Using duck proxies and surface water to inform hunting arrangements for 2024

Compiled by Marcel Klaassen

Surface water data:
Roxane Francis & Richard Kingsford
University of New South Wales

Victorian Duck Season Priority Waterbird Counts:
Kasey Stamation
Arthur Rylah Institute for Environmental Research

Eastern Australian Waterbird Survey data:
John Porter & Richard Kingsford
University of New South Wales

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Contents

Important abbreviations used in this document

Counts:

- PGC: priority game counts.
- VicC: Eastern Australian Waterbird Survey counts for Victoria.
- NSWC: Eastern Australian Waterbird Survey counts for NSW.

Explanatory variables:

- VIC: average water surface area (in %) across Victoria (VIC) over the past 12 months.
- MDB: water surface area (in %) across Murray-Darling Basin over the past 12 months.
- SEDB: water surface area (in %) across SE Australia south of the Murray-Darling Basin over the past 12 months.
- LEB: water surface area (in %) across Lake Eyre Basin over the past 12 months.
- VIC2: average water surface area (in %) across Victoria (VIC) over 13 to 36 months ago.
- MDB2: water surface area (in %) across Murray-Darling Basin over 13 to 36 months ago.
- SEDB2: water surface area (in %) across SE Australia south of the Murray-Darling Basin over 13 to 36 months ago.
- LEB2: water surface area (in %) across Lake Eyre Basin over 13 to 36 months ago.

Indices:

- iPGC: index of game counts based on water surface area model.
- iVicC: index of aerial survey for Victoria based on water surface area model.
- iNSWC: index of aerial survey for NSW based on water surface area model.
- tfVicC: index of aerial survey for Victoria based on actual count data.
- tfNSWC: index of aerial survey for NSW based on actual count data.
- aPS: aggregated point system calculated using all five, duck population indices.

1 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.

In the protocol outlined in *Relationships among duck population indices and abiotic drivers to guide annual duck harvest management* by Klaassen and Kingsford (2021) we proposed to calculate five indices reflecting the above four 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 and up to three years back in time. The models underlying these three indices are updated annually, making use of the latest LANDSAT and game count data. The three indices used in the models are based on the *Victorian Duck Season Priority Waterbird Counts* (from here on Priority Game Counts or PGC), the *Eastern Australian Waterbird Survey counts for Victoria* (Victoria aerial counts or VicC) and the *Eastern Australian Waterbird Survey counts for NSW* (NSW aerial counts or NSWC).

While the first three indices are based on the availability of water in the landscape in SE Australia over the past three years, the two remaining indices are directly calculated from the 2023 VicC and NSWC data. These indices are used in setting bag limits rather than to modify season length, since alterations in season length have shown to have limited effect (see Klaassen and Kingsford (2021))

After starting with presenting the water and count data in section 2, the updated models for the first three indices are presented in section 3. Next, in section 4, we present all five indices and compare these with actual hunting regulation data over the years 1991 to 2021 and briefly evaluate their use in advising on future annual hunting arrangements.

Finally, in section 5, a proposed hunting arrangement for 2024 is presented, which suggests to implement a bag limit of nine ducks per day.

2 The data

2.1 Water surface area across SE Australia

The monthly maximum water surface area in the landscape calculated from LANDSAT imagery using the DEA Sandbox tool were kindly obtained and shared by Roxane Francis and Richard Kingsford (UNSW) for the following regions (Figure 1):

- Lake Eyre Basin catchment (LEB)
- Murray-Darling Basin catchment (MDB)
- SE Australia south of the MDB (SEDB)
- Victoria (VIC)

Figure 1: The regions across which percentage of surface water was extracted from satellite imagery.

In Figure 2, the water surface area (in %) across Victoria (VIC), Murray-Darling Basin (MDB), SE Australia south of the MDB (SEDB) and Lake Eyre Basin (LEB) is depicted. The monthly values are plotted in blue with the last three years of data plotted in red. It is these last three years of data on which the graph also zooms in, since it is this period of water availability in the landscape that is used in making predictions on duck numbers and calculation of three of the five indices. The right-aligned, 12-month rolling average for the water surface areas (i.e., annual trends in water surface area corrected for monthly variations) are depicted in green.

The interim harvest model is a statistical model. This means that duck count and water surface data over the past three decades is used to make models which are then used to make predictions on waterfowl numbers using the latest water data. Such use of models to make predictions is only allowed when the input values are not outside the range of values used to make the predictive model. While we have experienced an unprecedented third La Niña year in a row, Figure 2 shows that the current amounts of water in the landscape across most of the four regions are high but largely fall within the previously observed ranges. This supports the modelling approach taken.

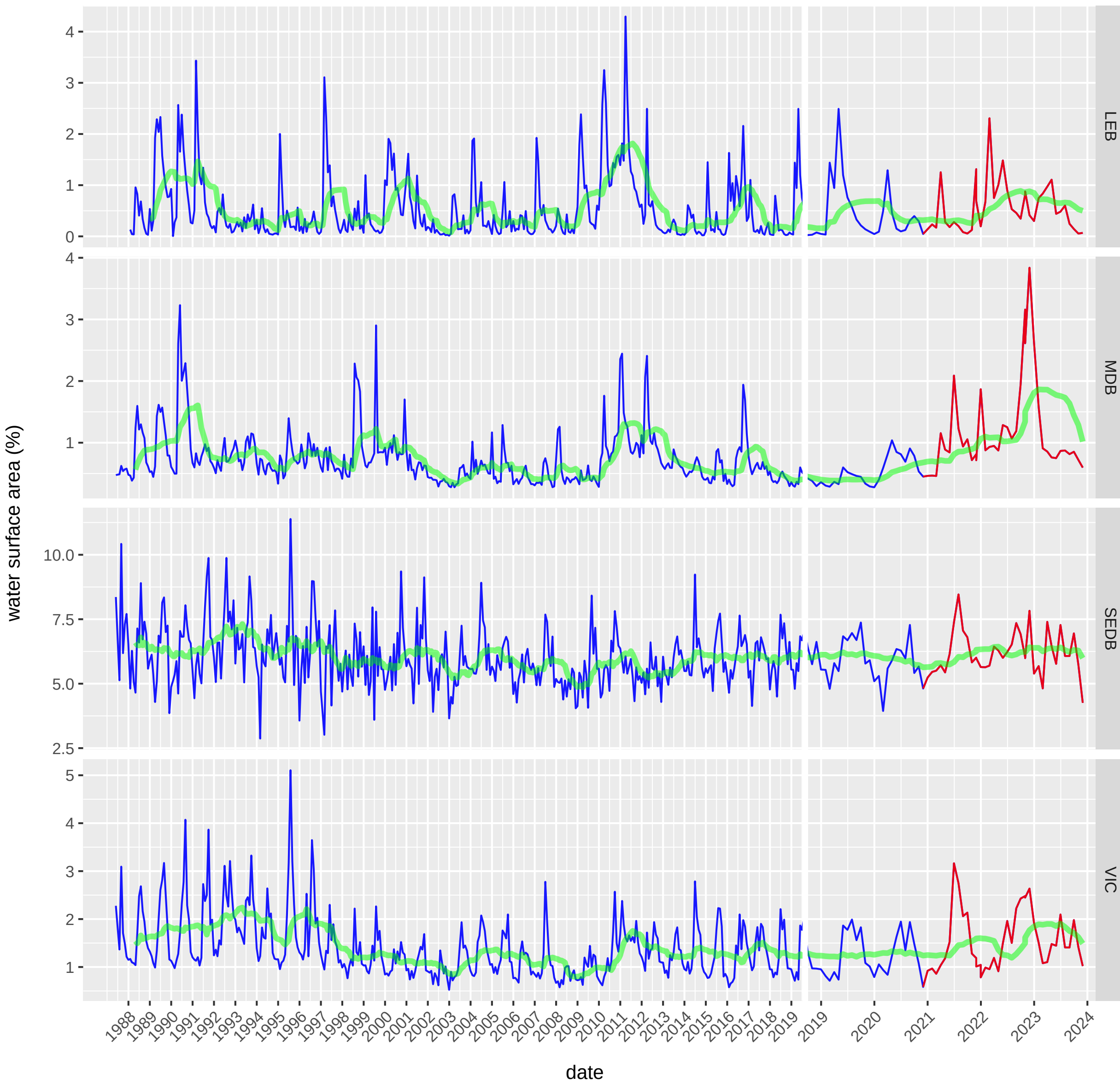

Figure 2: Percentage water surface area over time for four Australian regions considered to be of importance to duck numbers in Victoria.

2.2 Waterfowl across SE Australia

As mentioned earlier, the analyses presented here rely both on water surface data presented above and on three sets of waterbird counts of which we used counted game ducks exclusively:

- The Victorian Duck Season Priority Waterbird Counts (PGC; e.g. 2023 report), the latest available information of which was made available to the analyses presented here by Kasey Stamation (Arthur Rylah Institute for Environmental Research). These counts mostly take place in Februray, i.e., a month before the duck hunting season.
- the Victorian aerial counts (VicC) were extracted from the Eastern Australian Waterbird Survey data (EAWS; an annual aerial survey taking place in October of each year since 1983 as described in Kingsford, R. T., J. L. Porter, K. J. Brandis, and S. Ryall. 2020. Aerial surveys of waterbirds in Australia. Scientific Data 7:1-6.), with the latest 2023 update made available for the analyses by John Porter and Richard Kingsford (UNSW). From this data set we used bands 1-3 (Figure 3) to represent Victoria (and the SE of SA)
- The NSW aerial counts (NSWC) were extracted from the same EAWS data set as bands 4-6 (Figure 3) covering NSW and southern Queensland as well as the E of SA bordering NSW.

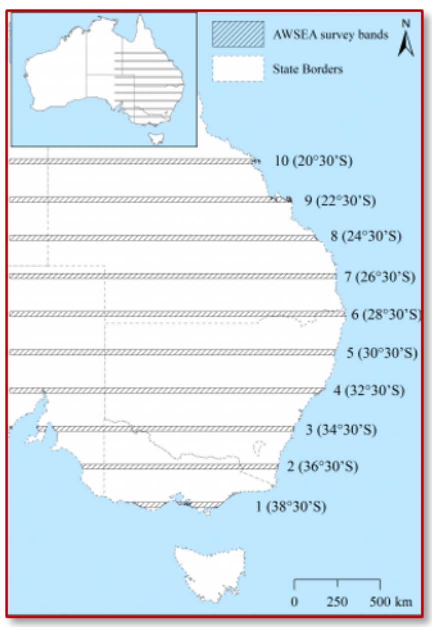

Figure 3: EAWS survey bands across the east of Australia.

In Figure 4 below, an overview of the count data used in the modelling and starting 1991 is presented. Also presented in this figure are the bag limits set over the period 1991-2022.

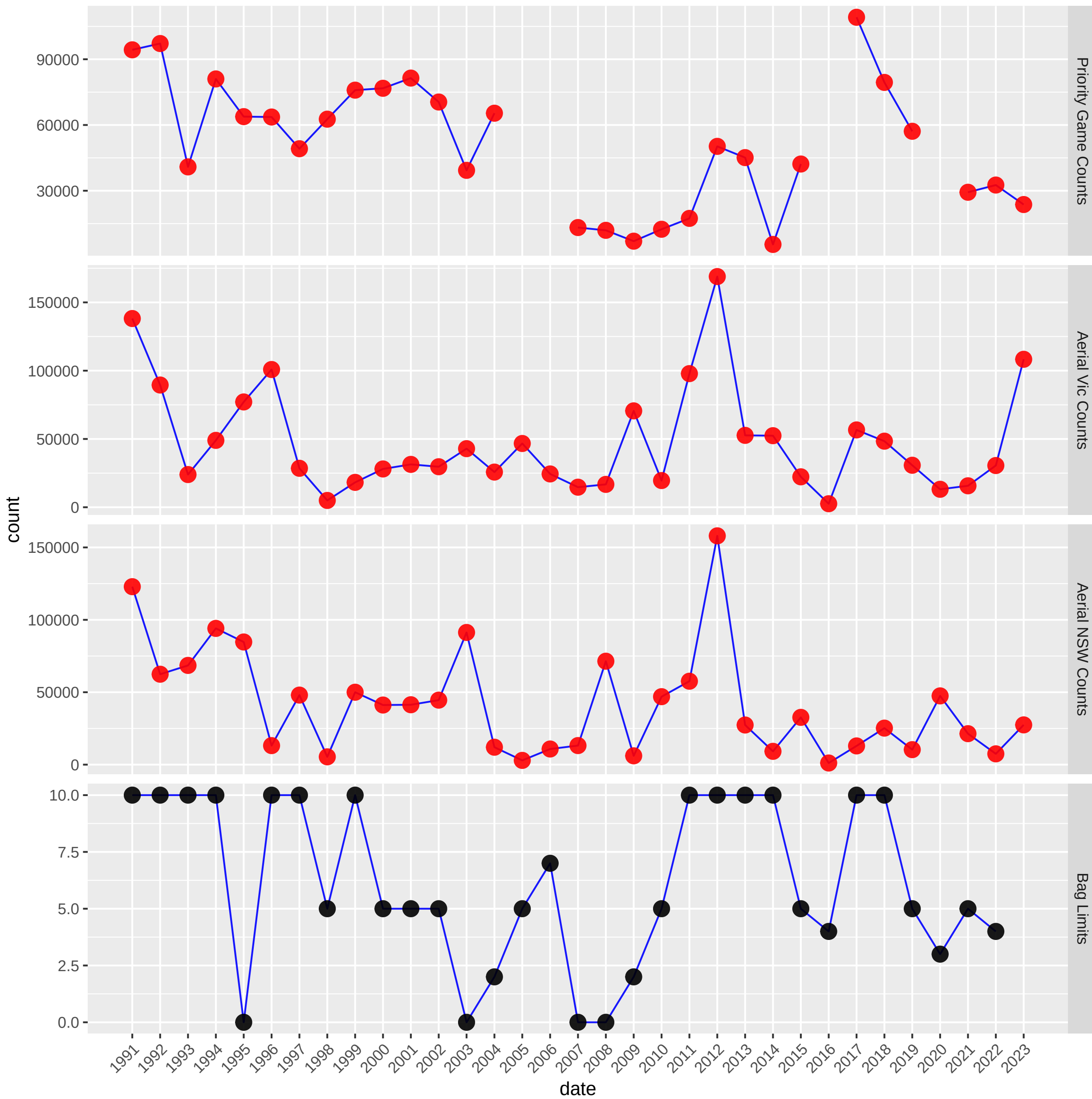

Figure 4: Overview of all the count data used in the modelling as well as the bag limits that have been imposed (note that there are some years without data for the Priority Game Counts and that for bag limits the year prior to the season is used.

3 The models and thresholds

3.1 Predictive models for priority game counts

We used linear modelling to conduct a regression across all priority game count data across 44 priority wetlands for the years in which water surface data was also available for all four regions. Water surface area was time-shifted by 4 months. This was done to allow already predicting in December what the expected duck numbers are going to be in March the following year, from which sensible hunting arrangements can next be gauged.

We ran models using the average water surface area over the preceding 12 months for all four regions (designated by the respective region codes LEB, MDB, SEDB and VIC) as explanatory variables. For all four regions, we also used the average water surface area over the period 13-36 months (i.e., 2 years of water data) prior to the "decision" point in December (designated by LEB2, MDB2, SEDB2 and VIC2). All possible combinations of these 8 explanatory *water surface* variables were tested.

We first present a correlation chart (Figure 5) for all variables used in the models, including their Pearson correlation coefficients. This correlation chart not only depicts the direct, one-on-one relationships between counts and the various water-surface-area explanatory variables, but also between each of the explanatory variables. It, for instance, highlights that water surface area in VIC is highly correlated with water surface area in SEDB. Thus, a model that for instance would include SEDB water data only, indirectly also includes a lot of "water information" from the whole of VIC. Next, in Table 1, we present the 25 best models ranked by their deltaAIC value, which is a measure of how good a model fits the data. Models with a deltaAIC between 0 and 2 are considered models with substantial statistical support and models with a score between 2 and 7 to have moderate statistical support only.

In Table 1, the use of a red font indicates models where all explanatory variables have a $P<0.05$. The orange columns indicate variables where we a priori expected a possible effect; for the Victorian priority game counts we would possibly expect to see effects of water surface area over the past three years in VIC, SEDB and the MDB but less so for LEB given that it is quite distant to Victoria.

We ultimately selected a model as the best fitting model when it:

1. was high ranking (i.e., had a low deltaAIC),
2. had significant and preferably positive parameter estimates for all its parameters (not considering the intercept),
3. had a high adjR2 or R-squared, indicating that the model explains a large percentage of the variation in the data.

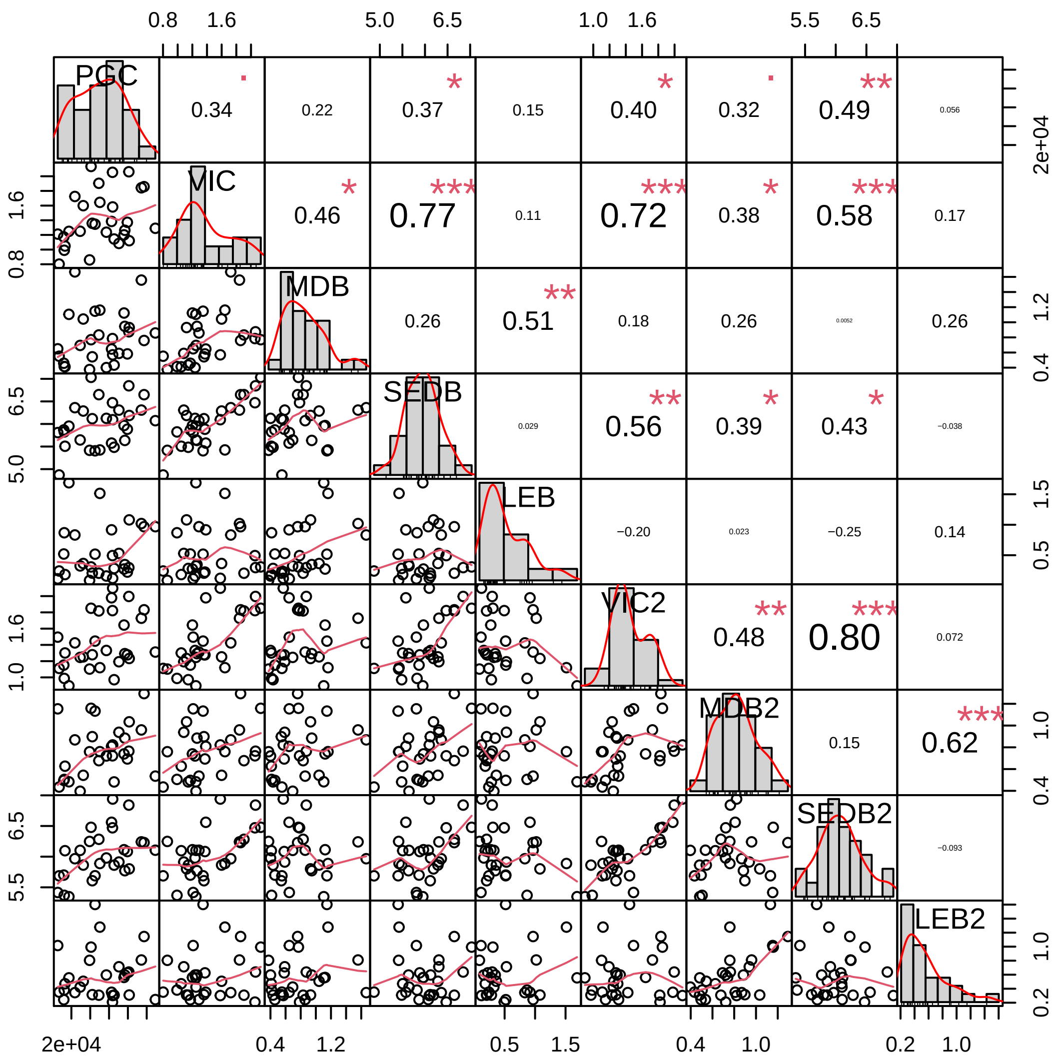

Figure 5: Correlation chart depicting the correlations between the annual game counts (PGC) and all eight explanatory water surface variables used in the models. Frequency distributions of the variables are depicted on the diagonal and the Pearson correlation coefficients presented in the top right half of the matrix. Stars indicate significance levels (* P<0.05, ** P<0.01, *** P<0.001).

Table 1: Top 25 models predicting game counts in Victorian priority wetlands ranked starting with best model (top row) first. The first nine columns present the estimated intercept and slopes for all eight explanatory water surface variables. NA indicates the variable was absent from the model. The three final columns contain quality indicators of each model: R squared, delta AIC and whether all model slopes were significantly different from zero (in which case the row values are depicted in red).

(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	delta	AllSignif
-207806	19628	NA	NA	NA	NA	41326	NA	NA	0.318	0.00	FALSE
-165924	NA	NA	NA	NA	NA	36130	NA	NA	0.240	0.42	TRUE
-211467	18603	NA	NA	28253	NA	38420	NA	NA	0.370	0.65	FALSE
-172206	NA	NA	NA	30341	NA	33301	NA	NA	0.300	0.74	FALSE
-180366	NA	NA	18937	NA	NA	36048	NA	NA	0.287	1.29	FALSE
-198498	NA	NA	NA	NA	11690	29907	NA	NA	0.272	1.91	FALSE
-229879	18144	NA	NA	NA	9058	36111	NA	NA	0.336	2.16	FALSE
-259922	NA	NA	NA	46619	NA	53166	NA	-31283	0.330	2.45	FALSE
-182008	NA	NA	14289	25053	NA	33732	NA	NA	0.325	2.64	FALSE
-206638	16078	NA	8401	NA	NA	40349	NA	NA	0.325	2.66	FALSE
-291452	18045	NA	NA	43376	NA	56647	NA	-28945	0.395	2.70	FALSE
-175291	NA	8715	NA	NA	NA	36837	NA	NA	0.251	2.72	FALSE
-212755	19021	5809	NA	NA	NA	41636	NA	NA	0.323	2.75	FALSE
-152843	NA	NA	NA	NA	NA	32272	7221	NA	0.246	2.92	FALSE
-212008	20049	NA	NA	NA	NA	42411	-1823	NA	0.318	2.93	FALSE
-202307	19629	NA	NA	NA	NA	39932	NA	2040	0.318	2.93	FALSE
-160489	NA	NA	NA	NA	NA	34752	NA	2016	0.241	3.12	FALSE
2243	NA	NA	NA	NA	NA	NA	NA	34800	0.162	3.28	TRUE
-189756	NA	NA	NA	25799	6636	30192	NA	NA	0.309	3.32	FALSE
-239441	21158	NA	NA	33336	NA	44955	-11850	NA	0.381	3.34	FALSE
-203148	19408	-11365	NA	38774	NA	36730	NA	NA	0.380	3.39	FALSE
-165190	NA	-7958	NA	37771	NA	31963	NA	NA	0.305	3.47	FALSE
-201057	NA	NA	15810	NA	8282	31653	NA	NA	0.301	3.64	FALSE
-175382	NA	NA	NA	31097	NA	34121	-1667	NA	0.301	3.67	FALSE
-221039	18034	NA	NA	25529	4073	36355	NA	NA	0.373	3.72	FALSE

3.2 Predicted versus observed PGC and threshold calculation

Based on the three criteria listed above we discarded model 1 (since not all parameter estimates were significantly different from zero) and selected model 2 as the preferred model. The critical statistics for this model are presented below, along with a plot of the predicted versus the observed Victorian Game counts. In this graph (Figure 6), the symbol colour reflects hunting bag limits for the season (not considering potential separate limitations for individual species and special restrictions during opening weekend). The 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. The black horizontal line is the threshold for the dependent variable, reflecting the lower limit above which unlimited seasons were called. The black square symbol resembles data for 2023. Since hunting bag limits were based on this methodology starting with the 2022 hunting season, the hunting bag limits for 2022 and 2023 were discarded in calculating the threshold.

Game counts in 2023 turned out lower than average and came out at 23705 or on the 24.1 percentile of all counts.

As expected, since adding a single year to the existing data set of 28 years is unlikely to change the outcome by much, the current model is very similar to the models calculated in 2021 and 2022 (as reported in Using duck proxies and surface water to inform hunting arrangements (Klaassen & Kingsford 2021) and Using duck proxies and surface water to inform hunting arrangements for 2023 (Klaassen 2022)) with a strong effect of SEDB2. The weak effect of MDB present in previous years, was no longer detectable with the addition of the 2023 data. The threshold value for the Victorian Game counts increased from 74,700 in 2021 and 77,000 in 2022 to 84,800 in 2023. This threshold value was calculated by taking the highest predicted PGC amongst years in which hunting restrictions were in place (i.e., the bag limit was less than 10; all non-purple symbols in Figure 6).

Observations	29
Dependent variable	PGC
Type	OLS linear regression

$F(1,27)$	8.55
R^2	0.24
Adj. R^2	0.21

	Est.	S.E.	t val.	p
(Intercept)	-165924.03	74580.43	-2.22	0.03
SEDB2	36130.28	12358.08	2.92	0.01

Standard errors: OLS

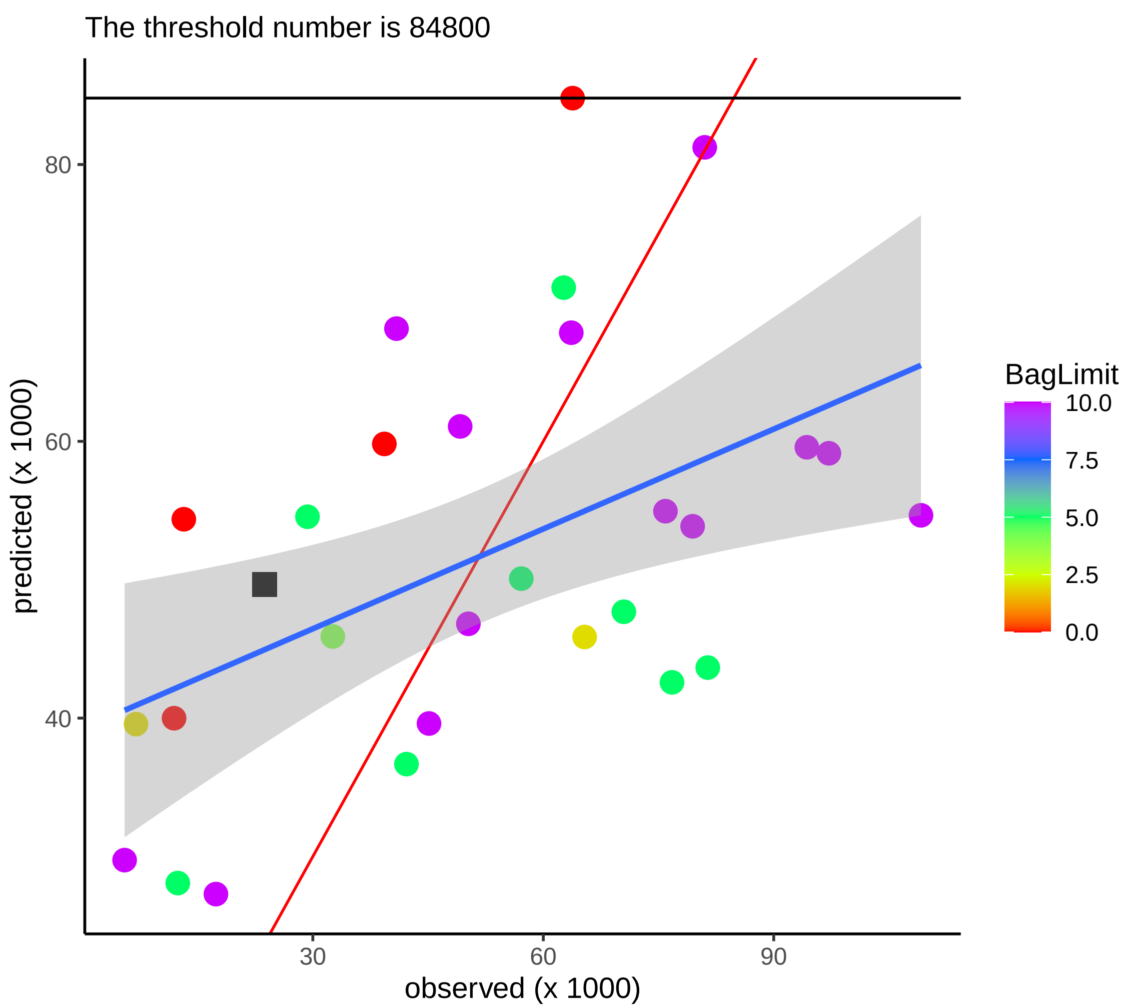

Figure 6: Predicted versus observed Victorian Game counts, where symbol colour corresponds with the season's hunting bag limit, and black square is the data for 2023. The red line is observed=predicted and the blue line is the linear regression relationship (with 95 percent confidence interval). The black horizontal line is the threshold or lower limit above which unlimited seasons were called.

3.3 Predictive models for aerial Victorian counts

We ran models analogous to what we presented above for the "Water surface areas and game counts in priority wetlands". The selection of the preferred model also followed the same selection criteria. We again present a correlation chart (Figure 7) for all variables used in the models, including their Pearson correlation coefficients as well as a table (Table 2) presenting the 25 best models, starting with the best model (deltaAIC=0).

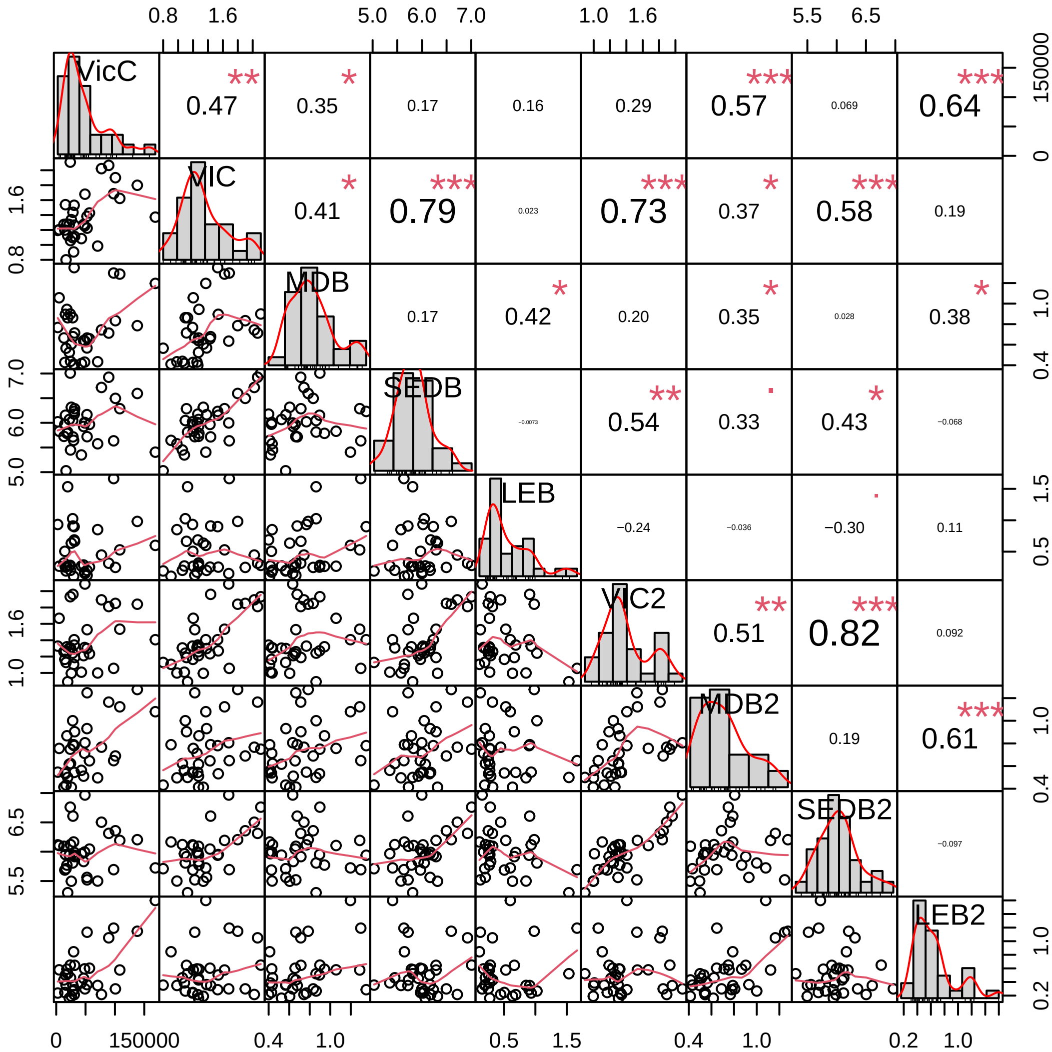

Figure 7: Correlation chart depicting the correlations between the annual EAWScounts for Victoria (VicC) and all eight explanatory water surface variables used in the models, with frequency distributions of the variables depicted on the diagonal and the Pearson correlation coefficients presented in the top right half of the matrix.

Table 2: Top 25 models predicting annual EAWS counts for Victoria ranked starting with best model (top row) first. The first nine columns present the estimated intercept and slopes for all eight explanatory water surface variables. NA indicates the variable was absent from the model. The three final columns contain quality indicators of each model: R squared, delta AIC and whether all model slopes were significantly different from zero (in which case the row values are depicted in red).

(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	delta	AllSignif
209986	NA	NA	NA	99514	-55472	NA	126456	-55644	0.613	0.00	TRUE
-46132	NA	65532	NA	NA	NA	NA	42567	NA	0.535	0.24	TRUE
353610	NA	NA	NA	77302	-53229	-33210	112768	NA	0.595	1.51	TRUE
47861	NA	59535	NA	NA	-20323	NA	65185	NA	0.553	1.79	FALSE
245959	NA	NA	-23097	108847	-62003	NA	144274	-63714	0.629	1.84	FALSE
-53223	NA	55078	NA	26750	NA	NA	37422	NA	0.551	1.92	FALSE
88573	NA	39479	NA	42818	-31580	NA	69478	NA	0.587	2.18	FALSE
28798	NA	62078	NA	NA	NA	-14553	52850	NA	0.547	2.20	FALSE
157086	NA	20667	NA	76127	-44252	NA	108281	-43541	0.625	2.24	FALSE
-50069	8835	64413	NA	NA	NA	NA	42548	NA	0.543	2.47	FALSE
249767	NA	27534	NA	52506	-39022	-25122	93649	NA	0.619	2.77	FALSE
-43559	NA	65250	NA	NA	NA	NA	46837	-5977	0.536	2.96	FALSE
-45652	NA	66080	-2275	NA	NA	NA	43223	NA	0.536	3.02	FALSE
203535	5245	NA	NA	98487	-54883	NA	123209	-51731	0.616	3.05	FALSE
255701	NA	NA	NA	94813	-55192	-9835	125878	-44243	0.615	3.06	FALSE
175151	NA	NA	NA	78945	-51266	NA	88374	NA	0.530	3.42	TRUE
157155	NA	54208	NA	NA	-23843	-18066	81868	NA	0.570	3.49	FALSE
409869	NA	NA	-21419	82937	-59023	-38343	127940	NA	0.609	3.62	FALSE
35198	NA	49356	NA	30833	NA	-17384	48920	NA	0.567	3.72	FALSE
-46965	NA	48318	NA	41218	NA	NA	51393	-23451	0.563	3.99	FALSE
-58856	10739	52470	NA	29943	NA	NA	36785	NA	0.562	4.09	FALSE
43800	8806	58428	NA	NA	-20294	NA	65134	NA	0.560	4.22	FALSE
244065	13124	NA	-32245	109974	-63114	NA	143208	-57118	0.642	4.24	FALSE
86965	11768	36118	NA	46834	-32597	NA	69812	NA	0.600	4.32	FALSE
194448	NA	19621	-22269	86311	-51117	NA	126381	-51935	0.640	4.42	FALSE

3.4 Predicted versus observed VicC and threshold calculation

Based on the criteria set out earlier we selected model 2 as the preferred model (since model 1 had multiple negative parameter estimates) for which we present the critical statistics below, followed by a plot of the predicted versus the observed EAWS counts for Victoria (Figure 8).

The EAWS count for Victoria in 2023 was the third highest since 1991, amounting to 108329, which was exactly at the 93.9 percentile of all counts used in the analyses.

Also here, adding a single year to the existing data set of 32 years did not result in a major change to this model compared to the two reported in previous years (Klaassen & Kingsford 2021 and Klaassen 2022). The explanatory variables remained unchanged (LEB2 and VIC) and the threshold value is similar (54,100 compared to 50,800 and 50,300 in previous years).

Observations	33
Dependent variable	VicC
Type	OLS linear regression

F(2,30)	17.28
R^2	0.54
Adj. R^2	0.50

	Est.	S.E.	t val.	p
(Intercept)	-46131.73	21316.22	-2.16	0.04
LEB2	65532.46	14515.87	4.51	0.00
VIC	42566.87	15088.86	2.82	0.01

Standard errors: OLS

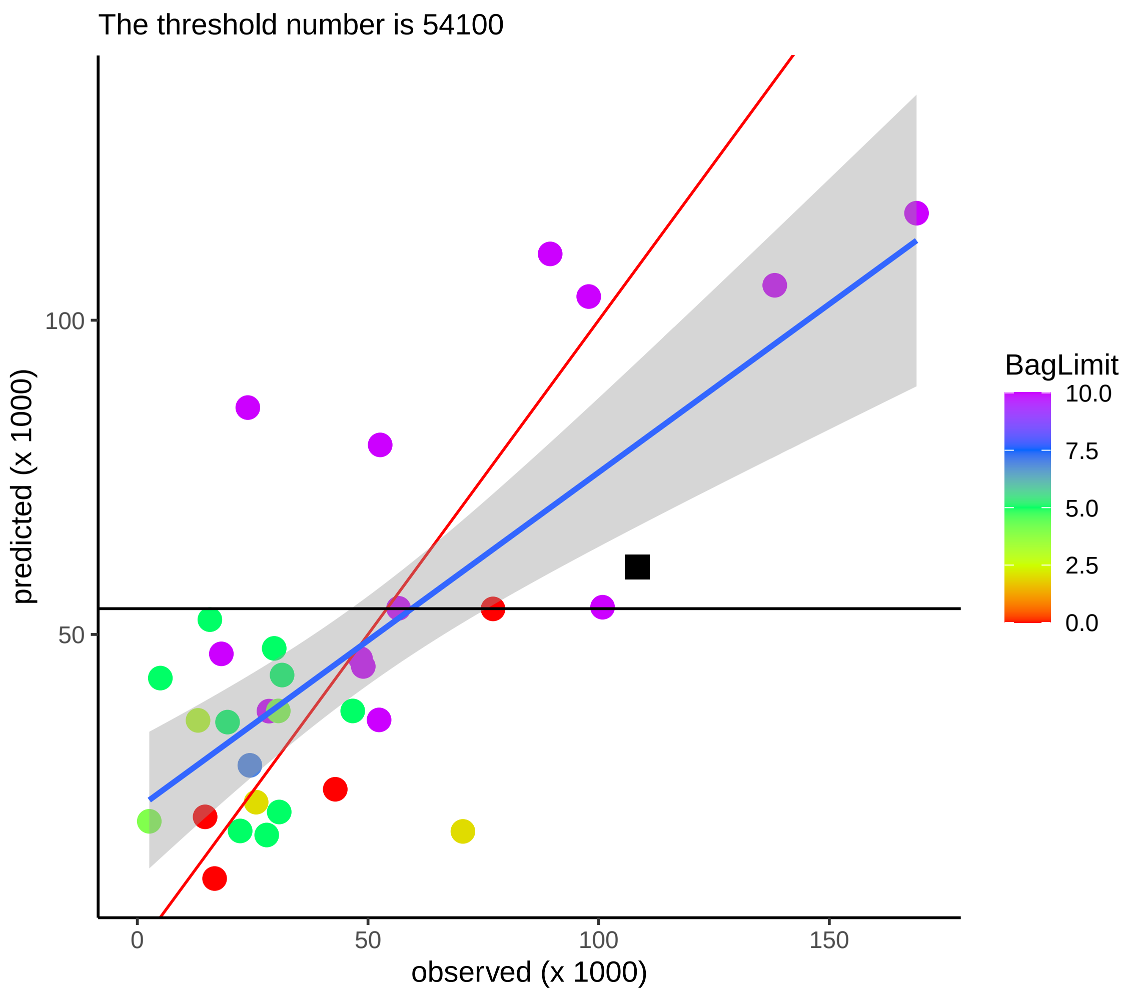

Figure 8: Predicted versus observed EAWS counts for Victoria, where symbol colour corresponds with the season's hunting bag limit, and black square is the data for 2022. The red line is observed equals predicted and the blue line is the linear regression relationship (with 95 percent confidence interval). The black horizontal line is the threshold or lower limit above which unlimited seasons were called.

3.5 Predictive models for aerial NSW counts

We again ran a series of models analogous to the above, differing in that they now predict annual EAWS counts from NSW from water surface areas across the four regions. The selection of the preferred model again followed the same selection criteria presented earlier. We present a correlation chart (Figure 9) for all variables used in the models, including their Pearson correlation coefficients as well as a table (Table 3) presenting the 25 best models.

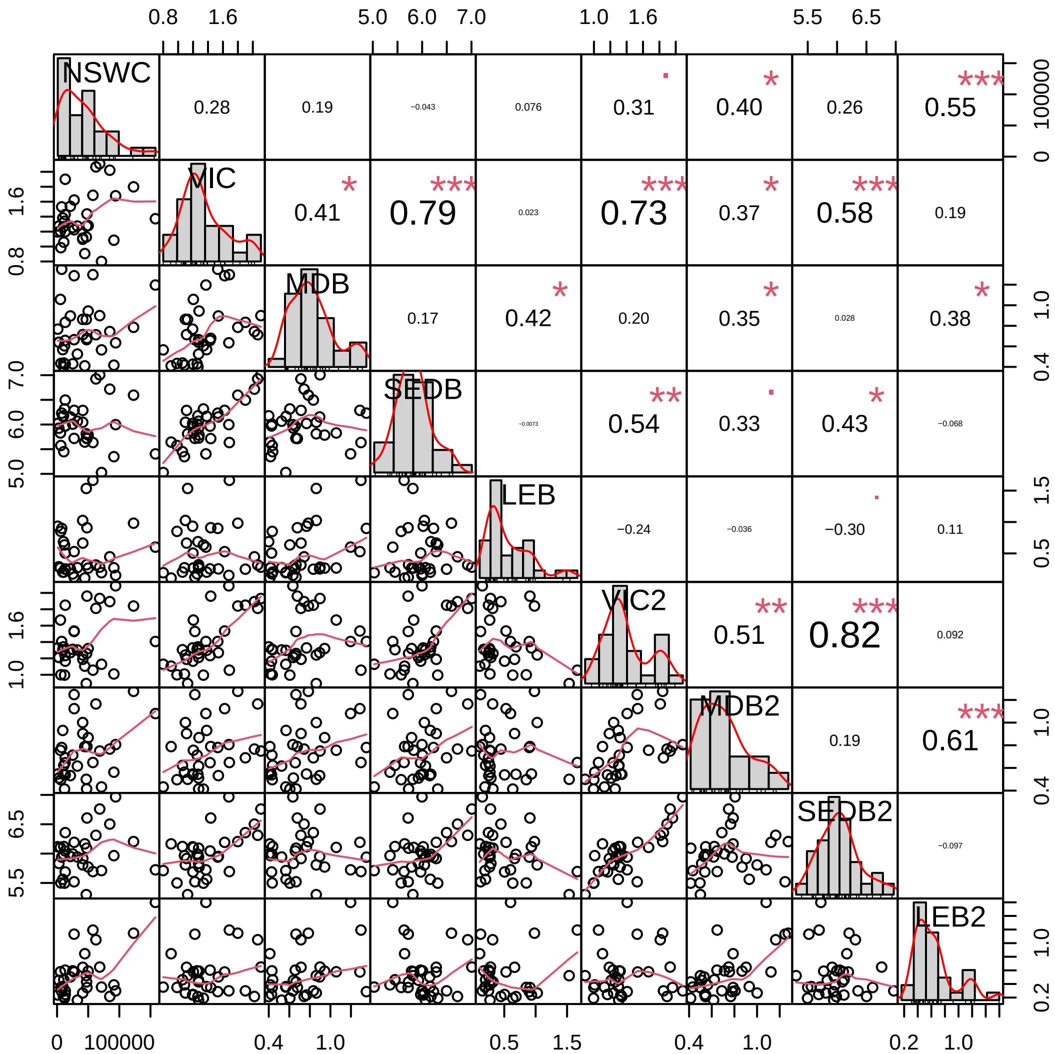

Figure 9: Correlation chart depicting the correlations between the annual EAWScounts for NSW (NSWC) and all eight explanatory water surface variables used in the models, with frequency distributions of the variables depicted on the diagonal and the Pearson correlation coefficients presented in the top right half of the matrix.

Table 3: Top 25 models predicting annual EAWScounts for NSW ranked starting with best model (top row) first. The first nine columns present the estimated intercept and slopes for all eight explanatory water surface variables. NA indicates the variable was absent from the model. The three final columns contain quality indicators of each model: R squared, delta AIC and whether all model slopes were significantly different from zero (in which case the row values are depicted in red).

(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	delta	AllSignif
-181652.8	NA	62559	NA	NA	NA	31594	NA	NA	0.398	0.00	TRUE
-138602.6	NA	62067	NA	NA	-14535	39006	NA	NA	0.422	1.44	FALSE
-30862.7	NA	56635	NA	NA	NA	NA	NA	30080	0.365	1.73	FALSE
-207071.1	11013	61518	NA	NA	NA	34978	NA	NA	0.410	2.10	FALSE
9567.4	NA	59219	NA	NA	NA	NA	NA	NA	0.299	2.43	TRUE
-179876.0	NA	64370	-6051	NA	NA	31880	NA	NA	0.399	2.70	FALSE
-188663.3	NA	63417	NA	NA	NA	33497	-3523	NA	0.398	2.76	FALSE
-188254.1	NA	62914	NA	NA	NA	33170	NA	-2184	0.398	2.79	FALSE
-182465.3	NA	63341	NA	-1762	NA	31877	NA	NA	0.398	2.79	FALSE
59492.4	NA	53878	NA	NA	-17987	NA	NA	43797	0.397	2.84	FALSE
159854.4	NA	44233	NA	NA	-38066	NA	62511	NA	0.397	2.85	FALSE
-13848.0	NA	52698	NA	NA	-32473	28713	35997	NA	0.446	3.05	FALSE
-164313.7	13494	60728	NA	NA	-16369	44088	NA	NA	0.440	3.38	FALSE
-16198.2	NA	55467	NA	NA	NA	NA	20146	NA	0.330	3.55	FALSE
254535.3	NA	NA	NA	57848	-61015	NA	79915	NA	0.379	3.78	TRUE
-37817.4	8072	55396	NA	NA	NA	NA	NA	32561	0.372	4.17	FALSE
-126529.0	NA	56563	NA	12241	-16705	38146	NA	NA	0.425	4.27	FALSE
-30032.6	NA	63148	NA	-16395	NA	NA	NA	35697	0.370	4.27	FALSE
-93546.7	NA	59923	NA	NA	-16721	30912	NA	12763	0.425	4.27	FALSE
-26943.0	NA	59485	-10109	NA	NA	NA	NA	31525	0.370	4.30	FALSE
136234.4	NA	46290	NA	NA	-35557	NA	39775	27916	0.424	4.35	FALSE
-138717.3	NA	62459	-1291	NA	-14368	38982	NA	NA	0.422	4.44	FALSE
-30041.9	NA	56984	NA	NA	NA	NA	-2835	32167	0.366	4.51	FALSE
-213622.6	16004	66106	-16914	NA	NA	37311	NA	NA	0.420	4.53	FALSE
772.1	NA	51877	NA	17209	NA	NA	NA	NA	0.307	4.65	FALSE

3.6 Predicted versus observed NSWC and threshold calculation

Based on the criteria set out earlier we selected model 1 as the preferred model for which we present the critical statistics below, followed by a plot of the predicted versus the observed EAWS counts for Victoria (Figure 10).

The EAWS count for NSW in 2023 turned out higher than last year's and was close to average at 27453 or at the 48.5 percentile of all counts.

Thus, also in this case, adding an additional year to the existing data set of 32 years did not result in a change of model compared to the one reported last year in Klaassen 2022, with only a moderate change in threshold from 54,900 in 2021 and 67,000 in 2022 to 66,000 this year.

Observations	33
Dependent variable	NSWC
Type	OLS linear regression

F(2,30)	9.91
R^2	0.40
Adj. R^2	0.36

	Est.	S.E.	t val.	p
(Intercept)	-181652.76	86613.95	-2.10	0.04
LEB2	62559.49	15424.72	4.06	0.00
SEDB2	31594.09	14219.53	2.22	0.03

Standard errors: OLS

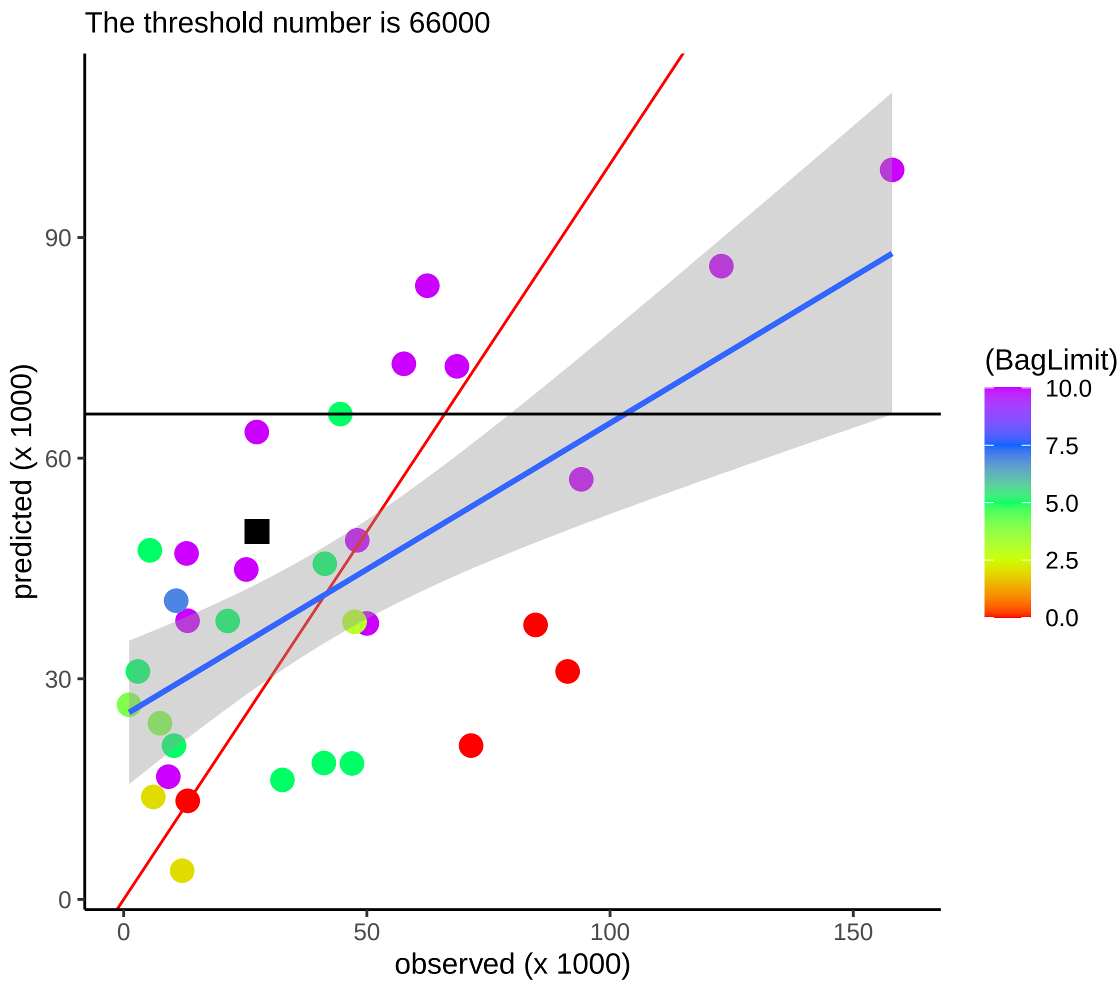

Figure 10: Predicted versus observed EAWS counts for NSW, where symbol colour corresponds with the season's hunting bag limit, and black square is the data for 2022. The red line is observed equals predicted and the blue line is the linear regression relationship (with 95 percent confidence interval). The black horizontal line is the threshold or lower limit above which unlimited seasons were called.

4 From predictive models to duck population indices

4.1 Summary of predictive models

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

PGC ~ SEDB2 (0.24)

VicC ~ LEB2 + VIC (0.54)

NSWC ~ LEB2 + SEDB2 (0.40)

It should be noted that in all models, long-term patterns in water availability (i.e., water in the landscape 2-3 years prior to the counts) appear crucial. Indeed, in the case of NSWC, water in the landscape 12-36 months prior to the counts appeared to be solely responsible for the number of birds counted.

Moreover, it should be noted that in all cases the birds counted not only depend on the local availability of habitat, but also on conditions elsewhere in SE Australia. Indeed, for PGC the water availability across Victoria as a whole was not in the top model. Similarly, for NSWC water surface area in NSW was also not in the preferred model. Also here, it should again be stressed that water surface areas in the different regions tended to be (highly) correlated (cf. Figure 3, 6 and 8).

Finally, given the nomadic nature of some duck species and populations, local duck numbers may rely on water availability in distant regions, as exemplified by the effect of LEB2 on both VicC and NSWC.

4.2 Calculation of the indices

Using the preferred predictive models as well as the two aerial game duck counts themselves, following the protocol outlined in *Relationships among duck population indices and abiotic drivers to guide annual duck harvest management* by Klaassen and Kingsford (2021) we calculated 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 in which restrictions on the prescribed bag limit of 10 were imposed (and, conversely, below which some years, but not all, had bag limit restrictions imposed; see figures 5, 8 and 10 in section 3.2, 3.4 and 3.6, respectively).

The five duck population indices are:

- iPGC: index of game counts limited to 44 priority wetlands using the predictive model from section 3.2 divided by the game count threshold of 84800
- iVicC: index of aerial survey for Victoria using the predictive model from section 3.4 divided by the threshold for these counts of 54100
- iNSWC: index of aerial survey for NSW using the predictive model from section 3.6 divided by the threshold for these counts of 66000

- **tfVicC**: index of aerial survey for Victoria using actual counts divided by the threshold for these counts of 54100
- **tfNSWC**: index of aerial survey for NSW using actual counts divided by the threshold for these counts of 66000

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.

4.3 Past performance of the indices

Below, in Figure 11, boxplots are presented for the five duck-population indices, as well as the median of these five indices. For all six of these, three box plots are drawn, one for hunting seasons in which the prescribed bag limit was not reduced from 10 (bag limit = 10, blue), one for cancelled hunting season (bag limit = 0, red) and one for hunting seasons where the bag limit was reduced from the prescribed limit of 10 (bag limit = 2-7, green).

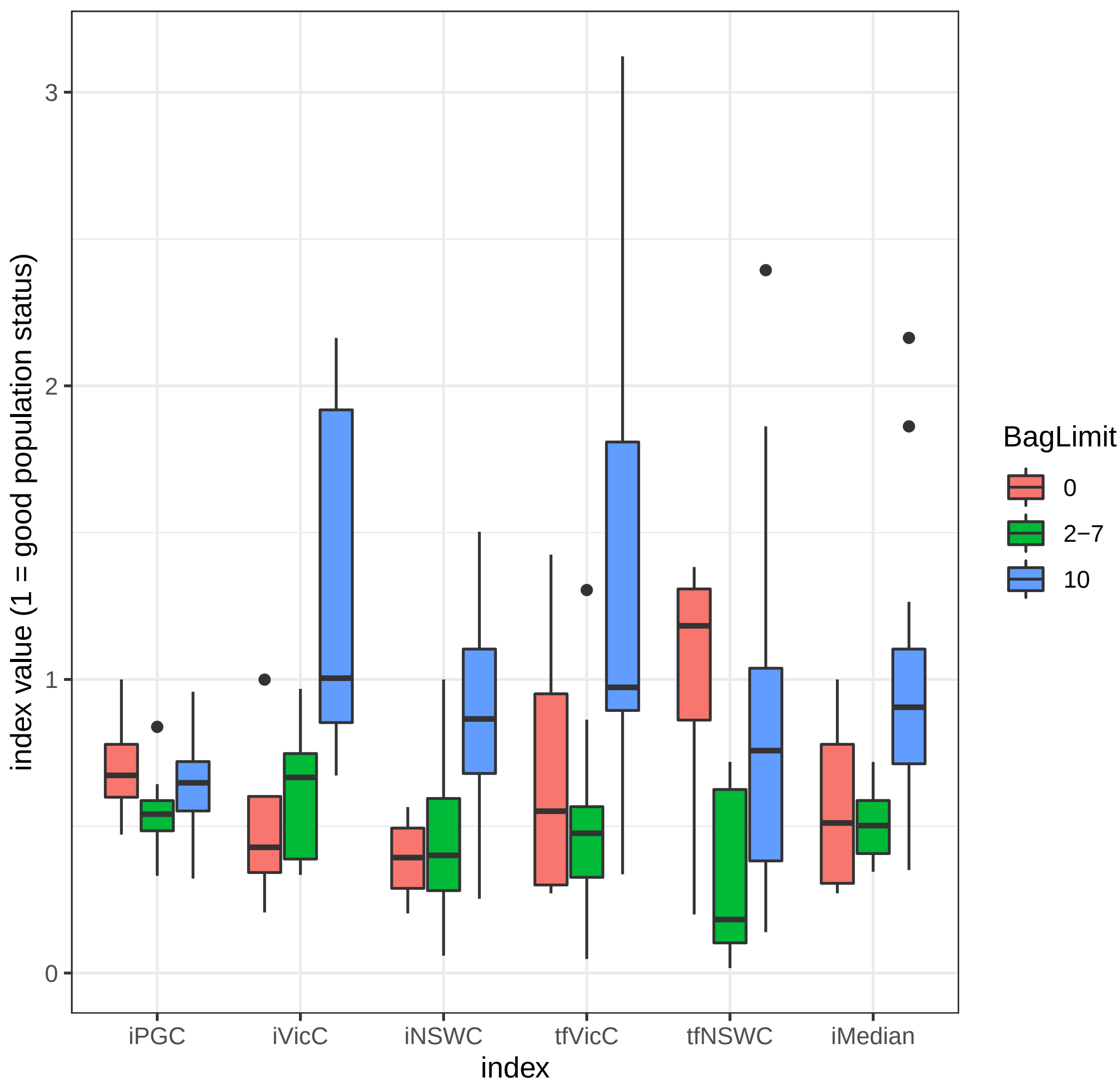

Figure 11: Boxplots of the five duck-population indices and their median separated for years without hunting (bag limit=0), where bag limits were not reduced from 10 and reduced bag limit levels. Boxplots depict minimum, 25 percentile, median, 75 percentile and maximum values as well as outliers.

Table 4: Overview of the annual bag limits, the five predicted duck population indices, as well as the aggregated point system for the years 1991-2021. Years are ranked by their bag limit.

		using water surface			using aerial counts		
Year	BagLimit	iPGC	iVicC	iNSWC	tfVicC	tfNSWC	aPS
2007	0	0.64	0.39	0.20	0.27	0.20	1
2008	0	0.47	0.21	0.32	0.31	1.08	2
2003	0	0.71	0.47	0.47	0.79	1.38	4
1995	0	1.00	1.00	0.57	1.43	1.28	9
2004	2	0.54	0.43	0.06	0.48	0.18	1
2009	2	0.47	0.34	0.21	1.30	0.09	2
2020	3	0.60	0.67	0.57	0.24	0.72	4
2016	4	0.58	0.37	0.40	0.05	0.02	1
2022	4	0.54	0.70	0.36	0.56	0.11	3
2015	5	0.43	0.35	0.25	0.41	0.49	0
2010	5	0.33	0.67	0.28	0.36	0.71	2
2005	5	0.37	0.70	0.47	0.86	0.04	2
2019	5	0.59	0.40	0.32	0.57	0.16	2
2000	5	0.50	0.33	0.28	0.52	0.62	3
1998	5	0.84	0.80	0.72	0.09	0.08	3
2021	5	0.64	0.97	0.57	0.29	0.32	4
2001	5	0.51	0.80	0.69	0.58	0.63	5
2002	5	0.56	0.88	1.00	0.55	0.67	6
2006	7	0.55	0.54	0.62	0.45	0.16	3
2014	10	0.35	0.67	0.25	0.97	0.14	3
2018	10	0.64	0.85	0.68	0.89	0.38	4
1999	10	0.65	0.87	0.57	0.34	0.76	4
1997	10	0.72	0.70	0.74	0.53	0.73	5
2013	10	0.47	1.48	0.96	0.97	0.41	6
2017	10	0.64	1.00	0.71	1.05	0.20	6
1996	10	0.80	1.00	0.57	1.86	0.20	6
2011	10	0.32	1.92	1.10	1.81	0.87	7
1993	10	0.80	1.59	1.10	0.44	1.04	7
1994	10	0.96	0.83	0.87	0.91	1.43	8
2012	10	0.55	2.16	1.50	3.12	2.39	9
1992	10	0.70	2.04	1.26	1.65	0.95	9
1991	10	0.70	1.95	1.30	2.55	1.86	9

Next, in Table 4, the five predicted duck population indices for the years 1991-2022 where years are ranked from most (BagLImit = 0) to least (BagLimit = 10) restricted bag limits (values are not considering opening weekend and species-specific regulations; note that for bag limits the year prior to the season is used). 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 five duck population indices in each year. For more detail on the calculation of aPS see section 5.

Finally, in Figure 12, the actual bag limits and the aggregated point system scores as calculated from the five duck population indices for the years 1991-2022 are plotted against each other. The blue line in this graph depicts the major axis relationship.

The average actual bag limit over the years was 6.1562 and the average aPS was 4.375. Although tending to be somewhat lower, the aggregated point system does not deviate much from the actual bag limits between 1991 and 2022, with a clear positive relationship between actual bag limits and aggregated point system over this period.

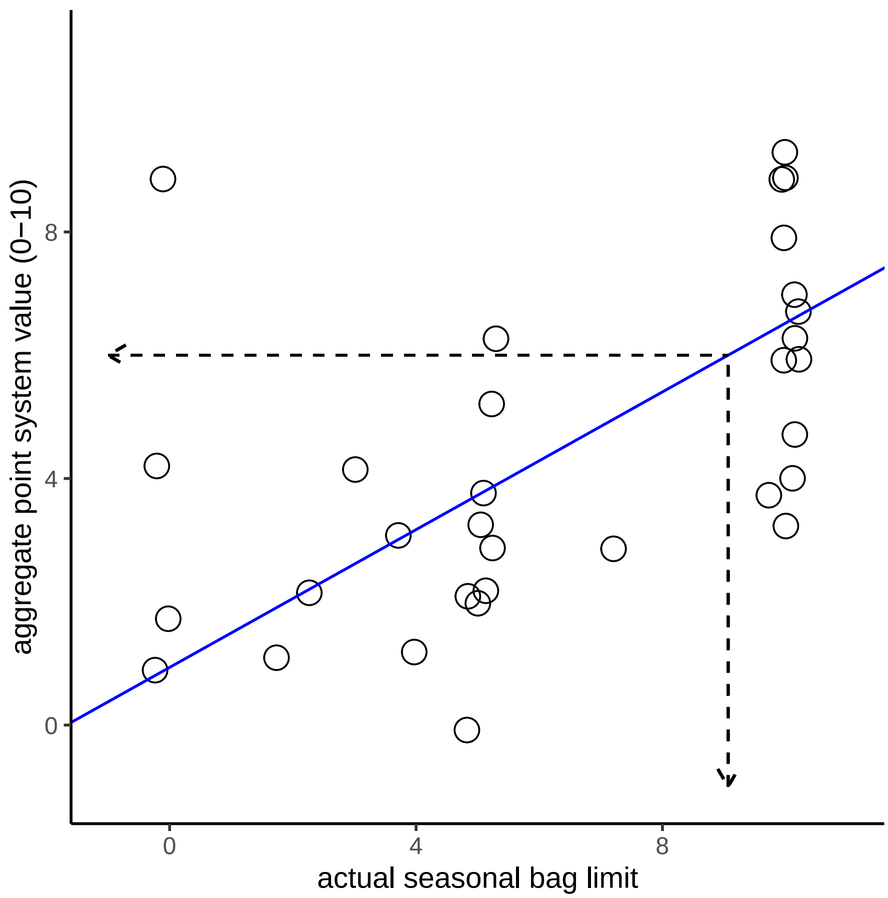

Figure 12: Relationship between the annual bag limit and the aggregated point system value based on the five predicted duck population indices for the years 1991-2022.A small amount of random variation has been added to otherwise overlapping data points to improve data presentation. The blue line is the major axis relationship between the two. Dashed drop lines from this major axis line connects the aPS and proposed bag limit for 2023 (i.e., for the 2024 hunting season).

5 Proposed hunting arrangement for 2024

Although some indices are less prone to error than others, collective use of these five indices should adequately address the four key elements that form part of a decision model. As outlined by Klaassen and Kingsford (2021), 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 the aggregate point system (*aPS*). In this system, each index with a value between 0 and 0.5 attracts 0 points, 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 2023 the five indices have the following values:

- Using water surface area, the Vic priority game count prediction is: 62338, resulting in an iPGC of:0.74, worth 1 aPS points.
- Using water surface area, the Vic aerial game count prediction is: 60709, resulting in an iVicC of: 1.12, worth 2 aPS points.
- Using water surface area, the NSW aerial game count prediction is: 50037, resulting in an iNSWC of: 0.76, worth 1 aPS points.
- Aerial game counts Vic amounted to: 108329 , and the concomitant tfVicC is: 2, worth 2 aPS points.
- Aerial game counts NSW amounted to: 27453 , and the concomitant tfNSWC is: 0.42, worth 0 aPS points.

Finally, using these five indices in the aggregated Point System calculation results in an aPS of: 6. Using the Major Axis relation between aPS and actual seasonal bag limits (blue line in Figure 12) this translates to a daily bag limit of 9 ducks per day recommended for the 2024 duck season.

With a proposed bag limit of 9 being only marginally lower than the prescribed maximum daily bag limit of 10, this may still seem prudent in light of the past three La Niña years in a row. It should be reiterated though that this rainfall follows a period of considerable drought and that not all parts of Australia (e.g., LEB) have similarly profited to the same extent from this rainfall (cf. Figure 2). Next, it should be reiterated that, based on the modelling results, duck numbers seemingly respond to long-term rainfall patterns (section 4.1). Also, duck counts, both on the ground (PGC) and from the air (NSWC), still show moderate to average numbers (cf. Figure 4). Finally, it needs stressing that the protocol followed here results in an integration of five indices in a single aPS score that, had it been used in the past, would have performed well in setting bag limits (c.f comparisons of aPS scores with actual seasonal bag limits between 1991-2021 in Table 4 and Figure 12).