- Murray-Darling Basin (MDB)
- SE Australia south of the MDB (SEDB, see image below)
- Lake Eyre Basin (LEB)

Below, the water surface area (in %) across Victoria (VIC), Murray-Darling Basin (MDB), SE Australia south of the MDB (SEDB; multiply by 2) and Lake Eyre Basin (LEB) is depicted. The monthly values are plotted in light shadings, whereas the right-aligned 12 month running mean is depicted in bold.



Only the 12 month rolling average water surface areas were used in subsequent analyses.

Water surface area and game counts in priority wetlands

This analysis relies on the Victorian Duck Season Priority Waterbird Counts (e.g. https://www.gma.vic.gov.au/__data/assets/pdf_file/0011/803459/DSPWC-2021-report.pdf) courtesy Peter Menkhorst (Arthur Rylah Institute for Environmental Research). These counts mostly take place a month before the duck hunting season.

Predictive models

We used linear modelling to conduct a regression across all game count data across 37 priority wetlands for which also water surface data was available for all four areas. Water surface area was time shifted by 4 months. This was done to see in how far one can judge in December what the expected hunting bag is going to be in March.

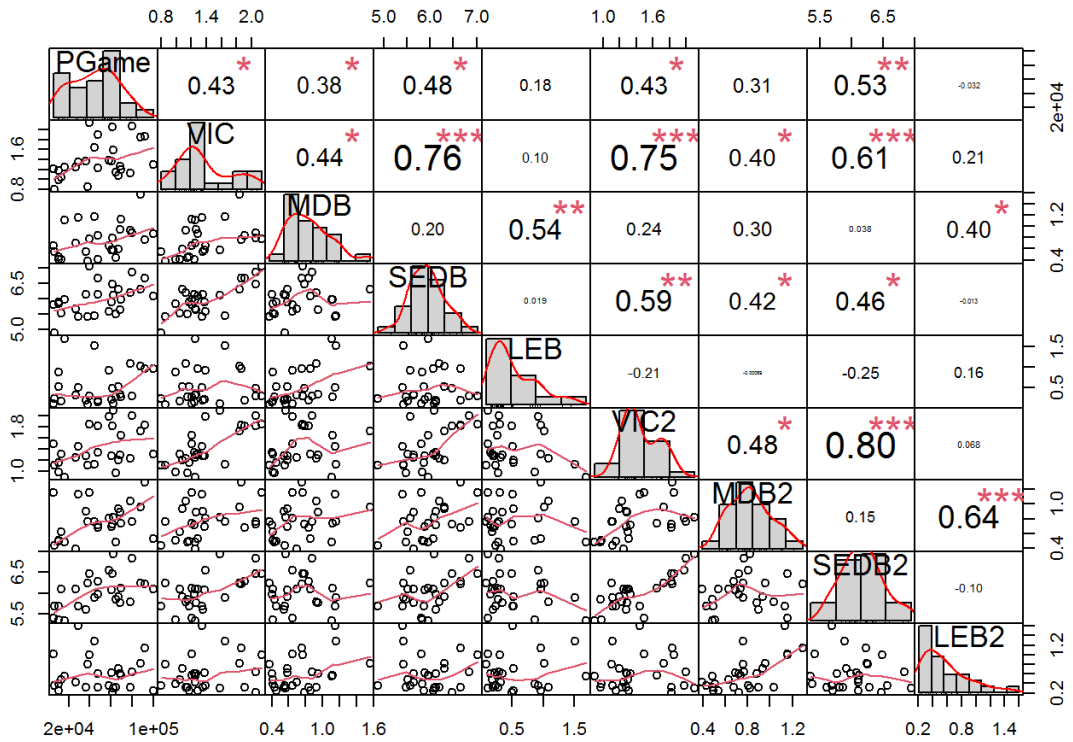
We ran models using as explanatory variables the average water surface area over the preceding 12 months and 13-36 months prior to the "decision" point in December for all 4 areas. All combinations of these 8 explanatory variables were tested.

We first present a correlation chart for all variables in the model, including Pearson correlation coefficients. Next, there is a table presenting all the models with a deltaAIC <= 7 (i.e.models with substantial to moderate statistical support) ranked from the best to the poorest model.

In the Table, red rows indicate models where all explanatory variables have a P<0.05. The orange columns indicate variables where we a priori expected a possible effect.

We ultimately selected a model as the most satisfying model that:

1. was high ranking
2. had significant and preferably positive parameter estimates for all its parameters (not considering the intercept)
3. had a high adjR^2 or R-squared



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	delta	AllSignif
-344540	NA	-45357	51617	87306	NA	67719	NA	-65692	0.641	0.00	TRUE
-187611	NA	NA	34654	NA	NA	34955	NA	NA	0.415	3.11	TRUE
-369991	NA	-41492	49788	80057	7060	66198	NA	-67689	0.650	3.42	FALSE
-355205	NA	NA	47781	NA	29526	41694	-42561	NA	0.529	3.64	FALSE
-346227	6093	-44483	45518	86547	NA	67458	NA	-62456	0.646	3.70	FALSE
-342894	NA	-45628	50733	87442	NA	67333	2598	-67239	0.642	4.07	FALSE
-217881	NA	NA	30812	NA	12341	28238	NA	NA	0.452	4.37	FALSE
-212535	20938	NA	NA	NA	NA	41522	NA	NA	0.385	4.48	FALSE
-166057	NA	-31014	39311	43097	NA	28354	NA	NA	0.512	4.61	FALSE
-217817	20390	NA	NA	25816	NA	39136	NA	NA	0.435	5.23	FALSE
-177578	NA	-11881	40476	NA	NA	33749	NA	NA	0.434	5.26	FALSE
-205771	10863	NA	25626	NA	NA	38121	NA	NA	0.434	5.28	FALSE
-189339	NA	NA	30727	16060	NA	33669	NA	NA	0.433	5.32	FALSE
-324623	NA	NA	37099	NA	17984	47343	NA	-32839	0.498	5.35	FALSE
-243897	18715	NA	NA	NA	13724	33338	NA	NA	0.432	5.37	FALSE
-237529	NA	NA	38976	NA	NA	46871	NA	-17645	0.431	5.42	FALSE
-309209	NA	NA	36007	36142	NA	60159	NA	-41609	0.491	5.72	FALSE

-167361	NA	NA	NA	NA	NA	35890	NA	NA	0.282	5.88	TRUE
-210847	NA	NA	NA	NA	16505	26767	NA	NA	0.352	5.90	FALSE
-201139	22776	-24553	NA	49519	NA	35555	NA	NA	0.488	5.92	FALSE
-203397	NA	NA	38356	NA	NA	38739	-7059	NA	0.419	5.96	FALSE
-407864	NA	NA	49537	NA	30806	52804	-36114	-22601	0.549	6.17	FALSE
-373370	10627	NA	39246	NA	29297	45146	-42990	NA	0.547	6.30	FALSE
-174166	NA	NA	NA	27170	NA	33534	NA	NA	0.337	6.48	FALSE
-370749	NA	NA	34927	29896	15265	58263	NA	-50365	0.538	6.80	FALSE
-304219	22728	-30714	NA	75886	NA	59001	NA	-38553	0.537	6.88	FALSE
-207516	NA	-11060	36361	NA	11923	27342	NA	NA	0.469	6.89	FALSE
-233922	10160	NA	22488	NA	11956	31408	NA	NA	0.469	6.90	FALSE
-354008	NA	NA	46066	11194	27739	42246	-43448	NA	0.536	6.91	FALSE
-187677	12569	-30668	27980	46024	NA	31818	NA	NA	0.536	6.93	FALSE

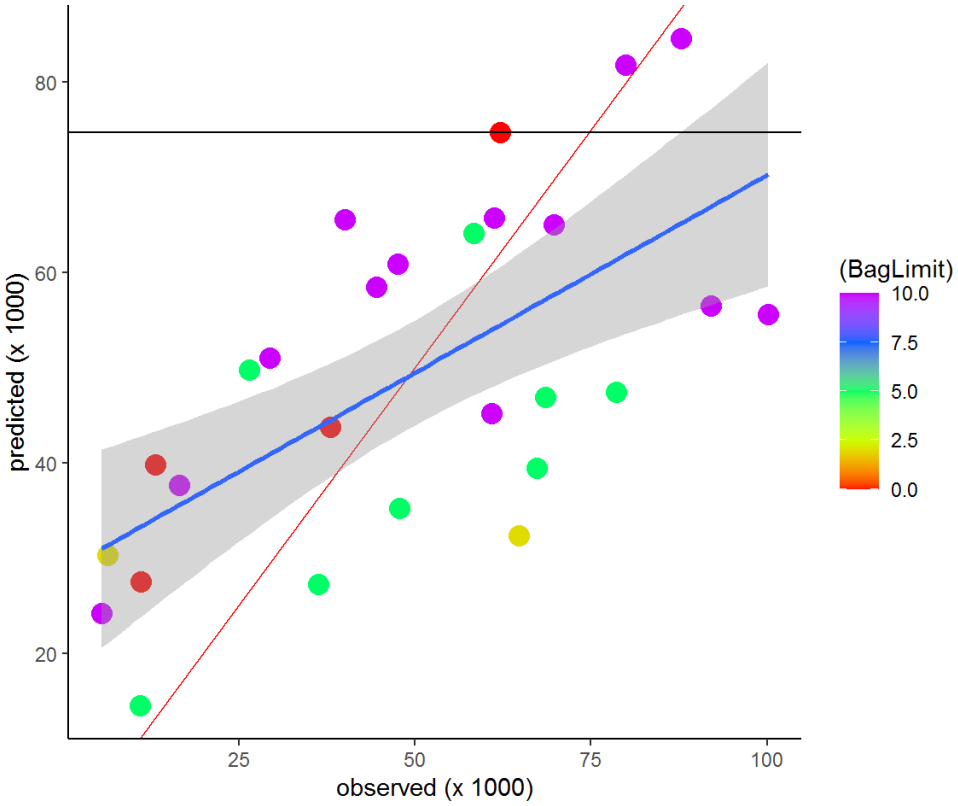
Predicted versus observed

We present the critical statistics for the ultimately preferred model and a plot of the predicted versus the observed Victorian Game counts. In this graph the symbol colour reflects hunting bag limits for the season (not considering potential separate limitations for individual species and special restrictions during opening weekend). Red line depicts *observed=predicted*, while the blue line is the linear regression relationship with grey shading reflecting the 95% confidence interval of this line. Black horizontal line is the threshold for the dependent variable, reflecting the lower limit above which unlimited seasons were called.

```
##
##    The preferred model selected: 2
##
##
##
```

```
##
## Call:
## lm(formula = PGame ~ MDB + SEDB2 + 1, data = Jc)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -26582 -17574  -4509  14077  44604
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -187611      64364   -2.91   0.0076 **
## MDB            34654      14821    2.34   0.0280 *
## SEDB2          34955      10560    3.31   0.0029 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 22100 on 24 degrees of freedom
## Multiple R-squared:  0.415,  Adjusted R-squared:  0.366
## F-statistic: 8.52 on 2 and 24 DF,  p-value: 0.0016
```

```
##
##    The threshold number is 74700
##
##
##
```

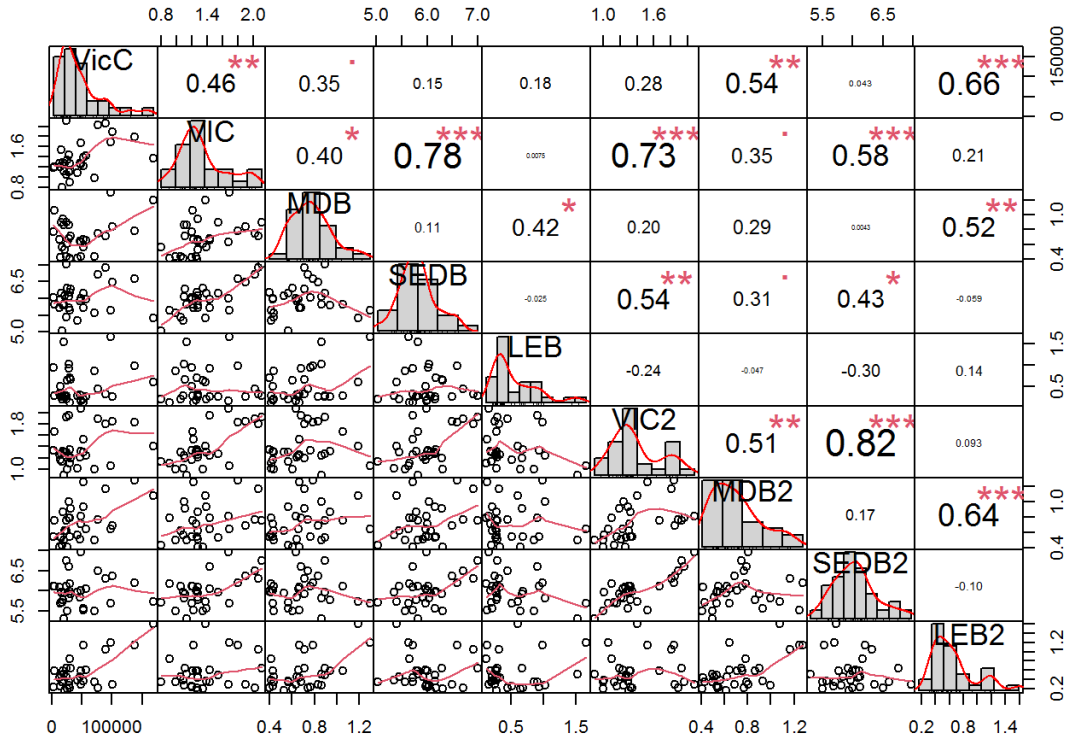


Water surface area and Eastern Australian Waterbird Survey counts for Victoria (i.e. band 1-3)

These analyses rely on the Eastern Australian Waterbird Survey data (Kingsford, R. T., J. L. Porter, K. J. Brandis, and S. Ryall. 2020. Aerial surveys of waterbirds in Australia. Scientific Data 7:1-6. https://www.nature.com/articles/s41597-020-0512-9), which typically take place in October of every year. The data is split into two: bands 1-3 representing Victoria (and the SE of SA) and bands 4-6 representing NSW and southern Queensland (and the E of SA bordering NSW).

We removed the Victoria counts from 1984, which formed an outlier (>4x higher count than any of the other counts in Victoria)

Predictive models



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	delta	AllSignif
-42924	NA	65260	NA	NA	NA	NA	39376	NA	0.547	0.00	TRUE
54255	NA	59043	NA	NA	-21005	NA	62729	NA	0.567	1.46	FALSE
39139	NA	61185	NA	NA	NA	-15940	50835	NA	0.562	1.82	FALSE
-37050	NA	72170	-23325	NA	NA	NA	44282	NA	0.560	2.01	FALSE
207933	NA	NA	NA	96246	-54699	NA	126577	-55646	0.600	2.10	TRUE
-47253	9586	63715	NA	NA	NA	NA	39624	NA	0.557	2.19	FALSE
-46923	NA	59691	NA	13849	NA	NA	37155	NA	0.551	2.59	FALSE
-40577	NA	64953	NA	NA	NA	NA	43352	-5495	0.548	2.79	FALSE
363580	NA	NA	NA	71782	-52592	-35147	114156	NA	0.591	2.86	TRUE
173697	NA	52853	NA	NA	-24883	-19715	81213	NA	0.590	2.93	FALSE
84967	NA	66907	-31468	NA	-25930	NA	74824	NA	0.589	3.00	FALSE
-40804	17959	74397	-40616	NA	NA	NA	48383	NA	0.587	3.13	FALSE
81842	NA	44550	NA	30259	-28856	NA	66606	NA	0.584	3.38	FALSE
255008	NA	61366	-42352	NA	-32810	-26314	103678	NA	0.626	3.45	FALSE
66256	NA	69061	-29871	NA	NA	-19747	59853	NA	0.582	3.52	FALSE
95774	20299	68774	-52015	NA	-29129	NA	83225	NA	0.623	3.66	FALSE
49893	9578	57501	NA	NA	-20997	NA	62967	NA	0.577	3.86	FALSE

249106	NA	30696	NA	42273	-37049	-25801	92334	NA	0.619	4.00	FALSE
-28222	NA	70790	NA	NA	NA	NA	NA	26055	0.485	4.03	FALSE
6626	NA	73067	NA	NA	NA	NA	NA	NA	0.436	4.17	TRUE
61115	NA	58370	NA	NA	-21738	NA	69421	-8123	0.570	4.40	FALSE
248729	NA	NA	-24479	103409	-61929	NA	143726	-62154	0.614	4.40	FALSE
43449	NA	53084	NA	18935	NA	-17840	49163	NA	0.570	4.41	FALSE
148926	NA	23775	NA	66707	-41930	NA	104299	-40089	0.614	4.41	FALSE
86257	NA	59535	NA	NA	NA	-26737	44257	19820	0.569	4.46	FALSE
21393	6158	60935	NA	NA	NA	-13034	48904	NA	0.566	4.67	FALSE
-91901	NA	74303	NA	NA	16351	NA	NA	NA	0.472	4.78	FALSE
324762	NA	39820	-40979	40579	-44232	-31942	113625	NA	0.653	4.80	FALSE
-53154	11005	56159	NA	18221	NA	NA	36738	NA	0.564	4.82	FALSE
440065	NA	NA	-28576	76717	-60822	-41367	133526	NA	0.608	4.87	FALSE
-33495	NA	72049	-24372	NA	NA	NA	50078	-7707	0.562	4.97	FALSE
-40317	NA	67710	-21666	9869	NA	NA	42351	NA	0.562	4.97	FALSE
198105	7766	NA	NA	94658	-53759	NA	121870	-49961	0.606	5.04	FALSE
278034	NA	NA	NA	88198	-54233	-15034	125404	-37862	0.606	5.05	FALSE
175333	NA	NA	NA	73905	-50674	NA	88296	NA	0.512	5.20	TRUE
-43193	NA	53754	NA	26228	NA	NA	47544	-17104	0.558	5.22	FALSE
-47556	9703	63729	NA	NA	NA	NA	39204	585	0.557	5.29	FALSE
107210	NA	53341	-29003	27036	-32559	NA	77340	NA	0.601	5.39	FALSE
-41254	15495	67944	NA	NA	NA	NA	NA	30943	0.508	5.44	FALSE
-9489	NA	58811	NA	32852	NA	NA	NA	NA	0.460	5.45	FALSE
227828	15620	63960	-55891	NA	-33835	-20821	104119	NA	0.644	5.53	FALSE
126139	22923	51349	-51461	35210	-38175	NA	87588	NA	0.644	5.56	FALSE
81456	12380	39798	NA	36020	-30340	NA	67652	NA	0.599	5.57	FALSE
35671	14443	71681	-42030	NA	NA	-14477	58996	NA	0.598	5.68	FALSE
334202	8446	NA	NA	72788	-51790	-30982	110226	NA	0.597	5.73	FALSE
225619	NA	50982	NA	NA	-25251	-31214	74690	21005	0.597	5.75	FALSE
90372	NA	65848	NA	NA	NA	-24950	NA	50292	0.502	5.81	FALSE

96960	NA	66438	-33512	NA	-27318	NA	85362	-11839	0.593	6.02	FALSE
-62591	NA	74362	NA	NA	NA	11436	NA	NA	0.449	6.12	FALSE
156553	5036	52812	NA	NA	-24397	-17264	79040	NA	0.592	6.12	FALSE
160665	17529	NA	NA	75471	-49480	NA	86500	NA	0.545	6.14	FALSE
183370	NA	32017	-32943	66106	-47233	NA	119655	-43454	0.637	6.19	FALSE
-45641	18721	68107	-38973	14126	NA	NA	45792	NA	0.591	6.20	FALSE
118827	NA	67519	-30886	NA	NA	-31711	52949	21726	0.589	6.32	FALSE
317215	NA	59498	-43736	NA	-33491	-39717	96930	24091	0.635	6.34	FALSE
2901	8889	71680	NA	NA	NA	NA	NA	NA	0.444	6.36	FALSE
-42009	18472	74498	-40787	NA	NA	NA	46711	2378	0.587	6.48	FALSE
-70740	NA	71987	NA	NA	8470	NA	NA	19687	0.491	6.49	FALSE
251471	15873	NA	-38179	104171	-64054	NA	143705	-54176	0.633	6.53	FALSE
67724	NA	62218	-27798	14717	NA	-20959	57928	NA	0.586	6.58	FALSE
300648	17714	40689	-56202	44484	-46493	-26254	115083	NA	0.677	6.62	FALSE
419363	16979	NA	-42907	81215	-63337	-36112	135339	NA	0.630	6.75	FALSE
5261	NA	72174	2643	NA	NA	NA	NA	NA	0.436	6.81	FALSE
-28705	NA	67179	NA	8907	NA	NA	NA	23149	0.486	6.82	FALSE
-26194	NA	72594	-5493	NA	NA	NA	NA	26660	0.485	6.85	FALSE

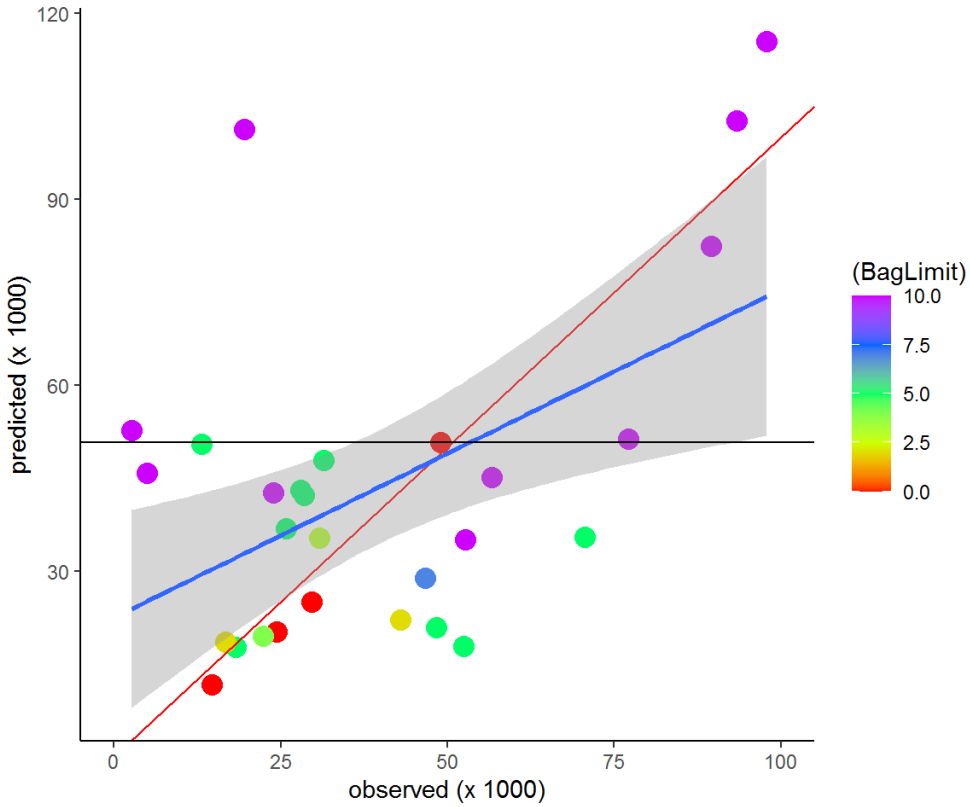
Predicted versus observed

```
##
##    The preferred model selected: 1
##
##
##
```

```
##
## Call:
## lm(formula = VicC ~ LEB2 + VIC + 1, data = Jc)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -58457 -17202   3193  10108  53486
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   -42924      20949   -2.05    0.050 *
## LEB2           65261      14377    4.54  9.8e-05 ***
## VIC            39376      15002    2.62    0.014 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

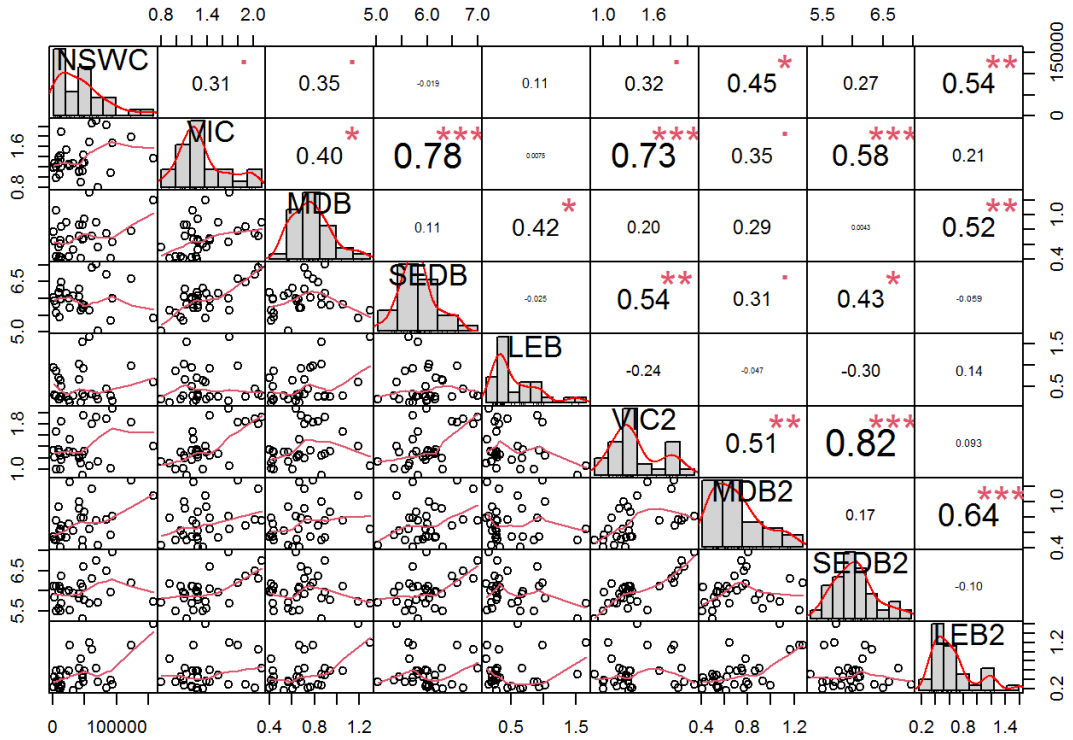
```
## Residual standard error: 27000 on 28 degrees of freedom
## Multiple R-squared:  0.547,  Adjusted R-squared:  0.515
## F-statistic: 16.9 on 2 and 28 DF,  p-value: 1.51e-05
```

```
##
##    The threshold number is 50800
##
##
##
```



Water surface area and Eastern Australian Waterbird Survey counts for NSW (i.e. band 4-6)

Predictive models



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	delta	AllSignif
-184465	NA	61673	NA	NA	NA	32355	NA	NA	0.397	0.00	TRUE
241657	NA	NA	NA	66473	-59776	NA	81035.56	NA	0.429	1.19	TRUE
-30483	NA	55277	NA	NA	NA	NA	NA	31289.6	0.365	1.62	FALSE
-145843	NA	61434	NA	NA	-13029	38944	NA	NA	0.417	1.83	FALSE
-214684	13404	60041	NA	NA	NA	36419	NA	NA	0.416	1.90	FALSE
11367	NA	58011	NA	NA	NA	NA	NA	NA	0.291	2.38	TRUE
157617	NA	42158	NA	NA	-37949	NA	65493.70	NA	0.401	2.65	FALSE
-187914	NA	57789	11360.6	NA	NA	31955	NA	NA	0.401	2.68	FALSE
-180517	NA	57273	NA	9764	NA	30911	NA	NA	0.399	2.76	FALSE
-185904	NA	61753	NA	NA	NA	32697	NA	-473.3	0.397	2.86	FALSE
-184318	NA	61654	NA	NA	NA	32315	73.31	NA	0.397	2.86	FALSE
51919	NA	52957	NA	NA	-16415	NA	NA	43631.5	0.392	3.14	FALSE
-17956	NA	53391	NA	NA	NA	NA	23302.27	NA	0.332	3.17	FALSE
-8228	NA	50752	NA	NA	-32564	27375	39828.41	NA	0.447	3.31	FALSE
200853	NA	19444	NA	47423	-50254	NA	71568.95	NA	0.443	3.50	FALSE
-175180	15332	59535	NA	NA	-14792	44485	NA	NA	0.441	3.65	FALSE
233400	9867	NA	NA	67354	-59104	NA	80025.07	NA	0.440	3.69	FALSE

174689	NA	NA	NA	67228	-59094	12503	71835.96	NA	0.439	3.71	FALSE
-39545	10776	53298	NA	NA	NA	NA	NA	34689.0	0.377	3.88	FALSE
-2965	NA	45332	NA	29217	NA	NA	NA	NA	0.311	4.13	FALSE
246889	NA	NA	NA	70058	-60422	NA	87179.80	-8931.4	0.431	4.16	FALSE
236453	NA	NA	3444.3	65832	-58825	NA	79252.47	NA	0.429	4.27	FALSE
-124740	NA	50493	NA	24120	-16858	37315	NA	NA	0.428	4.35	FALSE
-32774	NA	53240	6204.1	NA	NA	NA	NA	30606.5	0.366	4.43	FALSE
30444	NA	NA	NA	94909	-61860	46418	90801.67	-63842.1	0.485	4.44	FALSE
-30225	NA	57203	NA	-4752	NA	NA	NA	32840.0	0.365	4.46	FALSE
-30883	NA	55088	NA	NA	NA	NA	1404.76	30267.2	0.365	4.47	FALSE
135694	NA	44306	NA	NA	-35607	NA	44107.01	25962.2	0.425	4.49	FALSE
-147219	NA	56016	15783.7	NA	-14181	38971	NA	NA	0.424	4.58	FALSE
3338	NA	52758	15544.1	NA	NA	NA	NA	NA	0.298	4.74	FALSE
-100236	NA	59216	NA	NA	-15213	30741	NA	12865.6	0.420	4.76	FALSE
-210814	13955	54276	NA	12642	NA	34717	NA	NA	0.419	4.82	FALSE
-224725	14021	61086	NA	NA	NA	38934	-4322.63	NA	0.416	4.96	FALSE
9955	3370	57485	NA	NA	NA	NA	NA	NA	0.292	4.98	FALSE
-213270	13412	59960	NA	NA	NA	36081	NA	470.2	0.416	5.00	FALSE
-214776	13502	60173	-420.8	NA	NA	36464	NA	NA	0.416	5.00	FALSE
5020	NA	58091	NA	NA	1053	NA	NA	NA	0.291	5.03	FALSE
51289	13574	50160	NA	NA	-18563	NA	NA	49529.3	0.410	5.27	FALSE
58074	NA	31270	NA	37168	-43260	22024	49606.44	NA	0.471	5.31	FALSE
167649	NA	44726	-10278.6	NA	-39558	NA	69444.17	NA	0.404	5.62	FALSE
-183757	NA	52614	12155.8	10880	NA	30319	NA	NA	0.403	5.65	FALSE
155901	3767	41551	NA	NA	-37946	NA	65587.37	NA	0.403	5.67	FALSE
-23398	NA	45813	NA	18845	NA	NA	20280.08	NA	0.340	5.67	FALSE
119659	15820	NA	NA	69113	-57591	20306	64474.65	NA	0.464	5.71	FALSE
-196504	NA	58115	13423.1	NA	NA	34025	-3979.40	NA	0.401	5.75	FALSE
-198997	NA	58135	12115.1	NA	NA	34510	NA	-3568.6	0.401	5.77	FALSE
-210180	NA	56010	NA	16569	NA	37615	NA	-10656.9	0.401	5.78	FALSE

253357	NA	NA	NA	NA	-56657	NA	94196.68	NA	0.274	5.79	TRUE
-51054	12580	50649	NA	NA	-31348	33498	34400.57	NA	0.462	5.81	FALSE
-182061	NA	57412	NA	9917	NA	31320	-802.03	NA	0.399	5.85	FALSE
-9058	NA	NA	NA	71613	NA	NA	NA	NA	0.206	5.90	TRUE
-19663	3781	52782	NA	NA	NA	NA	23399.90	NA	0.334	5.96	FALSE
-185932	NA	61711	NA	NA	NA	32685	298.64	-678.9	0.397	5.96	FALSE
-18496	NA	52756	2143.5	NA	NA	NA	22851.42	NA	0.332	6.03	FALSE
-152524	17303	45589	NA	30206	-19814	43157	NA	NA	0.457	6.08	FALSE
50464	NA	50031	8759.1	NA	-16769	NA	NA	42933.6	0.394	6.14	FALSE
52925	NA	51663	NA	3111	-16649	NA	NA	42792.3	0.392	6.24	FALSE
-28301	NA	NA	38679.3	60792	NA	NA	NA	NA	0.257	6.50	FALSE
200612	7736	16474	NA	51023	-51182	NA	72222.52	NA	0.450	6.50	FALSE
-12343	NA	39078	17160.2	30265	NA	NA	NA	NA	0.319	6.63	FALSE
-10371	NA	50527	1116.0	NA	-32355	27549	39236.49	NA	0.447	6.68	FALSE
-6126	NA	50676	NA	NA	-32579	26909	39564.30	850.4	0.447	6.68	FALSE
-119377	15945	56688	NA	NA	-17592	34458	NA	16072.8	0.446	6.74	FALSE
-47419	NA	NA	NA	78087	-25777	31366	NA	NA	0.315	6.81	FALSE
206114	NA	21267	-6015.1	46755	-51022	NA	73795.16	NA	0.444	6.82	FALSE
-6535	5906	43442	NA	31449	NA	NA	NA	NA	0.315	6.82	FALSE
191254	NA	22416	NA	42208	-48383	NA	66175.40	5736.4	0.444	6.83	FALSE
26529	NA	42384	NA	35076	-5372	NA	NA	NA	0.315	6.84	FALSE
142700	NA	NA	11951.7	65164	-55652	15105	63734.70	NA	0.443	6.90	FALSE
-38659	12072	54817	-5352.3	NA	NA	NA	NA	35687.3	0.378	6.95	FALSE
-38995	11280	53665	NA	NA	NA	NA	-3417.77	37335.7	0.378	6.96	FALSE
-39294	10729	54894	NA	-3917	NA	NA	NA	35952.5	0.377	6.97	FALSE
244801	11895	NA	-8669.4	69147	-61360	NA	84305.42	NA	0.441	6.97	FALSE
-72161	NA	NA	42601.0	66364	-26900	33056	NA	NA	0.377	6.99	FALSE

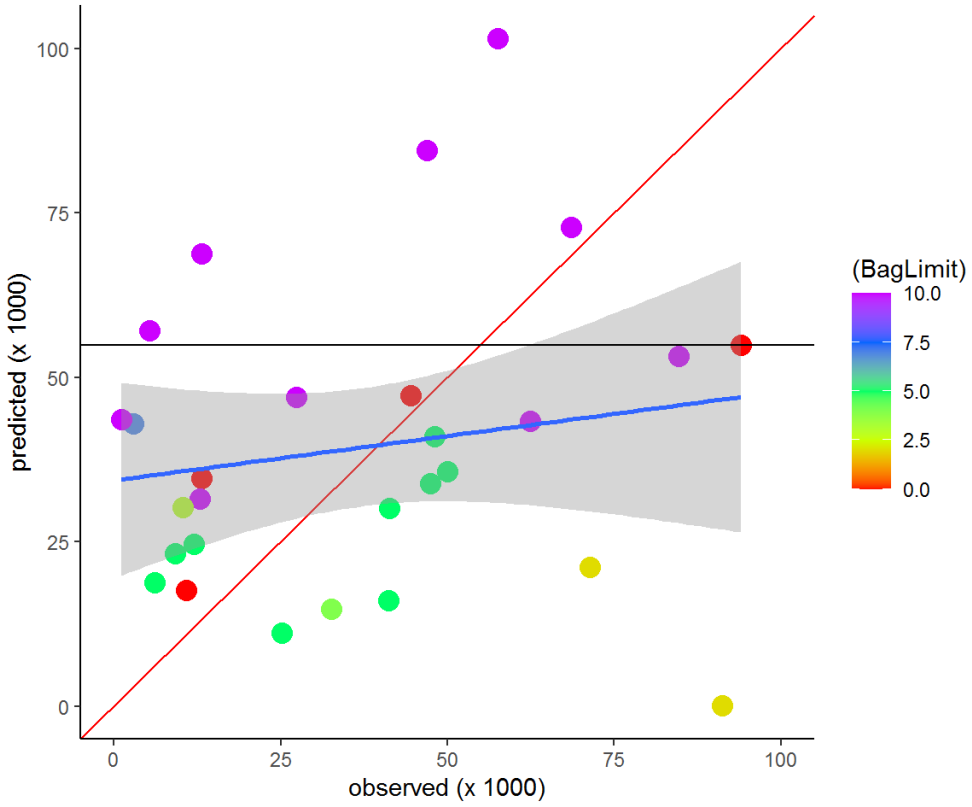
Predicted versus observed

```
##
##    The preferred model selected: 2
##
##
```

```
##
```

```
##
## Call:
## lm(formula = NSWC ~ MDB2 + SEDB + VIC + 1, data = Jc)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -54554 -21264  -4489  23228  56460
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   241657      92103    2.62   0.0141 *
## MDB2           66473      24530    2.71   0.0116 *
## SEDB          -59776      19606   -3.05   0.0051 **
## VIC            81036      26655    3.04   0.0052 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 30000 on 27 degrees of freedom
## Multiple R-squared:  0.429,  Adjusted R-squared:  0.365
## F-statistic: 6.76 on 3 and 27 DF,  p-value: 0.00151
```

```
##
##    The threshold number is 54900
##
##
##
```



From predictive models to duck population indices

Summary of predictive models

The following preferred models were selected (with R squared in brackets):

PGame ~ SEDB2 + MDB + 1 (0.415)

VicC ~ LEB2 + VIC + 1 (0.547)

NSWC ~ MDB2 + VIC +SEDB + 1 (0.429)

Calculation of the indices

Using the preferred predictive models as well as the two aerial duck counts themselves, we calculate indices that broadly inform on the current population status of ducks in SE Australia and Victoria in particular.

Threshold values for game counts in Victoria and aerial surveys for Victoria and NSW were selected above which no years ever had hunting restrictions imposed (and, conversely, below which some years, but not all, had bag limits imposed; see figures in sections 3, 4 and 5).

The five duck population indices are:

iPGame: index of game counts limited to 37 priority wetlands using the predictive model from section 3 divided by the game count threshold of 74700

iVicC: index of aerial survey for Victoria using the predictive model from section 4 divided by the threshold for these counts of 50800

iNSWC: index of aerial survey for NSW using the predictive model from section 5 divided by the threshold for these counts of 54900

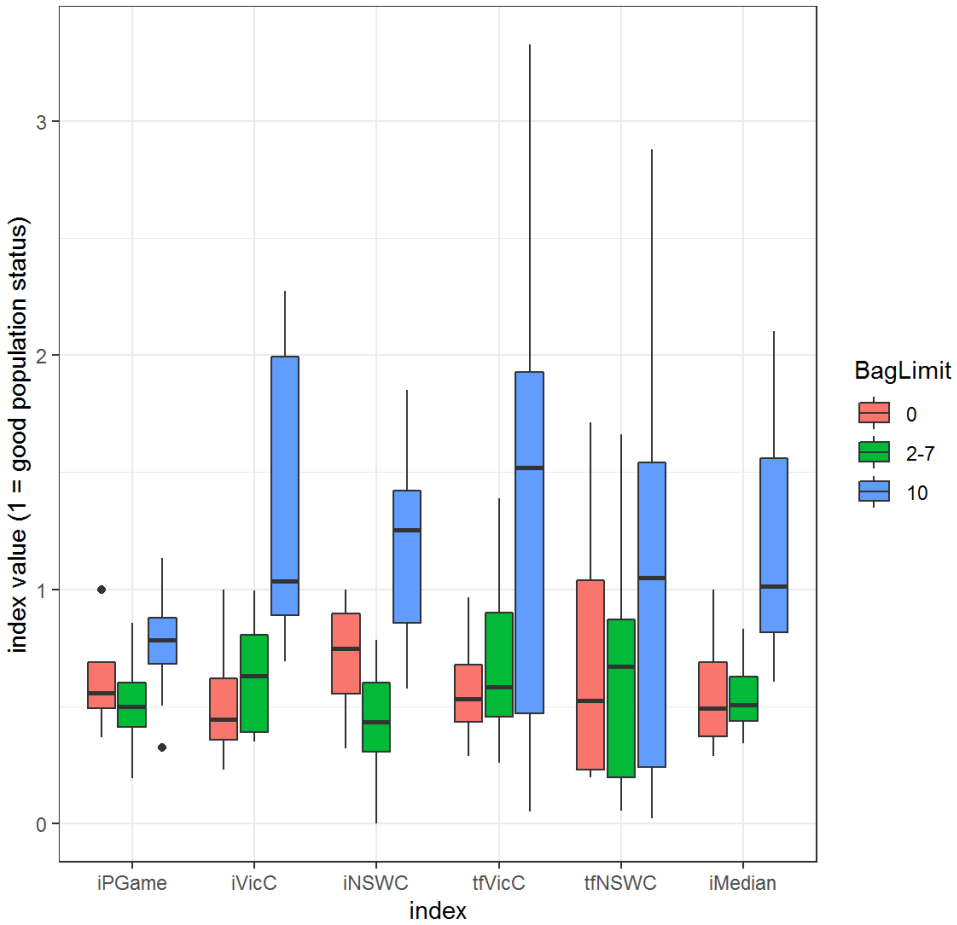
tfVicC: index of aerial survey for Victoria using actual counts divided by the threshold for these counts of 50800

tfNSWC: index of aerial survey for NSW using actual counts divided by the threshold for these counts of 54900

Index values higher than 1 indicate a good to excellent population status of ducks, while values lower than 1 indicate a poor to good population status.

Past performance of the indices

Below boxplots (depicting minimum, 25 percentile, median, 75 percentile and maximum) are presented for the five duck-population indices, as well as their median for unrestricted hunting seasons (bag limit = 10, blue) cancelled hunting season (bag limit = 0, red) and hunting seasons with restrictions (bag limit = 2-7, green).



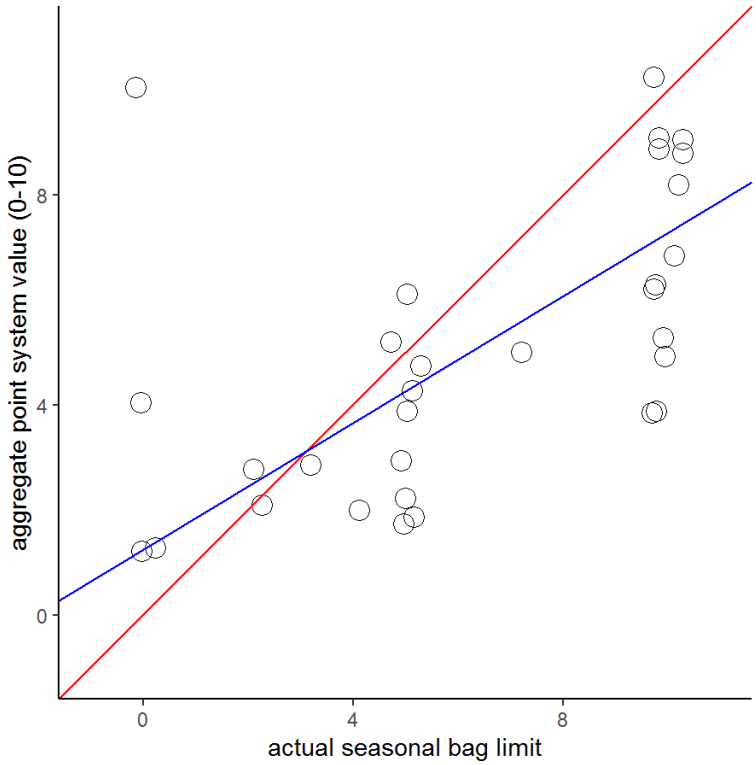
In the table below the five predicted duck population indices for the years 1991-2021 where years are ranked from most (BagLImit = 0) to least (BagLimit = 10) restricted hunting seasons (values are not considering opening weekend and species-specific regulations). The index values are colour coded with dark colours indicating good and light colours indicating poor population status. White indices relate to proxies from Victoria whereas yellow indices relate to proxies from NSW. In the final column an overall duck-population-valuation is presented using an aggregated point system (*aPS*) based on all duck population indices in each year. For more detail on the calculation of aPS see section 7.

		using water surface			using aerial counts		
Year	BagLimit	iPGame	iVicC	iNSWC	tfVicC	tfNSWC	aPS
2008	0	0.37	0.23	0.63	0.29	0.24	1
2007	0	0.53	0.40	0.32	0.48	0.20	1
2003	0	0.59	0.49	0.86	0.58	0.81	4
1995	0	1.00	1.00	1.00	0.96	1.71	10
2009	2	0.41	0.37	0.39	0.33	1.30	2
2004	2	0.43	0.44	0.00	0.84	1.66	3
2020	3	0.48	0.70	0.55	0.61	0.19	3
2016	4	0.52	0.39	0.27	0.44	0.59	2
2005	5	0.35	0.73	0.45	0.51	0.22	2
2015	5	0.36	0.35	0.42	1.03	0.17	2
2019	5	0.47	0.41	0.20	0.95	0.46	2
2010	5	0.19	0.70	0.34	1.39	0.11	3
2000	5	0.63	0.35	0.65	0.36	0.91	4
2001	5	0.63	0.85	0.29	0.55	0.75	4
2021	5	0.67	0.99	0.62	0.26	0.86	5
1998	5	0.86	0.83	0.75	0.56	0.87	5
2002	5	0.53	0.94	0.55	0.62	0.75	6
2006	7	0.52	0.57	0.78	0.92	0.05	5
2014	10	0.32	0.69	0.86	1.04	0.50	4
2017	10	0.74	1.04	0.79	0.05	0.02	4

2018	10	0.60	0.89	0.57	1.11	0.24	5
1999	10	0.87	0.90	1.04	0.10	0.10	5
2011	10	0.50	1.99	1.54	0.38	0.85	6
1997	10	0.81	0.72	1.25	1.99	0.24	6
1994	10	1.10	0.84	1.33	0.47	1.25	7
1993	10	0.88	1.62	0.79	1.76	1.14	8
2013	10	0.68	1.56	1.49	3.33	2.88	9
1992	10	0.76	2.10	1.32	2.72	2.24	9
2012	10	0.78	2.27	1.85	1.93	1.05	9
1996	10	0.88	1.01	0.97	1.52	1.54	9
1991	10	1.13	2.02	1.42	1.84	2.60	10

Actual versus proposed bag limits as calculated from the five duck population indices for the years 1991-2020. Red line depicts *actual=proposed*, while the blue line is the major axis relationship. A small amount of random variation has been added to otherwise overlapping data points to improve data presentation.

The average actual bag limit over the years was 6.2258 and the average aPS was 5. Conveniently, the aggregated point system does not deviate much from the actual bag limits between 1991 and 2021, with generally good agreement between actual bag limits and aggregated point system over this period (see Figure below).



Proposed hunting arrangement for 2022

Although some indices are less prone to error than others, collective use of these indices should adequately address the four key elements that should form part of a decision model. We thus propose to include all five indices in a highly straightforward and transparent manner in guiding decision-making for annual hunting arrangement of which seasonal bag limits form an important part. We propose to do this using an aggregate point system (*aPS*). In this system, each index with a value between 0.5 and 0.9 attracts 1 point and a value over 0.9 attracts 2 points. Given 5 indices, the maximum number of points amounts to 10, when all indices are >0.9. This aggregate point system thus provides a valuation of the overall population status of game ducks in Victoria on a scale from 0-10.

For 2022 the five indices have the following values:

- Using water surface area, the Vic priority game count prediction is: 49580, resulting in an iPGame of: “, 0.66, worth 1 aPS points.
- Using water surface area, the Vic aerial game count prediction is: 50516, resulting in an iVicC of: 0.99, worth 2 aPS points.

- Using water surface area, the NSW aerial game count prediction is: 33887, resulting in an iNSWC of: 0.62, worth 1 aPS points.
- Aerial game counts Vic amounted to: 15720 , and the concomitant tfVicC is: 0.31, worth 0 aPS points.
- Aerial game counts NSW amounted to: 21383 , and the concomitant tfNSWC is: 0.39, worth 0 aPS points.

Finally, using these five indices in the aggregated Point System calculation results in an aPS of: 4, or a daily bag limit of four ducks per day.