Relationships among duck population indices and abiotic drivers to guide annual duck harvest management

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Summary

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. We propose five indices reflecting 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. By comparing these indices with actual hunting regulations between 1991-2020, we evaluate their use in advising on future annual hunting arrangement.

Background[1]

The Victorian Government and its agencies have been considering for some time the potential role of formal population models in decision-making and enhancing public confidence in regulatory performance in setting arrangements for the annual duck hunting season.

In 2009, an expert panel of scientists from Australia, New Zealand and USA was convened to assess whether the approach to sustainable waterfowl harvesting in Victoria could be improved by a more robust scientific approach, and specifically a harvest management model that could be delivered at minimal cost.

The expert panel recommended an adaptive harvest management (AHM) approach be adopted, and developed prototype models of the population dynamics of example game species of waterfowl to inform this approach. Monitoring recommendations and simulation studies using the prototype models were provided in a report published in 2010 (Ramsey et al. 2010). However, the modelling approach recommended in the 2010 report was not implemented by the Victorian government at the time.

In 2016, the Victorian government committed to implementing adaptive harvest management for duck hunting in its Sustainable Hunting Action Plan. In response, the Victorian Game Management Authority (GMA) contracted scientists from the Victorian Arthur Rylah Institute for Environmental Research (ARI) and New South Wales Department of Primary Industries (NSW DPI) in 2017 to review the recommendations in the 2010 report given the passage of time, advances in monitoring technology and further experience in implementing AHM in North America and Europe. The review (Ramsey et al. 2017) recommended a changed approach to modelling and the development of a monitoring program to support implementation of an adaptive harvest management program, amongst other things.

A monitoring program was subsequently designed (Ramsey 2020) and implemented in a trial helicopter survey in November 2020 to test its performance and rigour. Absolute abundance estimates for game ducks in Victoria were inferred and recommendations for further improvements to the monitoring program were included in an evaluation report prepared by Ramsey and Fanson (2021). This report was reviewed by Dr Steve McLeod, NSW DPI (McLeod 2021).

In response to a 2018 election commitment, the Victorian government established an expert panel to review the findings and recommendations contained in the 2017 report. The expert panel report was completed in 2019 (Prowse et al. 2019) and made a series of findings and recommendations. Recommendation 3 was that "a simple harvest management framework be adopted initially, to clearly translate waterfowl monitoring and data on rainfall/wetland availability into harvest recommendations" while ongoing development of the adaptive harvest population model for waterfowl is developed simultaneously as a longer-term goal to assist management

The 2019 expert panel report provided further advice on the recommended harvest management framework:

"Therefore, consideration should be given to a simple, transparent process for setting harvest regulations which could then be modified or augmented to include modelling results as appropriate at a later date. Given the constraints in currently available scientific information, the panel therefore recommends that, in the short-term, appropriate and adequate information for management can be generated by a conceptually simple and defensible harvest management framework which combines

[1] Largely copied from *Request for Quote*

appropriate measures of spring wetland abundance/rainfall, summer abundance/rainfall, and available waterbird monitoring data to annually generate an abundance ranking for the coming season.

This could take a range of forms, such as a "traffic light" system reflecting risk levels (i.e. red light = Low abundance/High risk; orange = Medium abundance/Medium risk; Green light = High abundance/Low risk). The number of abundance/risk levels could be extended as appropriate, and this categorisation could be linked to appropriate management measures.

The proposed modelling of historical datasets could evaluate and test the capacity of various indices of rainfall/wetland availability to predict waterfowl population growth rates, and thereby recommend categories of harvesting with definitions based on these indices."

With this report, we aim to address the 2019 expert panel recommendations and inform decision making to guide annual harvest management. It was informed and improved by responses from a range of stakeholders on a draft version (provided as *Summary of issues raised in submissions received on the draft proposal* at the end of the document).

Introduction

Summarizing insights from a large body of literature and knowledge on the drivers for duck abundance and distribution in Australia yields a conceptual model of the driving factors and indices for game management decision-making (Figure 1). Current understanding suggests that duck numbers and distributions are importantly determined by water in the landscape and direct management of ducks, including hunting, with current duck numbers determining future duck numbers, as for any model of changes in abundance. For ducks, density dependence is generally low and environmental variability contributes most to variation in duck numbers (e.g. Pöysä et al. (2016) and citations therein). This is likely due to the typical life history of ducks, characterised by a young age at first reproduction and large clutch sizes. Although our knowledge of waterfowl movement in Australia in relation to spatially and temporally varying resource availability is incomplete, the counting, banding and tracking work available to date indicates that large numbers of waterfowl track resources over vast distances. Duck numbers in Victoria cannot be considered in isolation of duck numbers elsewhere, particularly in SE Australia. Taken together and also following (proposed) practices elsewhere in Australia (SA Dep Environ Water 2020) and overseas (e.g. U.S. Fish & Wildlife Service (2020)), as well as recommendations of the 2019 expert panel (Prowse et al. 2019), a duck harvest management framework for Victoria should contain indices that inform on the following elements:

1. breeding conditions in Victoria;
2. breeding conditions throughout SE Australia;
3. current or recent duck population size in Victoria and;
4. duck population size throughout SE Australia.

Breeding conditions are mainly reflected by water in the landscape, particularly for highly dependent aquatic waterbirds, determining habitat availability.

A conceptually simple management framework should be based on these four elements, but also be transparent and defensible. We propose five indices (Figure 1) and provide analyses supporting their value in reflecting the four elements. Next, by comparing these indices with actual hunting regulations (1991-2020), we evaluate their use in advising on future annual hunting arrangements.

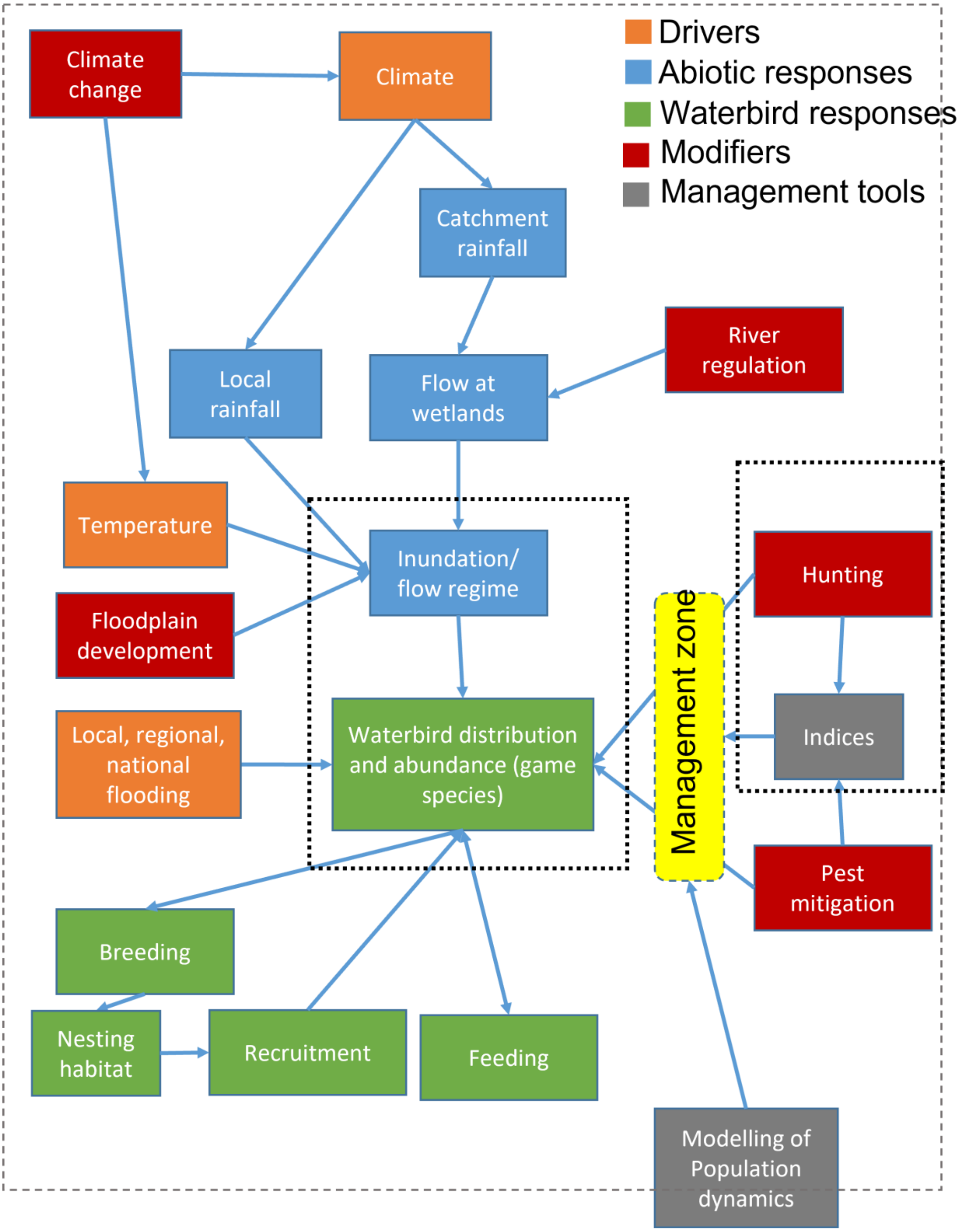

Figure 1. Conceptual model of the drivers of abundance of game species and the decision making space for harvesting ducks, where dotted lines indicate the focus of this report on relationships between flooding and waterbird abundance, linked to indices (adapted from Prowse et al. 2019).

Proxies for duck numbers

The number of ducks in Victoria and SE Australia are unknown and, despite the best of efforts and the use of advanced technology, likely also impossible to know with great accuracy. Next-best is a good estimate of duck numbers and status of the landscape informing on their breeding potential. For this the following three data sources come into focus.

- **Victorian hunting bags** during opening weekend have been collected and reported by ARI since 1973 (Menkhorst et al. 2019) and may provide a proxy for the game population when simultaneously considering the seasonal arrangements for duck hunting in every single year (Game Management Authority 2021).
- **Game-duck-species counts across Victoria** which started in 1987, have been conducted in the framework of the Victorian Duck Season Priority Waterbird Counts, which summarises ground-based counts in Victoria, with data collected from a large number of wetlands (100+ annually), mostly taking place a month ahead of the duck hunting season. The approach of the Victorian game counts changed in 2015, when a limited survey was introduced focussing on so-called "priority wetlands", which are also important duck hunting sites. To avoid bias, our analyses only used data from 37 priority wetlands, counted 20 or more times since 1987. Although not claiming to be an overall count of game across the state, it may serve as a proxy for duck game species in Victoria (Menkhorst et al. 2020). Due to counts being hampered by the COVID-19 outbreak, data from 2020 were incomplete and not considered in the analyses.
- **The Eastern Australian Aerial Waterbird Survey** counts, taking place in October of every year since 1983 forms yet another important data source, with its most southerly transects (bands 1-3) providing a proxy for birds in Victoria, southern NSW and SE SA with bands 4-6 providing a proxy for bird numbers for the remainder of SE Australia, i.e. eastern SA and the whole of NSW and the south of Queensland (from here onwards referred to as VIC and NSW aerial counts, respectively) (Kingsford et al. 2020).

The latter, aerial counts can be directly used as proxies for actual game numbers for Victoria and the whole of SE Australia, given that the survey is conveniently timed, a few months prior to when hunting arrangements for the upcoming hunting season are called and has used a consistent methodology.

The above data series are possibly not the only remarkable duck data series available. Another example is the long-term database on duck counts from Melbourne Water's Western Treatment Plant (WTP), a permanent wetland bordering Port Philip Bay in Victoria. Based on our analysis of these data we conclude that duck numbers in the WTP increase when conditions in the wider landscape become unfavourable for ducks. This function of the WTP as a refuge for waterfowl is also corroborated with previous analyses in the literature (Loyn et al. 2014, Clarke et al. 2015, Papas et al. 2021). It cautions against assessing duck population sizes across the state from single wetland counts, notably if the hydrology of these wetlands is disconnected from what is happening in the wider landscape.

Proxies for duck numbers and their relationships with water in the landscape

The four data sources allow for analyses of game numbers of ducks in relation to availability of water in the landscape using LANDSAT satellite imagery. Given that water availability is the key driver of waterbird numbers, we investigate relationships that allow predictions of habitat suitability for ducks from water availability in the landscape over time.

There are inherent uncertainties in every estimate, with observer/ methodological and sampling errors and this holds for water surface estimates, hunting bag estimates as well as on-the-ground and aerial counts. This is also clearly expressed by the authors of the reports from which these data were extracted. This fact cautions against expecting relationships explaining very high proportions of variation and necessitating the use of multiple indices in informing duck hunting arrangements (a multiple lines of evidence approach). These data sets vary in timing in relation to hunting and scale (Fig. 2).

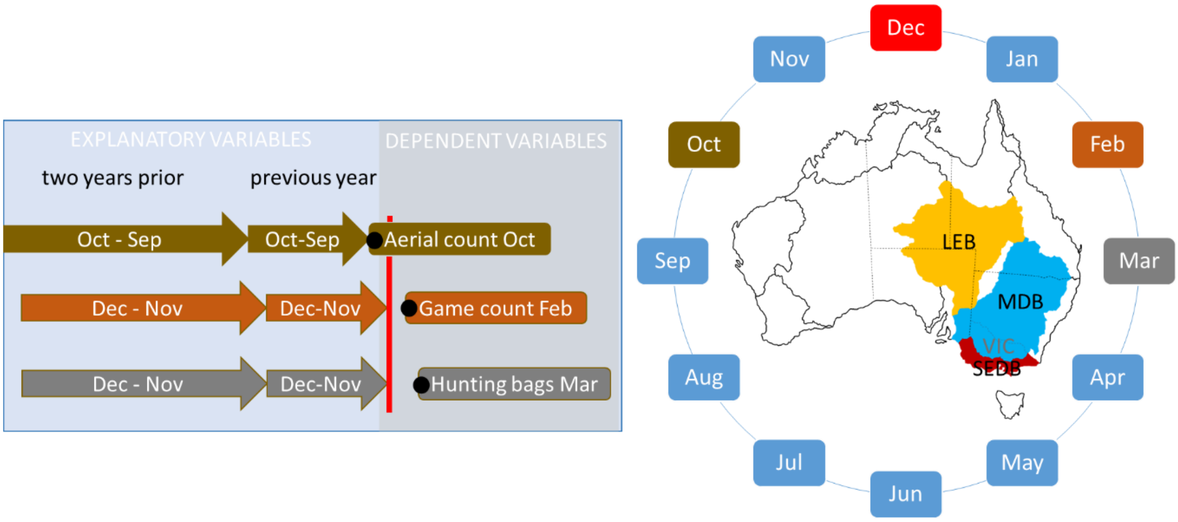

Figure 2. Map with the regions for which water in the landscape was measured, including the Lake Eyre Basin (LEB, mustard), Murray-Darling Basin (MDB, blue) and southeast SEDB (dark red). Victoria (VIC) was also considered a separate region for these analyses. The average water surface area across these regions in the year prior to the aerial counts and the two years prior to that were used as explanatory variables in the statistical analysis of aerial counts. For Game counts and hunting bags these water surface areas were similarly calculated, but using a 3 and 4 month time shift respectively, allowing for models that can generate predictions based on water surface area in the landscape over the preceding 3 years in December of each year.

A detailed account of the methods and results of our analyses, including programming code, is provided in the supplemental html "*an analysis of duck proxies and surface water to inform hunting arrangements*", with only an abridged version of methods and results provided here. Monthly water surface areas as % of total surface water area and starting July 1987, were extracted from LANDSAT satellite imagery following Pekel et al. (2016) for Victoria (*VIC*) Murray-Darling Basin (*MDB*), SE Australia south of the MDB (*SEDB*) and the Lake Eyre Basin (*LEB*) (Figure 2). To investigate the relationships between hunting bags, game counts and aerial survey counts for Victoria and NSW as dependent variables in relation to water surface areas as explanatory variables, we used linear modelling in R. As explanatory variables we used the average water surface area, over the year prior to which the dependent variables, were collected (abbreviated as *VIC, MDB, SEDB* and *LEB*, Fig. 2).

Generally, there were good relationships between the four proxies for duck numbers and water in the landscape in the preceding 12 months, notably so for the percentage of water surface area in Victoria and across the entire MDB. Modest time shifts of up to 6 months (i.e., using average water surface areas calculated from 0-12 months prior to the estimate of the dependant variable up to 6-

18 months prior) did not generally impact the fits, somewhat supporting an approach where decision-making on annual duck hunting arrangements is made based on environmental indicators a few months prior to the actual hunting season. These relationships based on 12 months of water surface data represent the availability of habitat for ducks and probably also reflect breeding capability.

To allow for longer-term effects of water availability in the landscape on duck populations, reflecting breeding and recruitment, we created an additional set of explanatory variables that consisted of the average water surface area over the two years prior to the explanatory variables outlined above (abbreviated as *VIC2, MDB2, SEDB2* and *LEB2*). Thus, in each analysis we used eight explanatory variables. We ignored data on water surface area between the 1st of December and the actual game counts and hunting bag assessments, since the aim was the development of models that can predict hunting bags and game counts in December of each year, prior to the actual game counts and assessments of hunting bags during opening weekend.

To have explanatory variables for water surface area covering one full year prior to the counts and hunting bag assessments and the two years before that, we time-shifted water surface estimates by 3 and 4 months for these two dependent variables, respectively. By doing so, we thus tried to explain the variation in the two dependent variables with explanatory variables for the four regions containing the average water surface area running from December two years before, until November in the previous year and from December four years ago until November two years ago. For the aerial survey counts across Eastern Australia, in October each year, we did not time shift the data and calculated average water surface areas 0-12 months prior to the October count and 12-36 months prior to the October counts for all four regions. We used function dredge in R to evaluate all possible combinations of the eight explanatory variables in explaining the four dependent variables, using a linear modelling approach.

Out of all these combinations we ultimately selected a model as the most satisfying model explaining the dependent variable using the following criteria: (i) all parameter estimates for the explanatory variables in the model were significantly different and larger than zero, (ii) its AIC ranking was high (i.e. its AIC value needed to be amongst the lowest across all models tested), (iii) the model's adjusted R^2 was amongst the highest of all models tested. The results of this exercise are in Table 1.

Table 1. Selected predictive models for annual hunting bag size during opening weekend, game counts in Victoria and aerial waterbird surveys for survey bands in Victoria and NSW across the years 1990 – 2020, using the average percentage of surface water over the previous year and the two years before this (i.e. total of three years' worth of surface water information), over four different geographic regions (SEDB, MDB, VIC, LEB). Only previous year's data for VIC and MDB were selected and data for the two years before that for MDB and LEB (i.e. MDB2 and LEB2, respectively).

Dependent variable	*Model*	*N*	*AIC rank*	*adjusted R^2*
Bag size	0.430 + 4.792 *MDB*	25	1	0.230
Game counts Victoria	-23008 + 75433 *VIC*	26	1	0.198
Aerial counts Victoria	-62400 + 82644 *VIC* + 108564 *LEB2*	31	3	0.530
Aerial counts NSW	-54758 + 75224 *VIC* + 99745 *LEB2*	31	1	0.380

For bag size, although measured during opening weekend in Victoria, the preferred model contained water availability over the previous year in MDB rather than Victoria. However, it should be considered that water surface area in the MDB is highly correlated with water surface area in Victoria ($r = 0.65$, $n=25$, $P< 0.01$). Moreover, the number of ducks in Victoria and thus the ease of shooting them, may not only be dependent on water and wetland conditions in Victoria but also elsewhere as we also a priori assumed (see Introduction page 5). The aerial counts for Victoria and NSW also reflect the importance of water in the landscape, although water availability in the landscape across the Lake Eyre Basin, 2-3 years prior to the counts, appears influential on duck numbers. Importantly, correlations between *LEB2* and *MDB2* ($r = 0.61$, $n=30$, $P< 0.01$) and *VIC* and *MDB* ($r = 0.69$, $n=30$, $P< 0.01$) are reasonably high.

Duck indices

Using the preferred predictive models from Table 1 as well as the two aerial duck counts (i.e. Victoria and NSW), we developed indices that broadly inform on the current population status of ducks in SE Australia and Victoria. We opted not to use bag size predictions from water surface area as an index of duck numbers since bag size may be biased by hunting bag limits imposed during 12 of the 25 years for which data were available. Using linear modelling across hunting bag data from unrestricted seasons only, also dramatically reduced sample size ($n=13$) and yielded no meaningful insights (i.e. insignificant relationships only).

To graphically illustrate the fit of the models to the data, we plotted predicted duck proxies using the remaining three models in Table 1, against observed duck proxies (Figure 3). Additionally, using symbols depicting seasonal bag limits (outside opening weekend and ignoring species-specific limitations imposed in some years and in some species), these graphs also allow identifying thresholds for these proxies above which restrictions were typically not imposed (and conversely below which, limitations to hunting were called). These threshold values for game duck counts in Victoria and aerial surveys for Victoria and NSW were 64000, 56300 and 53500, respectively. These threshold values were used to calculate five duck population indices:

iPGame: index of game counts limited to priority wetlands using the game counts predicted by the model in Table 1 divided by the game count threshold of 64,000

iVicC: index of aerial survey for Victoria using the predicted aerial counts for Victoria (Table 1) divided by the threshold for these counts of 56,300

iNSWC: index of aerial survey for NSW using the predicted aerial counts for NSW (Table 1) divided by the threshold for these counts of 53,500

tfVicC: index or threshold fraction of aerial survey for Victoria using actual counts divided by the threshold for these counts of 56,300

tfNSWC: index or threshold fraction of aerial survey for NSW using actual counts divided by the threshold for these counts of 53,500

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. These 5 indices cover the 4 elements mentioned in the introduction as follows:

1. Breeding conditions in Victoria is covered by *iPGame* and *iVicC.*
2. Breeding conditions throughout SE Australia is covered by *iPGame, iVicC* and *iNSWC*.

3. Current or recent duck population size in Victoria is covered by *tfVicC*.
4. Duck population size throughout SE Australia is covered by *tfVicC* and *tfNSWC*.

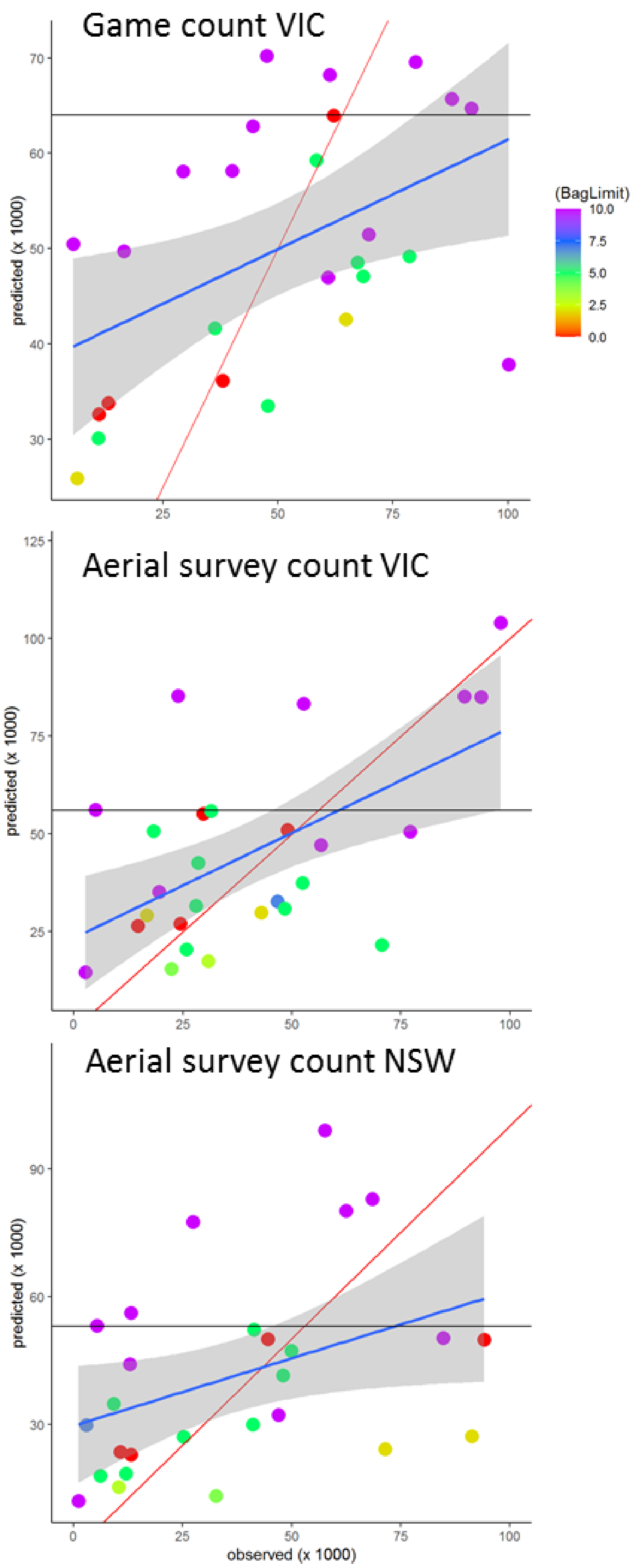

Figure 3. Observations versus model predictions for Game counts in Victoria and aerial waterbird survey counts of Victoria and NSW, with symbol colour reflecting hunting bag limits for the season (not considering potential separate limitations for individual species and special restrictions during opening 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 lines are thresholds values for these three dependent variables, reflecting the lower limit above which unlimited seasons were always called.*

Past performance of the indices

In Table 2 we present the predictions for the five indices, calculated for all years where we have complete sets of data available to allow these calculations (i.e. from 1991-2020). In this table, years are ranked from years with the most to the least restrictive hunting regulations (i.e. they are ranked by seasonal bag limit ranging between 0-10 ducks, not considering any opening-weekend or species-specific hunting regulations, 1995, 2003, 2007 and 2008 being the most restrictive). The index values are colour coded with dark colours indicating high and light colours indicating low population status. The same data are also presented graphically (Figure 4), where boxplots show all five indices as well as their median value across three categories of hunting season: unrestricted, somewhat restricted and cancelled hunting seasons. For these three categories, it is expected that indices should show high, intermediate, and low values, respectively. Although there is a clear tendency for this to occur, there is considerable variation both within and across indices.

Firstly, there is a need to reiterate that all proxies, as well as estimates of water in the landscape are prone to error. Also, the decisions in relation to setting of annual duck hunting regulations and seasons may be influenced by a range of factors. Thus, we should caution against naively expecting highly clear-cut patterns of index values for the various bag-limit categories.

Table 2. The five predicted duck population indices for the years 1991-2020 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; data from Game Management Authority (2021)). The index values are colour coded with dark colours indicating good and light colours indicating poor population status. Indices in white font (body of the table) relate to proxies from Victoria whereas indices in yellow font (body of the table) relate to proxies from NSW. In the final column the proposed hunting arrangement for each season is presented based on all five indices using an aggregate point system (aPS; see text below under "Annual duck hunting arrangements").

		using water surface			using aerial counts		
Year	BagLimit	iPGame	iVicC	iNSWC	tfVicC	tfNSWC	aPS
2007	0	0.53	0.48	0.50	0.43	0.20	1
2008	0	0.51	0.52	0.55	0.26	0.25	3
2003	0	0.56	0.53	0.55	0.53	0.83	5
1995	0	1.00	0.90	0.90	0.87	1.76	7
2009	2	0.40	0.39	0.42	0.30	1.34	2
2004	2	0.67	0.37	0.39	0.76	1.71	4
2020	3	0.57	0.19	0.22	0.55	0.19	2
2016	4	0.59	0.26	0.29	0.40	0.61	2
2019	5	0.52	0.32	0.34	0.86	0.47	2
2005	5	0.64	0.59	0.60	0.46	0.22	3
2015	5	0.65	0.28	0.31	0.93	0.17	3
2010	5	0.47	0.63	0.64	1.25	0.11	4
2000	5	0.74	0.56	0.58	0.32	0.93	5
2001	5	0.77	1.00	1.00	0.50	0.77	6
2002	5	0.76	0.98	0.99	0.56	0.77	7
1998	5	0.93	1.00	1.00	0.51	0.90	8
2006	7	0.62	0.49	0.51	0.83	0.05	3
2017	10	0.59	0.84	0.85	0.05	0.02	3
2018	10	0.73	0.55	0.57	1.01	0.24	5
1999	10	0.80	0.90	0.91	0.09	0.10	5
2011	10	0.78	1.84	1.82	0.35	0.88	6
1997	10	1.10	0.76	0.77	1.79	0.25	6
2014	10	0.79	0.67	0.68	0.93	0.51	6
1994	10	1.09	0.91	0.91	0.43	1.28	8
2012	10	0.98	2.16	2.12	1.74	1.08	10
1996	10	1.07	1.00	1.00	1.37	1.58	10
1991	10	1.03	1.87	1.84	1.66	2.67	10
1993	10	0.91	1.51	1.49	1.59	1.17	10
2013	10	0.91	1.48	1.47	3.00	2.95	10
1992	10	1.01	1.51	1.50	2.45	2.30	10

Next, we must consider that indices that rely on many (independent) estimates over considerable periods of time are less prone to error than indices relying on much fewer data. The indices based on water surface area, which are calculated based on monthly water surface estimates over 1-3 years, are thus expected to fluctuate less due to chance compared to the indices based on annual aerial counts, based on a single set of counts over a relatively short period of time. Indeed, *iPGame*, *iVicC* and *iNSWC* show clearer patterns across the three hunting restrictions categories in Figure 3 than *tfVicC* and *tfNSWC*. For the latter two indices, we observe generally more variation within the bag limit categories and more overlap between bag limit categories. The latter is notably the case for *tfNSWC*. However, for this index it should also be considered that it is based on counts entirely outside of Victoria, which may also be cause for a weaker correlation with annual hunting arrangements.

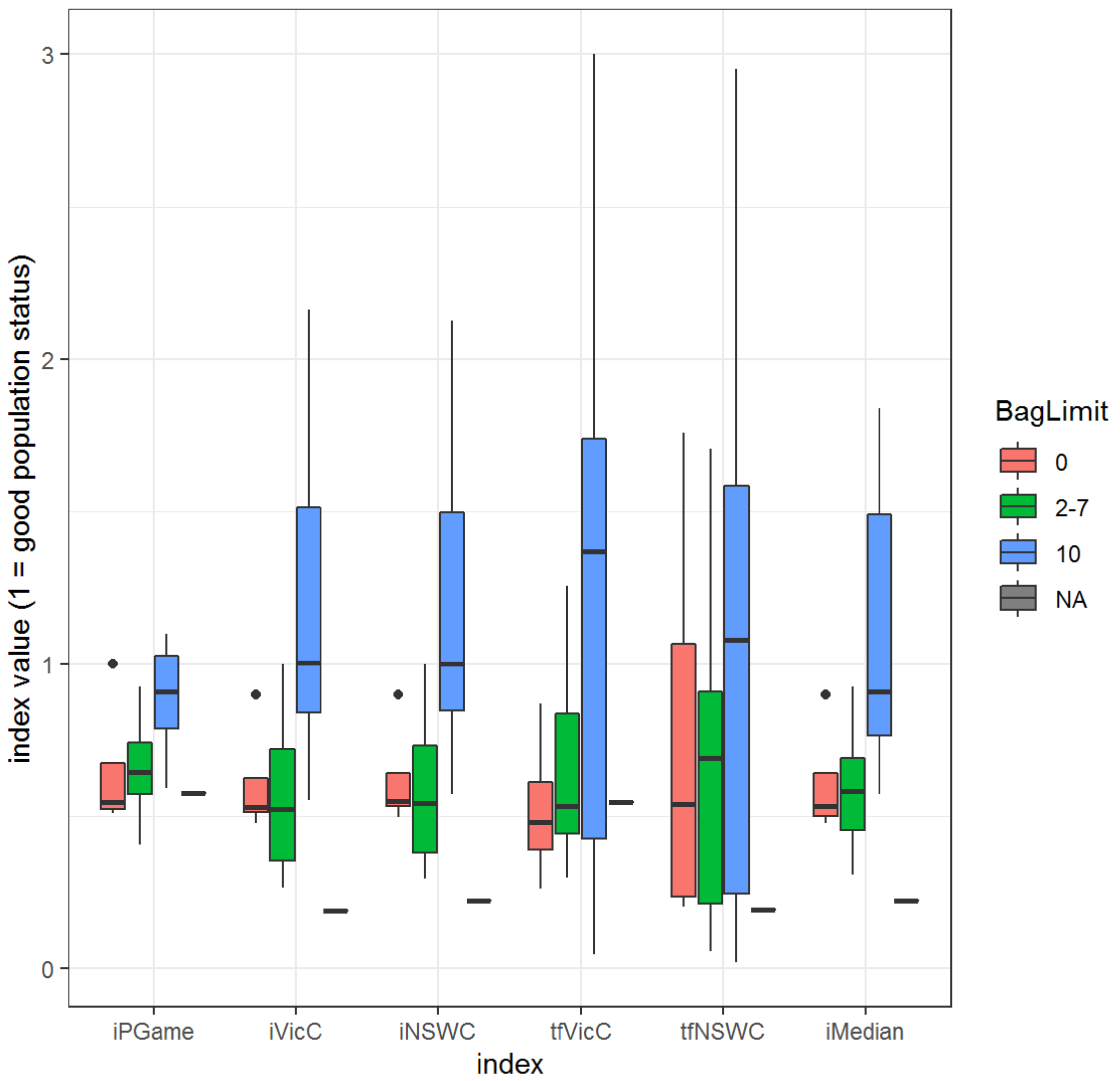

Figure 4. Boxplots (depicting minimum, 25 percentile, median, 75 percentile and maximum) for the five duck-population indices, as well as their median for unrestricted hunting seasons (bag limit = 10, blue) cancelled hunting season (bag limit = 0, red) and hunting seasons with restrictions (bag limit = 2-7, green).

Finally, while for many indices the unrestricted seasons truly stand out, there is striking overlap for all indices for the years where hunting was banned or restricted. We consider that the most prudent way forward is to use these indices to help set annual duck hunting arrangements. We consider this warranted given the indices' theoretical as well as empirical support, as outlined in introduction and results presented above using historic data and annual duck hunting arrangements over the years 1991-2020.

Annual duck hunting arrangements

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 as outlined in the introduction. Furthermore, there is no sound basis for weighting these indices differentially. 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. With all 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 (last column of Table 2). Conveniently, this aggregated point system does not deviate much from the actual bag limits between 1991 and 2020 (5.5 versus 6.3), with generally good agreement between actual bag limits and aggregated point system over this period (Figure 5). There are, however, also marked outliers, with notably 1995 and 2017 demanding explanation.

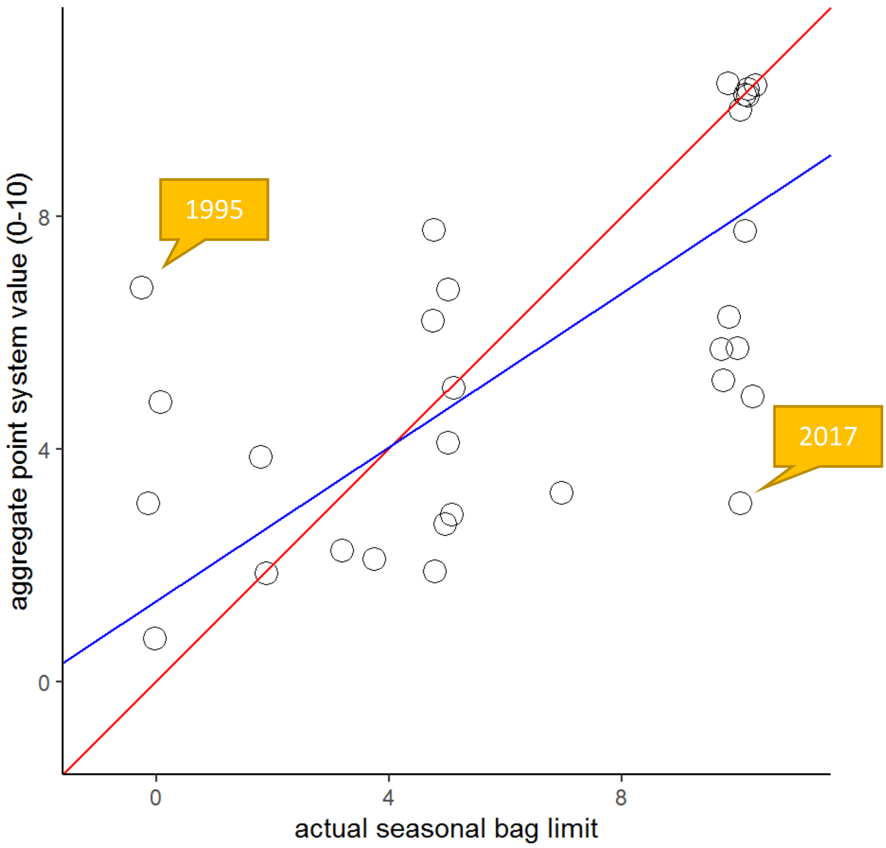

Figure 5. Actual bag limits versus the aggregate point system (aPS) proposed bag limits as calculated from the five duck population indices for the years 1991-2020. Red line depicts actual=aPS, while the blue line is the major axis regression. A small amount of random variation has been added to otherwise overlapping data points to improve data presentation.

Final caveats

We were asked to advice on the social, economic and ecological costs and benefits associated with reducing either season length or bag limits in relation to reductions in harvest. We have neither the expertise nor data to comment on the social or economic costs/benefits or the ecological cost/benefits in relation to hunting arrangements. Although changes in season length have an effect (Sunde and Asferg 2014, Madsen et al. 2016) it is limited. A phenomenon that may be due to recreational hunters either investing a fixed effort or aiming for a specific yield within a given season (Sunde and Asferg 2014). Data from GMA collected between 2009 and 2019 corroborate this with the number of days hunted in the season varying only little (3.3-4.6) across the 11 hunting season between 2009 and 2019 (Game Management Authority 2020). If recreational hunters aim for a fixed seasonal effort that would translate into a fixed number of days of hunting in each year, as suggested by the data available to date, limiting daily bags rather than season length might be more effective.

Our analyses and advice have not differentiated the eight different duck game species that all have their own specific life histories and ecology. Although species-specific game and aerial count data are available and we are in principle able to make species-specific indices, such approach would inflate error rates and likely reduce the confidence of the aggregate point system here applied.

We advocate that the model here presented be used as a tool to inform decision making for hunting arrangements; it should not be used to set hunting arrangements without due diligence. This means that the aPS or daily bag limit recommendation, is considered in the broader context. For instance, it should be realised that this is a statistical model, which means that predictions are based on past events. This also means that if any of the input would be truly extreme (and nothing like we have seen over the past 30 years) one should be mindful of that when using the model outcome.

We also encourage the use of the model as an “adaptive interim harvest model”, where the model is (annually) updated when additional data or even completely new sets of data (e.g. helicopter counts) become available. Using the proposed model as an adaptive model critically requires a continued and standardised effort in aerial surveys and game counts.

Three of the five indices presented importantly rely on surface water data extracted from LANDSAT satellite imagery. We should consider further investigating the possibility for increasing their accuracy, as well as their potential to inform even more accurately on the status of duck populations over time.

Knowledge on movements and population dynamics are crucial to assess species’ vulnerability to hunting and environmental fluctuations and change, requiring our ongoing attention. Notably in the Australian context, there is a need to understand how and when widespread drying conditions north of Victoria may affect numbers. Such knowledge is particularly needed for species that are not numerous and widespread in Victoria. As a first step, reanalysis of available banding data should be considered. Such analysis could be of importance for designing future banding projects to (i) provide explanations for the relationships on which the indices are based, (ii) potentially construct better indices and (iii) inform a future adaptive harvest model. Such analyses may also help updating our knowledge on movements to and from non-breeding and breeding areas, and between river basins and wetlands across SE Australia, as potential key drivers of fluctuations in abundances across this vast area. Importantly, such analysis may also help identify key caveats in our understanding of duck movements, assisting in designing future banding and tracking studies.

There is a need to better understand breeding and recruitment and relevant drivers across different scales as this is critical for hunting and management of species. This could be done by focused studies on breeding and recruitment in relation to flooding and flow and rainfall regimes. There may also be relevant data already available that is collected during hunting bag collection.

Acknowledgements

Monthly water surface area data were kindly extracted from LANDSAT satellite imagery by Roxane Francis, UNSW, Centre for Ecosystem Science. We thank Peter Menkhorst, Arthur Rylah Institute for Environmental Research, for analysing and summarising the key issues raised in the stakeholder submissions on the draft version of this report which greatly assisted us in preparing the final version of our report. Preparation of this report was jointly funded by the Victorian Department of Jobs, Precincts and Regions, the Victorian Department of Environment, Land, Water and Planning, and the Victorian Game Management Authority.

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Summary of issues raised in submissions received on the draft proposal

The table below provides a summary of points made in submissions received from stakeholder groups. It includes only issues directly relevant to the model itself, rather than duck hunting per se. Ten submissions were reviewed, from each of the following organisations:

AA – Animals Australia

ADA – Australian Deer Association

BLA – BirdLife Australia

CADS – Coalition Against Duck Shooting

DELWP

FGA – Field and Game Australia

GMA

RSPCA Victoria

RVOTDS – Rural Victorians Opposed To Duck Shooting

SSAA VIC – Sporting Shooters Association of Australia, Victorian Branch

The table below does not indicate whom raised the various points. The authors response to all points raised is provided in the final column. Although the feedback provided did ultimately neither result in major changes to our approach nor the outcome, it did result in considerable alterations in the analyses (e.g. in the estimation of threshold values and the way the Victorian Game Count data have been integrated in the modelling) and improvements, notably clarifications, in the main text.

Issue	Sub-issue	Stakeholder comment	Response
Modelling as a tool for decision making		1. Can be useful for highlighting relationships or trends but is dangerous when used definitively to determine fate of declining species. 2. Welcome the attempt to widen consideration of relevant environmental factors, but urge caution 3. The establishment of a robust total population estimate could also be an appropriate way to determine an appropriate annual offtake, as an interim measure	1. This is not a population model. Rather the model tracks overall game duck numbers in Victoria over time in relation to predictor variables related to abundances. We advocate that the model be used as a tool to inform hunting arrangements only. We will stress this is a tool to inform decision making. It should not be used to set hunting arrangements without due diligence. 2. As above. 3. As yet problematic. The tool provides an overall index summarising the population status of all game ducks rather than providing an estimate of duck numbers present or harvestable.
The indices			
		1. The parameters in the indices are sensible.	1. Noted.
	Weighting	1. Need further justification for equal weighting given to the 5 indices. 2. Why not give greater weighting to the statistical relationships that appear stronger – goodness of fit?	1. Possibly one of the best arguments against weighting is that we a priori define a number of elements that should be integral to the interim harvest model and are of equal importance. Each of these indices addresses other elements and should thus all count equally to the ultimate “aggregate Point System” 2. Following on from the above: since each index covers a different aspect of the elements that should collectively inform on the population status of all game ducks. Weighting some indices (and thus elements) more than others is not advisable.

	SWC/DSPWC	1. Data is unsuitable for inclusion in model – inconsistent effort and coverage between years. 2. Should not be included in model because 'not in tune' with the other 4 indices. Rather, remove iGame and upscale the other 4 indices by 5/4 to retain a maximum bag limit of 10 [but they then admit that this would remove the only index that specifically relates to surface water in the MDB]. 3. If the proposed framework is adopted, the number of wetlands surveyed in DSPWC will need to be increased.	1. This is a fair criticism and we have reanalysed the Victorian Game Count data focussing on wetlands that have been generally counted consistently across years, which should make the years more comparable with respect to effort; 2020 was removed from the analyses as due to COVID-19 few wetlands were counted. The outcomes of this new analysis are similar to those presented earlier. 2. See above. This index is as good as the other indices. 3. Future game counts have in principle no influence on the outcome of the model, unless the model is used as an "adaptive interim harvest model", where the model is regularly updated with additional data or even completely new sets of data (e.g. helicopter counts). Using the model as an adaptive model is a realistic possibility.
	Addition of Vic aerial count [the 'helicopter survey']	1. Why not included? Some stakeholders will find it difficult to accept that the significant investment in helicopter surveys is not being utilised in the interim model. 2. Should use Vic aerial count data rather than EAWS. 3. It is imperative that the helicopter surveys from SE Australia eventually are built into the modelling. 4. The AEGD [Vic aerial count] should provide robust data and allow for a comparison of the proposed arrangements with a set population take. A comparison is	1. Likely to be included in future when fully standardised and deemed adequate (see also former point that the model is in principle adaptable) and there are sufficient long-term data. 2. Partially agree. It should be included (in future) but not replace VIC EAWS data. 3. Agree (see above). 4. Modelling of the AEGD will only be possible after a considerable number of years (e.g. 6). Using it as an index could be achieved after fewer years if we can settle on a threshold/reference number of animals to calculate the index with.

		considered important to give stakeholders confidence that the indices and modelling estimates are delivering reasonable outcomes. 5. Is there a role for results of Vic aerial surveys in the interim framework, or to complement outputs from the framework?	5. Not as yet, but definitely in future years.
	EAWS	1. EAWS data is the best available and has been ignored. 2. Disregarding EAWS data from Qld has not been justified. 3. Reliance on EAWS remains an issue (poor coverage in Vic) and it is the main input to 2 of the 5 indices. 4. EAWS was never designed as a tool for game management or game season setting.	1. This is a misinterpretation since 3 of the 5 indices rely on EAWS data. 2. It is imperative that hunting arrangements within Victoria should also consider ducks elsewhere in SE Australia, but within limits. Including parts of the Australian duck populations that have limited chance to impact duck numbers in Victoria will make the model less informative. Bands 1 (southern Victoria) to 6 (southern Queensland) of the EAWS have been included in the analyses. 3. The issue of "error" and the limitations of the data are amply addressed. We need to do with what is available. We highlight that the model is a tool and that needs to inform the ultimate decisions. 4. The EAWS was actually designed to learn more about game duck populations and monitor abundance, distribution and habitat availability to ensure sustainable hunting (Braithwaite et al. 1986). Still, none of the inputs was designed for setting game management seasons in the here employed fashion, but that does not make them necessarily inadequate or less suitable.

	Surface water area	1. Agree is a useful proxy for habitat but should be used as a guide not a definitive tool. 2. In a concerning development, the 2020 EAWS found that longstanding link between surface water area and waterbird breeding had broken. 3. Should not be a replacement for consideration of all relevant environmental data. 4. Surface water includes some wetlands that are poor duck habitat – saline, deep impoundments 5. Support indices incorporating the spatial and temporal fluctuation of water in the landscape.	1. Surface water area is guiding 3 of the 5 indices. We highlight that the model is a tool and that needs to inform the ultimate decisions. 2. This is not necessarily correct. There is a need for more than a year to assess the relationships between waterbird breeding and water. Our analyses underlying the ultimate model are novel, investigating the relationship between different parts of the EAWS counts (VIC and NSW) with a set of 8 different water surface variables spanning 3 years prior to each count. Their outcome is only partly comparable with earlier analyses relating surface water area and bird numbers. 3. See point 1. 4. In the analyses it not so much the absolute amount of water in the landscape but the relative changes in the amount of water in the landscape that matter. This means that these areas with stable water levels (e.g. large dams) will remain static over time. As long as the directions of annual change in suitable and unsuitable duck habitat is the same, it is of little concern when unsuitable water bodies are included in the analyses.
	Satellite imagery in 1990s	1. Was it any better than the 1980s data which was not modelled?	1. Adequate imagery for this purpose only became available in 1987.
	Figure 3 - caption	1. Does Figure 3 refer to all waterbirds or just the Victorian game duck species?	1. Game waterbirds.
Model structure			
	Aims of the model	1. Is the aim of the model to determine maximum	1. The model is not a population model. The model

		sustainable yield or a more conservative take? 2. Fails to translate into management measures – need clarification on how aPS relates to the level of risk. 3. The stated objective of providing five seasonal arrangement options to government would suggest that opinion-based decision-making may continue to play a significant part in the duck season setting process - in deciding which of the 5 possible arrangements to adopt.	produces an index extrapolating past practice into the future, founded on the best available data, without providing an estimate of population size and a proposed harvest limit. 2. The model provides an overall index (aPS) summarising the population status of all game ducks rather than providing an estimate of duck numbers present or harvestable. The aPS thus also informs on the risk of hunting to game duck populations if no hunting arrangements would be in place. The aPS can be used to inform hunting arrangements and we provide a suggestion on to directly translate aPS into specific hunting arrangements. 3. This was part of the original brief but we have now provided a suggestion for translating aPS directly into bag limits. Nevertheless, the model should still be used as a tool to <u>inform</u> hunting arrangements not to set it. The approach uses multiple lines of evidence for management decisions, which do not reflect opinion-based decision-making.
	Aggregated points score	1. Why is threshold 0.9 rather than 1.0? 2. Rounding of the aPS is suspect, is it rounded up or down? 3. Decision to 'round off' to an even number is a tacit admission that the model has considerable limitations. 4. Why does aPS scale allocate a max score of 2 when the index is >0.9 rather than ≥1.0? This	1. The index brackets are somewhat arbitrary. Importantly, the settings of these brackets yield outcomes that are by and large comparable with decisions for hunting arrangements made in previous years. There is neither a more liberal nor a more restrictive outcome from the model compared to previous years. The model provides an overall index

		effectively liberalises the criterion for a full season by 10% at a time when sustainability is most at risk. 5. Rules for rounding need clarification. 6. The aPS table could provide a simple basis for allocating a daily bag limit. 7. Scaling and assumptions made to establish the aPS are not appropriate – the model should be set to achieve a 10-bird bag limit in an average season. 8. Clarify how aPS relates to bag limit, season length, species conservation, season closures, i.e., to sustainable management. 9. How do the aPS scores (0-10) relate to management settings?	(aPS) summarising the population status of all game ducks rather than providing an estimate of duck numbers present or harvestable. 2. This was related to the original brief requesting a 5 tier system. This has now been abolished. 3. Unfounded comment. 4. See 1. 5. See 2. 6. Correct. We provide a suggestion for translating aPS directly into bag limits. Nevertheless, the model should still be used as a tool to <u>inform</u> hunting arrangements not to set it without due diligence. 7. See above. 8. See above. 9. See above.
	Consideration of individual species	1. Is lacking. How would declining spp and listed threatened spp be handled? 2. How to handle species with a low count in the aerial survey [not sure if this means EAWC or 'new' Vic count]. 3. Does not address the need for species specific management. 4. Species-specific indices should be determined and published with appropriate discussion of limitations. 5. The model cannot account for particular species at risk. Hence protections, or lack of them, will be subjective assessments. E.g., failure to protect Hardhead, now listed for Vic as Vulnerable. 6. A model based on long-term (30-year) data	1-6. Irrespective of practicalities regarding implementation into hunting arrangements, we acknowledge that it would be desirable to have species-specific indices of population status. However, it should be understood that all game duck count estimates are prone to error (i.e. uncertainty in the data) and that the impact of that error will be magnified if we are further sub-setting the data (e.g. by species or by region within Victoria). Individual species models are likely to be less robust if there is high variability or even low numbers of a particular species. Sub-setting will thus lead to increasingly weaker relationships since the error will become more dominant. Thus, with the data at hand we cannot, at least not yet,

		patterns will likely mask shorter-term precipitous declines, as currently happening for Pink-eared Duck, for example.	meaningfully generate species-specific models. Also with respect to this point, we again like to highlight that the model should be used to inform hunting arrangements not to set it without due diligence. It should be used as multiple lines of evidence approach.
	Decision date of 1 December	1. Too early relative to season opening, doesn't allow for inclusion of recent [current summer] seasonal data on climate and bird numbers. 2. Decisions on duck shooting should be deferred as late as possible to assess how the ducks and their habitat survive the blast of summer. 1 December date needs justification. 3. Artificially imposed date will undermine public confidence in future adaptive harvest models	1-3. Part of brief.
	Bag limits	1. Bag limits flowing from the framework should be treated with caution. 2. Currently there are 11 options for bag limit (0-10). Would there be value in reducing to 4 or 5, for example? Would this simplify communication? What would be impact on harvest levels?	1. In the current version we propose a straightforward translation of the aPS into bag limits, yielding outcomes that are by and large comparable with decisions for hunting arrangements made in previous years. Nevertheless, the model should still be used as a tool to inform hunting arrangements not to set it without due diligence. 2. We originally had 5 tiers, but we have now moved to suggesting a continuous, straight-forward scale from 0-10.
	Season length	1. Do not agree that season length can be excluded from the management options.	1. Research (including analyses of hunters' behaviour in Victoria) indicates that manipulating season length is less effective than modifying

		2. Model does not consider advantages of a shorter season length, such as reduced ecological damage and easier enforcement load. Nor does it recognise that historically seasons were shorter. 3. Need to consider the combined effects of bag limit and season length, rather than dismissing season length. 4. Vic data on season length and total days hunted supports the contention that season length is not a good management lever to control harvest.	bag limits. But that indeed does not invalidate it as a management option. To be effective season length will have to be drastically modulated. 2. Modulating season length appears to have limited impact of hunters' behaviour and therewith on total number of ducks hunted and total "ecological damage". The point regarding enforcement load is valid. 3. See above. 4. Correct. See 1.
	Level of sustainable take	1. The suggested 10% take likely to be challenged. 2. The actual percentage figure would need to be established, but a reasonable take would be expected to be 20% of the population	1-2. This is not a population model. The model provides an overall index (aPS) summarising the population status of all game ducks rather than providing an estimate of duck numbers present or harvestable. We propose a straightforward approach to translating aPS into bag limits extrapolating past practice.
	Threshold values for game duck counts	1. Arbitrarily selected – need further explanation and clarification, including the process of expert appraisal. 2. Threshold values are vulnerable to manipulation by vested interests 3. Re the 'arbitrary threshold values' for game duck counts in Vic – is arbitrary the most appropriate word given that some thought and evidence was used to produce the numbers?	1-3. The wording ("arbitrarily selected") was unfortunate and incorrect and the criteria for setting the thresholds was too loosely defined. This has been corrected, which has led to more objective threshold settings.

	Threshold for aPS	1. We are concerned that the aPS score is the maximum value of 2, even when the index is below that threshold (for any index value exceeding 0.9). 2. A lower set threshold will result in more full seasons because it will increase index values giving higher aPS.	See response to comments raised under "*Aggregated points score*" above.
	Other sources of data	1. Is it appropriate to consider other sources of data, and in exceptional circumstances use this additional information in reaching a final decision? 2. Data from the annual telephone surveys of hunter activity and success could be used to examine impacts of different harvest settings.	1. Yes. We advocate that the model be used as a tool to <u>inform</u> hunting arrangements not to set it without due diligence. 2. That is worth considering but is likely to have a similar issue as the bag limit analysis conducted for this report. When limiting the data to years where there were no bag limits implemented, very few years (n =13) remained. This dramatically reduced the power of the analysis and also resulted into discarding these data for ultimate use in the model.
Data used			
	2021 data	1. Why was data for the 2021 season not used?	1. Because of limited availability of data.
	2020 data	1. In Table 2 the bag limit was 3, not 5 as shown. All input data needs to be double-checked.	1. Corrected.
Model performance			
	Predictive power	1. Model is not a good fit for the actual data – wide error range. Scatterplots suggest very weak positive relationships with many points outside the CIs. 2. Line of best fit shows the predicted values are too low in good seasons and too high in dry years, risking over-estimating abundance during drought, leading to over-	1. These are in fact very strong relationships for ecological studies, notably when taking into account that the data on which the analyses rely are not integral estimates but samples and prone to considerable error. The ultimate outcome of the models are further buffered against a large ultimate error by integrating as 5 independent indices.

		generous bag limits at critical times. 3. The peculiar result of no relationship between NSW EAWC data and MDB surface water, but rather with surface water outside NSW, should ring alarm bells. Therefore, there are problems with 3 of the regression relationships and thus with 3 of the indices. 4. Explanatory values are quite low. Relationships could be spurious – describing noise in data rather than actual relationships. 5. The indices and aPS system 'perform quite well' in highlighting the years of poor, moderate and good duck numbers. Use should help prevent poor decisions, as seen in the past. 6. The fit of the model will vary between environmental conditions in any given year. Old relationships may eclipse new relationships as the weight of years influence coefficients in the formulae. This is especially problematic in times of rapid change such as under climate change and current changes in land use.	2. In Fig. 5 we have now replaced the linear regression line with, given the nature of the data which are both prone to error, a more appropriate reduced major axis line, showing that there is no such bias. 3. That some counts in certain areas show a (slightly) stronger relationships with other but the local water surface area is not unexpected and not worrying for two reasons. Firstly, the 8 water surface areas are, as might be expected, highly correlated (see supplemental html file with details on the analyses). Secondly, it confirms that ducks move and that a wider but a local geographic scale should be considered. 4. The relationships cannot describe noise as long as the noise is random, which is a defendable assumption. Indeed, the noise does result in less predictive power. See also 1 above. 5. Indeed, it is important to consider that "error" is possibly also present in past hunting arrangement decisions. Using a multi-pronged approach as here advocated integrating 5 independent indices harnesses against (grossly) incorrect decisions. 6. Highly valid point, calling for the presented approach as an <u>adaptive</u> model, which is also a realistic possibility.
	Retrospective analysis	1. Model appears to have potential for retrospective check on quality of decisions on season controls.	1. Noted. 2. As stated under point 1, the model has flagged years where counts and environmental conditions do not corroborate the ultimate

		2. Request for advice on how the 2 aberrant decisions (1995 & 2017) can be dealt with objectively. Could the decision framework be adjusted to account for them?	decision made. It would require detailed analyses of the decision making process (including meeting notes) to understand the discrepancy between model outcome and ultimate decisions made in those two years.
	Retrospective application	1. Model would have recommended 4 closed seasons since 1990, the same number that were actually imposed. Since duck populations are declining this is not acceptable.	1. Indeed, the model ultimately extrapolates past decisions into the future, yet based on objective indices describing the population status of game ducks. There is currently no scientific basis to amend this either upward or downward.
	Model based on past arrangements	1. A model based on past flawed, unscientific process will likely perpetuate past policies and the flawed outcomes they produced. 2. If the threshold is set at a level to replicate past decisions, we are simply enshrining past mistakes for posterity. “More of the same” ignores on-going declines and puts species at further risk. 3. Concerned that arbitrary values for indices have been selected to retrofit the new model to account for previous season settings which were not based on science. 4. Fig 4 boxplots for the indices should not be used to distinguish the merit of those indices because decisions over the past 30 years were based on a range of influence, not all being rational/evidence-based.	1. The model indeed extrapolates past decisions into the future, assuming that past decisions on hunting arrangements were (at least on average) correct. The crucial difference between the advocated approach and the process used in the past is that the model outcome is based on objective indices describing the population status of game ducks. 2. Thresholds are objectively set. We indeed assume that past decisions on hunting arrangements may have been prone to error but were at least on average made correctly. 3. We apologise for earlier wording used in the draft report but there is no arbitrariness in the values used in generating the indices. See also 2 above. 4. See above.
Management levers			
	Cancellation of season	1. How will the framework be used to determine if and when a season	1. The model, with the aPS providing a clear guide, can

		cancellation should take place? Need clear decision framework.	be used to inform decision making.
	Bag limits	1. Framework outcomes need to be considered with caution. 2. A bag limit of 10 birds should apply in an average season, not only in the best seasons.	1. We advocate that the model be used as a tool to <u>inform</u> hunting arrangements not to set it without due diligence. 2. The suggested and straightforward translation of aPS into bag limits is based on past hunting arrangements. There is no noticeable upward or downward correction implemented.
	Bag limits and season length	1. Need to incorporate the option of exceeding the current 10 bag limit and 87-day season length in good years. 2. Support emphasis on adjustment of bag size rather than season length.	1. We provided a suggestion on how the aPS can be translated into bag limits, departing from past hunting arrangements, including a maximum bag of 10. We feel it is not prudent to increase this and that there is also no scientific basis for lowering it. 2. Noted.
Public acceptance			
		1. Model is <u>not</u> conceptually simple – difficult to 'sell' to public. 2. Explanation of the model needs to be simplified in order to gain acceptance amongst hunters. 3. Proposed interim arrangements do not provide clarity and transparency on how seasons and bag limits will be set. 4. Needs a clear decision-making matrix – currently no clear relationship between model outputs and season settings. 5. The framework achieves the objective of being conceptually simple, transparent and defensible. Report provides an excellent detailed explanation.	1. This report is not written to inform the general public and should allow for detailed scrutiny of the analyses. This inherently results in some level of unavoidable complexity. We feel that the essence of the analysis is straightforward and can very easily be conveyed to the general public. 2. See 1. 3. In the current version we propose a straightforward translation of aPS into bag limits, which hopefully mollifies this earlier shortcoming. 4. Although the brief was proposing a decision matrix, where to set the cut-off points for the various rows/categories in the matrix will lead to a lot of discussion (exemplified by the feedback

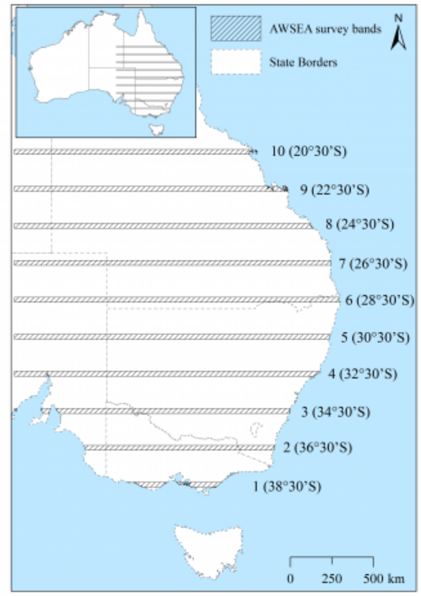
			received and summarised here). We thus opted for a continuous aPS scale rather than a “decision matrix”. 5. Noted.

an analysis of duck proxies and surface water to inform hunting arrangements

Marcel Klaassen

29 November 2021

Contents



1 Introduction

Ducks require water to breed and thrive. It is thus reasonable to assume that water drives duck numbers.

It is also reasonable to assume that duck counts of key water bodies and aerial transect counts of ducks, as well as hunting bags, are all proxies for the true number of ducks in the landscape.

Combining these hypotheses we here investigate the correlation between water availability in the landscape with:

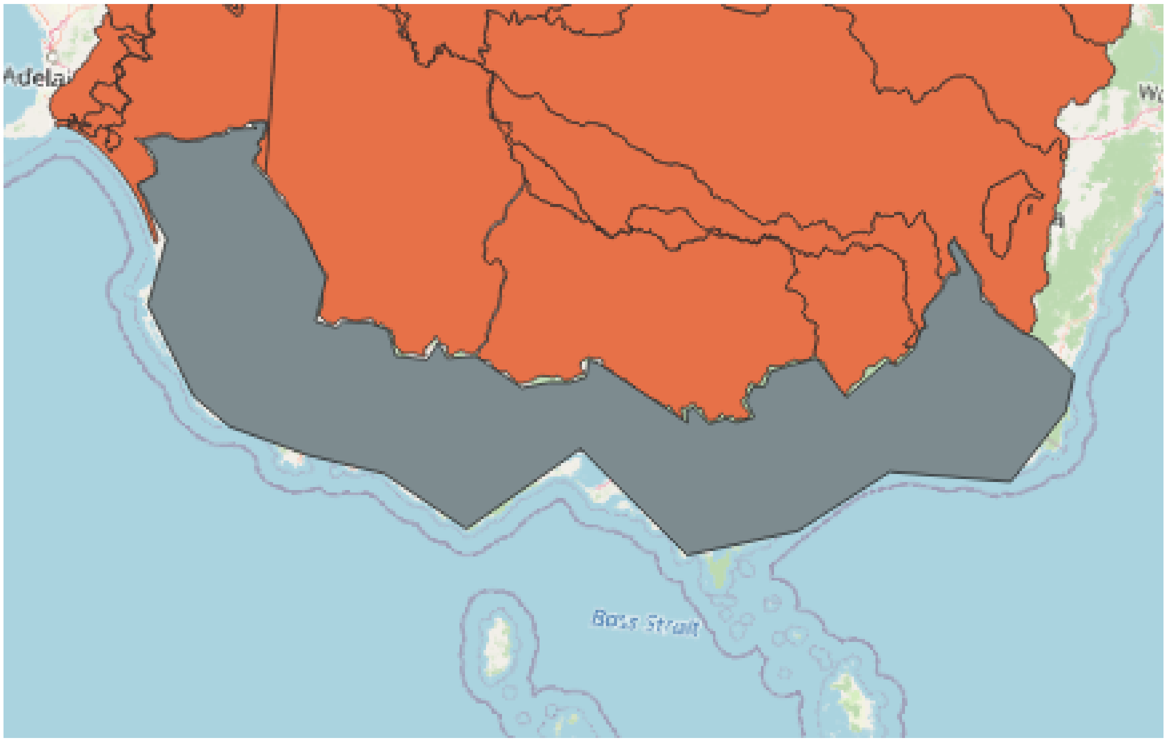
- Victorian hunting bags during opening weekend (https://www.gma.vic.gov.au/___data/assets/pdf_file/0003/503166/Hunters-Bag-Survey-2019.pdf) and water availability in the landscape. Bag limits for the opening weekends throughout the years were obtained from https://www.gma.vic.gov.au/hunting/duck/duck-season-considerations/historical-summary-of-seasonal-arrangements.
- Game duck species counts extracted from https://www.gma.vic.gov.au/___data/assets/pdf_file/0007/583216/Victorian-Duck-Season-Priority-Waterbird-Count,-2020-.pdf. These counts mostly take place a month before the duck hunting season.
- Eastern Australian Waterbird Survey data, provided by Richard Kingsford. For a description of the surveys, which typically take place in October of every year, see https://www.ecosystem.unsw.edu.au/research-projects/rivers-and-wetlands/waterbirds/eastern-australian-waterbird-survey. 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).

Next, using these relationships, we develop five indices that broadly inform on the current population status of ducks in SE Australia and Victoria in particular. Collectively, these five indices can be used to inform seasonal duck hunting regulations.

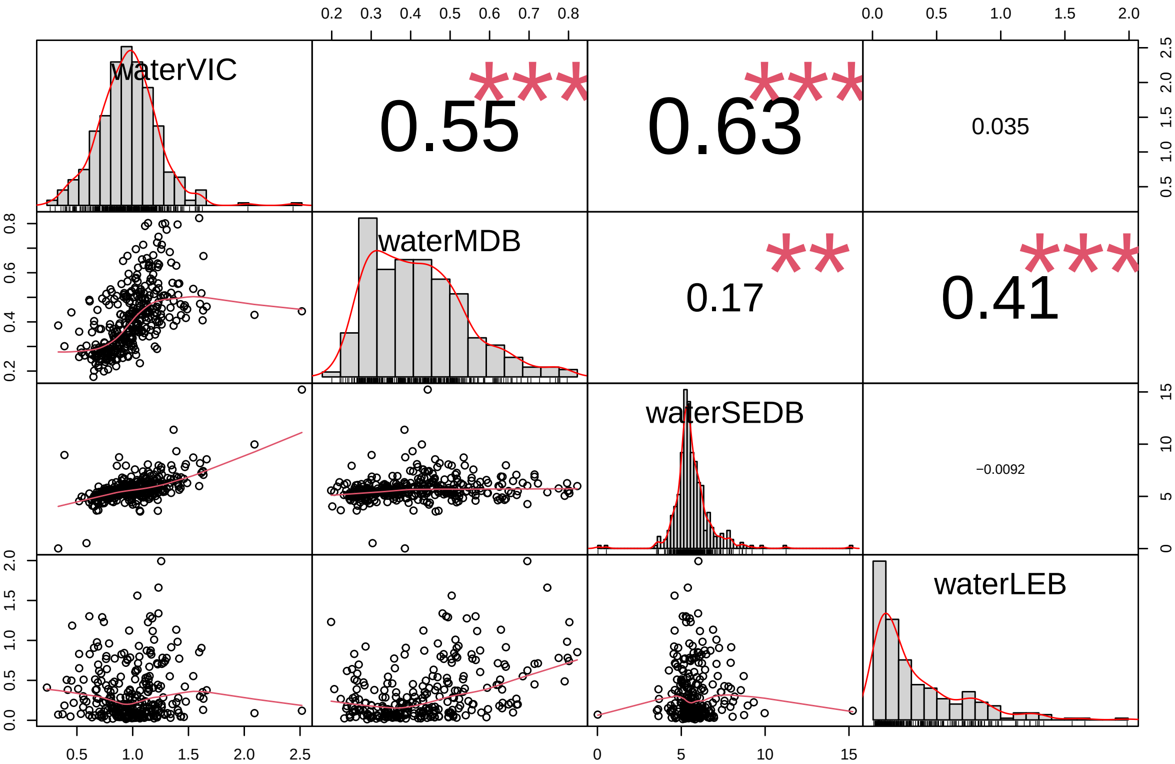
2 Water surface area across SE Australia

The monthly water surface area was kindly obtained by Roxane Francis (UNSW) from LANDSAT satellite imagery for

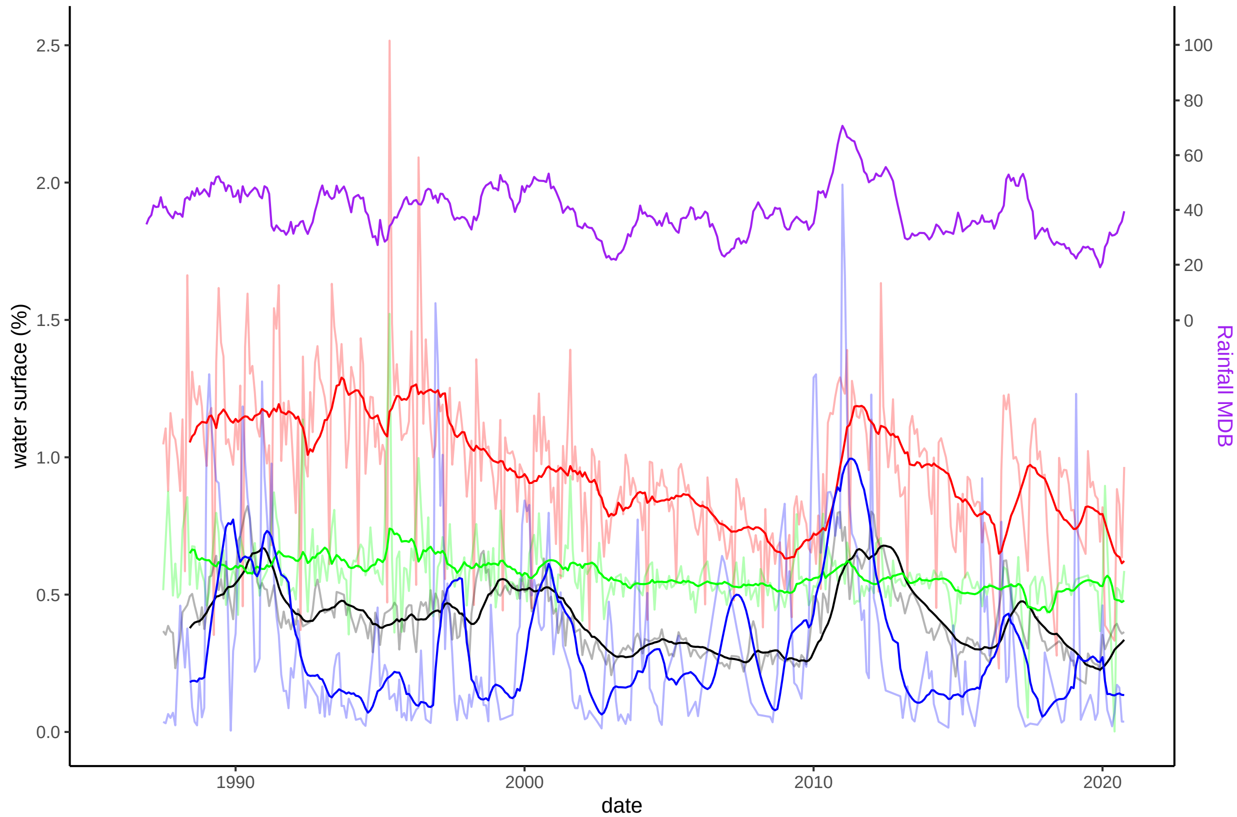
- Victoria (VIC)
- Murray-Darling Basin (MDB)
- SE Australia south of the MDB (SEDB, see image below)
- Lake Eyre Basin (LEB)



Below a matrix plot is presented depicting the relationship between the monthly water surfaces between these 4 regions.



Below, the water surface area (in %) across Victoria (VIC, red),Murray-Darling Basin (MDB, black), SE Australia south of the MDB (SEDB, x10; green) and Lake Eyre Basin (LEB, blue) is depicted. The monthly values are plotted in light shadings, whereas the right-aligned 12 month running mean is depicted in bold. For comparison the 12 month right-aligned running mean of rainfall across the Murray-Darling Basin is also depicted.



Monthly variations in water surface area are (unrealistically) variable from month to month and there seems to be an annual pattern in this variability, which may relate to systematic temporal bias. Therefore, only the 12 month rolling average water surface areas were used in subsequent analyses.

3 Water surface area and hunting bags

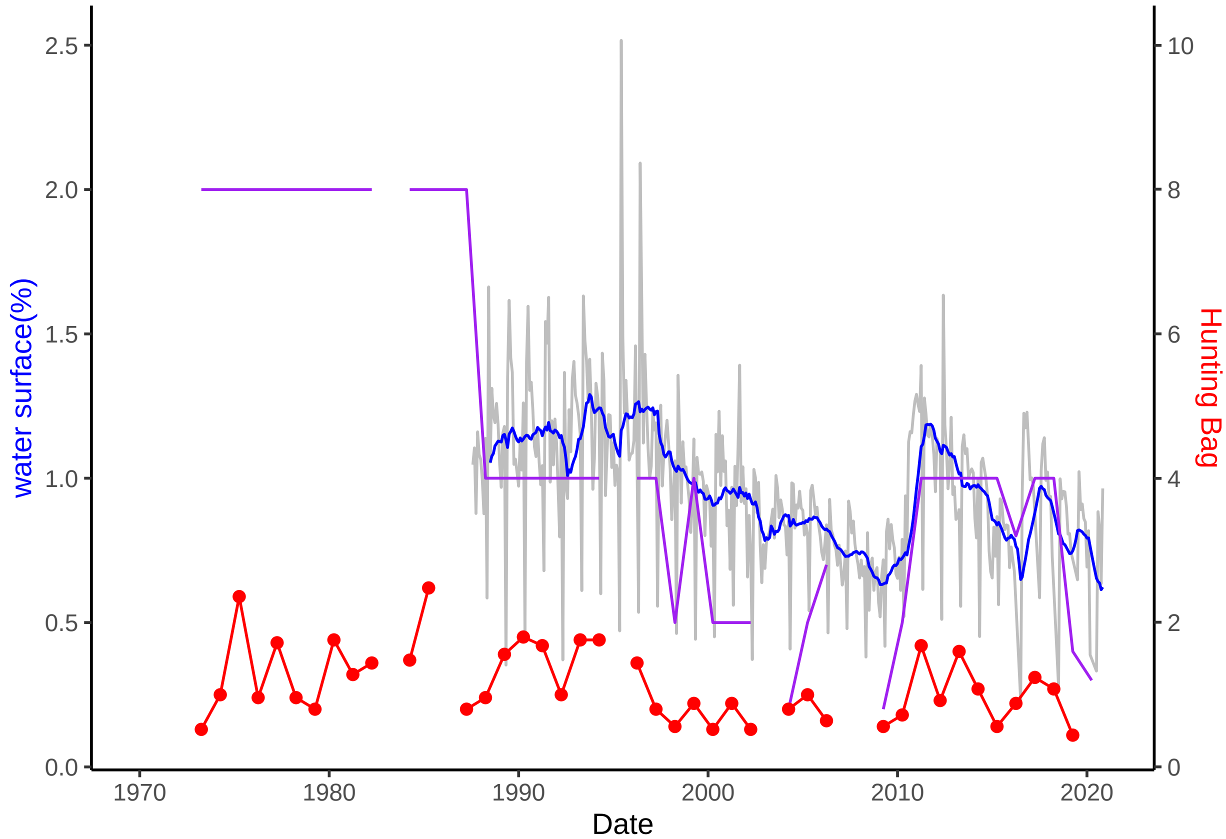
Four times three plots are produced, for VIC, MDB, SEDB and LEB. In the **first plot** of the three, the right aligned rolling mean of the availability of surface water is plotted in blue; it thus portrays the mean surface water area in the preceding 12 months (the underlying monthly data are depicted in grey).

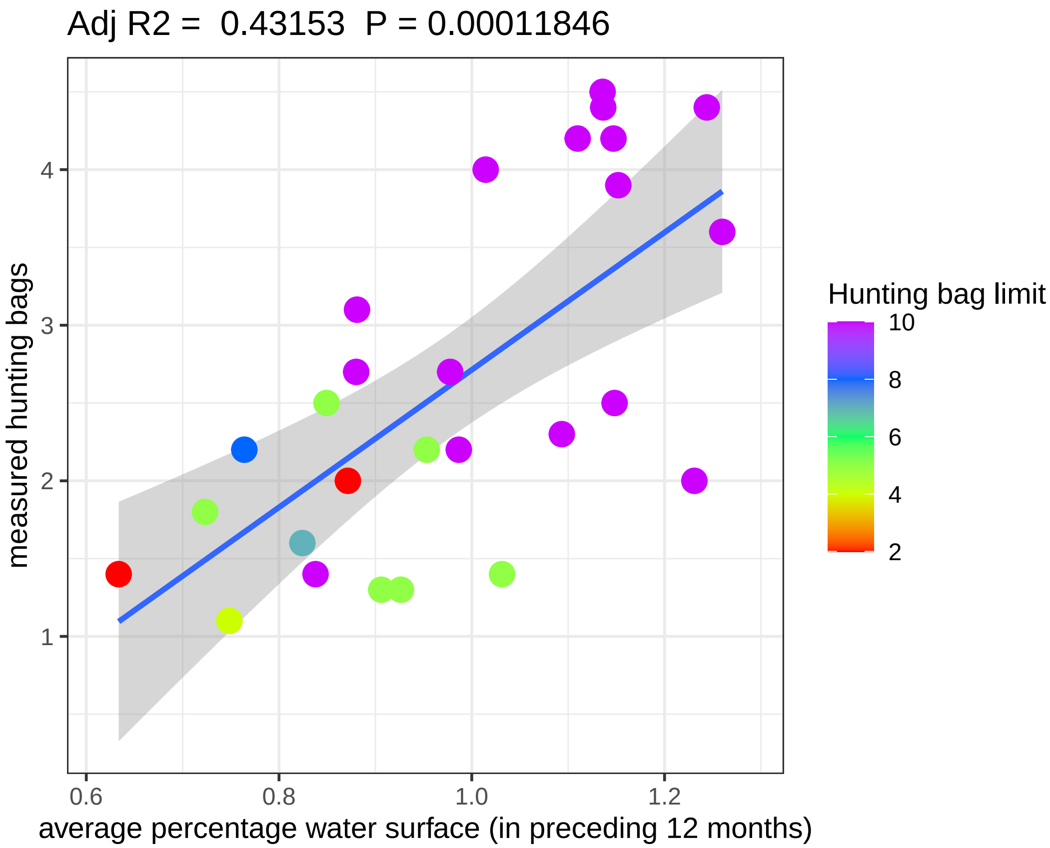
Also plotted in the same graph is the mean bag size obtained by hunters on the opening day of the duck hunting season, 1972 to 2019, except for 1986 when no Hunting Bag Survey was conducted. Hunting bag is plotted as red dots. The hunting bag limit (on opening weekend) is plotted in purple.

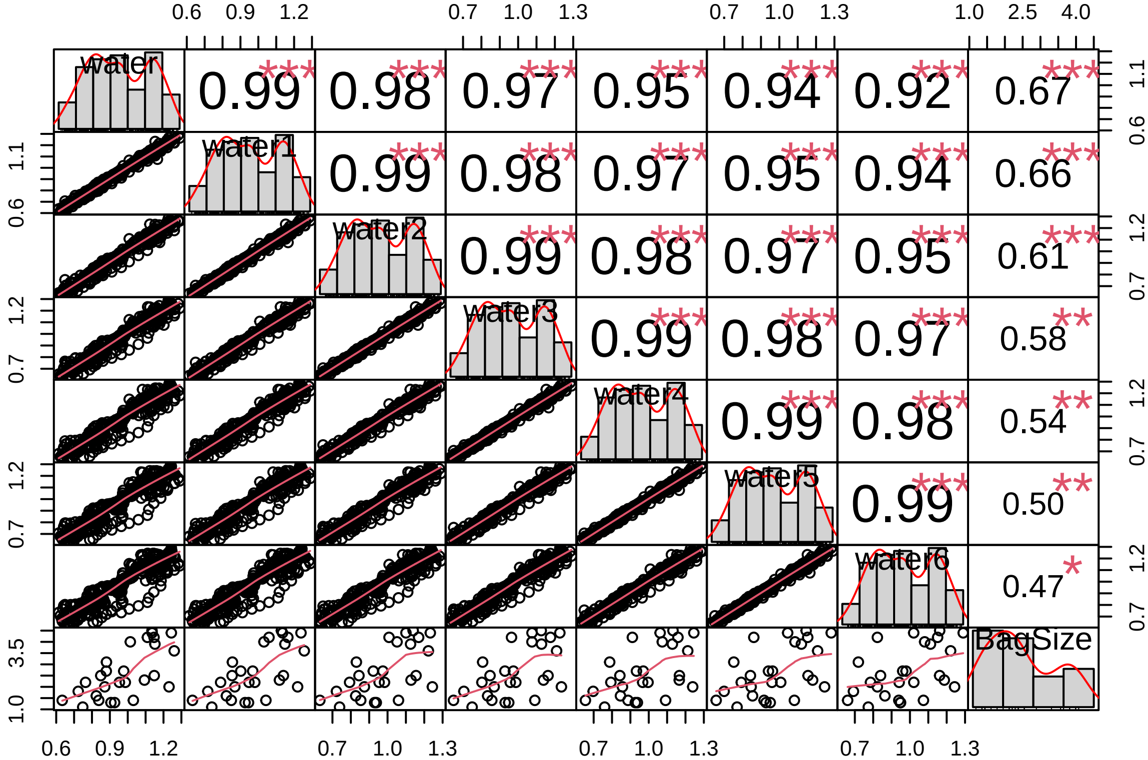
The **second plot** depicts the direct relationship between hunting bag size and the average amount of surface water in the preceding 12 months. The colours of the symbols depict the hunting bag limits.

Finally, the **third plot** in each series of three is a matrix plot showing how this relationship changes if we allow a lag period for water surface area varying from 1-6 months.

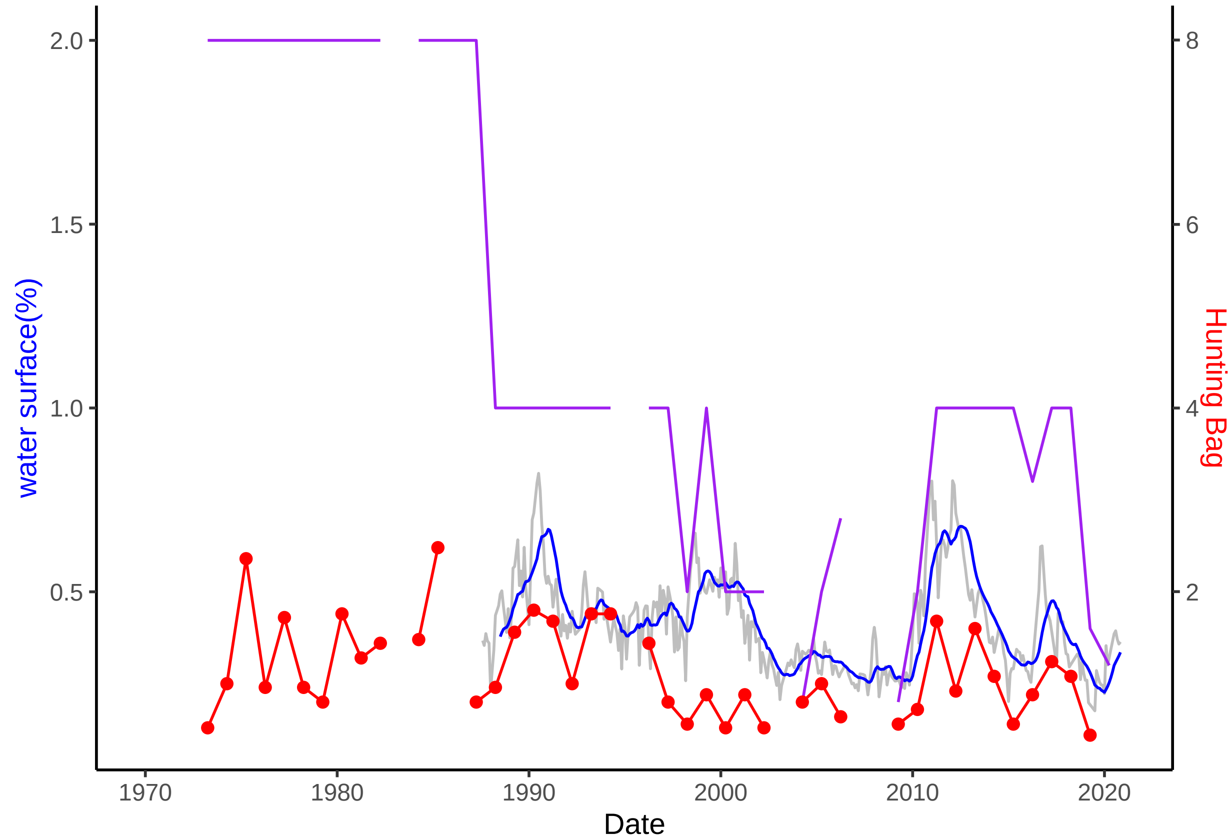
```
##
##
##  VIC
##
```


water surface(%)
Hunting Bag
Date
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
1970
1980
1990
2000
2010
2020

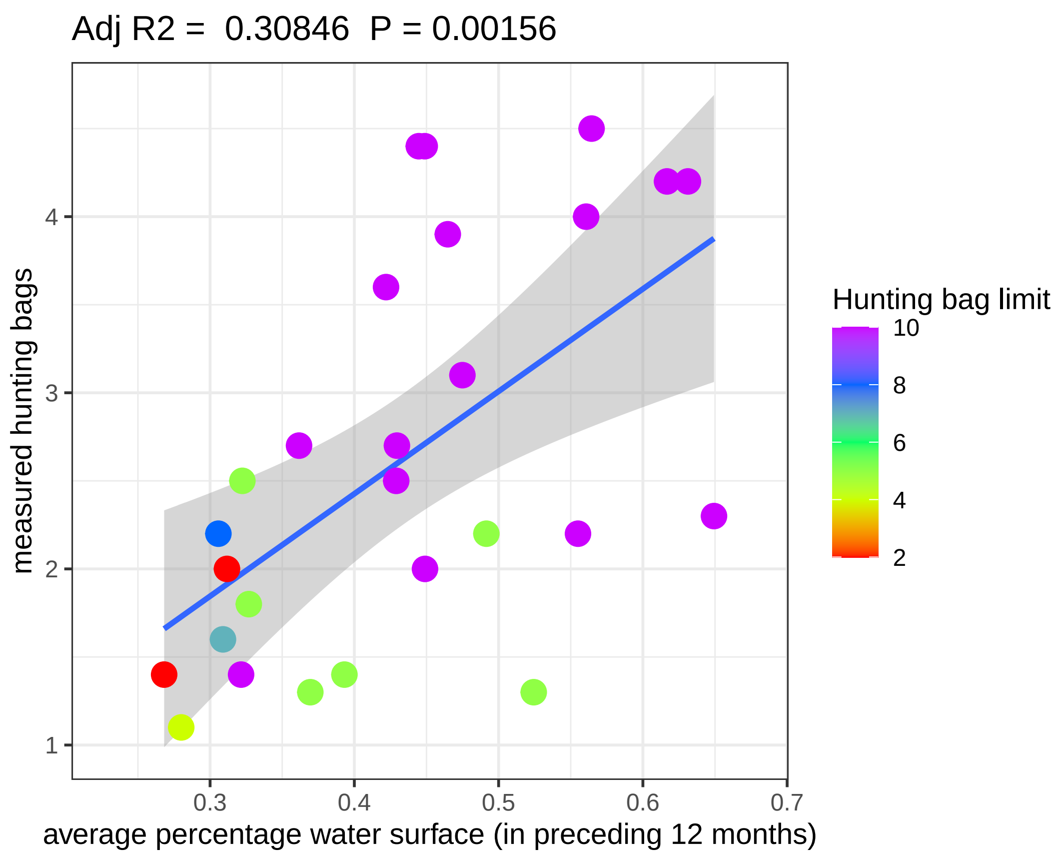

Adj R2 = 0.43153 P = 0.00011846
measured hunting bags
average percentage water surface (in preceding 12 months)
Hunting bag limit
10
8
6
4
2
0.6
0.8
1.0
1.2
1
2
3
4


water
water1
water2
water3
water4
water5
water6
BagSize
0.99
0.98
0.97
0.95
0.94
0.92
0.67
0.66
0.61
0.58
0.54
0.50
0.47

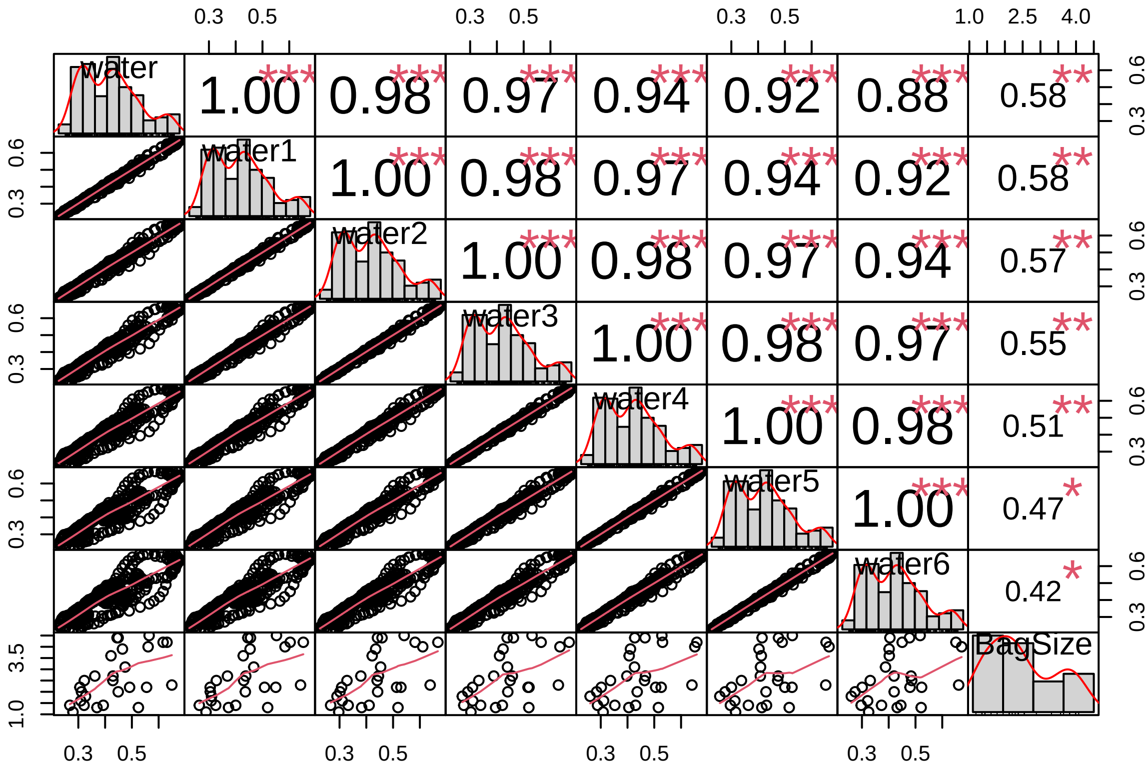
```
##
##
##  MDB
##
```



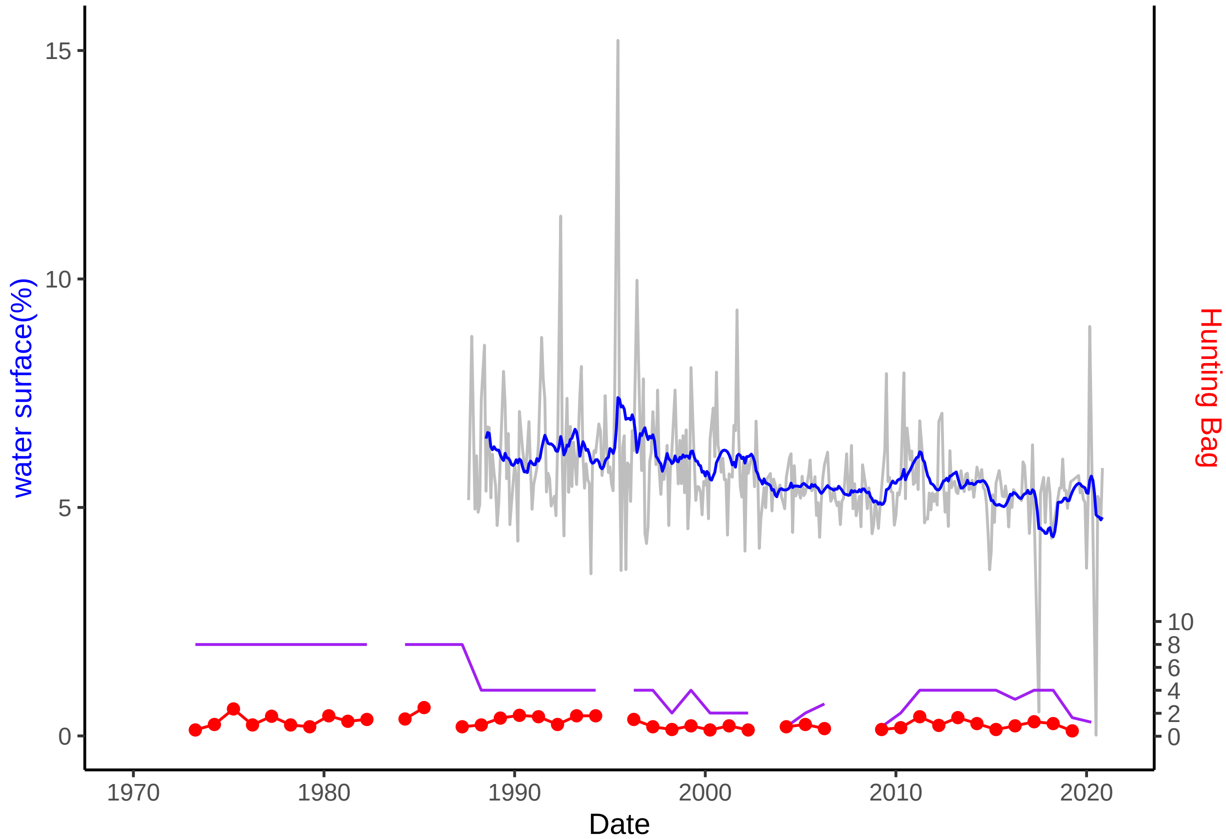
water surface(%)
Hunting Bag
2.0
1.5
1.0
0.5
8
6
4
2
1970
1980
1990
2000
2010
2020
Date



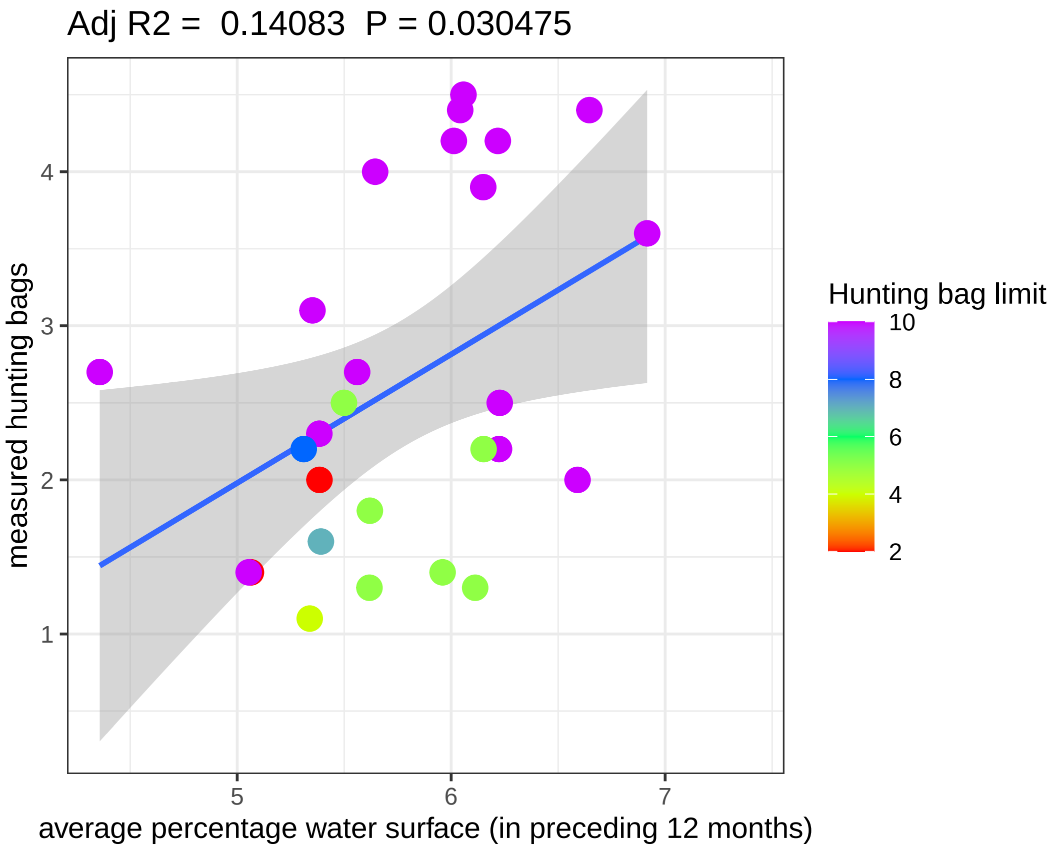
Adj R2 = 0.30846 P = 0.00156
measured hunting bags
average percentage water surface (in preceding 12 months)
Hunting bag limit
10
8
6
4
2
1
2
3
4
0.3
0.4
0.5
0.6
0.7


water
water1
water2
water3
water4
water5
water6
BagSize
1.00
0.98
0.97
0.94
0.92
0.88
0.58
0.57
0.55
0.51
0.47
0.42

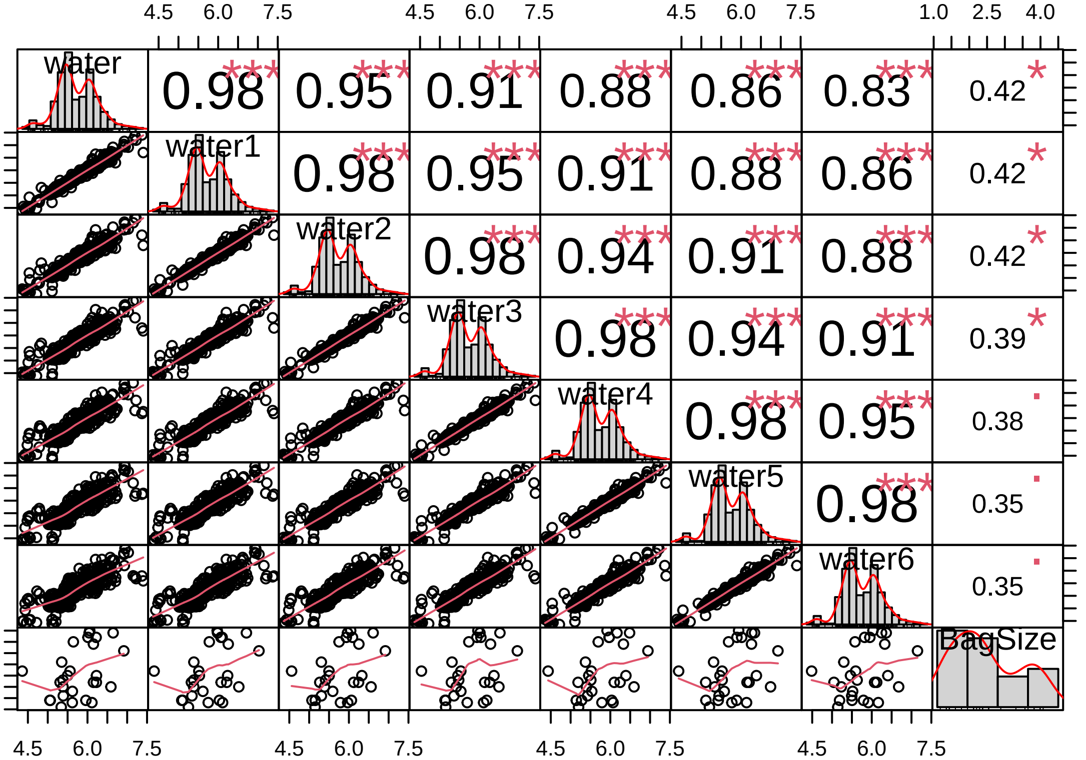
```
##
##
##   SEDB
##
```



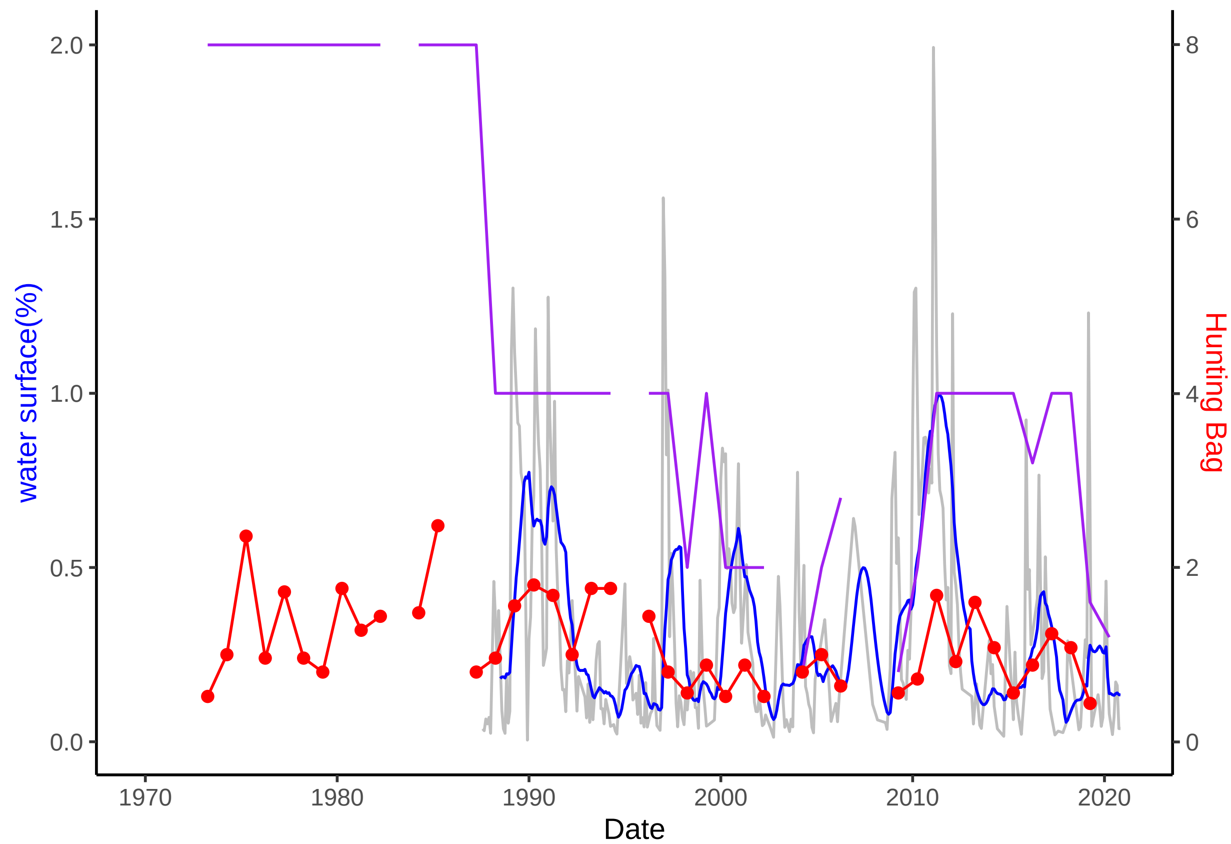
water surface(%)
Hunting Bag
15
10
5
0
10
8
6
4
2
0
1970
1980
1990
2000
2010
2020
Date



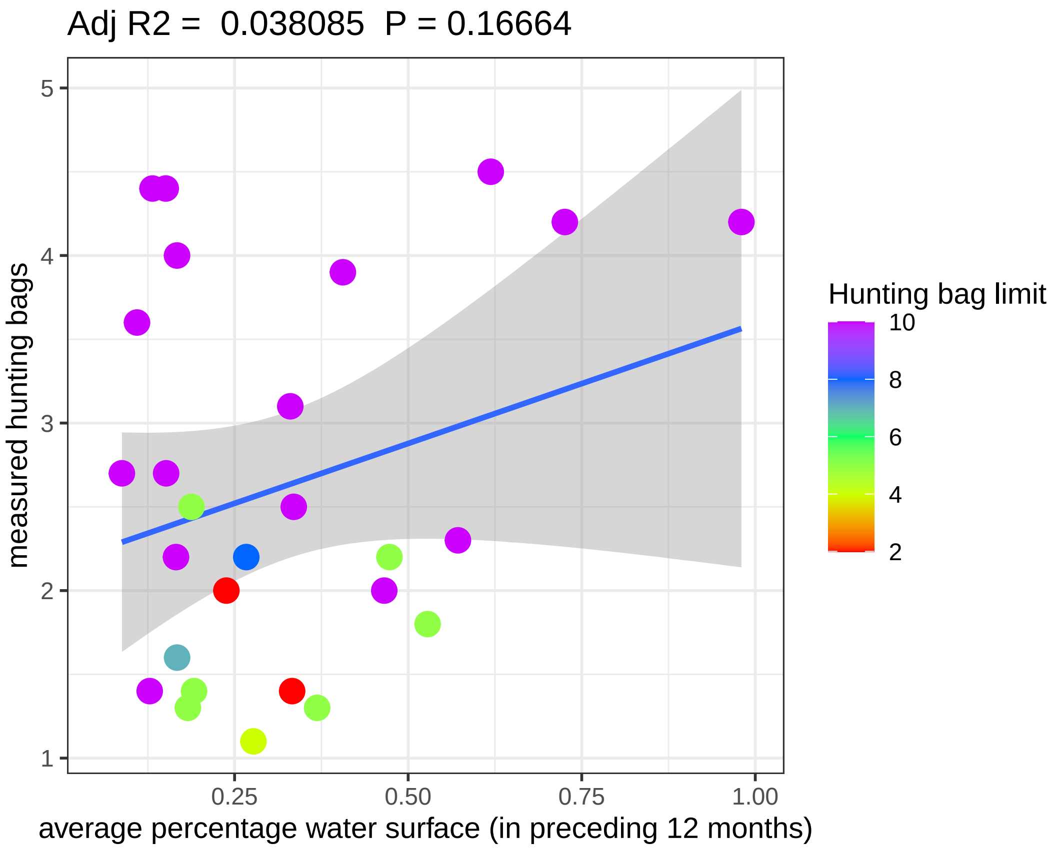
Adj R2 = 0.14083 P = 0.030475
measured hunting bags
average percentage water surface (in preceding 12 months)
Hunting bag limit
10
8
6
4
2
1
2
3
4
5
6
7

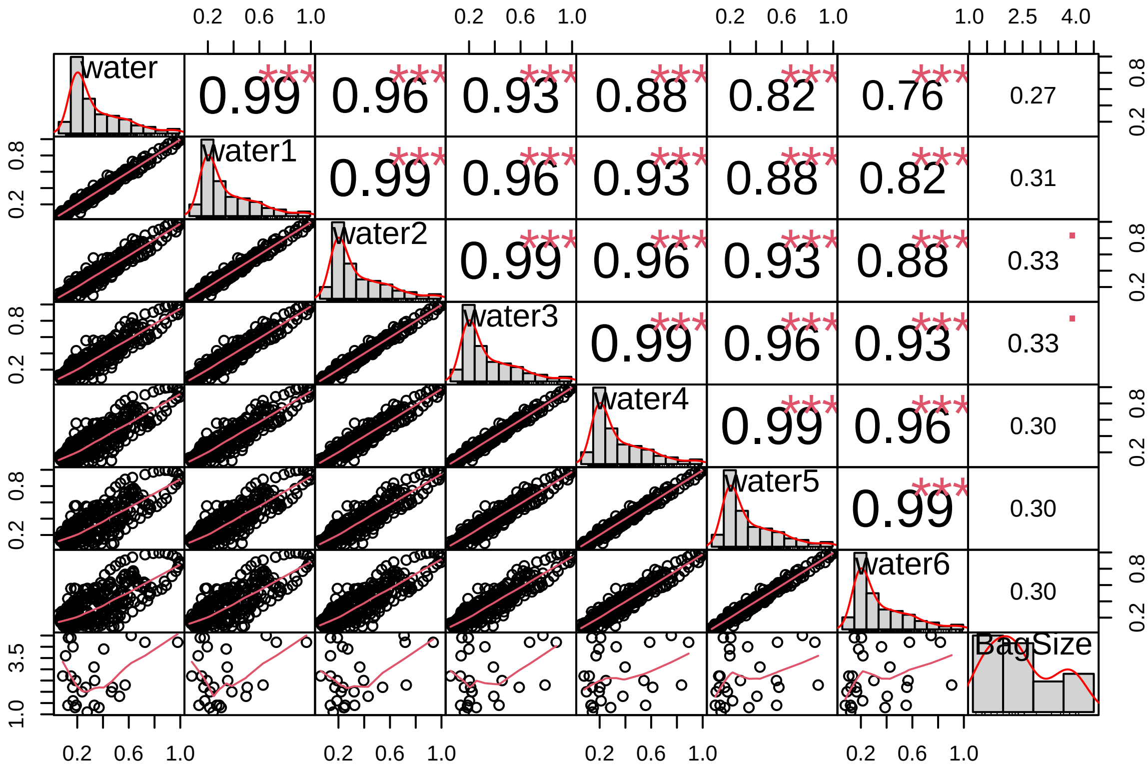

water
water1
water2
water3
water4
water5
water6
BagSize
0.98
0.95
0.91
0.88
0.86
0.83
0.42
0.39
0.38
0.35
4.5
6.0
7.5
6.5
1.0
2.5
4.0
3.5

```
##
##
##  LEB
##
```



water surface(%)
Hunting Bag
Date
0.0
0.5
1.0
1.5
2.0
0
2
4
6
8
1970
1980
1990
2000
2010
2020


Adj R2 = 0.038085 P = 0.16664
measured hunting bags
average percentage water surface (in preceding 12 months)
Hunting bag limit
10
8
6
4
2
5
4
3
2
1
0.25
0.50
0.75
1.00



3.1 Predictive models

We used linear modelling to conduct a regression across all hunting bag data 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.

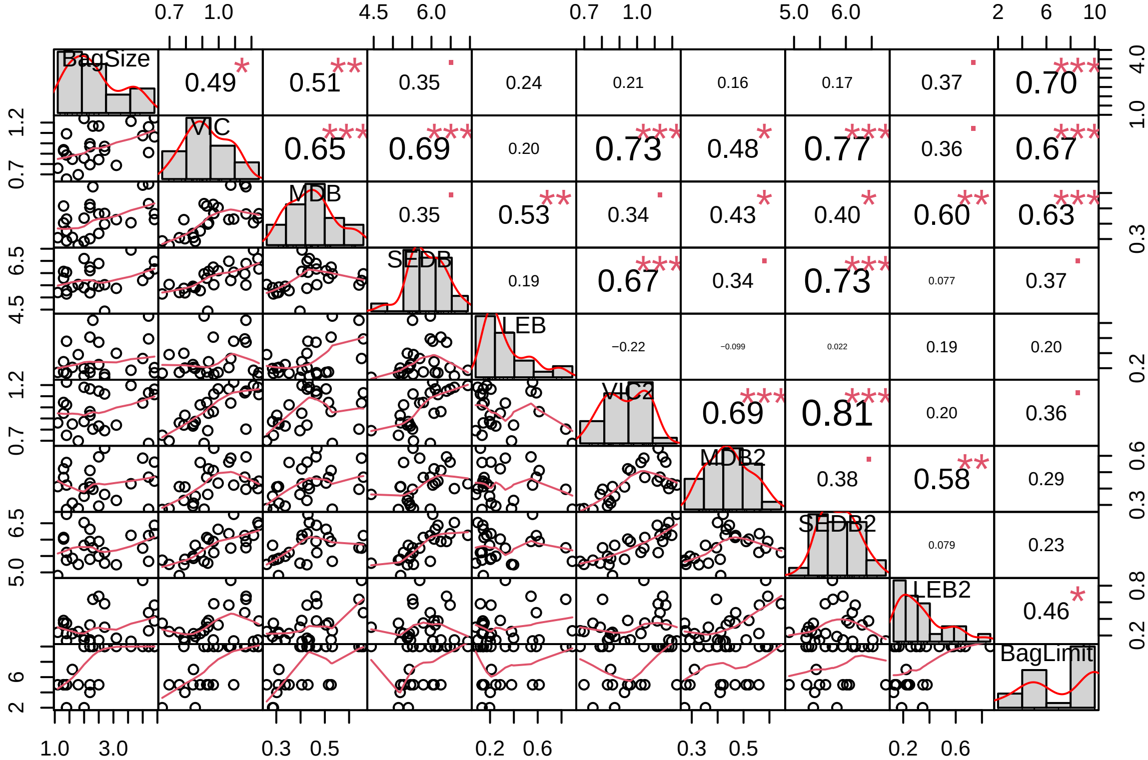
In the table below, after first presenting a correlation chart for all variables in the model, including Pearson correlation coefficients, the resulting models are ranked from the best to the poorest model for all models with a deltaAIC <= 7. Models with similar statistical support as the best model have a deltaAIC <=2.

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 parameter estimates for all its parameters (except possibly the intercept)
3. had a high adjR^2

We also present statistics for the model average for all models with deltaAIC <=2.



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	df	delta	weight	AllSignif
0.4304	NA	NA	4.792	NA	NA	NA	NA	NA	0.2773	3	0.0000	0.074855	TRUE
3.8053	NA	NA	NA	NA	NA	-1.1423	5.484	NA	0.3612	4	0.0076	0.074572	FALSE
-0.4795	NA	NA	NA	NA	NA	NA	3.080	NA	0.2537	3	0.7464	0.051541	TRUE
-0.5130	NA	NA	3.141	NA	NA	NA	1.712	NA	0.3228	4	1.3526	0.038063	FALSE
3.2277	NA	NA	2.433	NA	NA	-0.9952	4.115	NA	0.4009	5	1.6954	0.032068	FALSE
-1.4261	NA	NA	4.155	NA	0.3702	NA	NA	NA	0.3118	4	1.7247	0.031602	FALSE
3.1138	NA	NA	NA	NA	0.5053	-1.4391	4.967	NA	0.3925	5	2.0145	0.027339	FALSE
0.0563	NA	NA	NA	NA	NA	NA	4.495	-1.9551	0.3018	4	2.0594	0.026732	FALSE
-0.3902	NA	1.2229	NA	NA	NA	NA	2.570	NA	0.3016	4	2.0660	0.026643	FALSE
0.4973	NA	0.5687	4.202	NA	NA	NA	NA	NA	0.2850	4	2.6102	0.020297	FALSE
3.3241	NA	0.7027	NA	NA	NA	-1.0004	4.893	NA	0.3754	5	2.6514	0.019883	FALSE
0.6064	NA	NA	5.071	-0.6908	NA	NA	NA	NA	0.2815	4	2.7228	0.019185	FALSE
0.3999	-0.1961	NA	5.004	NA	NA	NA	NA	NA	0.2787	4	2.8135	0.018335	FALSE
0.2492	NA	NA	4.670	NA	NA	NA	NA	0.2400	0.2787	4	2.8137	0.018333	FALSE
0.8614	NA	NA	4.929	NA	NA	-0.0847	NA	NA	0.2785	4	2.8181	0.018292	FALSE
-0.5177	0.7081	NA	NA	NA	NA	NA	2.891	NA	0.2776	4	2.8491	0.018011	FALSE
3.5388	0.4173	NA	NA	NA	NA	-1.0773	5.236	NA	0.3692	5	2.8785	0.017749	FALSE
3.8971	NA	NA	NA	-0.8389	NA	-1.1363	5.725	NA	0.3670	5	2.9555	0.017078	FALSE
3.5800	NA	NA	NA	NA	NA	-1.0537	5.581	-0.3913	0.3625	5	3.1195	0.015734	FALSE
0.2691	NA	NA	4.641	NA	0.7934	-0.7501	NA	NA	0.3620	5	3.1378	0.015590	FALSE
-0.3539	NA	NA	NA	-0.9206	NA	NA	3.358	NA	0.2607	4	3.3844	0.013782	FALSE
0.0507	NA	1.9476	NA	-2.8431	NA	NA	3.129	NA	0.3516	5	3.5103	0.012941	FALSE
-1.6807	NA	1.8706	NA	NA	0.6190	NA	NA	NA	0.2567	4	3.5105	0.012940	FALSE
-0.6359	NA	NA	NA	NA	0.0438	NA	2.981	NA	0.2540	4	3.5945	0.012408	FALSE
-0.1050	NA	NA	2.659	NA	NA	NA	2.986	-1.4702	0.3484	5	3.6238	0.012227	FALSE
2.4066	NA	NA	2.652	NA	0.5620	-1.3121	3.417	NA	0.4393	6	3.6963	0.011792	FALSE
1.8385	NA	2.0044	NA	NA	NA	NA	NA	NA	0.1473	3	3.8606	0.010862	FALSE
0.0898	NA	1.1134	NA	NA	NA	NA	3.905	-1.7809	0.3411	5	3.8800	0.010757	FALSE
-0.3139	NA	NA	3.426	-1.4808	NA	NA	2.036	NA	0.3404	5	3.9050	0.010623	FALSE
-0.4590	NA	0.6377	2.443	NA	NA	NA	1.751	NA	0.3324	5	4.1811	0.009254	FALSE
-1.3602	NA	NA	NA	NA	0.6705	NA	NA	NA	0.1292	3	4.3519	0.008496	FALSE
-1.0996	NA	NA	3.270	NA	0.1639	NA	1.286	NA	0.3268	5	4.3760	0.008394	FALSE

-1.5498	NA	0.8067	3.244	NA	0.4139	NA	NA	NA	0.3267	5	4.3763	0.008393	FALSE
-1.3748	NA	NA	4.554	-1.2039	0.4212	NA	NA	NA	0.3238	5	4.4755	0.007987	FALSE
-0.5158	0.0724	NA	3.038	NA	NA	NA	1.738	NA	0.3230	5	4.5045	0.007872	FALSE
-1.5920	NA	NA	4.308	NA	0.5296	NA	NA	-0.8390	0.3219	5	4.5402	0.007733	FALSE
-0.4287	0.5910	1.1320	NA	NA	NA	NA	2.451	NA	0.3179	5	4.6763	0.007224	FALSE
3.3057	NA	NA	2.701	-1.2924	NA	-0.9698	4.336	NA	0.4142	6	4.6908	0.007172	FALSE
2.4622	NA	0.8481	NA	NA	0.5571	-1.2982	4.200	NA	0.4128	6	4.7477	0.006971	FALSE
-1.4601	-0.2027	NA	4.374	NA	0.3707	NA	NA	NA	0.3133	5	4.8338	0.006677	FALSE
-0.7993	NA	NA	NA	NA	0.2630	NA	4.122	-2.2612	0.3110	5	4.9085	0.006432	FALSE
2.5000	NA	NA	NA	NA	NA	NA	NA	NA	0.0000	2	5.0166	0.006094	TRUE
-1.0813	NA	1.3284	NA	NA	0.1956	NA	2.084	NA	0.3070	5	5.0437	0.006012	FALSE
3.1320	NA	1.3305	NA	-2.1723	NA	-0.8579	4.989	NA	0.4031	6	5.1223	0.005780	FALSE
0.0487	NA	NA	NA	0.6255	NA	NA	4.511	-2.2390	0.3040	5	5.1436	0.005719	FALSE
-0.0240	0.2356	NA	NA	NA	NA	NA	4.254	-1.7086	0.3037	5	5.1551	0.005686	FALSE
3.1479	NA	0.1779	2.256	NA	NA	-0.9700	4.065	NA	0.4016	6	5.1776	0.005622	FALSE
3.2593	-0.1006	NA	2.571	NA	NA	-1.0026	4.097	NA	0.4013	6	5.1914	0.005584	FALSE
3.1994	NA	NA	2.424	NA	NA	-0.9838	4.133	-0.0531	0.4010	6	5.2033	0.005551	FALSE
3.2044	NA	NA	NA	-0.8637	0.5082	-1.4346	5.213	NA	0.3987	6	5.2901	0.005315	FALSE
-1.6909	NA	2.6608	NA	-2.6155	0.7705	NA	NA	NA	0.2986	5	5.3220	0.005231	FALSE
0.8976	NA	0.9502	4.370	-1.3942	NA	NA	NA	NA	0.2985	5	5.3247	0.005224	FALSE
2.7304	NA	NA	NA	NA	0.5240	-1.3092	5.102	-0.6217	0.3957	6	5.4030	0.005023	FALSE
2.9869	0.2663	NA	NA	NA	0.4738	-1.3791	4.841	NA	0.3956	6	5.4059	0.005016	FALSE
0.1903	NA	NA	4.996	-1.5735	NA	NA	NA	0.8494	0.2916	5	5.5521	0.004662	FALSE
1.6606	NA	NA	4.891	NA	NA	-0.4036	NA	1.0909	0.2893	5	5.6291	0.004486	FALSE
0.6337	-0.4212	NA	5.673	-1.0542	NA	NA	NA	NA	0.2866	5	5.7152	0.004297	FALSE
0.3116	NA	0.5715	4.074	NA	NA	NA	NA	0.2464	0.2864	5	5.7219	0.004283	FALSE
0.4773	-0.1094	0.5426	4.348	NA	NA	NA	NA	NA	0.2854	5	5.7549	0.004213	FALSE
0.7053	NA	0.5452	4.294	NA	NA	-0.0414	NA	NA	0.2853	5	5.7591	0.004204	FALSE
1.6376	0.8340	1.8248	NA	NA	NA	NA	NA	NA	0.1805	4	5.7869	0.004146	FALSE
0.8371	NA	NA	5.127	-0.6373	NA	-0.0480	NA	NA	0.2819	5	5.8689	0.003979	FALSE
0.9679	-0.2569	NA	5.253	NA	NA	-0.1135	NA	NA	0.2807	5	5.9054	0.003907	FALSE
3.1009	0.3830	0.6716	NA	NA	NA	-0.9469	4.691	NA	0.3820	6	5.9146	0.003889	FALSE
-0.4371	0.6551	NA	NA	-0.5693	NA	NA	3.077	NA	0.2801	5	5.9252	0.003869	FALSE
0.2903	-0.1304	NA	4.853	NA	NA	NA	NA	0.1587	0.2791	5	5.9573	0.003807	FALSE
-0.5572	0.7065	NA	NA	NA	0.0111	NA	2.866	NA	0.2776	5	6.0064	0.003715	FALSE
-0.6617	NA	1.8950	NA	NA	0.8936	-0.4507	NA	NA	0.2757	5	6.0674	0.003603	FALSE
2.9835	NA	0.7373	NA	NA	NA	-0.8687	4.999	-0.5505	0.3779	6	6.0684	0.003602	FALSE
2.1490	1.1252	NA	NA	NA	NA	NA	NA	NA	0.0626	3	6.0858	0.003570	FALSE
0.4923	-0.6947	NA	5.487	NA	0.8800	-0.9005	NA	NA	0.3770	6	6.0991	0.003547	FALSE
-0.0435	NA	1.9434	NA	NA	NA	0.3287	NA	NA	0.1688	4	6.1175	0.003514	FALSE
1.0182	NA	1.8560	NA	NA	NA	NA	NA	0.8922	0.1676	4	6.1515	0.003455	FALSE
-0.0417	NA	1.3829	2.135	-2.6348	NA	NA	2.372	NA	0.3749	6	6.1789	0.003408	FALSE
-1.5742	0.5761	1.7559	NA	NA	0.5758	NA	NA	NA	0.2720	5	6.1846	0.003398	FALSE
3.6499	0.3551	NA	NA	-0.6524	NA	-1.0822	5.460	NA	0.3725	6	6.2654	0.003264	FALSE
-1.2330	0.8438	NA	NA	NA	0.6027	NA	NA	NA	0.1631	4	6.2777	0.003244	FALSE
-1.8710	NA	1.9792	NA	NA	0.7949	NA	NA	-0.8810	0.2677	5	6.3219	0.003173	FALSE
0.0809	NA	0.6284	3.905	NA	0.8045	-0.7095	NA	NA	0.3709	6	6.3237	0.003170	FALSE
3.6109	0.4548	NA	NA	NA	NA	-1.1092	5.172	0.1669	0.3693	6	6.3811	0.003080	FALSE
0.2231	NA	NA	4.909	-0.8827	0.8099	-0.7131	NA	NA	0.3683	6	6.4172	0.003025	FALSE
4.0963	NA	NA	NA	-1.0459	NA	-1.2043	5.709	0.3069	0.3675	6	6.4486	0.002978	FALSE
-1.5615	NA	1.5934	3.202	-2.5585	0.5647	NA	NA	NA	0.3669	6	6.4715	0.002944	FALSE
1.2160	NA	NA	NA	NA	NA	NA	NA	1.3179	0.0462	3	6.4964	0.002908	FALSE
-0.5261	NA	NA	NA	-0.9250	0.0484	NA	3.251	NA	0.2611	5	6.5312	0.002858	FALSE
0.6941	NA	NA	4.631	NA	0.7670	-0.8897	NA	0.5533	0.3647	6	6.5504	0.002830	FALSE
-0.9987	NA	2.1792	NA	-3.0998	0.3084	NA	2.414	NA	0.3646	6	6.5516	0.002829	FALSE
2.1042	NA	2.2613	NA	-0.8163	NA	NA	NA	NA	0.1520	4	6.5875	0.002778	FALSE
-1.2349	NA	1.3065	NA	NA	0.4090	NA	3.223	-2.2266	0.3623	6	6.6358	0.002712	FALSE
-1.1646	NA	NA	2.800	NA	0.3231	NA	2.448	-1.8205	0.3622	6	6.6387	0.002708	FALSE
-0.0395	NA	0.6722	1.913	NA	NA	NA	3.053	-1.5010	0.3590	6	6.7534	0.002557	FALSE
-0.4275	NA	NA	NA	NA	0.9215	-0.4108	NA	NA	0.1450	4	6.7792	0.002524	FALSE
0.2167	NA	NA	NA	NA	NA	0.3946	NA	NA	0.0313	3	6.8626	0.002421	FALSE
0.1335	NA	1.7166	NA	-2.1126	NA	NA	3.531	-0.7277	0.3549	6	6.9019	0.002374	FALSE
-0.0068	0.2766	1.8402	NA	-2.5888	NA	NA	3.023	NA	0.3548	6	6.9060	0.002369	FALSE
0.0258	-0.4826	NA	3.213	NA	NA	NA	3.166	-1.8741	0.3542	6	6.9250	0.002347	FALSE
0.3655	1.4063	NA	NA	NA	NA	NA	NA	1.7405	0.1393	4	6.9363	0.002334	FALSE
1.8058	NA	NA	NA	1.6171	NA	NA	NA	NA	0.0280	3	6.9418	0.002327	FALSE

```
##                       VIC  MDB  SEDB2 SEDB
## Sum of weights:       0.65 0.58 0.35  0.10
## N containing models:    4    4    2     1
```

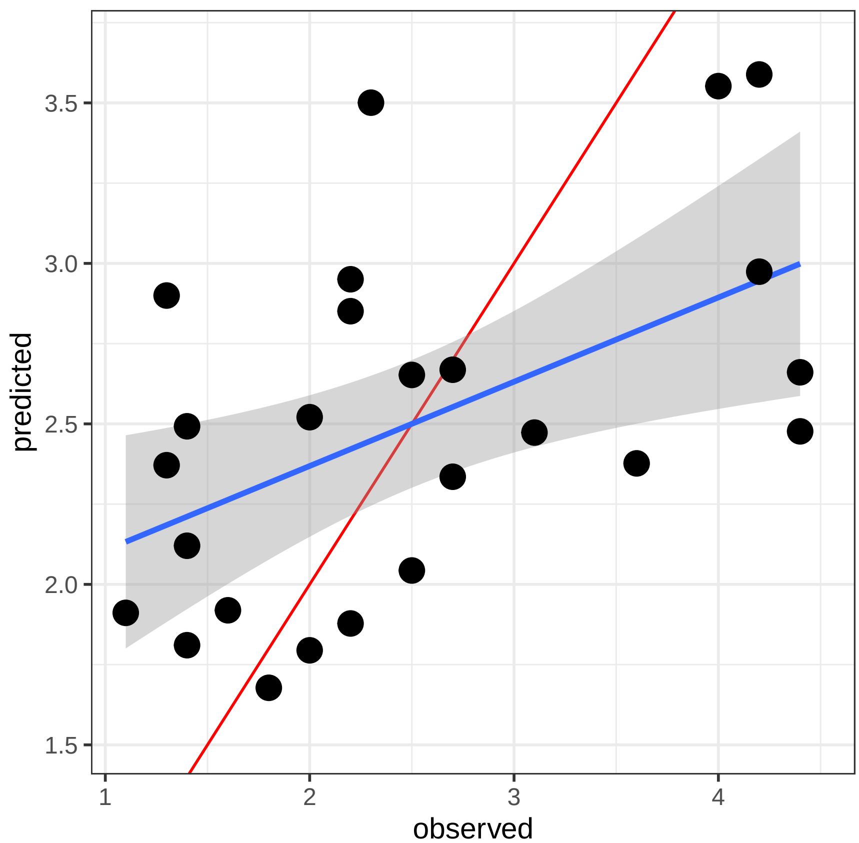
The above results are based on 25 cases.

3.2 Predicted versus observed

We present the critical statistics for the ultimately preferred model using the 4 criteria described above. Next a plot of the predicted versus the observed hunting bag is presented where 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 preferred model selected: 1
##
##
##
```

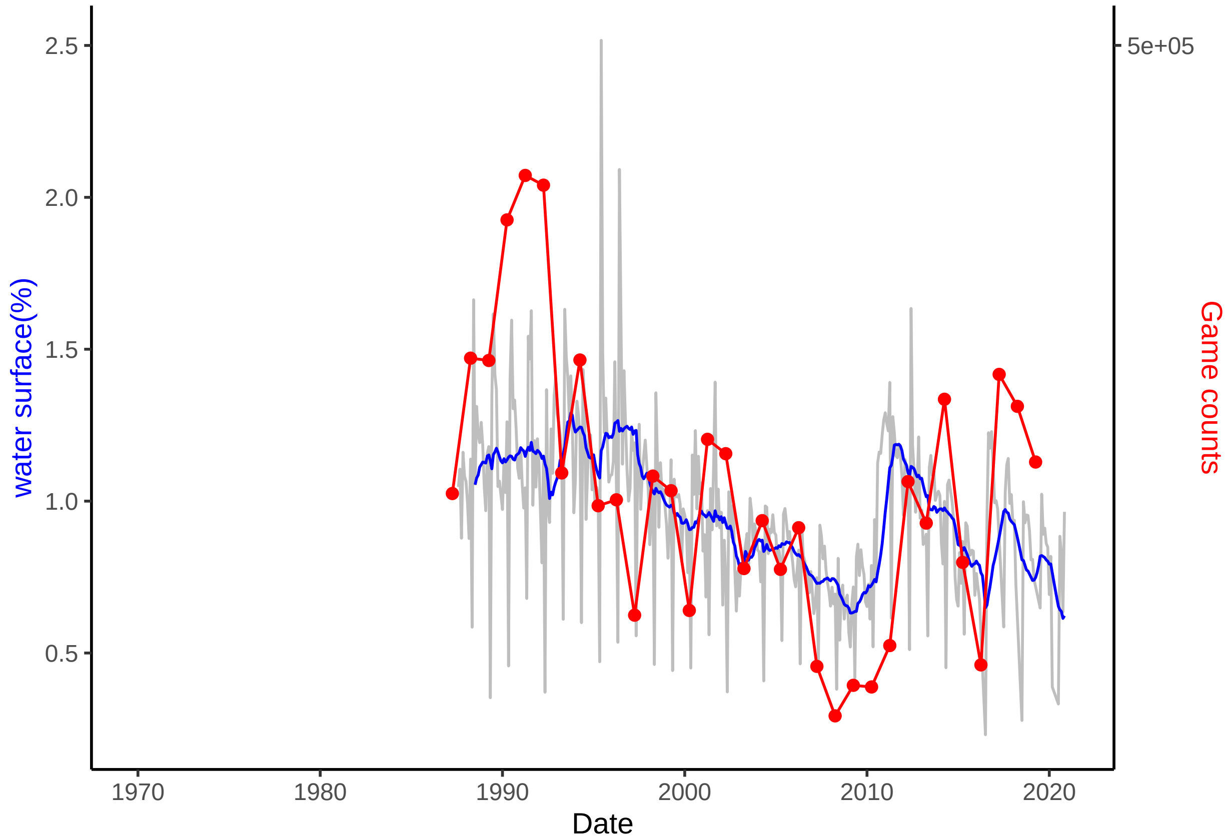
```
##
## Call:
## lm(formula = BagSize ~ MDB + 1, data = Jc)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.5998 -0.7203  0.0313  0.4568  1.9233
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)    0.430      0.747    0.58   0.5702
## MDB            4.792      1.675    2.86   0.0088 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.939 on 23 degrees of freedom
## Multiple R-squared:  0.263,  Adjusted R-squared:  0.23
## F-statistic: 8.19 on 1 and 23 DF,  p-value: 0.00882
```



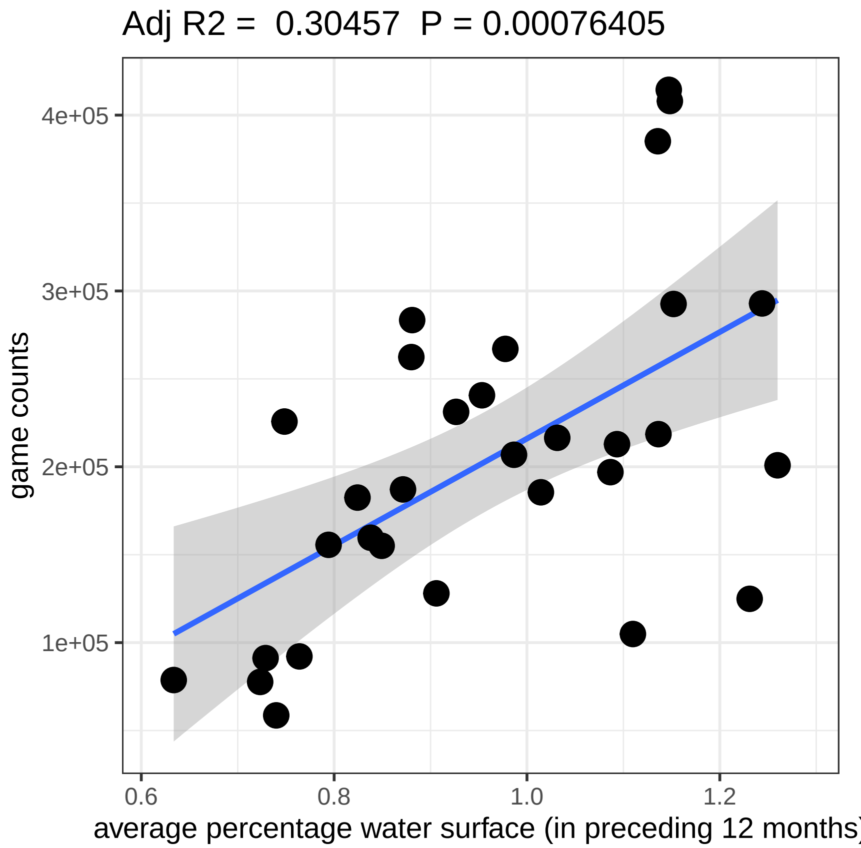
4 Water surface area and game counts

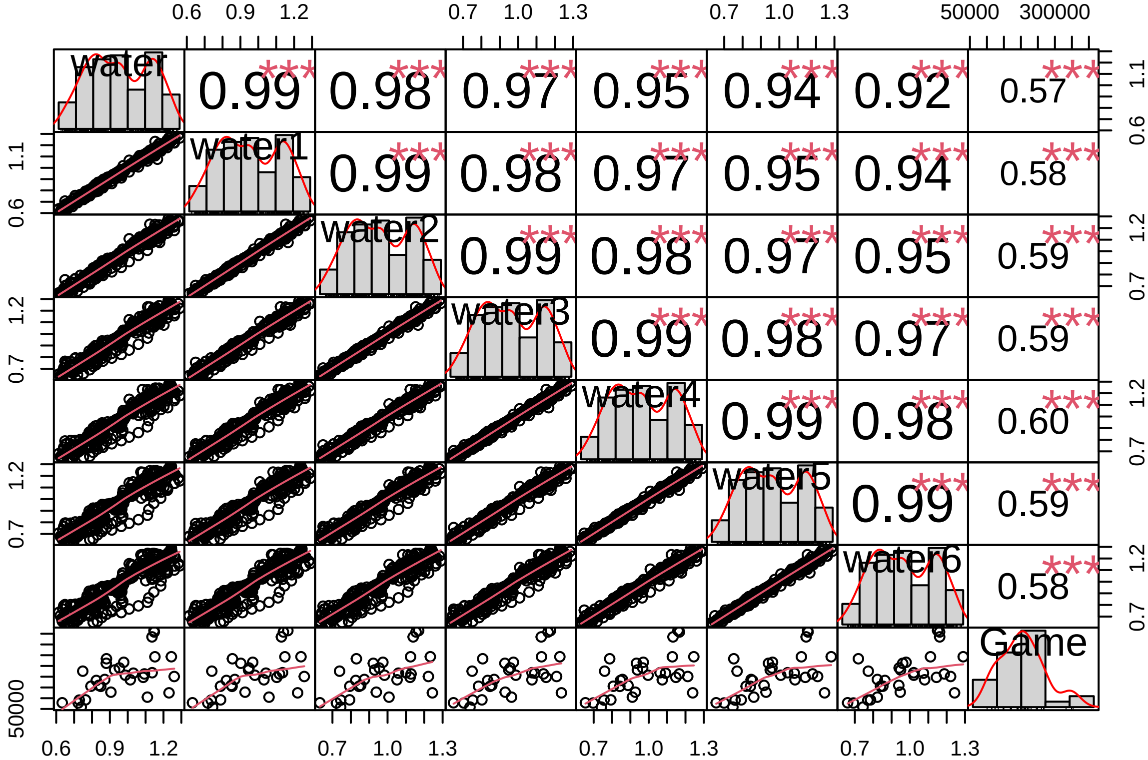
Similar to "Water surface area and hunting bags" but now using game counts in Victoria as the dependent variable. Game counts for 2020 were ignored since these had a very poor coverage due to the COVID-19 pandemic.

```
##
##
##  VIC
##
```

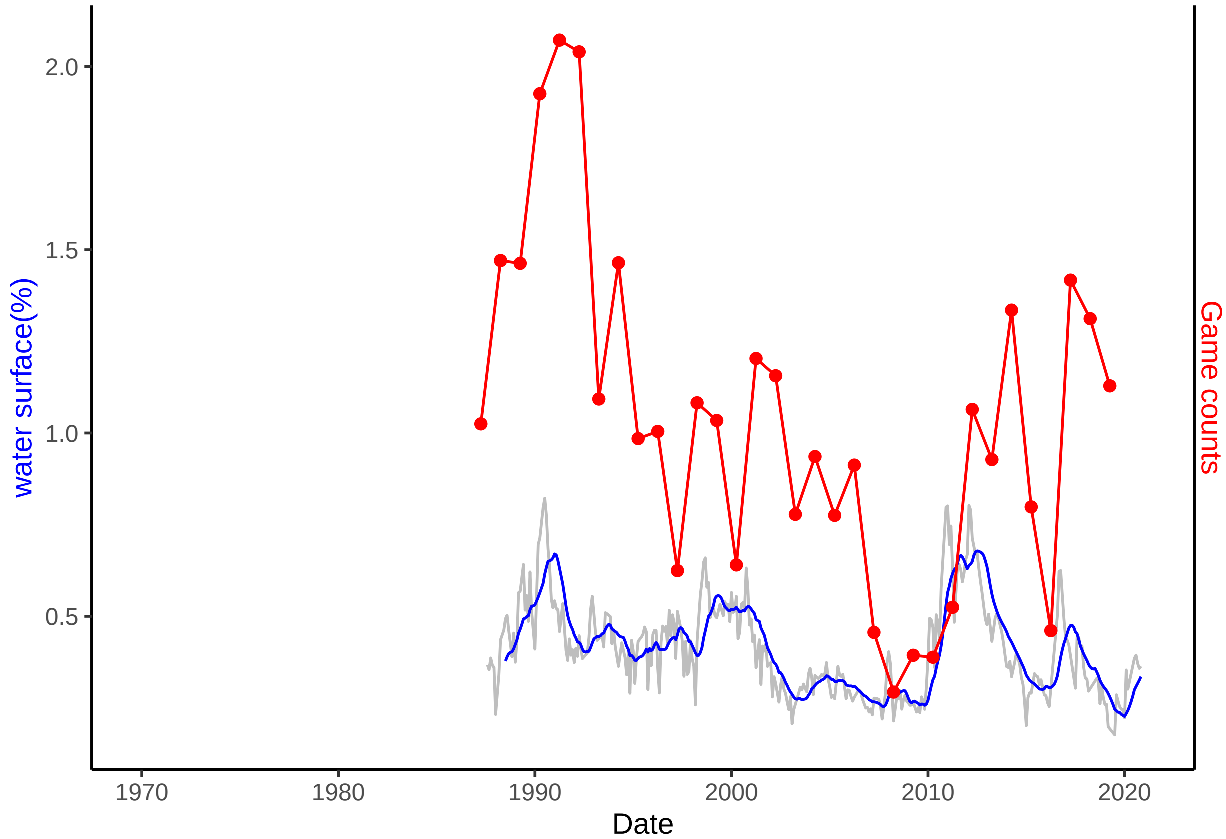


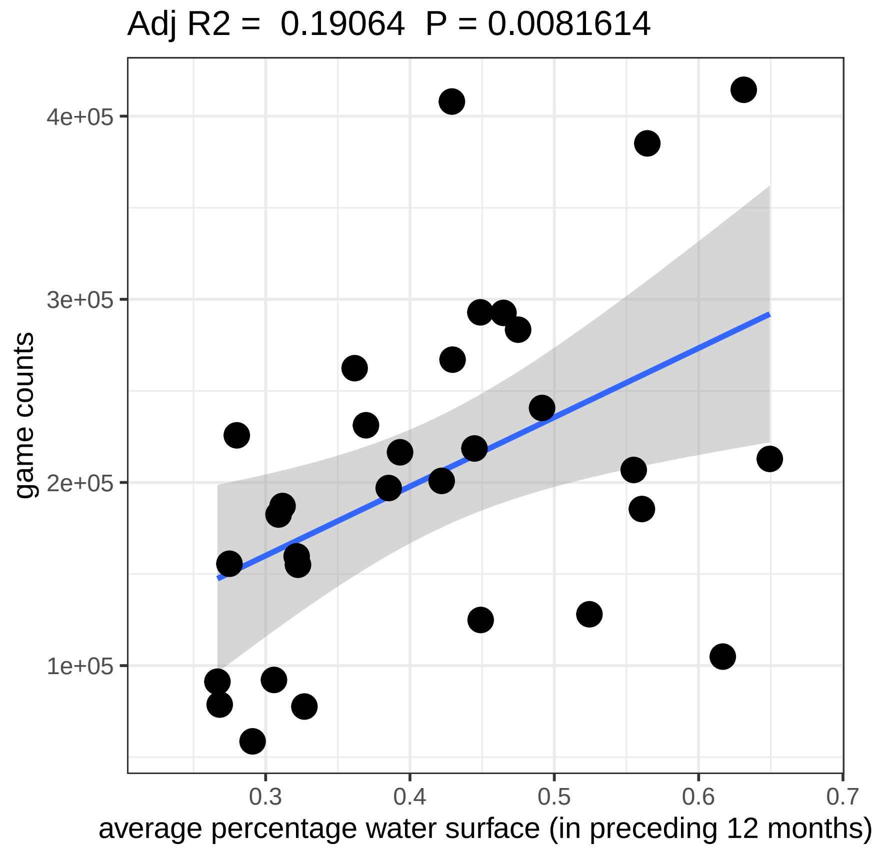
2.5
2.0
1.5
1.0
0.5
water surface(%)
5e+05
Game counts
1970
1980
1990
2000
2010
2020
Date

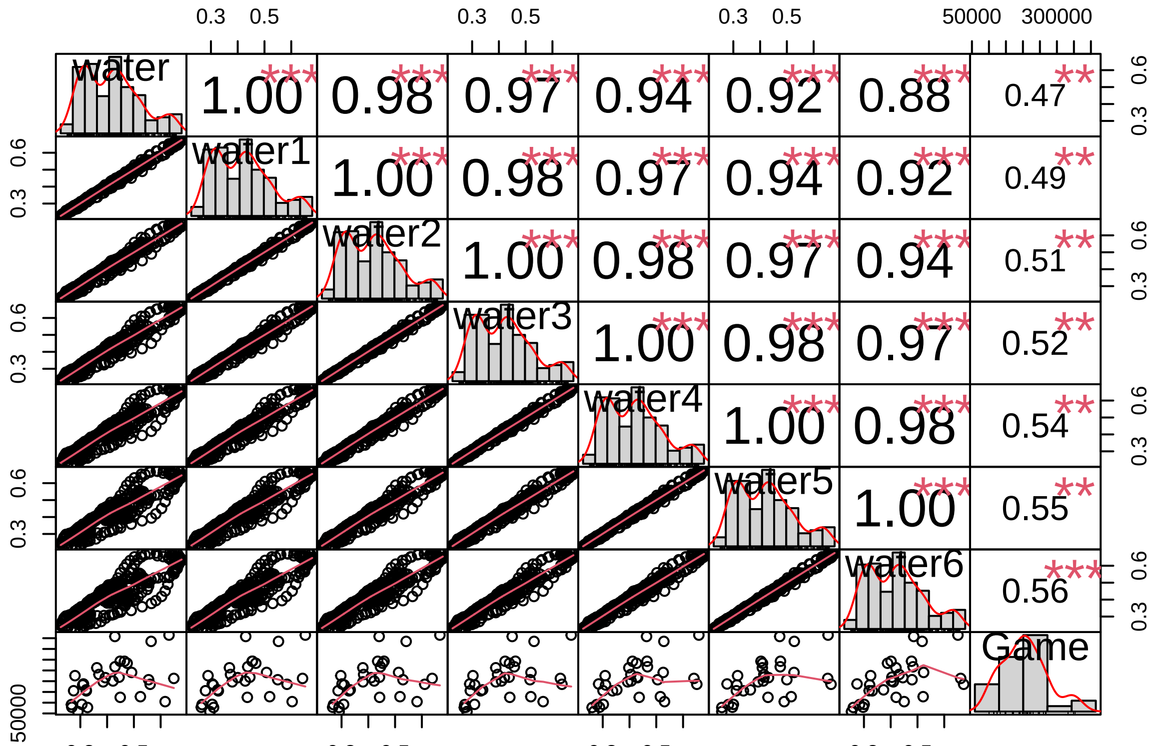

Adj R2 = 0.30457 P = 0.00076405
game counts
4e+05
3e+05
2e+05
1e+05
0.6
0.8
1.0
1.2
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
Game
0.99
0.98
0.97
0.95
0.94
0.92
0.57
0.58
0.59
0.60
0.6
0.9
1.2
0.7
1.0
1.3
1.1
50000
300000

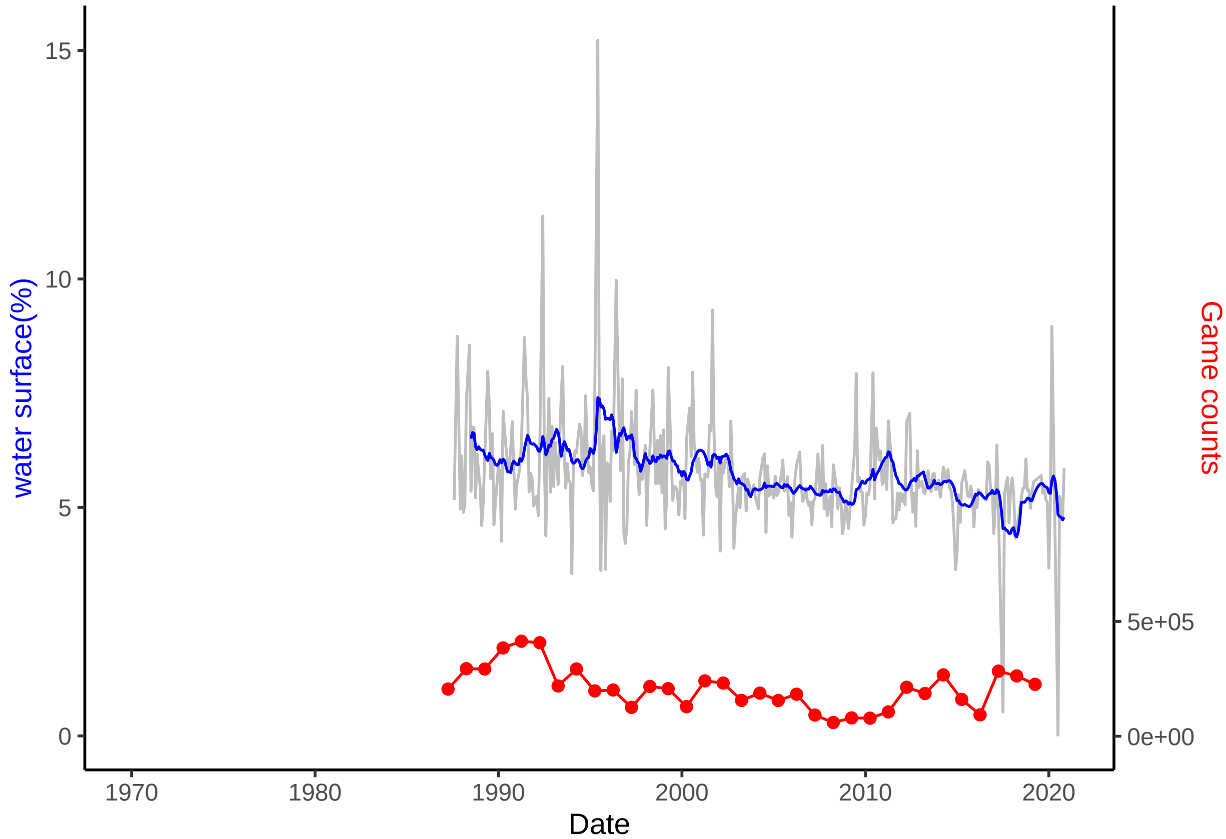
```
##
##
##  MDB
##
```


water surface(%)
Game counts
2.0
1.5
1.0
0.5
1970
1980
1990
2000
2010
2020
Date

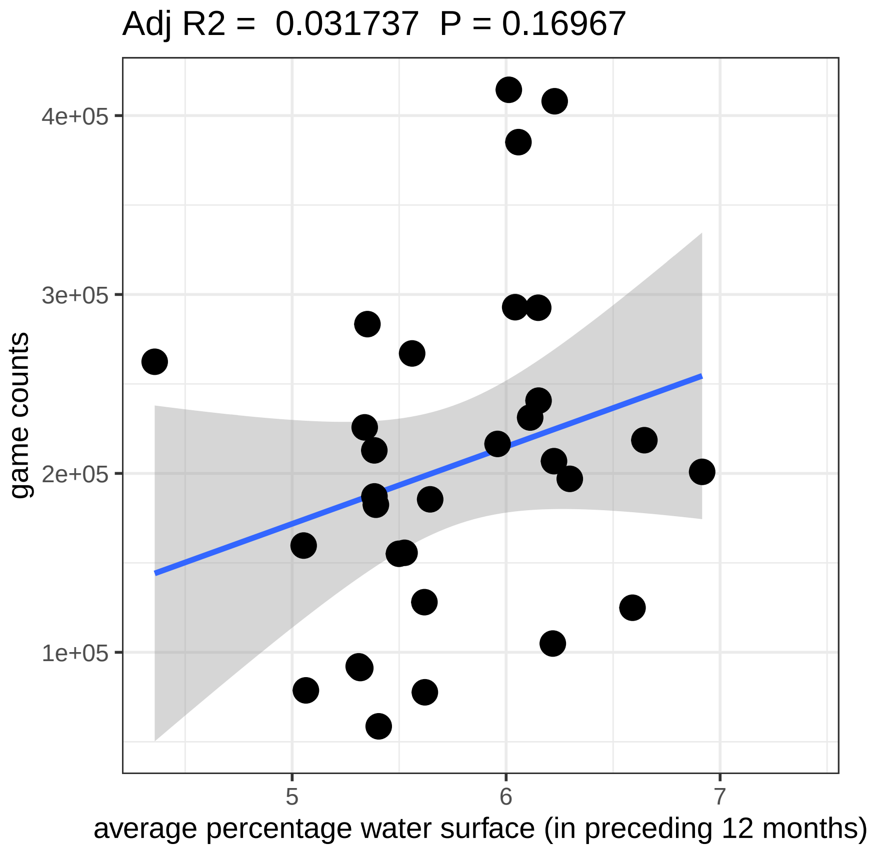

Adj R2 = 0.19064 P = 0.0081614
game counts
4e+05
3e+05
2e+05
1e+05
0.3
0.4
0.5
0.6
0.7
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
Game
1.00
0.98
0.97
0.94
0.92
0.88
0.47
0.49
0.51
0.52
0.54
0.55
0.56
0.3
0.5
0.6
50000
300000

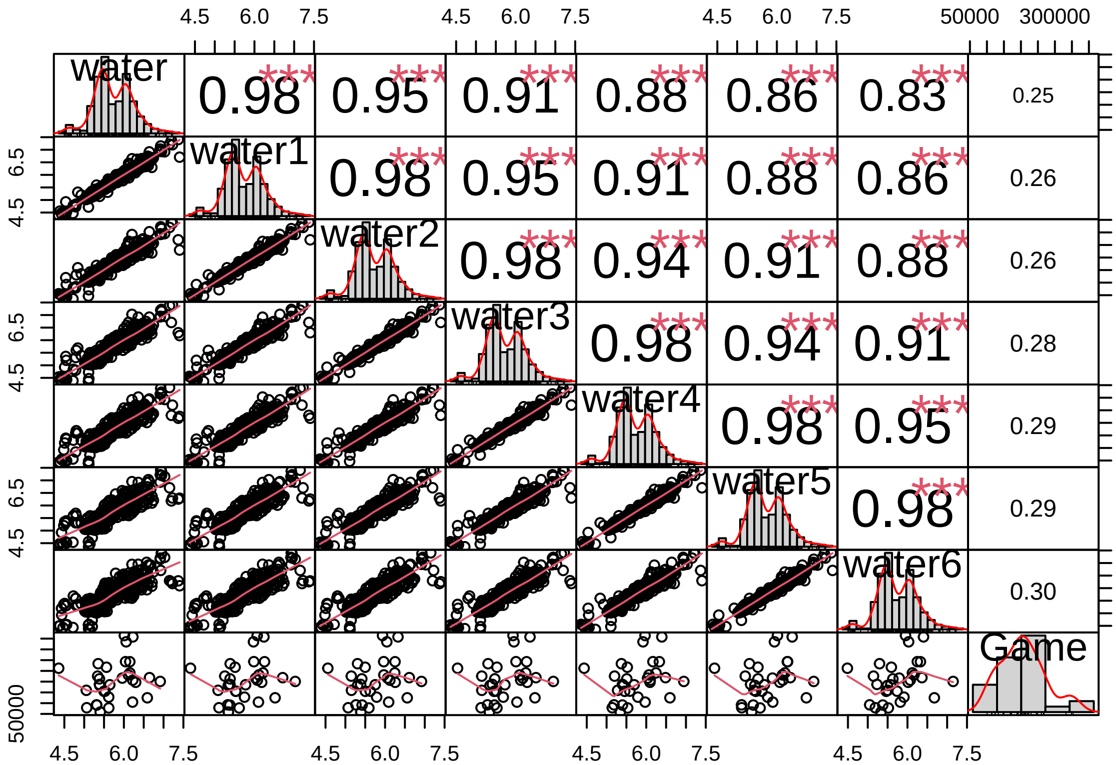
```
##
##
##   SEDB
##
```



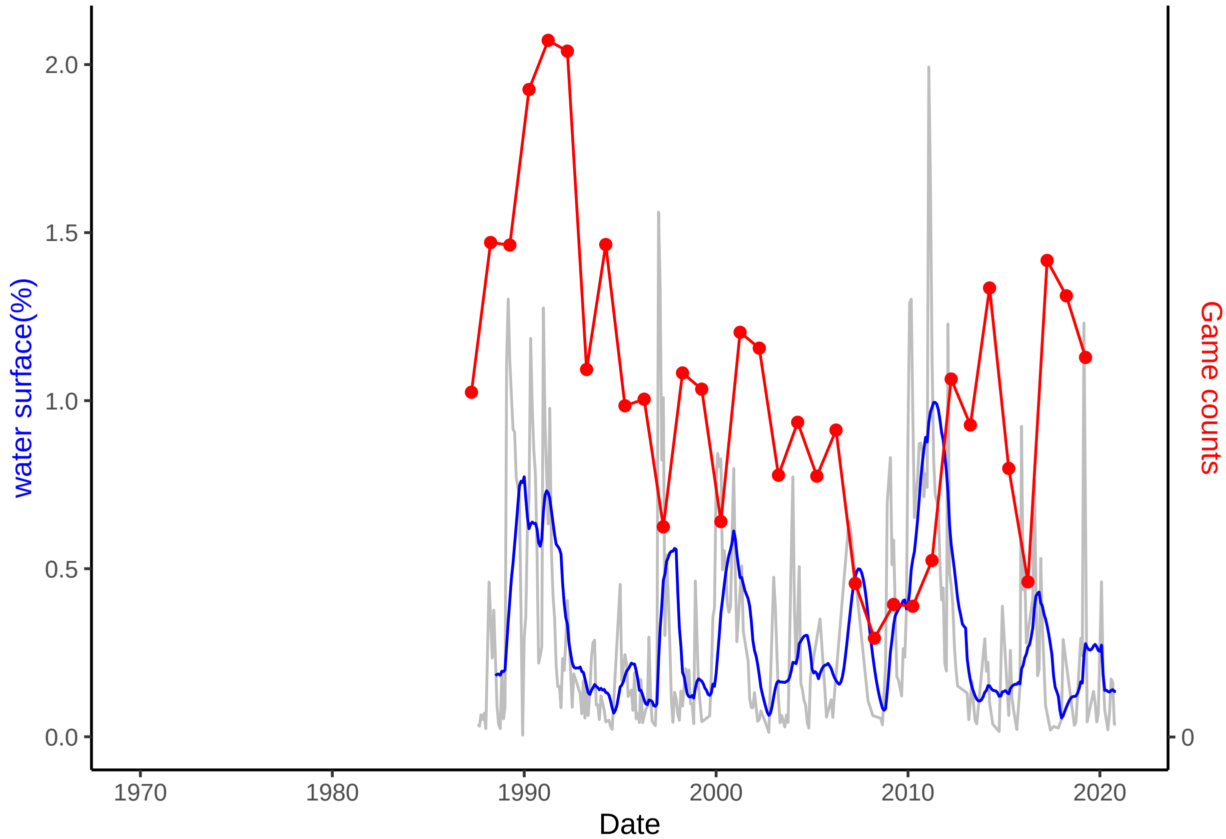
15
10
5
0
water surface(%)
Game counts
5e+05
0e+00
1970
1980
1990
2000
2010
2020
Date



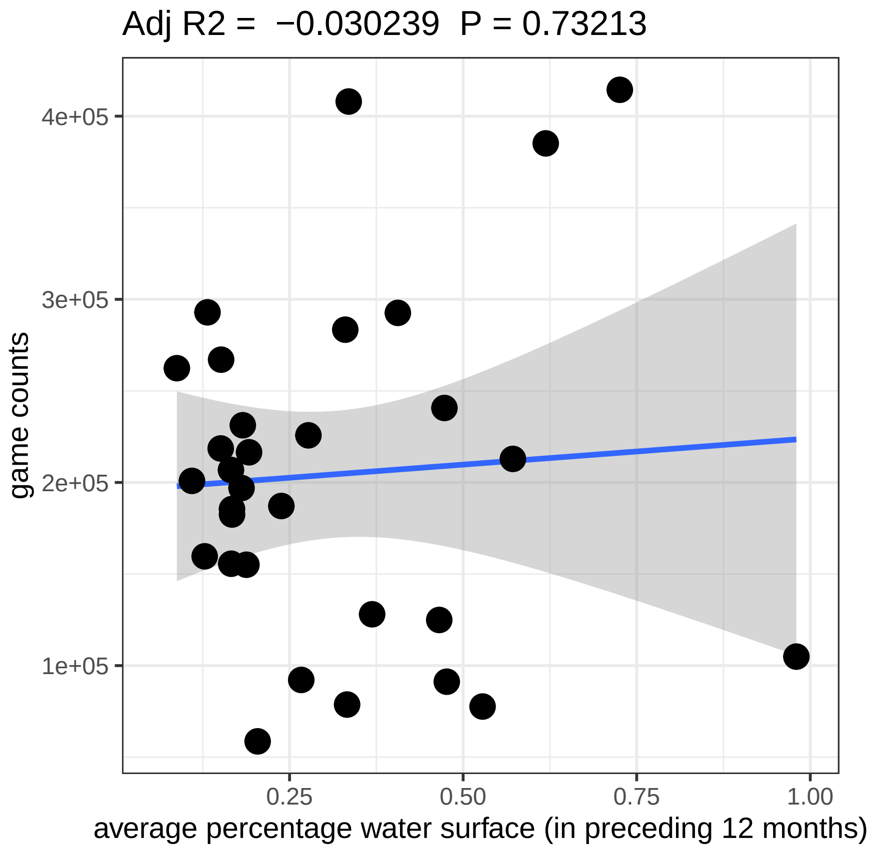
Adj R2 = 0.031737 P = 0.16967
4e+05
3e+05
2e+05
1e+05
game counts
5
6
7
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
Game
0.98
0.95
0.91
0.88
0.86
0.83
0.25
0.98
0.95
0.91
0.88
0.86
0.26
0.98
0.94
0.91
0.88
0.26
0.98
0.94
0.91
0.28
0.98
0.95
0.29
0.98
0.29
0.30
4.5
6.0
7.5
6.5
50000
300000

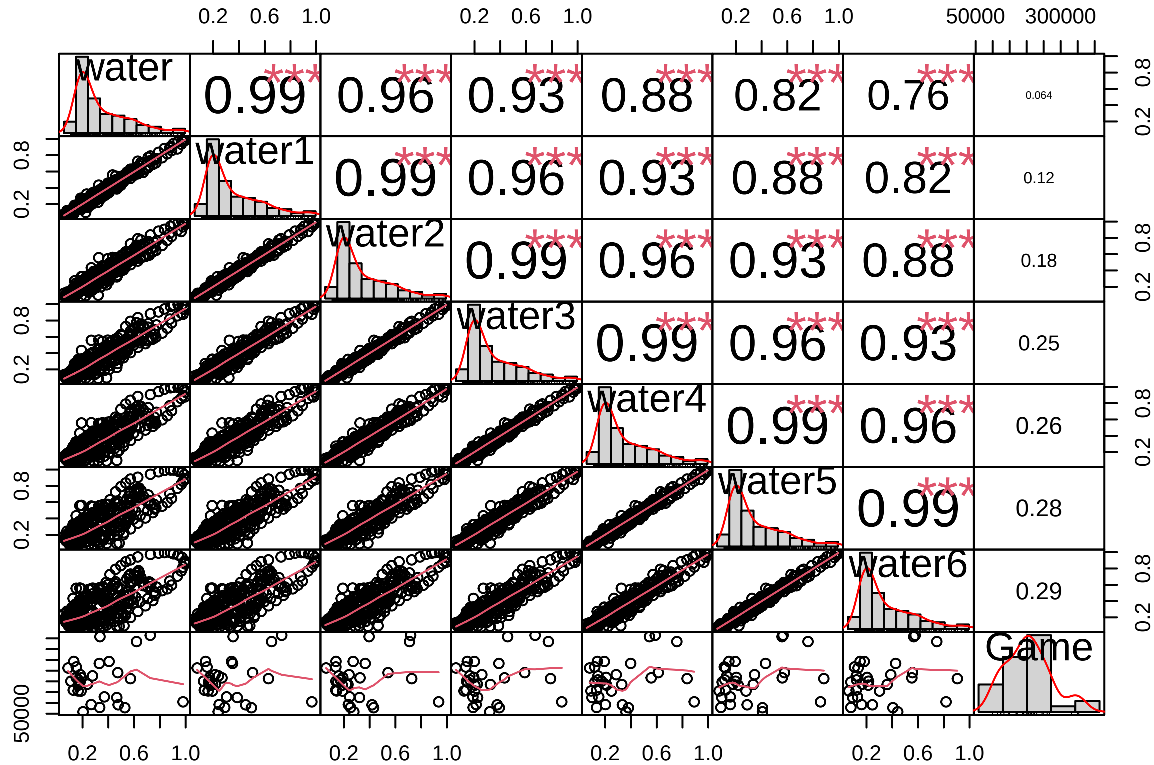
```
##
##
##   LEB
##
```



water surface(%)
2.0
1.5
1.0
0.5
0.0
Game counts
0
1970
1980
1990
2000
2010
2020
Date

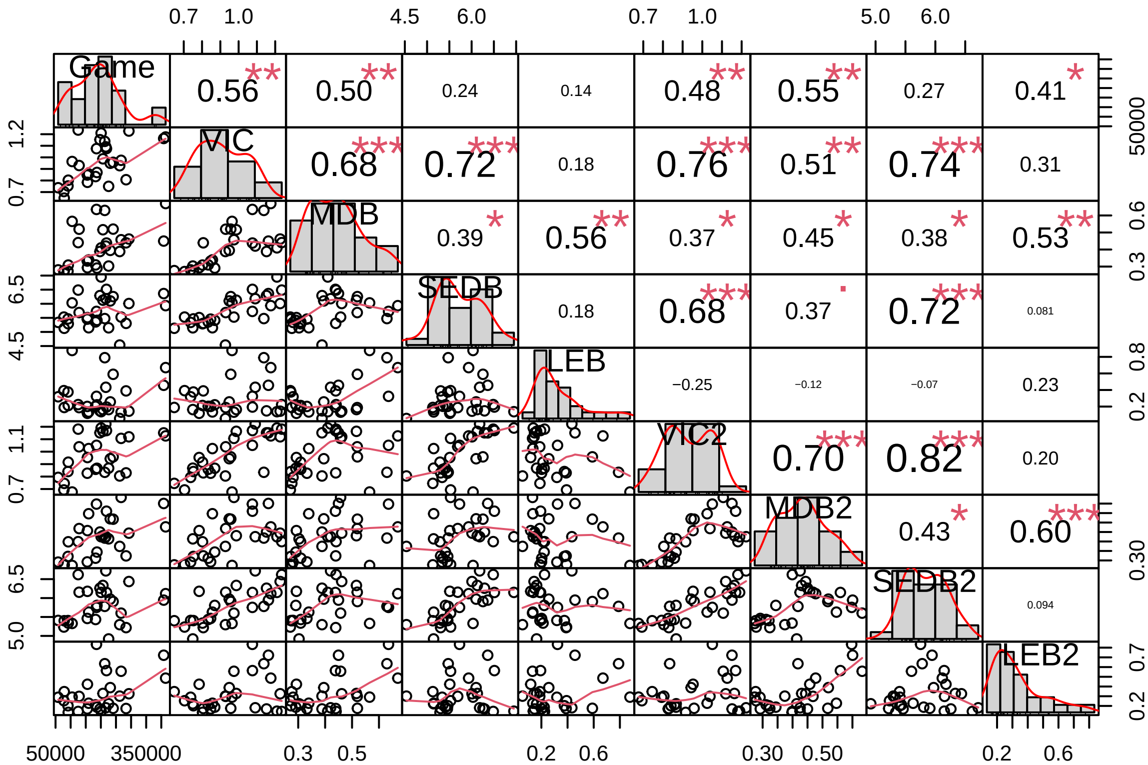


Adj R2 = −0.030239 P = 0.73213
game counts
4e+05
3e+05
2e+05
1e+05
0.25
0.50
0.75
1.00
average percentage water surface (in preceding 12 months)



4.1 Predictive models

Same as “Models predicting huntings bags from surface water estimates” but now for Victorian game counts. The time lag used here was 3 instead of 4 months.



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	df	delta	weight	AllSignif
-115047	NA	NA	NA	302629	NA	NA	191260	NA	0.4116	4	0.0000	0.054689	TRUE
142962	NA	NA	NA	321308	NA	-66564	316804	NA	0.4674	5	0.0545	0.053220	FALSE
83408	NA	NA	NA	301307	-54800	NA	313345	NA	0.4647	5	0.1988	0.049515	FALSE
-49167	NA	NA	236906	345381	NA	NA	NA	NA	0.3854	4	1.2621	0.029096	FALSE
-76618	NA	NA	NA	NA	NA	NA	285326	NA	0.3157	3	1.6737	0.023685	TRUE
-78078	NA	123328	NA	NA	NA	NA	244951	NA	0.3766	4	1.6763	0.023654	FALSE
123227	NA	NA	NA	NA	-55230	NA	407956	NA	0.3696	4	1.9990	0.020129	FALSE
-1429	NA	NA	NA	464709	NA	NA	NA	NA	0.3071	3	2.0331	0.019789	TRUE
210915	NA	NA	NA	315232	-38405	-48214	367753	NA	0.4892	6	2.0494	0.019628	FALSE
294185	NA	NA	NA	NA	NA	-113906	318059	265938	0.4293	5	2.0585	0.019539	FALSE
-124209	55161	NA	NA	334014	NA	NA	169556	NA	0.4269	5	2.1800	0.018387	FALSE
81860	63054	NA	NA	337123	-57264	NA	294026	NA	0.4845	6	2.3135	0.017200	FALSE
-110259	NA	NA	117022	284154	NA	NA	143506	NA	0.4242	5	2.3147	0.017190	FALSE
-95294	NA	NA	NA	369984	NA	NA	243027	-100683	0.4222	5	2.4129	0.016366	FALSE
154599	NA	NA	NA	NA	NA	-59109	401964	NA	0.3599	4	2.4413	0.016136	FALSE
-108187	NA	56061	NA	243380	NA	NA	191323	NA	0.4205	5	2.4994	0.015673	FALSE
210425	NA	NA	309451	NA	NA	-87676	NA	375879	0.4198	5	2.5340	0.015405	FALSE
-37445	90076	NA	NA	485925	NA	NA	NA	NA	0.3514	4	2.8246	0.013321	FALSE
-97637	NA	NA	281500	NA	NA	NA	NA	181738	0.3513	4	2.8305	0.013282	FALSE
194279	NA	NA	NA	263614	NA	-84550	302505	93787	0.4725	6	2.9817	0.012315	FALSE
84184	NA	103329	NA	NA	-44778	NA	350920	NA	0.4104	5	2.9989	0.012210	FALSE
119598	26227	NA	NA	334854	NA	-61660	297235	NA	0.4705	6	3.0921	0.011654	FALSE
129774	NA	NA	54132	311647	NA	-62591	287219	NA	0.4699	6	3.1277	0.011448	FALSE
74670	NA	NA	73073	289848	-51561	NA	276311	NA	0.4694	6	3.1512	0.011314	FALSE
136287	NA	15682	NA	304112	NA	-64347	312640	NA	0.4680	6	3.2293	0.010881	FALSE
-73140	NA	NA	166719	NA	NA	NA	209111	NA	0.3419	4	3.2446	0.010798	FALSE
77814	NA	23456	NA	276573	-52462	NA	308164	NA	0.4662	6	3.3288	0.010353	FALSE
105194	NA	106168	NA	NA	NA	-46800	342918	NA	0.4031	5	3.3553	0.010216	FALSE
80797	NA	NA	NA	314633	-53003	NA	319551	-19856	0.4651	6	3.3889	0.010046	FALSE
241421	NA	95662	NA	NA	NA	-99577	269814	250224	0.4641	6	3.4405	0.009790	FALSE
388694	NA	NA	NA	NA	-48497	-94434	374969	283039	0.4639	6	3.4538	0.009726	FALSE
-69888	NA	154766	NA	NA	NA	NA	NA	221847	0.3333	4	3.6209	0.008946	FALSE

129258	NA	NA	NA	NA	-67840	NA	334249	140847	0.3969	5	3.6569	0.008787	FALSE
-87416	NA	NA	228983	261623	NA	NA	NA	79433	0.3967	5	3.6661	0.008746	FALSE
266060	NA	NA	176006	NA	NA	-107953	203990	296213	0.4558	6	3.8886	0.007825	FALSE
-50133	NA	NA	NA	357452	NA	NA	NA	97092	0.3241	4	4.0189	0.007332	FALSE
-96324	NA	NA	NA	NA	NA	NA	234710	70095	0.3231	4	4.0625	0.007174	FALSE
209024	150185	NA	NA	NA	NA	-98707	NA	529132	0.3879	5	4.0874	0.007085	FALSE
54867	NA	NA	313305	NA	-43794	NA	NA	269874	0.3874	5	4.1125	0.006996	FALSE
101767	190374	NA	NA	NA	-74682	NA	NA	479307	0.3874	5	4.1127	0.006996	FALSE
-101127	NA	126222	NA	NA	NA	NA	184888	81866	0.3867	5	4.1427	0.006892	FALSE
-20334	NA	NA	244906	352827	-6157	NA	NA	NA	0.3865	5	4.1513	0.006862	FALSE
-50959	14324	NA	217381	358590	NA	NA	NA	NA	0.3860	5	4.1764	0.006776	FALSE
-24769	NA	NA	241537	352574	NA	-5070	NA	NA	0.3860	5	4.1780	0.006771	FALSE
228501	NA	NA	NA	NA	-41903	-39240	455797	NA	0.3860	5	4.1782	0.006770	FALSE
-50363	NA	-5259	239632	349561	NA	NA	NA	NA	0.3855	5	4.2009	0.006694	FALSE
-115682	108871	NA	NA	334605	NA	NA	NA	140987	0.3853	5	4.2080	0.006670	FALSE
275945	76676	NA	NA	NA	NA	-117741	242114	358592	0.4494	6	4.2276	0.006605	FALSE
105639	NA	NA	125361	NA	-49647	NA	338250	NA	0.3839	5	4.2752	0.006450	FALSE
38537	NA	NA	377805	NA	NA	NA	NA	NA	0.2506	3	4.3059	0.006352	TRUE
-78306	17979	NA	NA	NA	NA	NA	281431	NA	0.3174	4	4.3069	0.006348	FALSE
5442	NA	55845	NA	405742	NA	NA	NA	NA	0.3160	4	4.3672	0.006160	FALSE
397173	122635	NA	NA	NA	-67818	-92812	276174	438043	0.5098	7	4.3700	0.006151	FALSE
142511	125650	NA	NA	NA	-87295	NA	233741	302164	0.4452	6	4.4473	0.005918	FALSE
-76599	NA	109216	62870	NA	NA	NA	220830	NA	0.3795	5	4.4812	0.005819	FALSE
-95431	NA	94145	202032	NA	NA	NA	NA	182015	0.3794	5	4.4865	0.005803	FALSE
-77905	-1891	123734	NA	NA	NA	NA	245228	NA	0.3766	5	4.6174	0.005435	FALSE
-39887	NA	NA	NA	450214	7777	NA	NA	NA	0.3090	4	4.6590	0.005324	FALSE
-43707	NA	NA	NA	448811	NA	8462	NA	NA	0.3087	4	4.6715	0.005290	FALSE
124510	25391	NA	NA	NA	-56243	NA	404705	NA	0.3730	5	4.7827	0.005004	FALSE
124700	NA	NA	119553	NA	NA	-50828	330970	NA	0.3726	5	4.8046	0.004950	FALSE
-123899	118668	NA	NA	NA	NA	NA	NA	292522	0.3047	4	4.8419	0.004858	FALSE
90411	NA	102652	NA	NA	-57332	NA	278312	139461	0.4372	6	4.8607	0.004813	FALSE
-117865	84984	127281	NA	NA	NA	NA	NA	254213	0.3677	5	5.0305	0.004421	FALSE
-52624	NA	NA	NA	NA	NA	NA	NA	255730	0.2315	3	5.0368	0.004407	TRUE
286556	NA	NA	NA	237150	-42206	-70552	353593	125951	0.4983	7	5.0438	0.004392	FALSE
182278	NA	65403	251551	NA	NA	-79229	NA	357367	0.4328	6	5.0891	0.004293	FALSE
181538	43589	NA	NA	336900	-43748	-37510	342319	NA	0.4975	7	5.0912	0.004289	FALSE
154166	NA	NA	273181	152563	NA	-69968	NA	277010	0.4325	6	5.1037	0.004262	FALSE
302953	197481	NA	NA	NA	-56971	-75516	NA	616029	0.4314	6	5.1579	0.004148	FALSE
142949	NA	144361	NA	NA	NA	-59383	NA	360592	0.3649	5	5.1581	0.004148	FALSE
57861	166875	NA	NA	257480	-58059	NA	NA	321125	0.4310	6	5.1777	0.004107	FALSE
251217	NA	NA	323467	NA	-25141	-74369	NA	397010	0.4301	6	5.2232	0.004015	FALSE
-118699	45629	32090	NA	294676	NA	NA	173342	NA	0.4293	6	5.2646	0.003933	FALSE
-112855	42817	NA	NA	358717	NA	NA	198797	-47426	0.4285	6	5.3086	0.003847	FALSE
-119284	39183	NA	55526	316157	NA	NA	153184	NA	0.4284	6	5.3107	0.003843	FALSE
-105554	NA	NA	210528	NA	NA	NA	103478	118551	0.3615	5	5.3132	0.003838	FALSE
97951	98418	NA	NA	270659	-70315	NA	242882	128959	0.4933	7	5.3289	0.003808	FALSE
211173	57429	NA	234721	NA	NA	-94210	NA	428342	0.4277	6	5.3490	0.003770	FALSE
164075	-10866	NA	NA	NA	NA	-61271	408583	NA	0.3605	5	5.3573	0.003755	FALSE
-99145	NA	NA	85372	331466	NA	NA	188945	-63254	0.4275	6	5.3586	0.003752	FALSE
-107306	NA	32760	91215	253605	NA	NA	154074	NA	0.4266	6	5.4015	0.003673	FALSE
166375	118830	101504	NA	NA	NA	-84636	NA	464851	0.4263	6	5.4198	0.003639	FALSE
199802	NA	NA	39060	308403	-37502	-45778	345208	NA	0.4905	7	5.4914	0.003511	FALSE
-96720	NA	33498	NA	315742	NA	NA	228586	-72522	0.4246	6	5.5042	0.003489	FALSE
105610	NA	NA	179657	NA	-63097	NA	215300	177251	0.4245	6	5.5096	0.003479	FALSE
330293	NA	82983	NA	NA	-42016	-84607	325512	267122	0.4895	7	5.5495	0.003411	FALSE
209753	NA	2174	NA	312869	-38271	-47970	366998	NA	0.4892	7	5.5639	0.003386	FALSE
122521	134510	NA	NA	236892	NA	-71336	NA	356236	0.4219	6	5.6379	0.003263	FALSE
-84532	90479	NA	NA	468373	NA	9392	NA	NA	0.3534	5	5.6769	0.003200	FALSE
171212	NA	96250	NA	NA	-34815	-31442	393161	NA	0.4208	6	5.6964	0.003169	FALSE
67388	152735	95509	NA	NA	-61806	NA	NA	418357	0.4204	6	5.7162	0.003138	FALSE
88927	81645	NA	-62922	357550	-60779	NA	320219	NA	0.4863	7	5.7284	0.003119	FALSE
-105013	19073	NA	255989	NA	NA	NA	NA	194357	0.3522	5	5.7319	0.003113	FALSE
-35126	87350	9994	NA	474731	NA	NA	NA	NA	0.3516	5	5.7558	0.003076	FALSE
-31164	90857	NA	NA	488594	-1333	NA	NA	NA	0.3515	5	5.7643	0.003063	FALSE
356602	NA	NA	159548	NA	-45112	-90397	267593	309290	0.4855	7	5.7754	0.003046	FALSE
85671	68213	-16512	NA	357465	-59111	NA	296092	NA	0.4851	7	5.7953	0.003016	FALSE
188623	60055	NA	NA	240842	NA	-90091	244365	181228	0.4845	7	5.8286	0.002966	FALSE
-62600	NA	101625	NA	195154	NA	NA	NA	146872	0.3489	5	5.8762	0.002897	FALSE

40937	NA	93631	298917	NA	NA	NA	NA	NA	0.2785	4	5.9150	0.002841	FALSE
201315	NA	NA	NA	NA	NA	-71239	NA	419444	0.2775	4	5.9521	0.002789	FALSE
29454	-83339	NA	460056	NA	NA	NA	NA	NA	0.2772	4	5.9656	0.002770	FALSE
-68503	-37512	NA	220233	NA	NA	NA	192772	NA	0.3468	5	5.9731	0.002760	FALSE
22746	NA	NA	262403	211617	-32196	NA	NA	163782	0.4146	6	6.0048	0.002716	FALSE
196339	NA	NA	101555	215357	NA	-86489	239535	142769	0.4799	7	6.0884	0.002605	FALSE
81804	NA	94738	40098	NA	-43861	NA	333366	NA	0.4116	6	6.1502	0.002526	FALSE
6147	NA	151412	NA	NA	-21026	NA	NA	268911	0.3420	5	6.1854	0.002482	FALSE
85274	7651	101467	NA	NA	-45272	NA	350969	NA	0.4107	6	6.1937	0.002472	FALSE
83999	110028	NA	181088	NA	-64380	NA	NA	384099	0.4096	6	6.2519	0.002401	FALSE
197738	NA	43768	NA	190787	NA	-86104	284729	134156	0.4765	7	6.2764	0.002371	FALSE
234032	57947	84067	NA	NA	NA	-104213	218267	322151	0.4751	7	6.3556	0.002279	FALSE
-121983	62675	NA	NA	NA	NA	NA	170338	140440	0.3366	5	6.4194	0.002208	FALSE
90527	NA	NA	NA	306247	NA	-39560	NA	210730	0.3364	5	6.4285	0.002198	FALSE
124226	-23693	109675	NA	NA	NA	-51108	355402	NA	0.4058	6	6.4345	0.002191	FALSE
34282	NA	75251	245125	NA	-37377	NA	NA	257180	0.4046	6	6.4961	0.002125	FALSE
100689	NA	100060	29378	NA	NA	-45473	328869	NA	0.4038	6	6.5347	0.002084	FALSE
237152	NA	72723	105893	NA	NA	-99431	212754	272207	0.4717	7	6.5419	0.002077	FALSE
119694	19111	NA	25626	326605	NA	-61110	288539	NA	0.4708	7	6.5893	0.002028	FALSE
118708	25104	4442	NA	329403	NA	-61242	296894	NA	0.4706	7	6.6048	0.002012	FALSE
-105097	47552	NA	161734	279787	NA	NA	NA	103791	0.4021	6	6.6141	0.002003	FALSE
128786	NA	3863	51439	307891	NA	-62242	287665	NA	0.4699	7	6.6411	0.001976	FALSE
75797	NA	NA	79355	279278	-52575	NA	268663	14282	0.4696	7	6.6581	0.001959	FALSE
73622	NA	6933	68009	283332	-51095	NA	277346	NA	0.4695	7	6.6606	0.001957	FALSE
-57803	NA	NA	350014	NA	NA	18625	NA	NA	0.2589	4	6.6905	0.001928	FALSE
-88372	NA	32298	210523	217767	NA	NA	NA	96678	0.3988	6	6.7776	0.001846	FALSE
110709	101501	77306	NA	NA	-75643	NA	210933	270116	0.4663	7	6.8395	0.001789	FALSE
77719	NA	23069	NA	277938	-52372	NA	308695	-1425	0.4662	7	6.8439	0.001786	FALSE
-6904	NA	NA	NA	343982	-12040	NA	NA	129598	0.3268	5	6.8443	0.001785	FALSE
-7957	NA	NA	361102	NA	9317	NA	NA	NA	0.2533	4	6.9077	0.001729	FALSE
198182	NA	NA	103035	NA	-39322	-33327	391296	NA	0.3953	6	6.9454	0.001697	FALSE
-104951	NA	102896	107469	NA	NA	NA	127104	104427	0.3945	6	6.9800	0.001668	FALSE

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	11162	156490	160921	0.0694	0.9447
MDB2	314277	145294	152458	2.0614	0.0393
VIC	282799	119372	123844	2.2835	0.0224
SEDB2	-66564	41144	43234	1.5396	0.1237
SEDB	-54924	35440	37219	1.4757	0.1400
MDB	236906	130166	136513	1.7354	0.0827
LEB2	123328	77369	81141	1.5199	0.1285

```
##                       VIC  MDB2 SEDB SEDB2 MDB  LEB2
## Sum of weights:       0.89 0.73 0.27 0.21  0.11 0.09
## N containing models:     6    4    2    1     1    1
```

The above results are based on 29 cases.

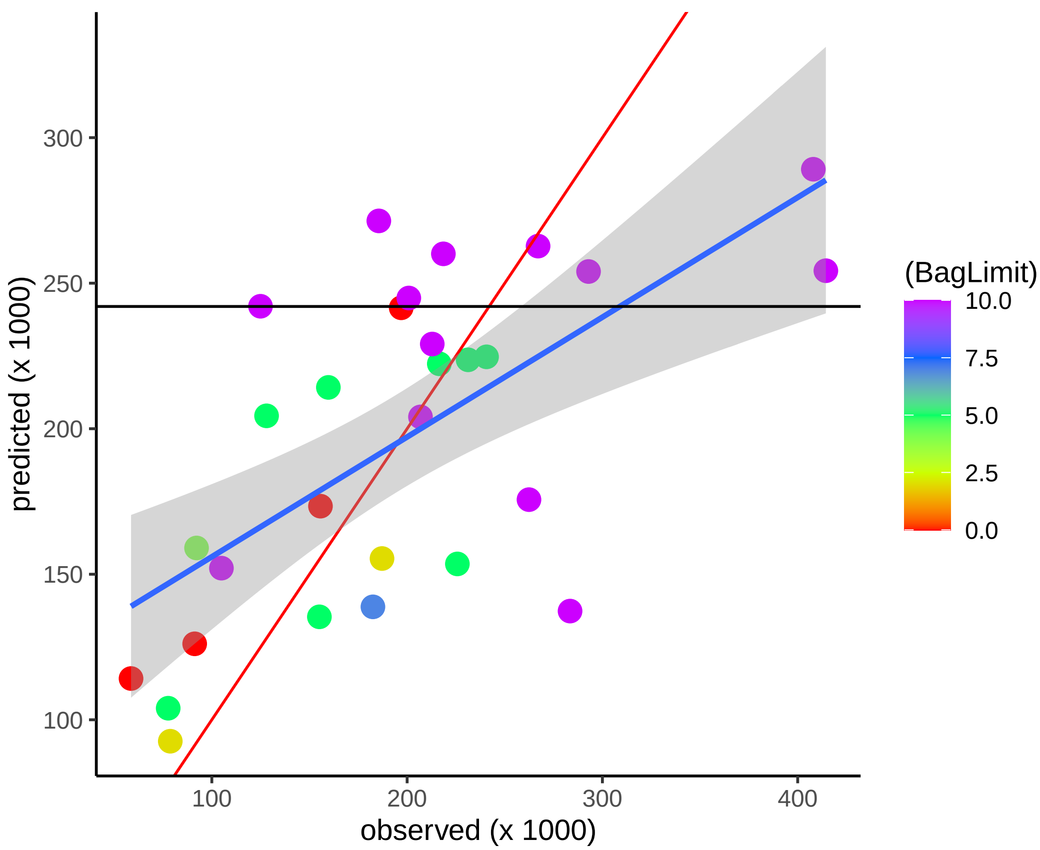
4.2 Predicted versus observed

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 generally called.

```
##
```

```
##    The preferred model selected: 1 with a threshold number of 242000
##
##
##

##
## Call:
## lm(formula = Game ~ MDB2 + VIC + 1, data = Jc)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -117159  -44587  -13906   31736  160136
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -115047      76244   -1.51    0.143
## MDB2          302629     146982    2.06    0.050 *
## VIC           191260      89017    2.15    0.041 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 69900 on 26 degrees of freedom
## Multiple R-squared:  0.412,  Adjusted R-squared:  0.366
## F-statistic: 9.09 on 2 and 26 DF,  p-value: 0.00101
```



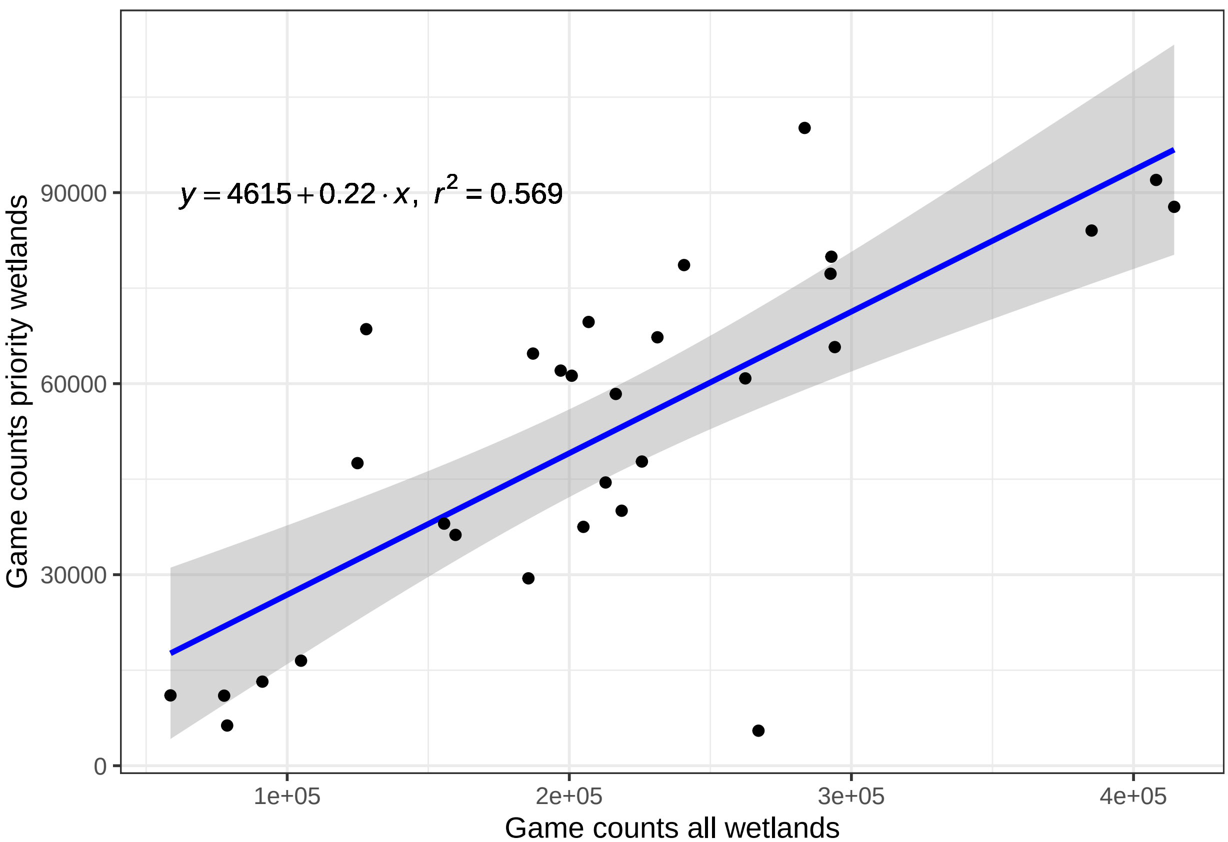
5 The Victorian Game counts limited to priority wetlands

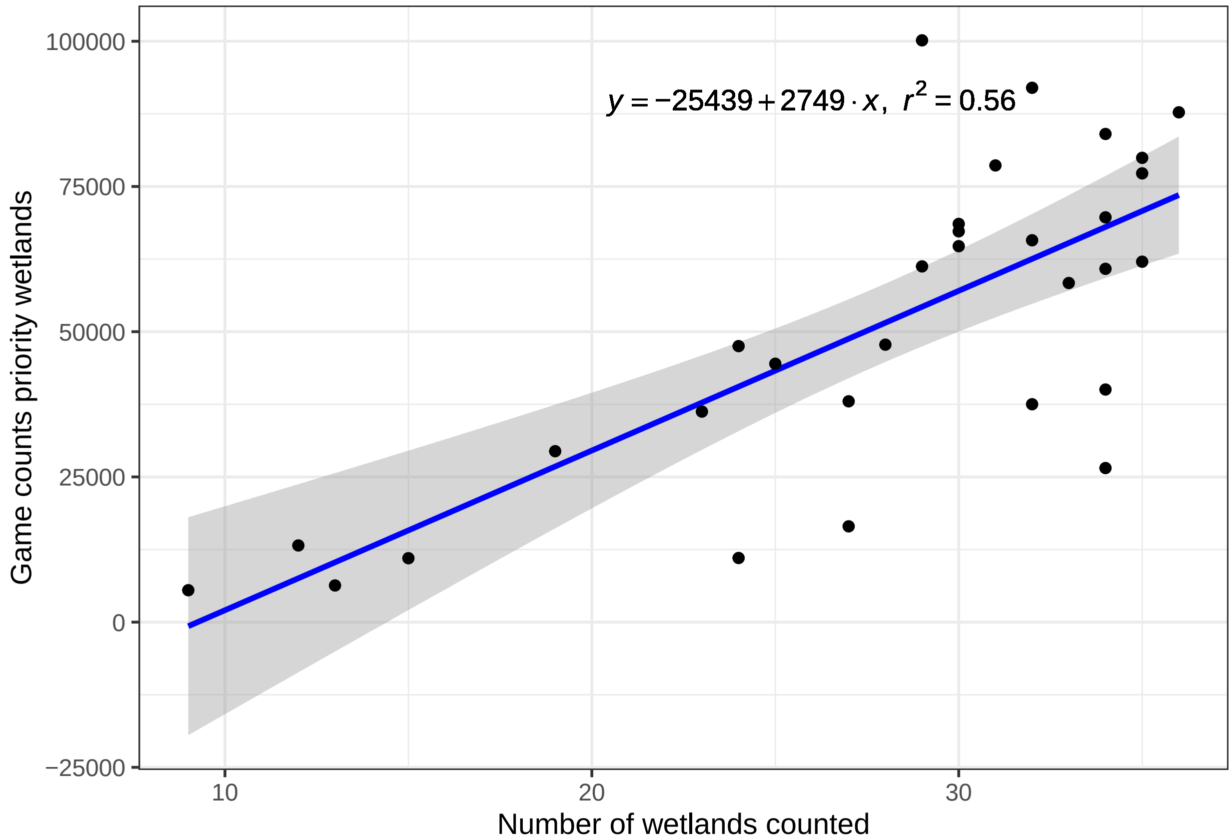
The approach of the Victorian Game Counts changed in 2015, when a limited survey was introduced focussing on wetlands that are also important duck hunting sites.

Below we focus on these so-called "priority wetland" counts, again omitting the data from 2020. Of these priority wetlands we only use those wetlands that have been counted 20 or more times since 1987.

Two graphs are plotted. The first showing that the counts across the priority wetlands follows the same trend as found across all wetlands, which is reassuring. The next plot is showing the obvious: the more priority wetlands are being counted the more birds are being seen. The critical question is: those wetlands not counted are they thought to be void of birds and is that the reason they are not being counted? We assume that this is indeed the case and that the counts across the priority wetlands reflect the true number of ducks in the landscape.

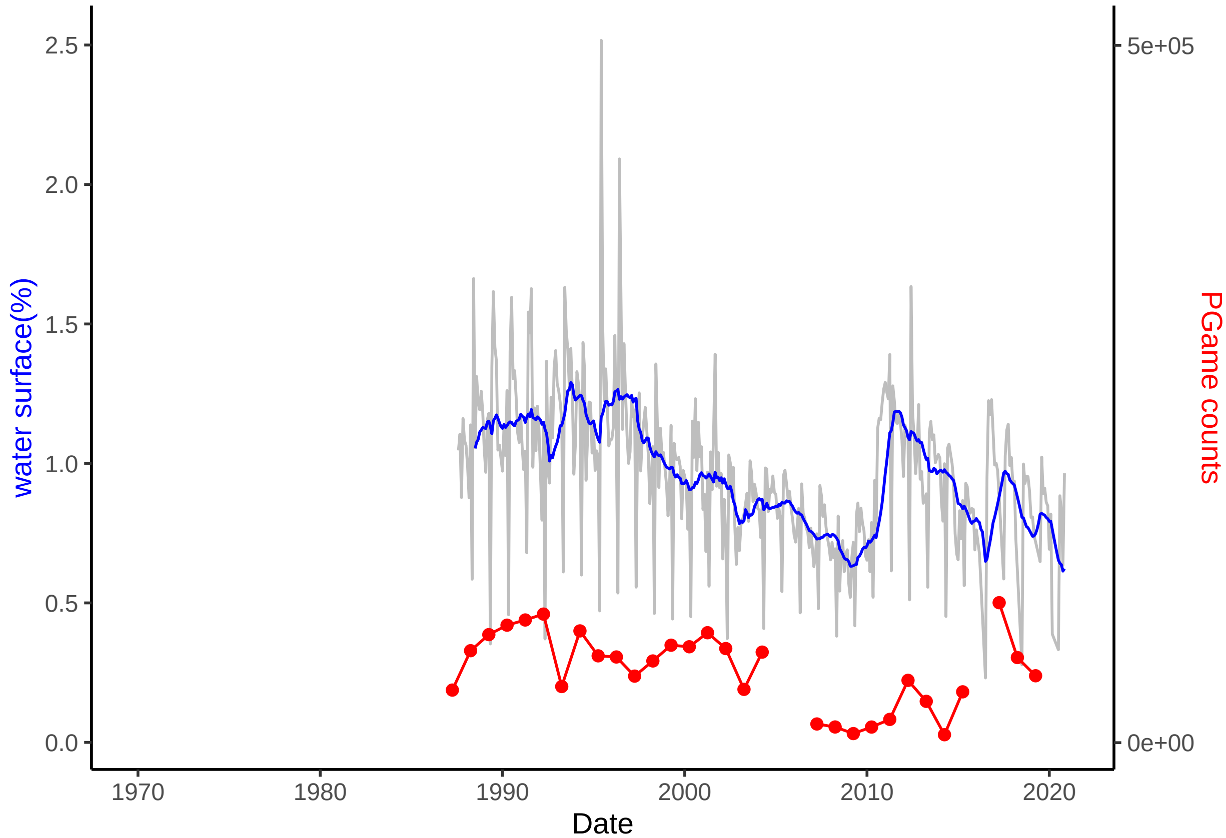
```
## [1] "number of wetlands used:  37"
```



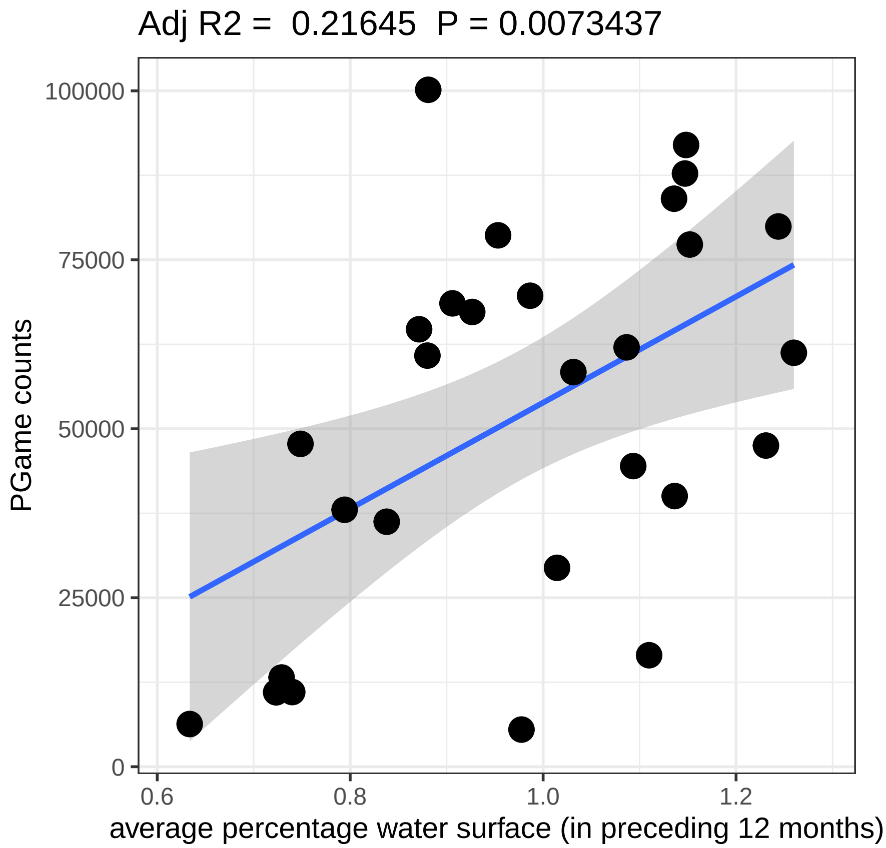


6 Water surface area and game counts in priority wetlands

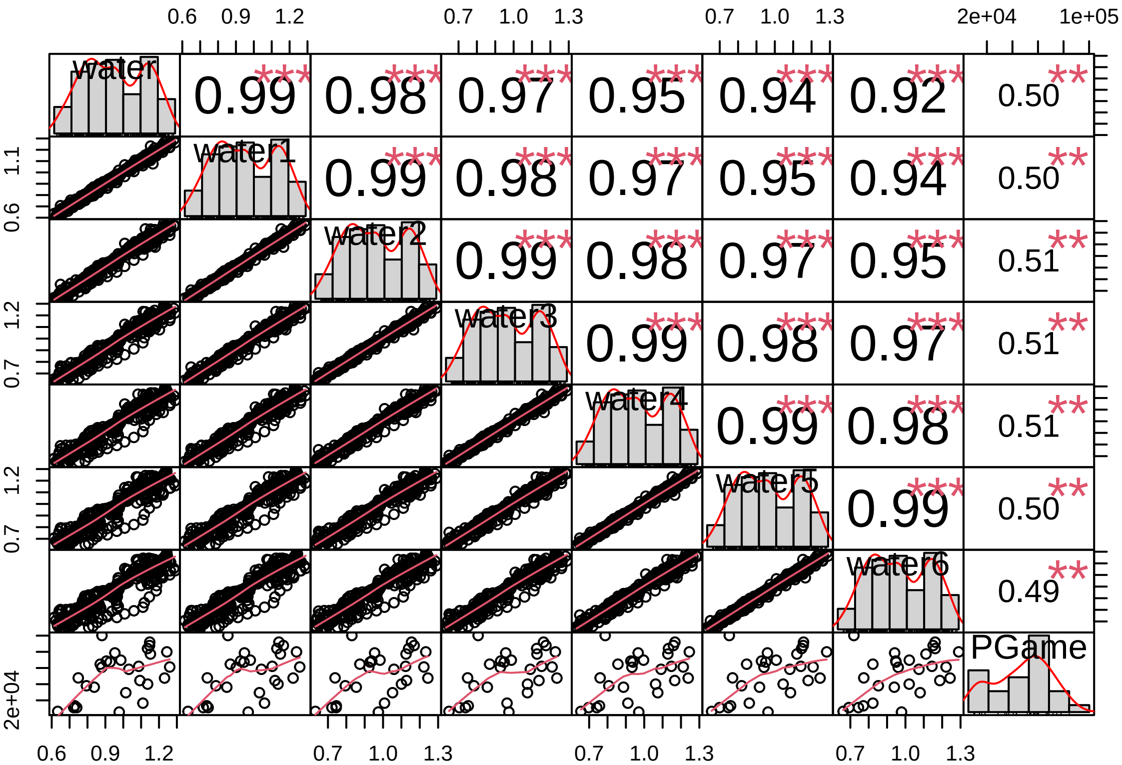
```
##
##
##  VIC
##
```



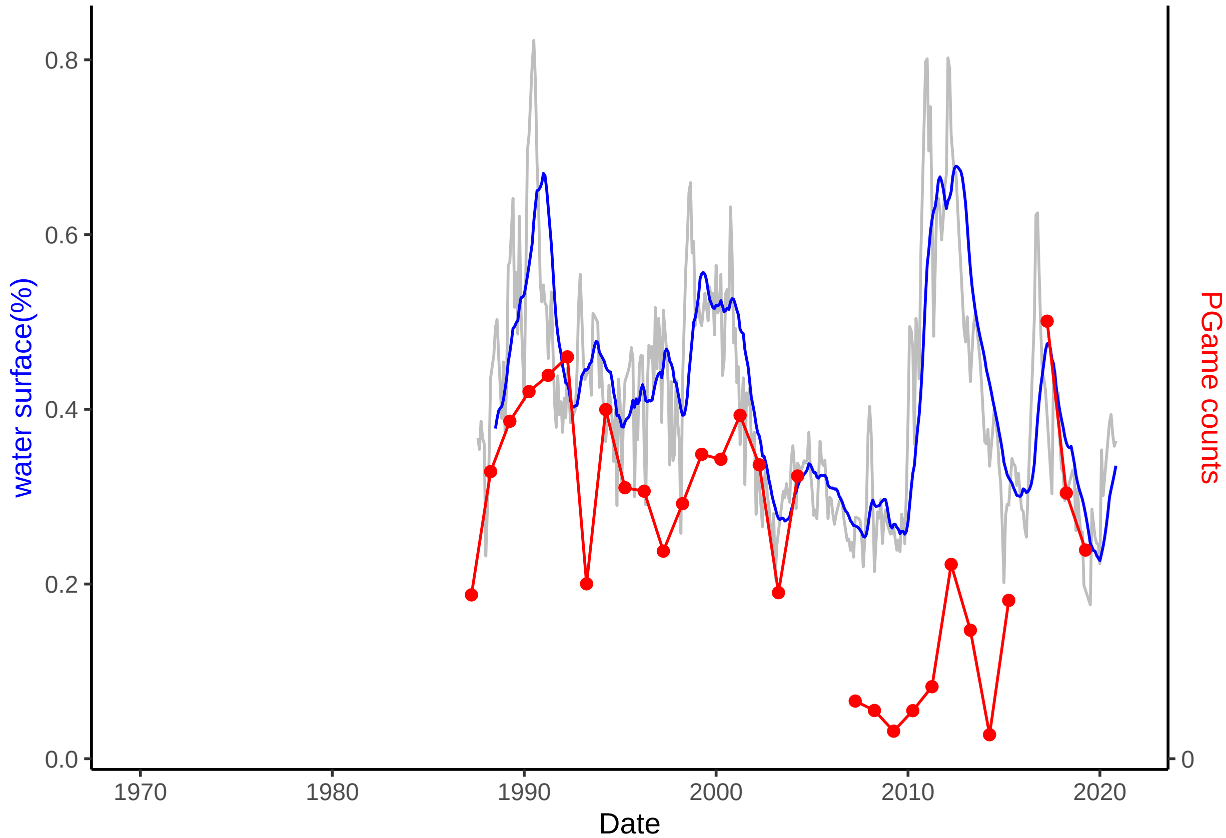
water surface(%)
PGame counts
Date
2.5
2.0
1.5
1.0
0.5
0.0
5e+05
0e+00
1970
1980
1990
2000
2010
2020



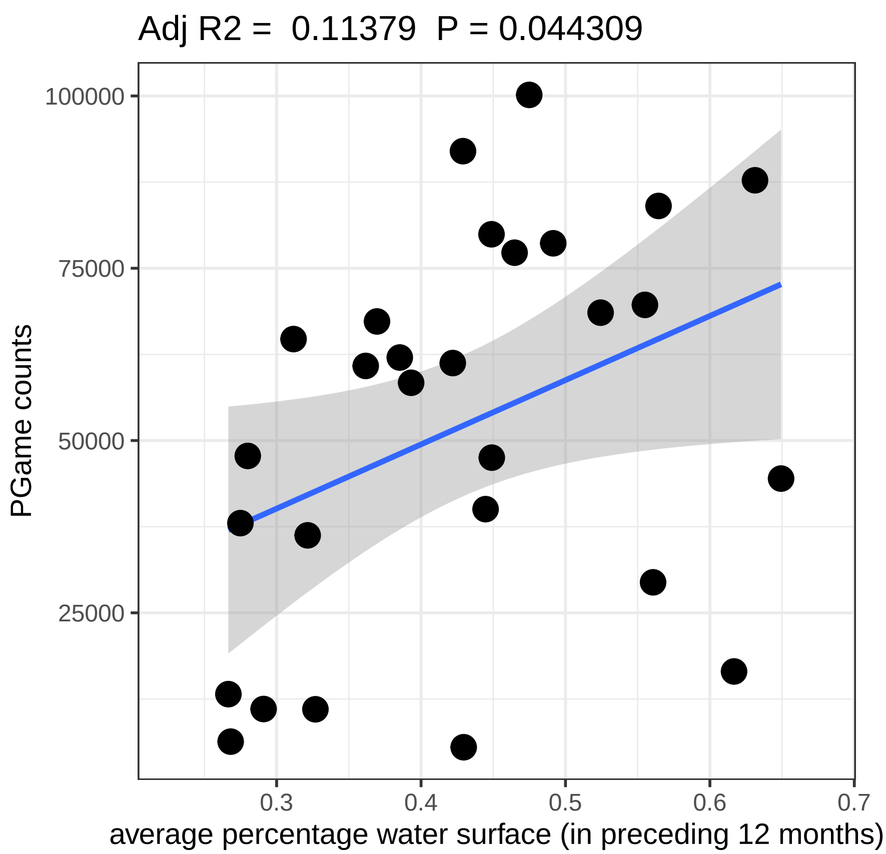
Adj R2 = 0.21645 P = 0.0073437
PGame counts
100000
75000
50000
25000
0
0.6
0.8
1.0
1.2
average percentage water surface (in preceding 12 months)

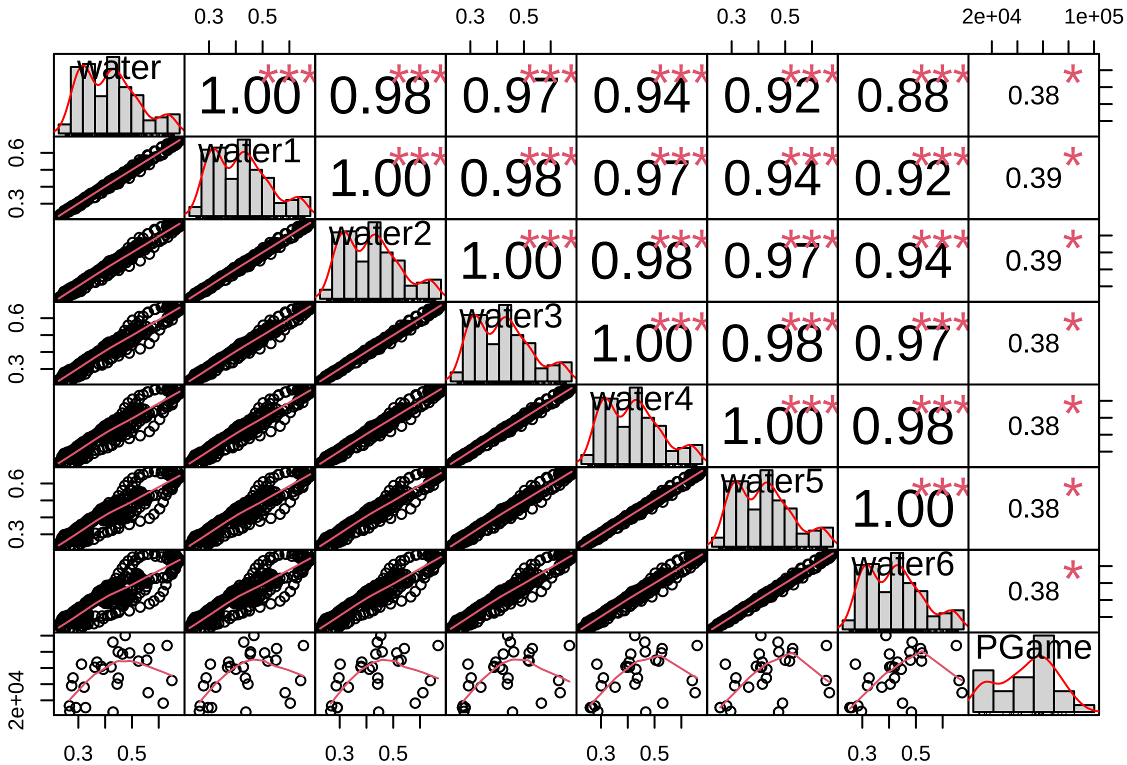

water
water1
water2
water3
water4
water5
water6
PGame
0.99
0.98
0.97
0.95
0.94
0.92
0.50
0.51
0.49
***
**
0.6
0.9
1.2
0.7
1.0
1.3
1.1
2e+04
1e+05

```
##
##
##   MDB
##
```

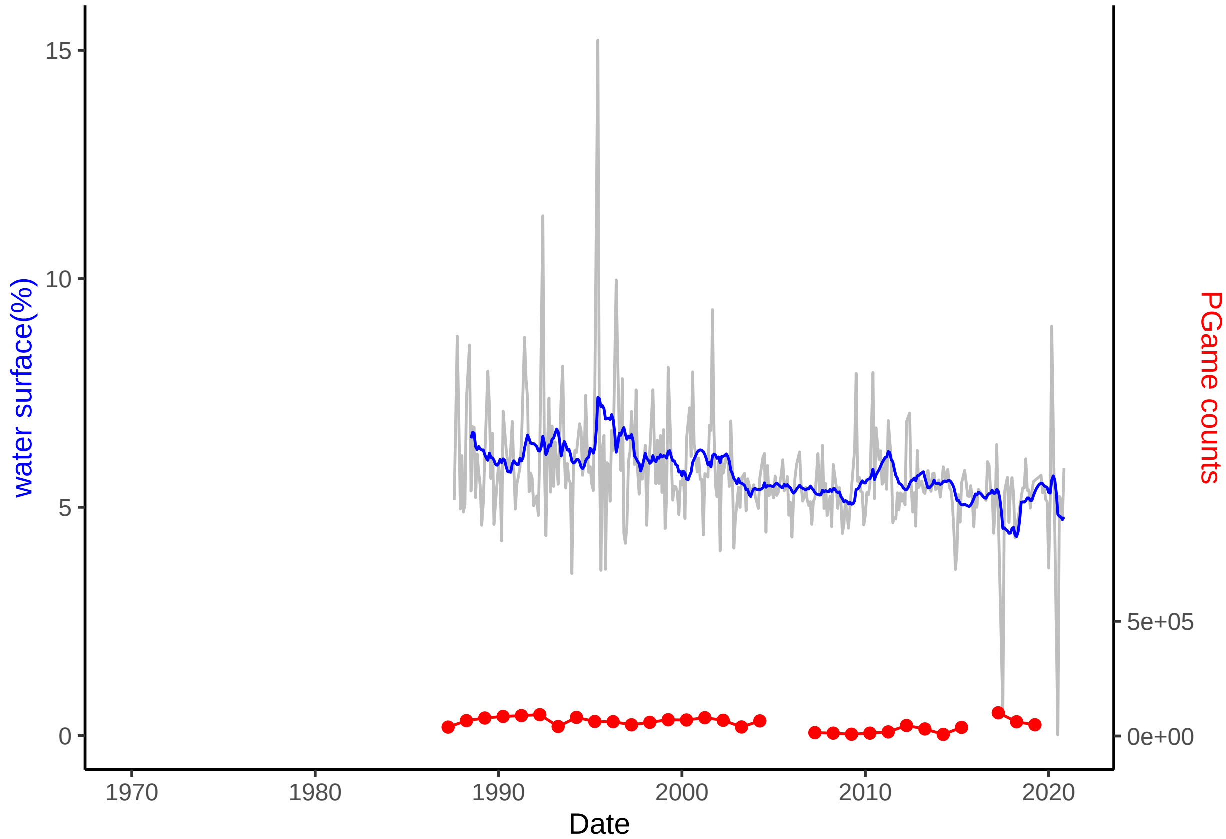


0.8
0.6
0.4
0.2
0.0
water surface(%)
PGame counts
0
1970
1980
1990
2000
2010
2020
Date

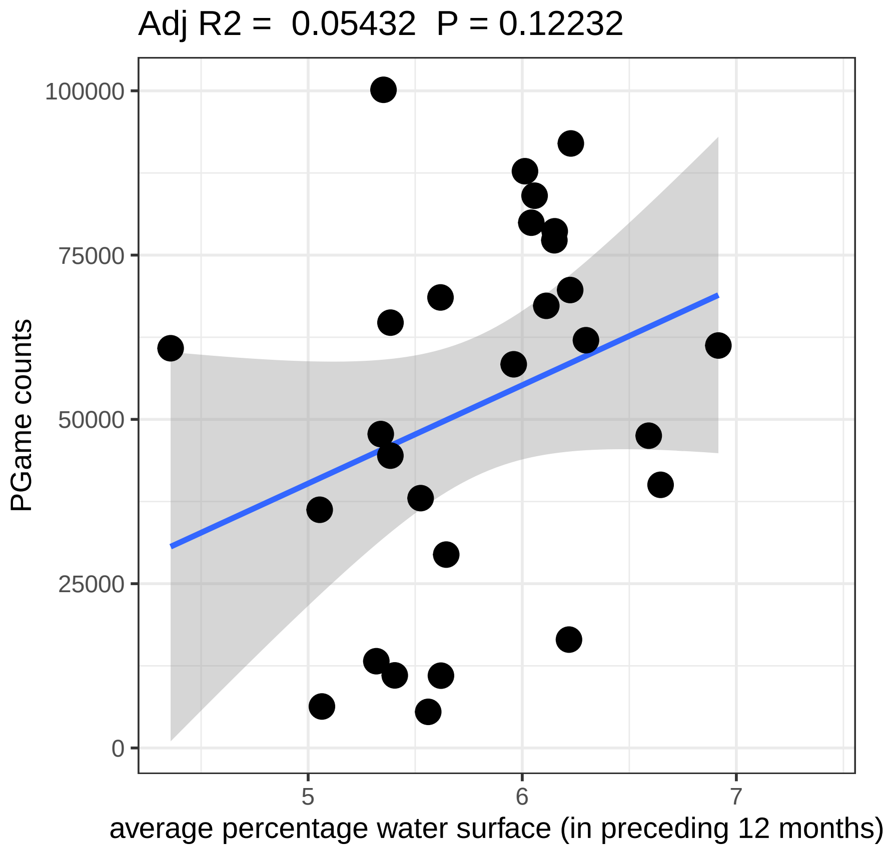

Adj R2 = 0.11379 P = 0.044309
PGame counts
100000
75000
50000
25000
0.3
0.4
0.5
0.6
0.7
average percentage water surface (in preceding 12 months)

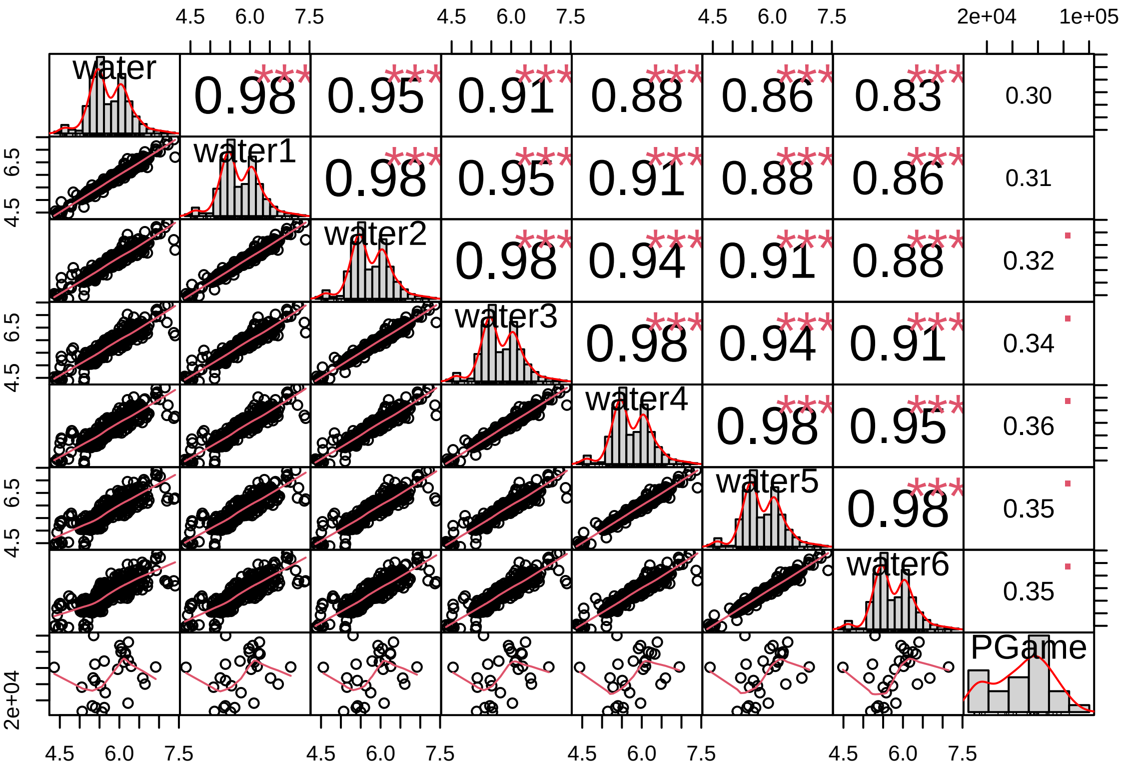

water
water1
water2
water3
water4
water5
water6
PGame
1.00
0.98
0.97
0.94
0.92
0.88
0.38
0.39
0.3
0.5
0.6
2e+04
1e+05

```
##
##
##   SEDB
##
```

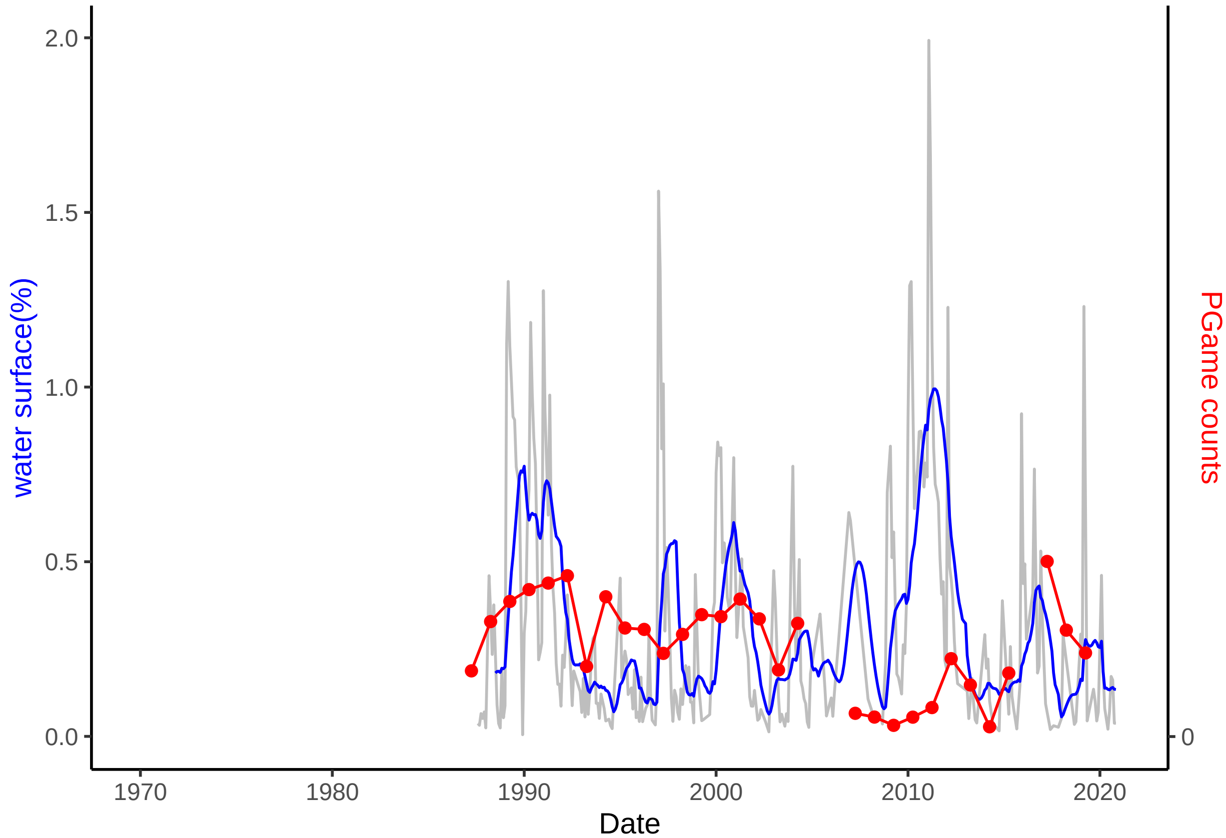


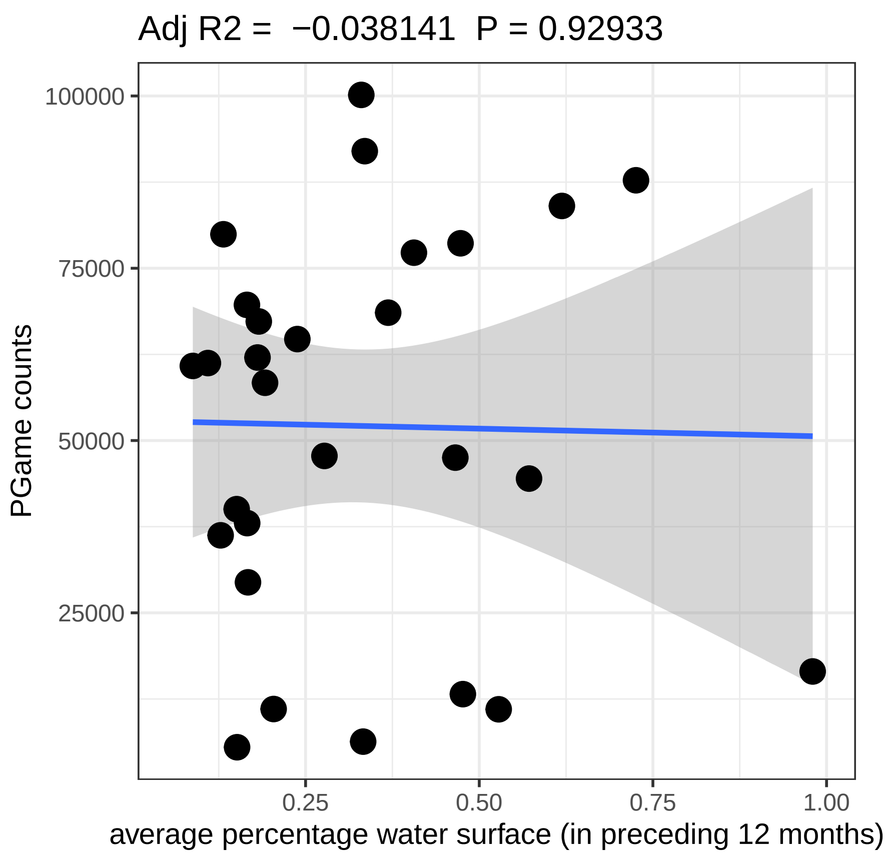
water surface(%)
PGame counts
15
10
5
0
5e+05
0e+00
1970
1980
1990
2000
2010
2020
Date


Adj R2 = 0.05432 P = 0.12232
100000
75000
50000
25000
0
PGame counts
5
6
7
average percentage water surface (in preceding 12 months)

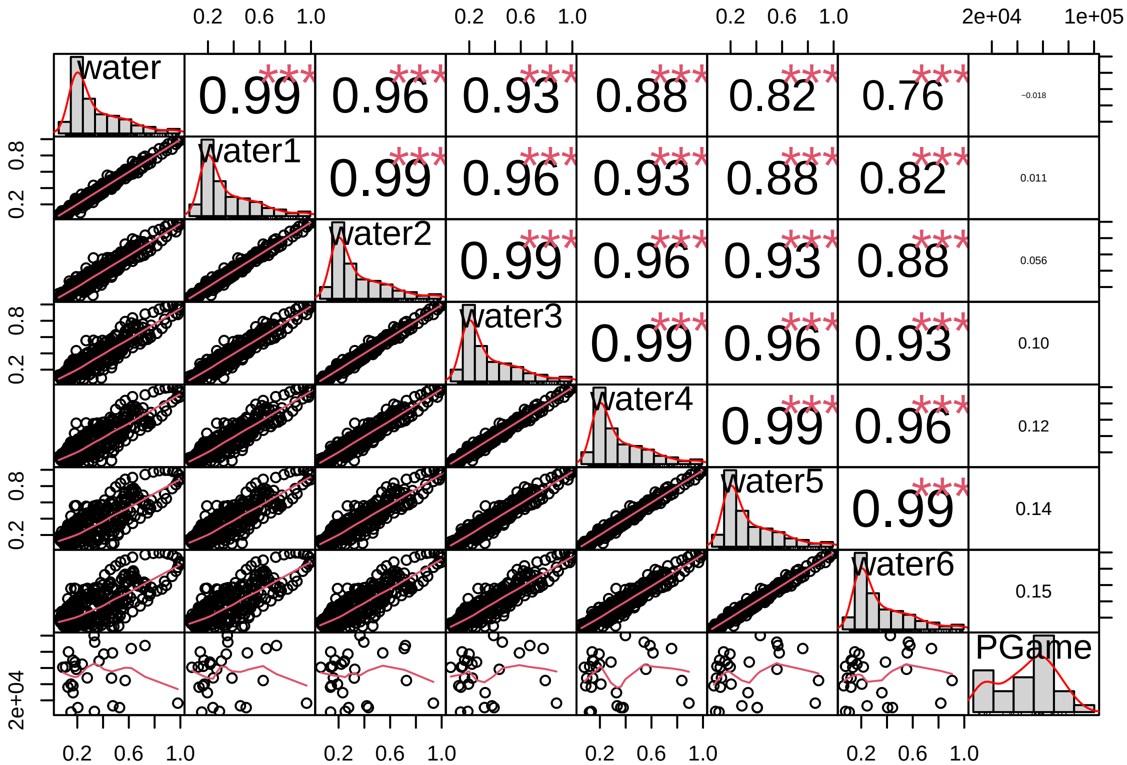

water
water1
water2
water3
water4
water5
water6
PGame
0.98 ***
0.95 ***
0.91 ***
0.88 ***
0.86 ***
0.83 ***
0.30
0.31
0.32
0.34
0.36
0.35
0.35
0.94 ***
0.91 ***
0.88 ***
4.5
6.0
7.5
6.5
2e+04
1e+05

```
##
##
##   LEB
##
```

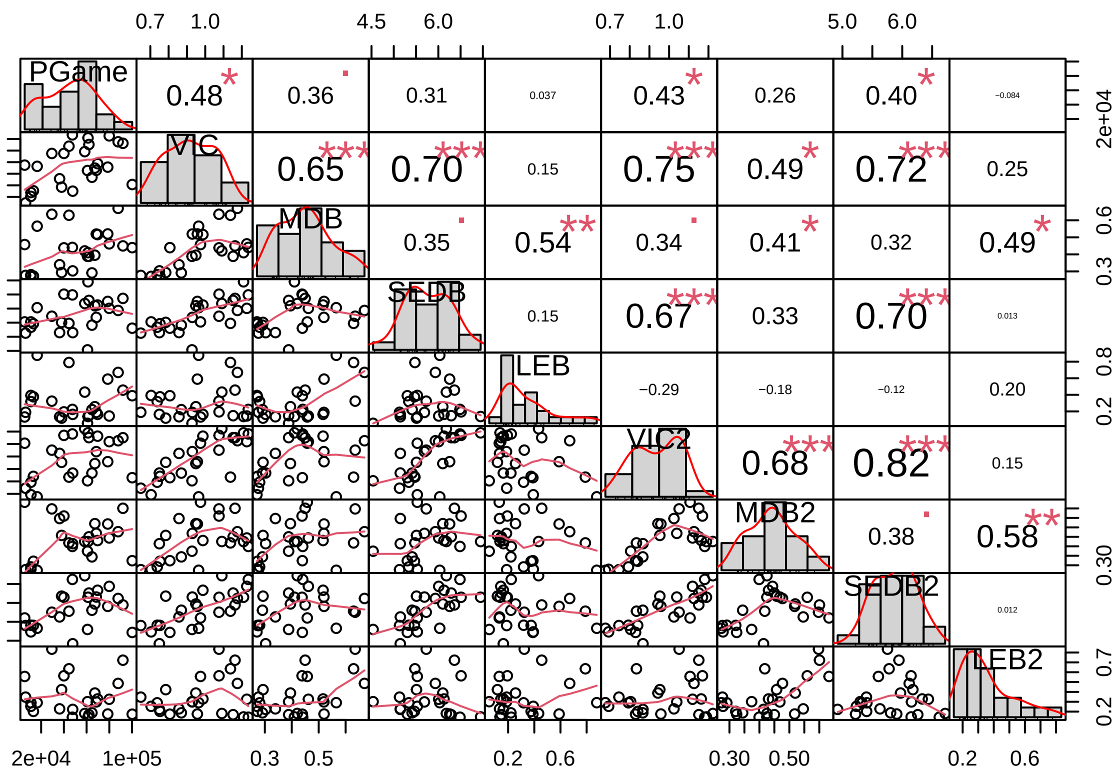

water surface(%)
PGame counts
Date
2.0
1.5
1.0
0.5
0.0
0
1970
1980
1990
2000
2010
2020



Adj R2 = −0.038141 P = 0.92933
100000
75000
50000
25000
PGame counts
0.25
0.50
0.75
1.00
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
PGame
0.99
0.96
0.93
0.88
0.82
0.76
-0.018
0.011
0.056
0.10
0.12
0.14
0.15
0.2
0.6
1.0
0.8
2e+04
1e+05

6.1 Predictive models



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	df	delta	weight	AllSignif
-23007.87	NA	NA	NA	NA	NA	NA	75433	NA	0.2297	3	0.000	0.089979	TRUE
-20299.47	NA	-32661	NA	NA	NA	NA	84158	NA	0.2746	4	1.251	0.048139	FALSE
-19012.69	NA	NA	NA	NA	NA	NA	NA	70297	0.1846	3	1.481	0.042910	TRUE
-90245.30	NA	NA	NA	NA	NA	24022.4	NA	NA	0.1635	3	2.145	0.030792	TRUE
-30549.25	NA	NA	NA	NA	NA	NA	56422	26433	0.2412	4	2.423	0.026796	FALSE
-29253.61	NA	-50213	97960	NA	NA	NA	NA	55675	0.3248	5	2.483	0.025997	FALSE
-30576.14	NA	NA	58396	NA	NA	NA	NA	56732	0.2386	4	2.512	0.025623	FALSE
-52596.56	NA	NA	NA	NA	NA	7401.7	61366	NA	0.2372	4	2.558	0.025037	FALSE
-23103.00	NA	NA	20465	NA	NA	NA	66519	NA	0.2340	4	2.669	0.023688	FALSE
-13023.88	NA	NA	NA	NA	-2715.5	NA	81328	NA	0.2311	4	2.765	0.022577	FALSE
-22385.67	-4582.52	NA	NA	NA	NA	NA	76264	NA	0.2309	4	2.772	0.022499	FALSE
-24373.84	NA	NA	NA	8810	NA	NA	72898	NA	0.2305	4	2.786	0.022349	FALSE
-87707.41	NA	NA	61734	NA	NA	19082.2	NA	NA	0.2246	4	2.985	0.020232	FALSE
-13201.36	NA	-78541	111145	98315	NA	NA	NA	NA	0.3103	5	3.035	0.019725	FALSE
13846.19	NA	-51349	125884	NA	NA	NA	NA	NA	0.2221	4	3.068	0.019409	FALSE
13330.47	NA	NA	85951	NA	NA	NA	NA	NA	0.1320	3	3.106	0.019040	FALSE
-19464.20	NA	-46215	62112	NA	NA	NA	60723	NA	0.3063	5	3.188	0.018281	FALSE
-28385.94	NA	-49210	NA	61008	NA	NA	71021	NA	0.3032	5	3.302	0.017265	FALSE
-34544.00	22977.54	NA	NA	NA	NA	NA	NA	78845	0.2135	4	3.355	0.016811	FALSE
-14921.56	NA	-22434	NA	NA	NA	NA	NA	73931	0.2067	4	3.579	0.015034	FALSE
-72514.53	NA	-43599	99177	NA	NA	16295.5	NA	NA	0.2877	5	3.875	0.012963	FALSE
-53590.79	NA	NA	NA	NA	NA	9529.6	NA	48855	0.1931	4	4.021	0.012052	FALSE
-26980.45	NA	-31723	NA	NA	NA	NA	67261	23144	0.2834	5	4.029	0.011999	FALSE
4754.92	NA	-36130	NA	NA	-6736.2	NA	99708	NA	0.2830	5	4.046	0.011903	FALSE
-41252.63	NA	NA	NA	NA	15787.6	NA	NA	NA	0.0960	3	4.161	0.011235	FALSE
49933.46	NA	NA	NA	NA	NA	NA	NA	NA	0.0000	2	4.216	0.010930	TRUE
-18630.43	NA	NA	NA	-16955	NA	NA	NA	77399	0.1867	4	4.225	0.010880	FALSE
-26183.15	NA	NA	NA	NA	1959.9	NA	NA	66066	0.1854	4	4.269	0.010645	FALSE
-32600.27	NA	-31276	NA	NA	NA	3048.4	77994	NA	0.2758	5	4.303	0.010464	FALSE

-20297.43	-17.05	-32657	NA	NA	NA	NA	84160	NA	0.2746	5	4.346	0.010242	FALSE
10155.70	-33736.78	-54892	162036	NA	NA	NA	NA	NA	0.2701	5	4.509	0.009441	FALSE
-88108.56	NA	NA	NA	32287	NA	21258.5	NA	NA	0.1760	4	4.565	0.009179	FALSE
-86103.20	NA	-13227	NA	NA	NA	24086.0	NA	NA	0.1713	4	4.713	0.008527	FALSE
-97359.78	11192.70	NA	NA	NA	NA	24644.9	NA	NA	0.1709	4	4.727	0.008465	FALSE
-40923.00	NA	NA	68816	NA	10656.6	NA	NA	NA	0.1705	4	4.740	0.008409	FALSE
10116.99	-29095.52	NA	114752	NA	NA	NA	NA	NA	0.1679	4	4.819	0.008084	FALSE
-92986.06	NA	NA	NA	NA	2697.5	21822.1	NA	NA	0.1649	4	4.914	0.007710	FALSE
20119.79	NA	NA	NA	68801	NA	NA	NA	NA	0.0668	3	4.987	0.007434	FALSE
-33636.11	29965.12	-30878	NA	NA	NA	NA	NA	86446	0.2528	5	5.117	0.006965	FALSE
-33043.22	NA	NA	33943	NA	NA	NA	35747	34621	0.2519	5	5.150	0.006851	FALSE
-28700.31	NA	-67308	71025	70585	NA	NA	42160	NA	0.3438	6	5.160	0.006817	FALSE
-31146.17	NA	NA	66074	-42160	NA	NA	NA	72606	0.2511	5	5.176	0.006762	FALSE
-11516.18	NA	NA	NA	NA	-5644.8	NA	64338	32464	0.2468	5	5.325	0.006279	FALSE
-62372.24	NA	NA	30805	NA	NA	9811.3	43368	NA	0.2461	5	5.349	0.006203	FALSE
-57957.54	NA	NA	56880	NA	NA	7628.9	NA	39918	0.2440	5	5.421	0.005985	FALSE
14671.10	NA	-51987	NA	122312	NA	NA	NA	NA	0.1480	4	5.434	0.005947	FALSE
-41587.20	NA	NA	NA	NA	-6113.9	10270.7	69185	NA	0.2434	5	5.443	0.005918	FALSE
-33602.77	6528.14	NA	NA	NA	NA	NA	49775	34028	0.2428	5	5.465	0.005855	FALSE
-30176.92	NA	NA	NA	-12936	NA	NA	56028	32158	0.2425	5	5.475	0.005826	FALSE
-21185.07	-14847.95	NA	41557	NA	NA	NA	60023	NA	0.2424	5	5.478	0.005816	FALSE
3602.25	NA	NA	73173	35008	NA	NA	NA	NA	0.1463	4	5.486	0.005794	FALSE
-26013.76	NA	-46634	109644	NA	7820.1	NA	NA	NA	0.2421	5	5.487	0.005791	FALSE
-40804.81	NA	NA	NA	NA	NA	2932.2	54545	21294	0.2419	5	5.492	0.005774	FALSE
-28312.77	NA	-62948	99838	44779	NA	NA	NA	38546	0.3334	6	5.572	0.005549	FALSE
-27650.08	NA	NA	58918	NA	-828.0	NA	NA	58398	0.2387	5	5.603	0.005465	FALSE
-31168.27	1427.97	NA	56512	NA	NA	NA	NA	57701	0.2386	5	5.606	0.005457	FALSE
-53272.24	NA	NA	NA	7344	NA	7285.8	59472	NA	0.2378	5	5.634	0.005380	FALSE
-8506.99	NA	-53499	104235	NA	-5846.6	NA	NA	67370	0.3314	6	5.648	0.005343	FALSE
-51655.02	-942.94	NA	NA	NA	NA	7198.2	61924	NA	0.2373	5	5.652	0.005331	FALSE
-30973.95	NA	-48467	79988	NA	NA	NA	24261	40705	0.3308	6	5.672	0.005278	FALSE
-60028.62	NA	-67576	98119	75866	NA	10001.2	NA	NA	0.3304	6	5.688	0.005236	FALSE
-16461.98	NA	NA	18793	NA	-1804.2	NA	71163	NA	0.2346	5	5.744	0.005092	FALSE
-24053.67	NA	NA	19584	6158	NA	NA	65130	NA	0.2344	5	5.751	0.005074	FALSE
-12987.91	-4287.01	NA	NA	NA	-2567.0	NA	81783	NA	0.2322	5	5.824	0.004891	FALSE
-14506.53	NA	NA	NA	8575	-2673.9	NA	78770	NA	0.2319	5	5.834	0.004868	FALSE
-78260.88	-13807.49	NA	78031	NA	NA	17010.1	NA	NA	0.2316	5	5.844	0.004844	FALSE
-23456.39	-3806.30	NA	NA	6226	NA	NA	74331	NA	0.2313	5	5.854	0.004818	FALSE
-26673.02	-6176.69	-50948	106688	NA	NA	NA	NA	51468	0.3258	6	5.865	0.004793	FALSE
-28188.94	NA	-50341	98119	NA	NA	-295.7	NA	56324	0.3248	6	5.904	0.004700	FALSE
-16495.91	-21130.54	-49248	94863	NA	NA	NA	51098	NA	0.3229	6	5.975	0.004536	FALSE
-87169.31	NA	NA	58913	9883	NA	18461.9	NA	NA	0.2257	5	6.045	0.004381	FALSE
-87154.68	NA	NA	62072	NA	-530.3	19487.7	NA	NA	0.2247	5	6.078	0.004308	FALSE
-44492.17	NA	NA	NA	46717	12843.5	NA	NA	NA	0.1235	4	6.173	0.004109	FALSE
2587.17	NA	-55087	NA	66492	-8523.0	NA	89514	NA	0.3163	6	6.229	0.003996	FALSE
-10535.22	-12553.34	-75799	126798	83633	NA	NA	NA	NA	0.3150	6	6.280	0.003895	FALSE
-19637.84	27731.81	NA	NA	NA	-4952.7	NA	NA	91305	0.2174	5	6.320	0.003818	FALSE
-55264.13	21273.00	NA	NA	NA	NA	6027.9	NA	64647	0.2168	5	6.342	0.003775	FALSE
-73109.52	NA	-38226	NA	78046	NA	17525.4	NA	NA	0.2166	5	6.349	0.003763	FALSE
-34261.25	23187.17	NA	NA	-18826	NA	NA	NA	86808	0.2162	5	6.362	0.003739	FALSE
-23287.08	NA	-75871	107217	93535	2236.7	NA	NA	NA	0.3117	6	6.403	0.003663	FALSE
-45568.94	NA	-44405	67317	NA	NA	6486.6	45644	NA	0.3115	6	6.413	0.003644	FALSE
-95.86	NA	-48247	59107	NA	-5218.3	NA	73902	NA	0.3112	6	6.423	0.003626	FALSE
-32040.49	12849.95	-56045	NA	76981	NA	NA	65919	NA	0.3107	6	6.443	0.003590	FALSE
-14031.50	NA	-31368	NA	32786	NA	NA	NA	61646	0.2113	5	6.522	0.003451	FALSE
-40162.19	NA	-20526	NA	NA	NA	6860.3	NA	58186	0.2110	5	6.533	0.003431	FALSE
54198.02	NA	-12498	NA	NA	NA	NA	NA	NA	0.0070	3	6.602	0.003316	FALSE
-17757.27	NA	-22237	NA	NA	765.3	NA	NA	72247	0.2068	5	6.670	0.003205	FALSE
-56360.60	-21608.94	-47531	128059	NA	NA	12801.4	NA	NA	0.3043	6	6.681	0.003187	FALSE
-26700.39	NA	-52633	NA	72001	NA	NA	76601	-10887	0.3042	6	6.685	0.003181	FALSE
-26576.64	NA	-49541	NA	61451	NA	-463.0	71861	NA	0.3032	6	6.722	0.003123	FALSE
48464.63	4721.39	NA	NA	NA	NA	NA	NA	NA	0.0013	3	6.751	0.003078	FALSE
-37118.98	NA	-13101	NA	NA	15846.0	NA	NA	NA	0.1037	4	6.752	0.003076	FALSE
-41575.90	-27709.07	NA	97005	NA	10183.8	NA	NA	NA	0.2030	5	6.795	0.003011	FALSE
6394.00	NA	-36339	NA	NA	-9744.1	NA	82504	33077	0.2993	6	6.870	0.002900	FALSE
-41288.61	-1265.13	NA	NA	NA	15862.0	NA	NA	NA	0.0961	4	6.972	0.002755	FALSE

```
##                      VIC  LEB2 VIC2
## Sum of weights:      0.76 0.27 0.24
## N containing models:    2    1    1
```

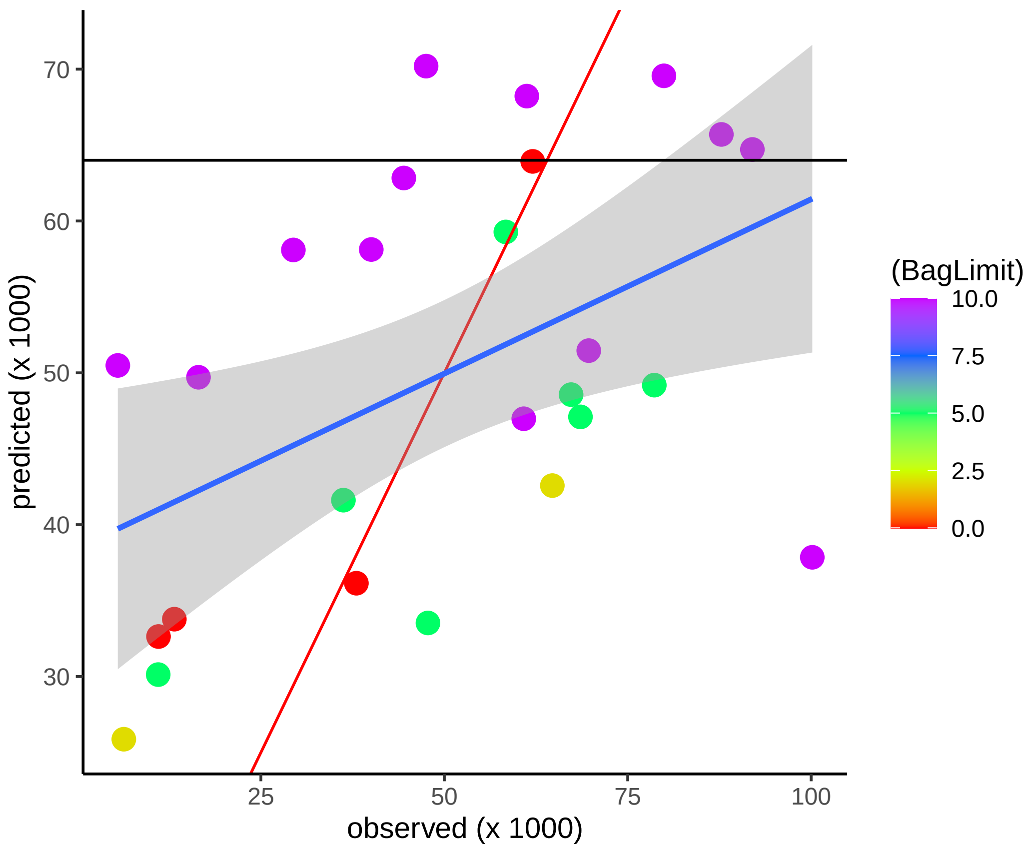
The above results are based on 26 cases.

6.2 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 priority wetlands only. 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 generally called.

```
##
##    The preferred model selected: 1 with a threshold number of 64000
##
##
##
```

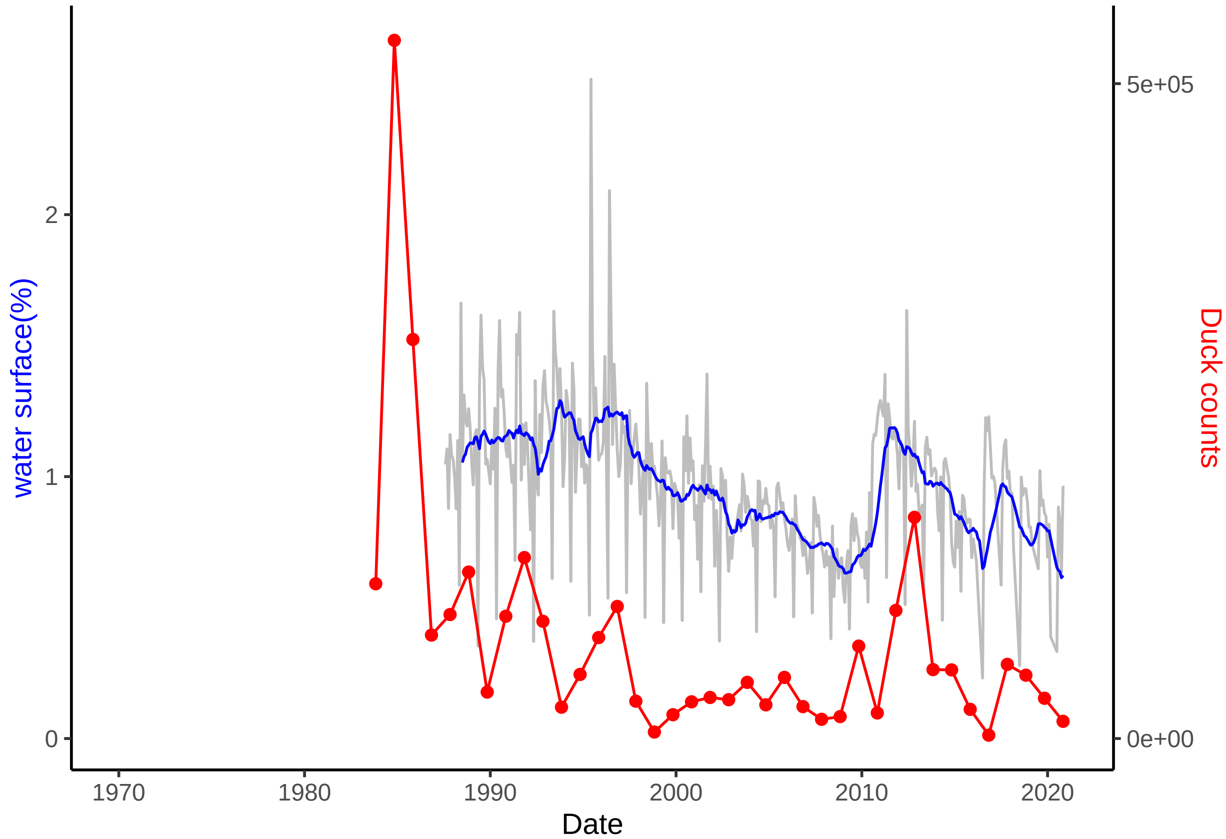
```
##
## Call:
## lm(formula = PGame ~ VIC + 1, data = Jc)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -44991 -19450  -1386  18592  62305
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   -23008      27702   -0.83    0.414
## VIC            75433      28197    2.68    0.013 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 25000 on 24 degrees of freedom
## Multiple R-squared:  0.23,   Adjusted R-squared:  0.198
## F-statistic: 7.16 on 1 and 24 DF,  p-value: 0.0132
```



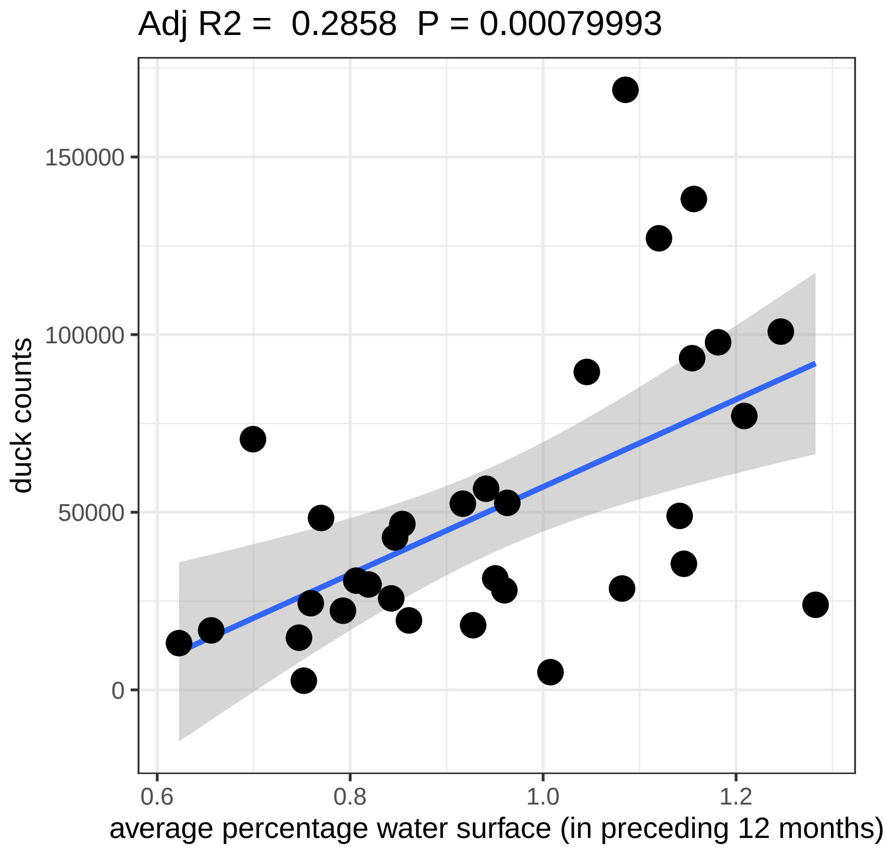
7 Water surface area and Eastern Australian Waterbird Survey counts for Victoria (i.e. band 1-3)

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

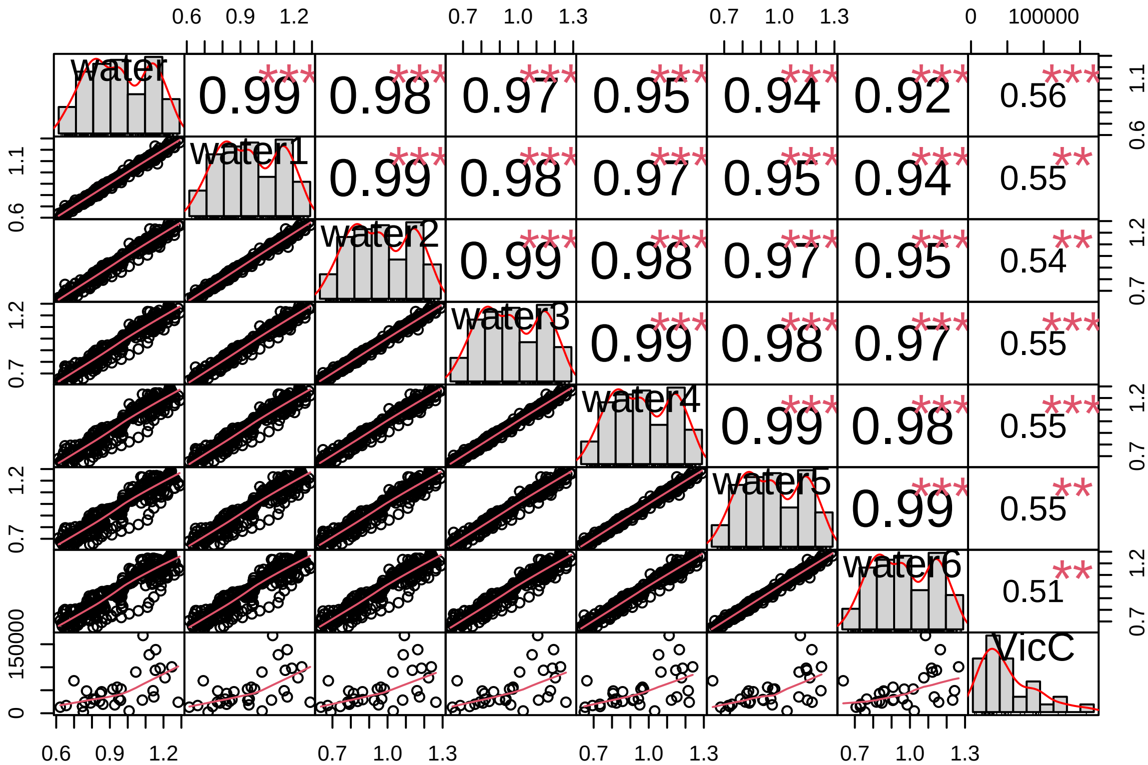
```
##
##
##  VIC
##
```



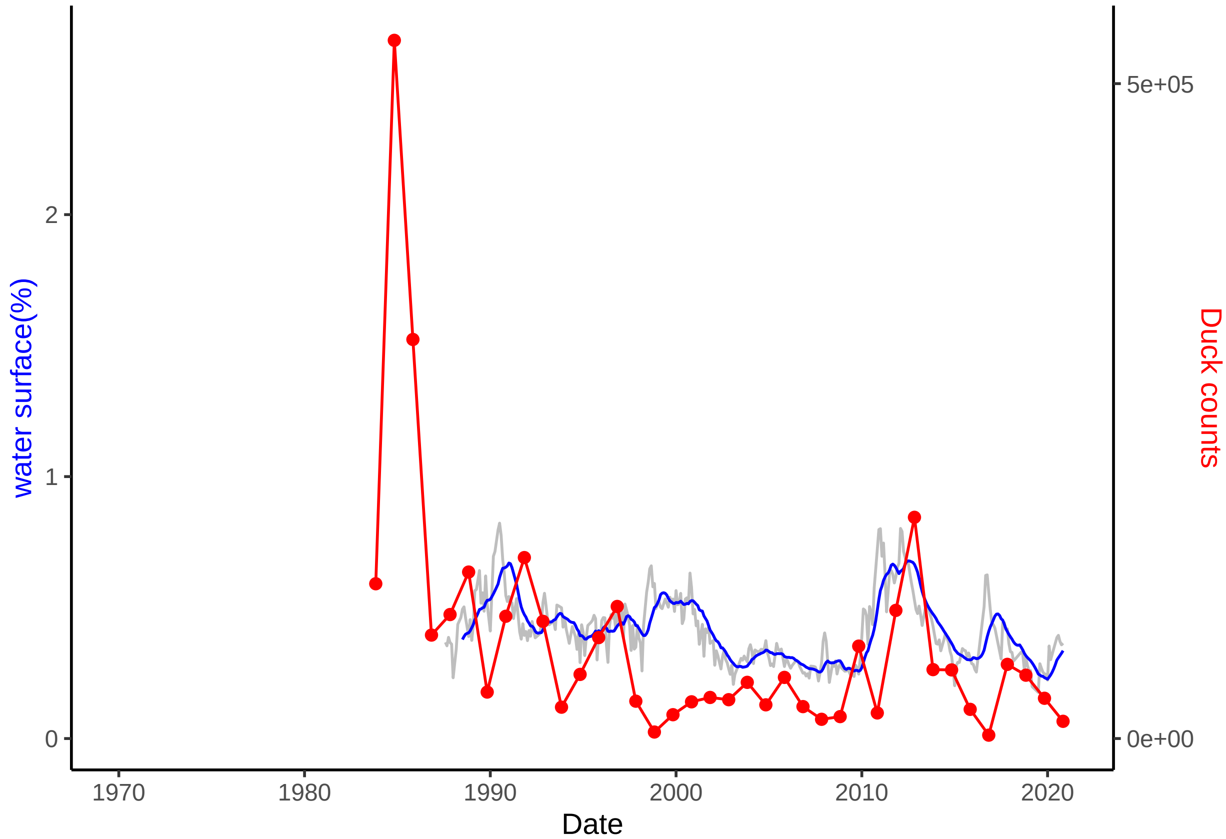
water surface(%)
Duck counts
2
1
0
5e+05
0e+00
1970
1980
1990
2000
2010
2020
Date



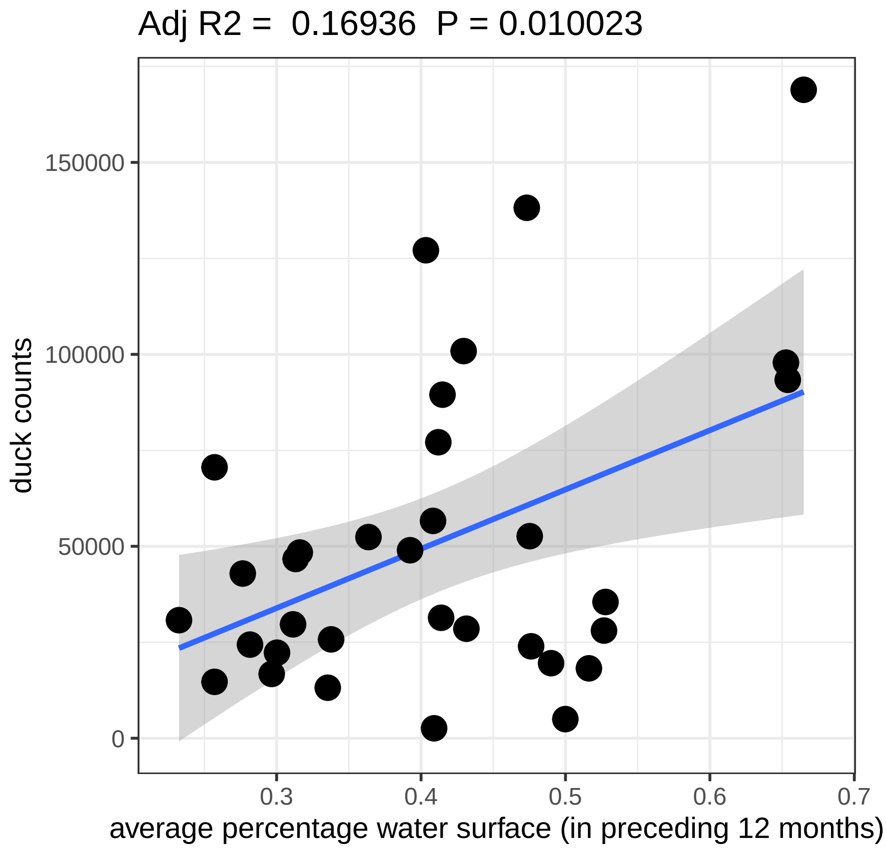
Adj R2 = 0.2858 P = 0.00079993
150000
100000
50000
0
duck counts
0.6
0.8
1.0
1.2
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
VicC
0.99
0.98
0.97
0.95
0.94
0.92
0.56
0.55
0.54
0.51

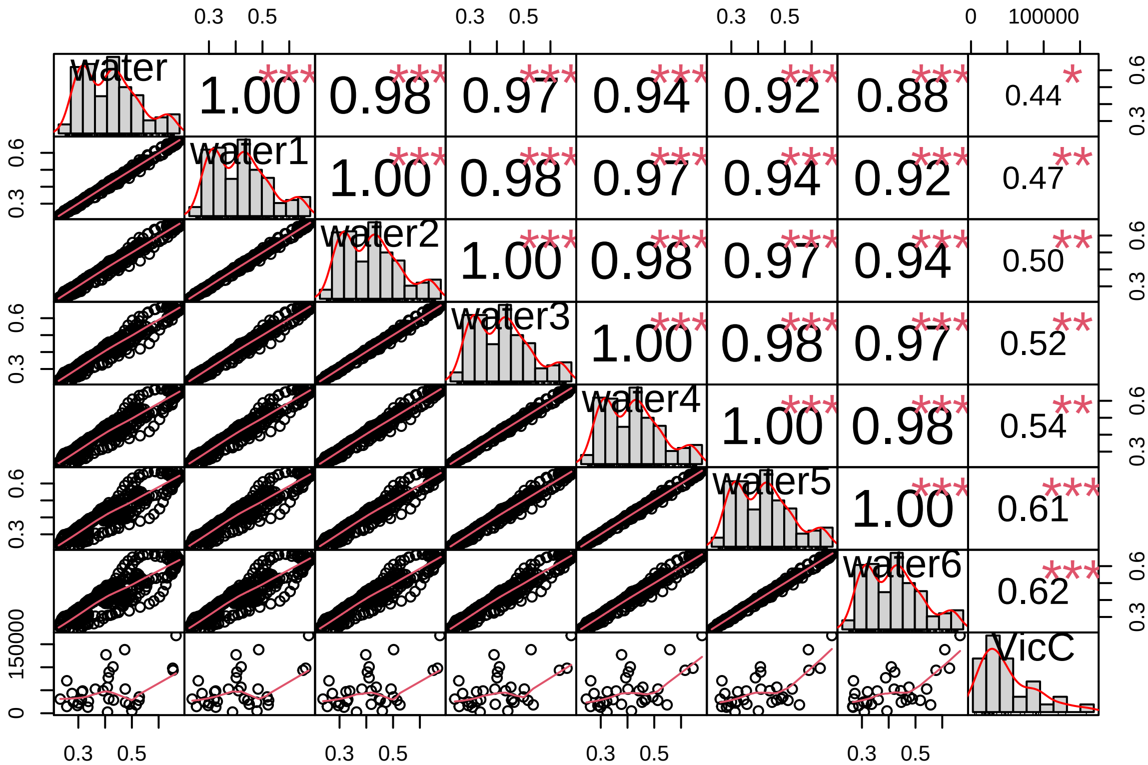
```
##
##
##  MDB
##
```



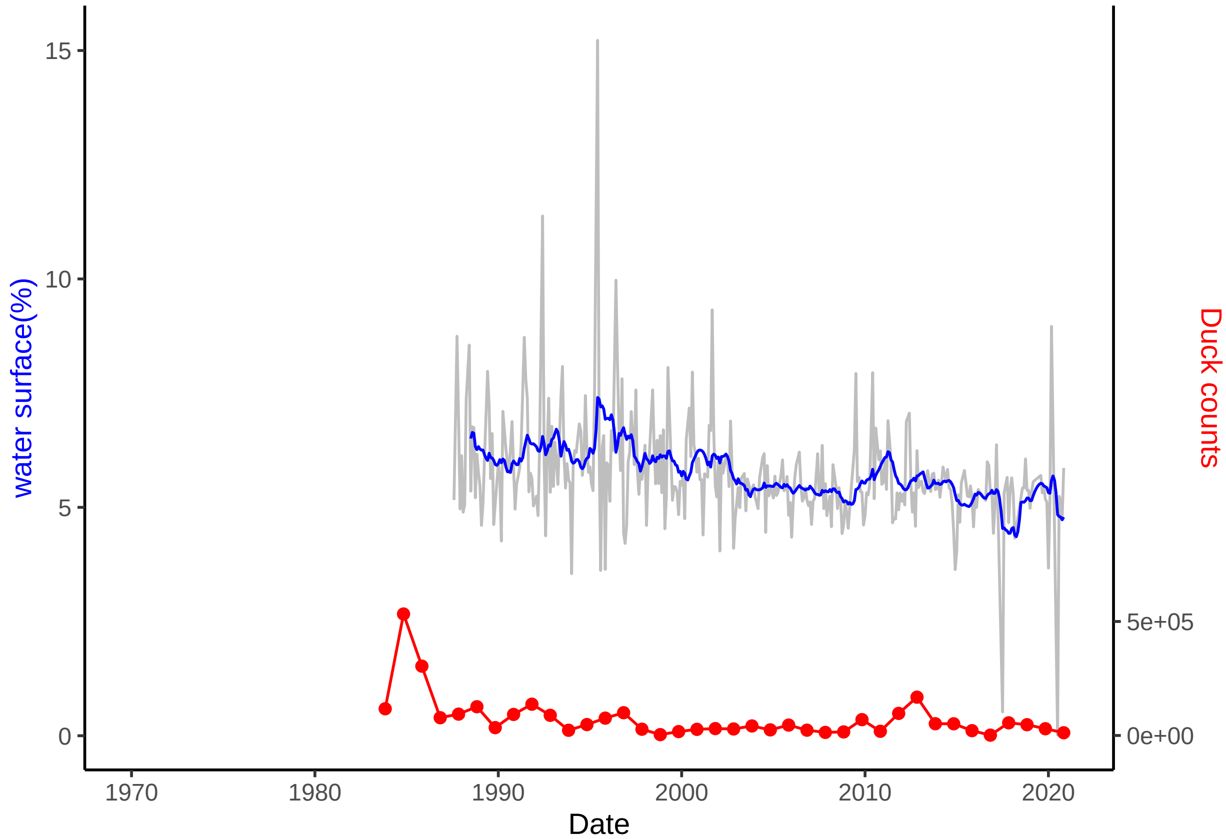
water surface(%)
Duck counts
2
1
0
5e+05
0e+00
1970
1980
1990
2000
2010
2020
Date



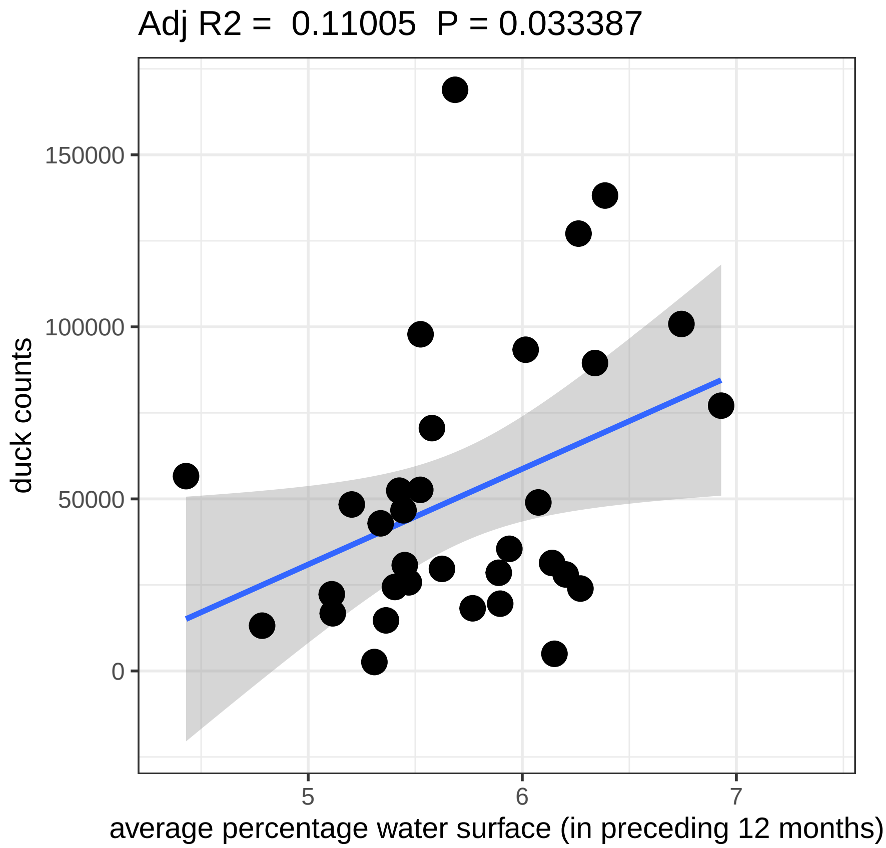
Adj R2 = 0.16936 P = 0.010023
150000
100000
50000
0
duck counts
0.3
0.4
0.5
0.6
0.7
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
VicC
1.00
0.98
0.97
0.94
0.92
0.88
0.44
0.47
0.50
0.52
0.54
0.61
0.62
0.3
0.5
0.6
0
100000
150000

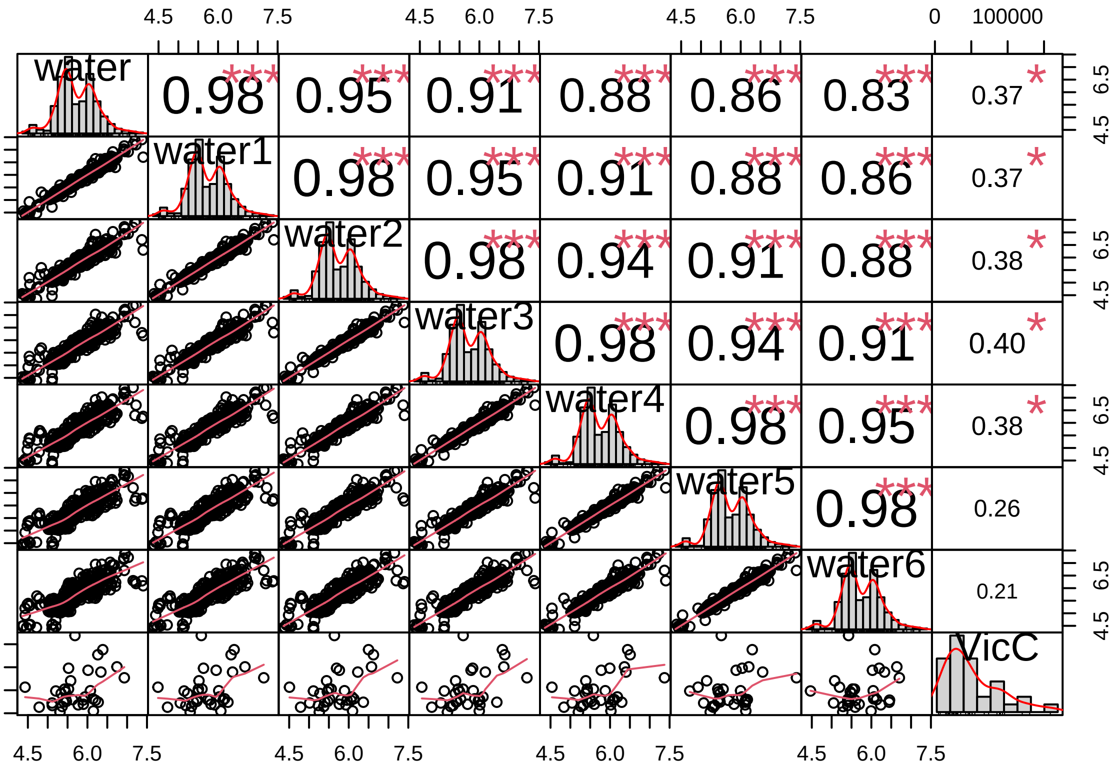
```
##
##
## SEDB
##
```



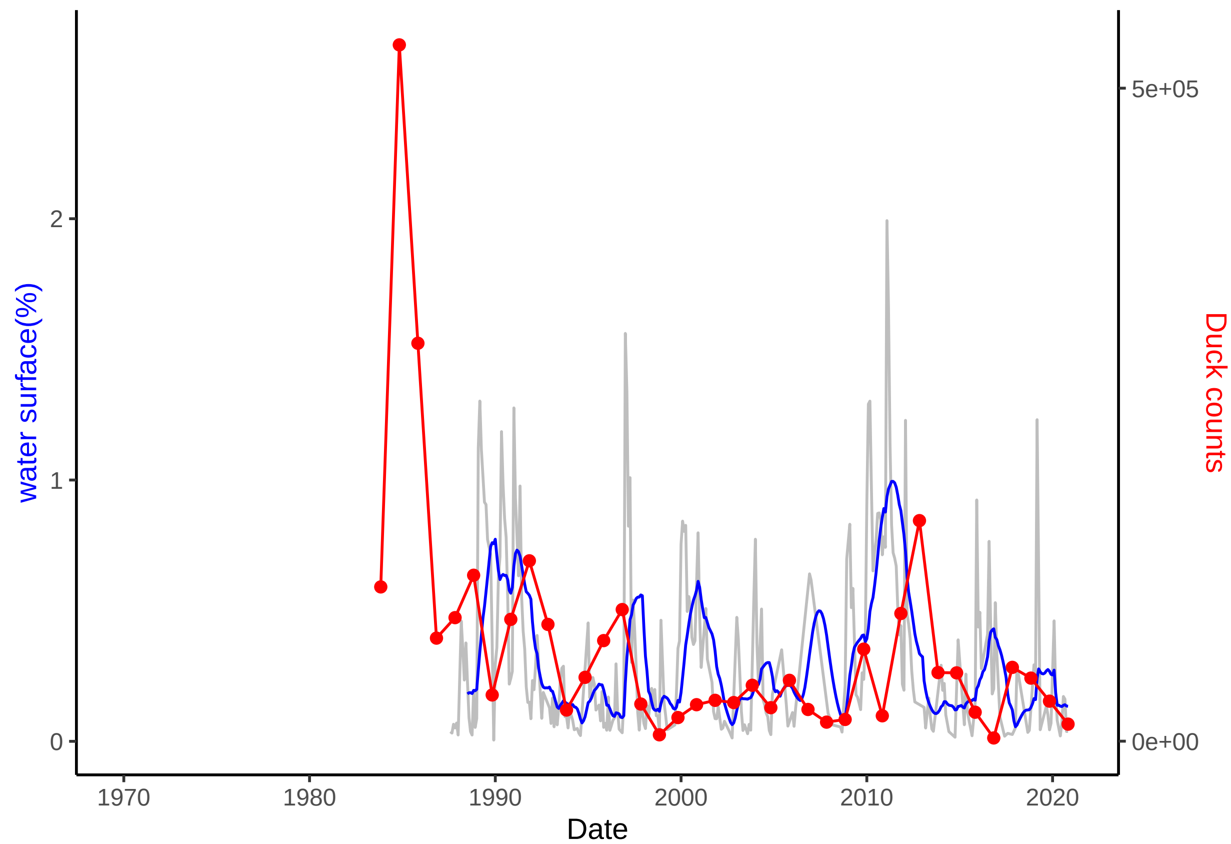
water surface(%)
Duck counts
15
10
5
0
5e+05
0e+00
1970
1980
1990
2000
2010
2020
Date

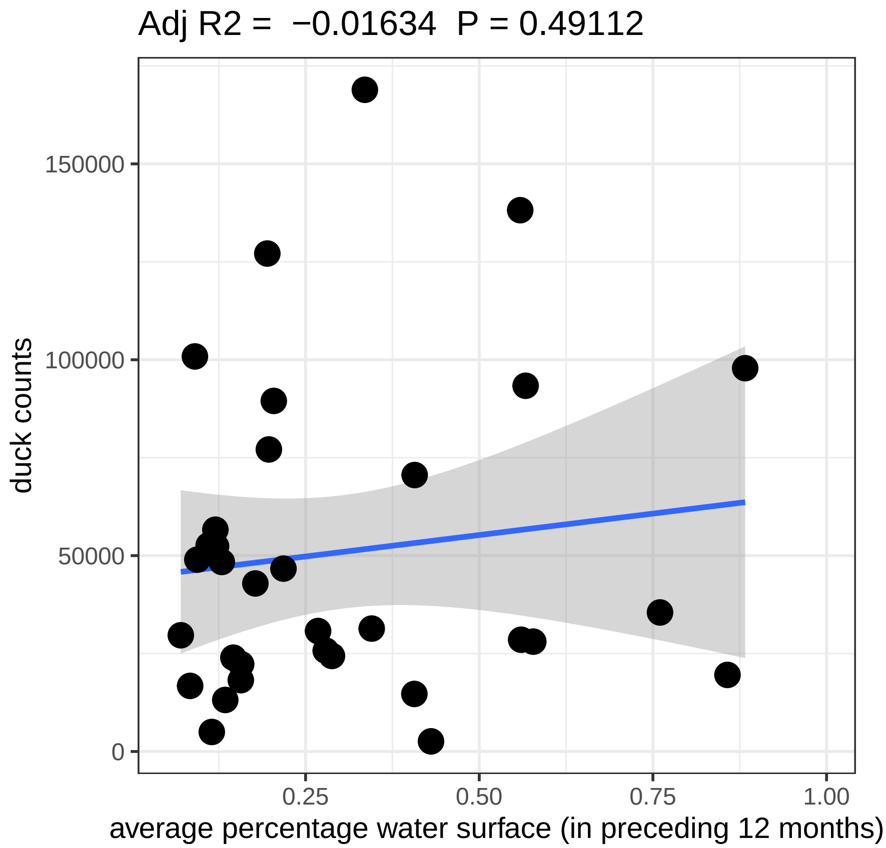


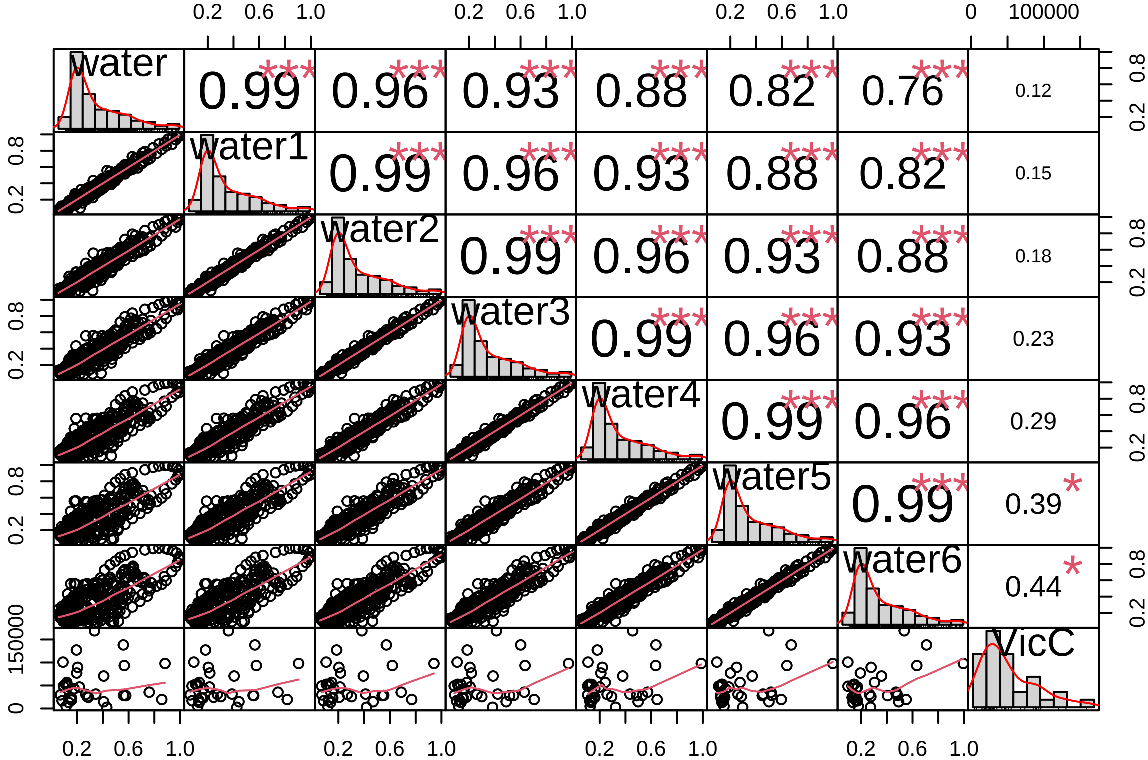
Adj R2 = 0.11005 P = 0.033387
150000
100000
50000
0
duck counts
5
6
7
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
VicC
0.98
0.95
0.91
0.88
0.86
0.83
0.37
0.40
0.38
0.26
0.21
4.5
6.0
7.5
6.5
0
100000
150000

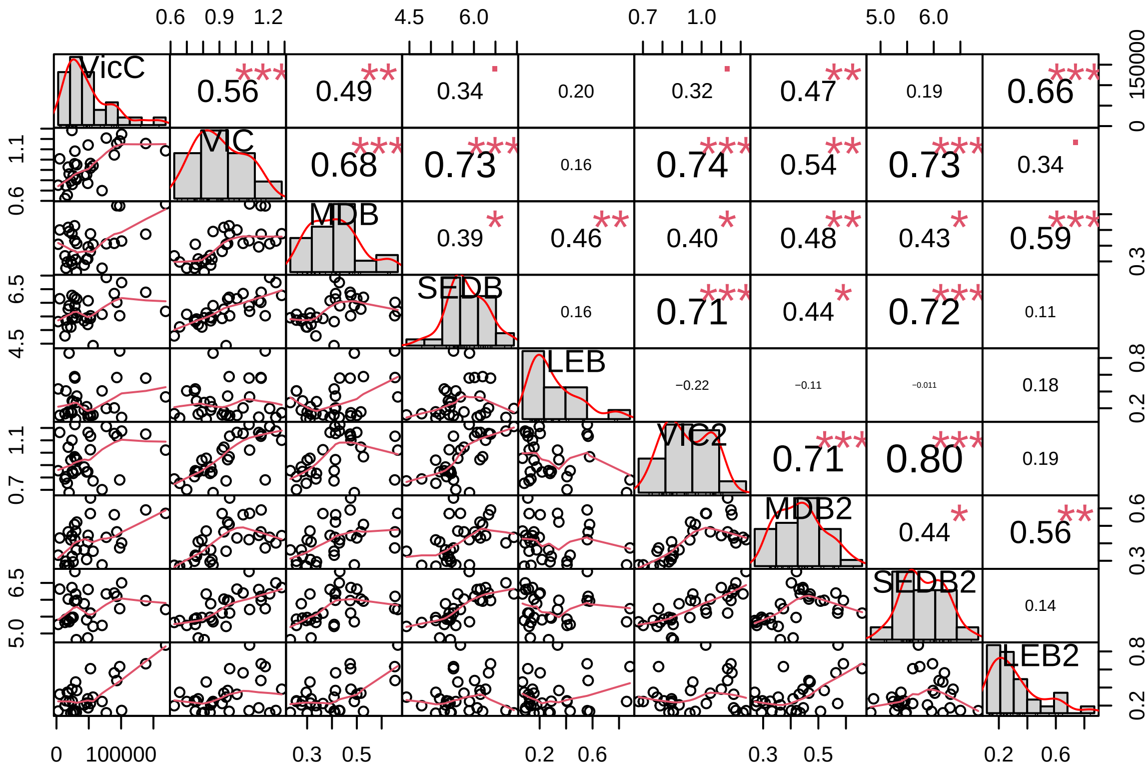
```
##
##
##   LEB
##
```


water surface(%)
0
1
2
Duck counts
0e+00
5e+05
1970
1980
1990
2000
2010
2020
Date


Adj R2 = −0.01634 P = 0.49112
duck counts
150000
100000
50000
0
0.25
0.50
0.75
1.00
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
VicC
0.99
0.96
0.93
0.88
0.82
0.76
0.12
0.15
0.18
0.23
0.29
0.39
0.44
0.2 0.6 1.0
0 100000
0 150000

7.1 Predictive models



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	df	delta	weight	AllSignif
51691	NA	99299	NA	NA	NA	-29132	142586	NA	0.6208	5	0.000	0.215584	TRUE
54235	NA	116877	-70631	NA	NA	-29760	168519	NA	0.6384	6	1.627	0.095582	FALSE
-62400	NA	108564	NA	NA	NA	NA	82644	NA	0.5614	4	1.652	0.094398	TRUE
26727	NA	103436	NA	NA	12483.6	-34302	123686	NA	0.6324	6	2.145	0.073778	FALSE
62189	NA	99411	NA	NA	NA	-33845	134950	24704	0.6241	6	2.831	0.052356	FALSE
51836	NA	98632	NA	2651	NA	-29254	142227	NA	0.6209	6	3.098	0.045808	FALSE
51693	-3.579	99299	NA	NA	NA	-29132	142588	NA	0.6208	6	3.100	0.045757	FALSE
-62320	NA	125022	-65391	NA	NA	NA	105458	NA	0.5765	5	3.427	0.038864	FALSE
-51982	NA	106455	NA	NA	NA	NA	105335	-32339	0.5697	5	3.922	0.030340	FALSE
32017	NA	119243	-65467	NA	11017.7	-34277	149942	NA	0.6473	7	4.226	0.026054	FALSE
-63249	7758.510	107321	NA	NA	NA	NA	81537	NA	0.5632	5	4.384	0.024075	FALSE
-59760	NA	113521	NA	-20951	NA	NA	87471	NA	0.5632	5	4.389	0.024023	FALSE
-65648	NA	108979	NA	NA	896.6	NA	80523	NA	0.5615	5	4.508	0.022628	FALSE
46216	15754.194	120457	-92840	NA	NA	-28145	170697	NA	0.6440	7	4.518	0.022515	FALSE
59952	NA	116089	-67215	NA	NA	-32351	163017	13742	0.6394	7	4.913	0.018486	FALSE
54091	NA	117638	-70866	-2795	NA	-29633	168984	NA	0.6385	7	4.994	0.017752	FALSE
-103848	NA	129375	NA	NA	19742.5	NA	NA	NA	0.5064	4	5.314	0.015129	TRUE
35639	NA	103247	NA	NA	11677.6	-37246	119596	17179	0.6339	7	5.384	0.014604	FALSE
27918	-3410.156	103977	NA	NA	12842.5	-34843	124436	NA	0.6327	7	5.486	0.013877	FALSE
-64959	24513.201	129905	-100390	NA	NA	NA	114170	NA	0.5904	6	5.497	0.013803	FALSE
26070	NA	104858	NA	-5419	12663.9	-34127	124147	NA	0.6325	7	5.505	0.013749	FALSE
-48761	NA	125263	-77237	NA	NA	NA	139089	-42042	0.5900	6	5.521	0.013636	FALSE
69720	NA	108861	NA	-37195	NA	-36422	133030	47213	0.6267	7	5.984	0.010819	FALSE
61802	7317.176	98546	NA	NA	NA	-34668	129476	33434	0.6253	7	6.104	0.010187	FALSE
-58983	NA	131895	-67824	-26455	NA	NA	112402	NA	0.5793	6	6.322	0.009136	FALSE
51661	342.710	98513	NA	2956	NA	-29229	142056	NA	0.6209	7	6.467	0.008498	FALSE
-60271	NA	124837	-65697	NA	-565.8	NA	106903	NA	0.5766	6	6.525	0.008257	FALSE
-67820	NA	108348	NA	NA	4864.3	NA	97699	-37862	0.5715	6	6.893	0.006869	FALSE
-69553	NA	131946	NA	NA	30087.9	-16362	NA	NA	0.5262	5	6.911	0.006807	FALSE

-51371	NA	101216	NA	19513	NA	NA	107525	-41869	0.5705	6	6.964	0.006629	FALSE

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	25735	72142	74242	0.3466	0.7289
LEB2	105598	28499	29755	3.5489	0.0004
SEDB2	-29325	14147	14818	1.9790	0.0478
VIC	134746	48849	50399	2.6736	0.0075
MDB	-70631	62787	65848	1.0726	0.2834

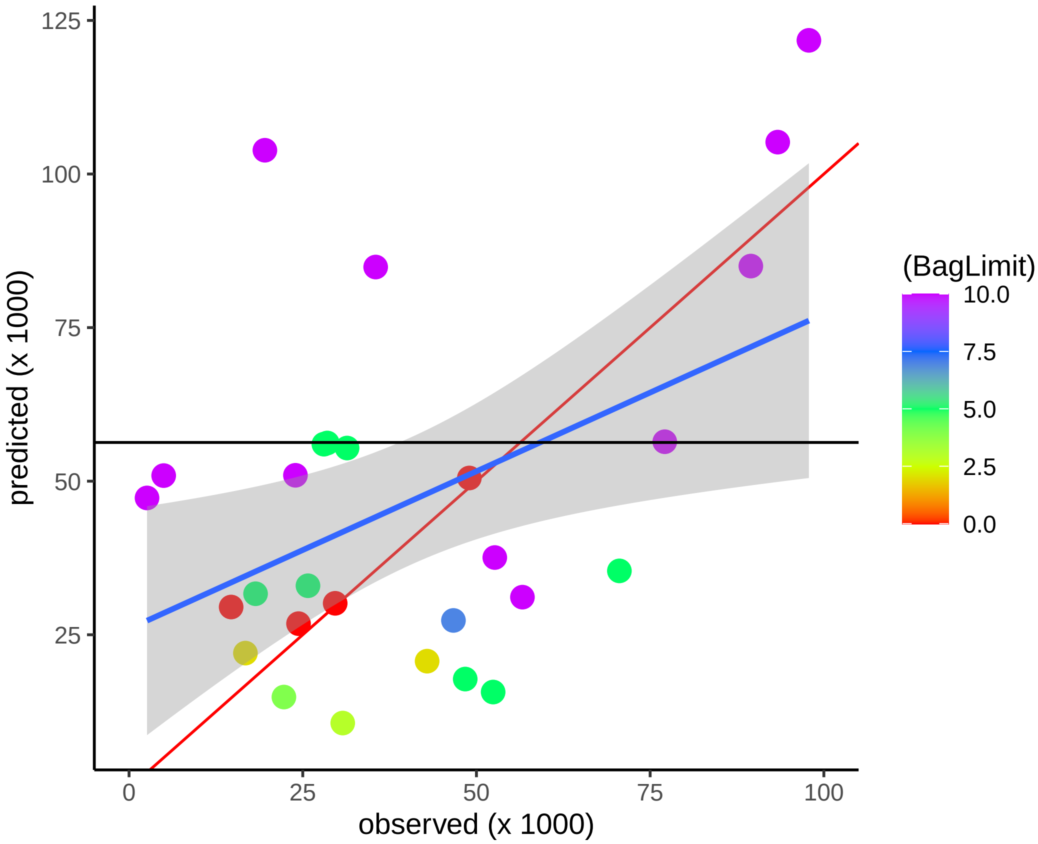
```
##                        LEB2 VIC  SEDB2 MDB
## Sum of weights:        1.00 1.00 0.77  0.24
## N containing models:      3    3    2     1
```

The above results are based on 31 cases.

7.2 Predicted versus observed

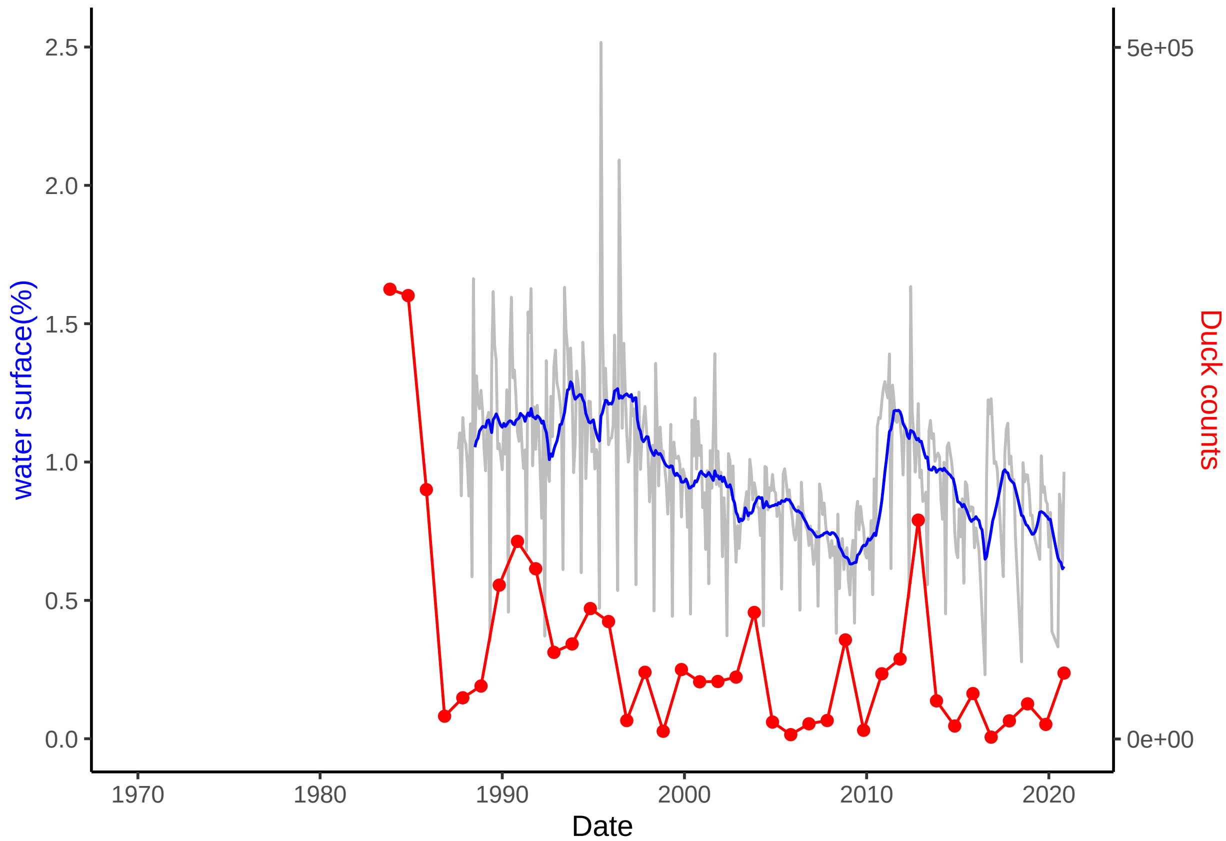
```
##
##    The preferred model selected: 3 with a threshold number of 56300
##
##
##
```

```
##
## Call:
## lm(formula = VicC ~ LEB2 + VIC + 1, data = Jc)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -61066 -13434   2532  13339  48560
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   -62400      25773   -2.42  0.02220 *
## LEB2          108564      27430    3.96  0.00047 ***
## VIC            82644      28689    2.88  0.00753 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 26900 on 28 degrees of freedom
## Multiple R-squared:  0.561,  Adjusted R-squared:  0.53
## F-statistic: 17.9 on 2 and 28 DF,  p-value: 9.74e-06
```

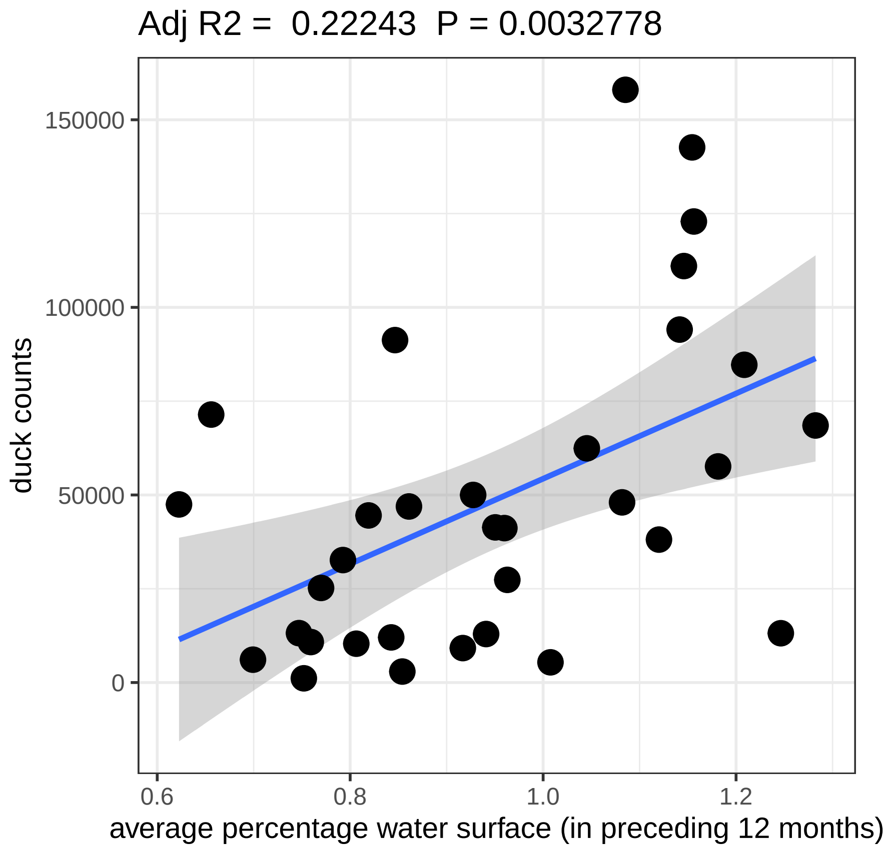


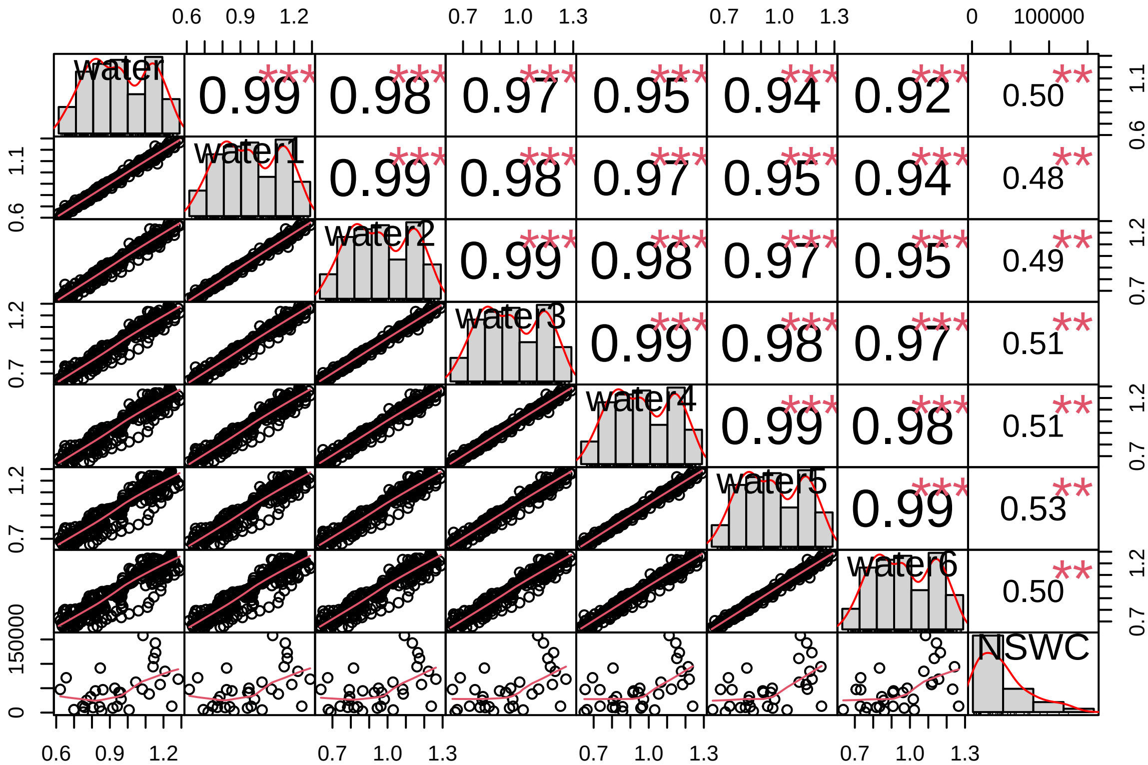
8 Water surface area and Eastern Australian Waterbird Survey counts for NSW (i.e. band 4-6)

```
##
##
##  VIC
##
```

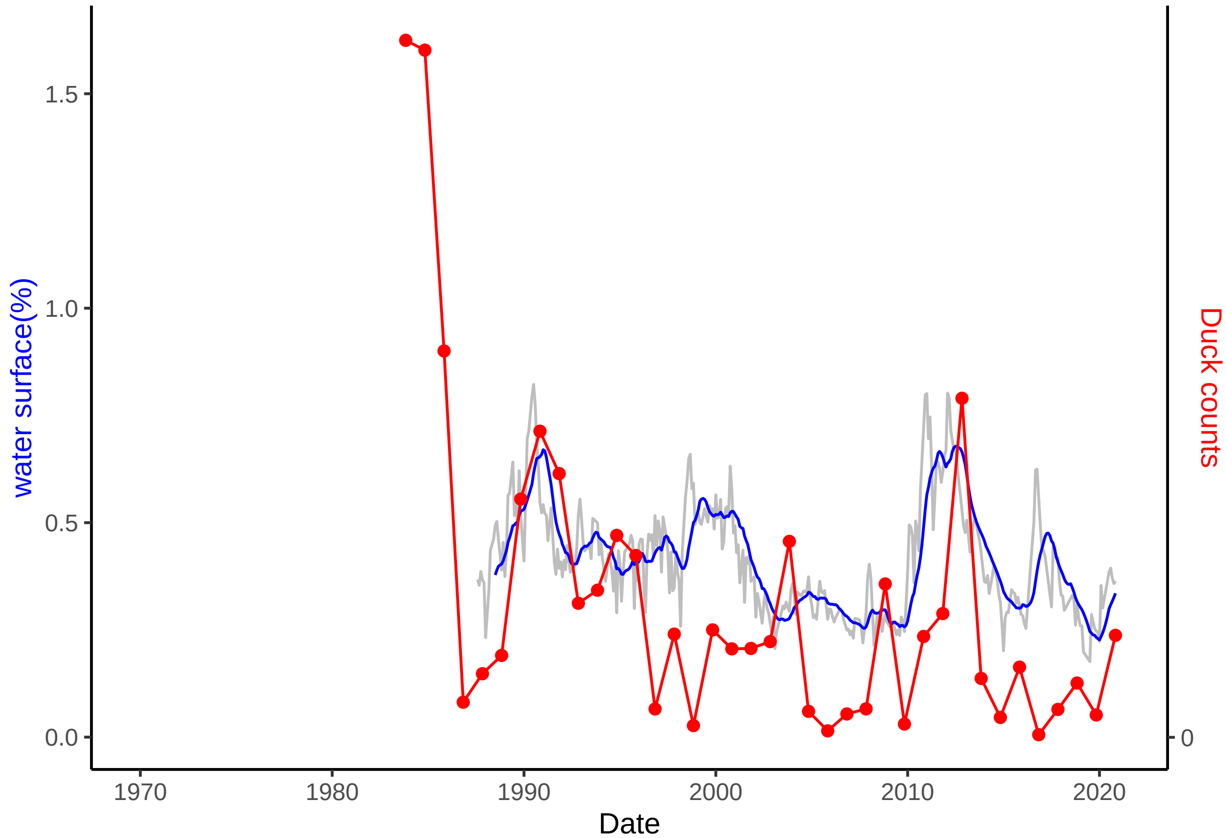


2.5
2.0
1.5
1.0
0.5
0.0
water surface(%)
5e+05
0e+00
Duck counts
1970
1980
1990
2000
2010
2020
Date

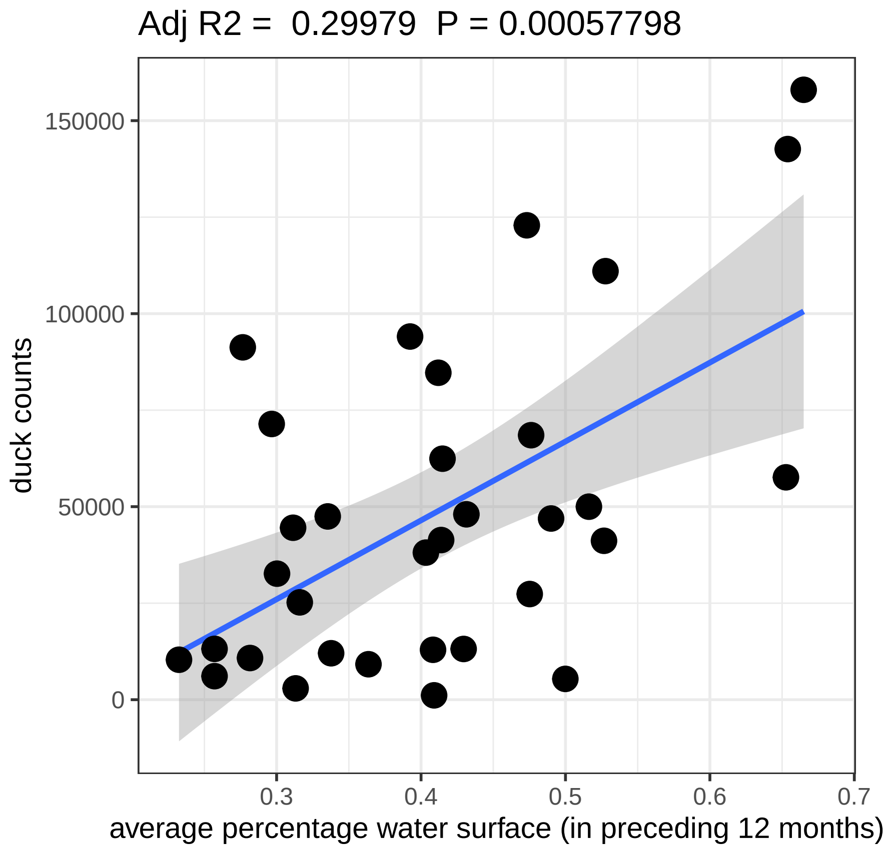

Adj R2 = 0.22243 P = 0.0032778
150000
100000
50000
0
duck counts
0.6
0.8
1.0
1.2
average percentage water surface (in preceding 12 months)

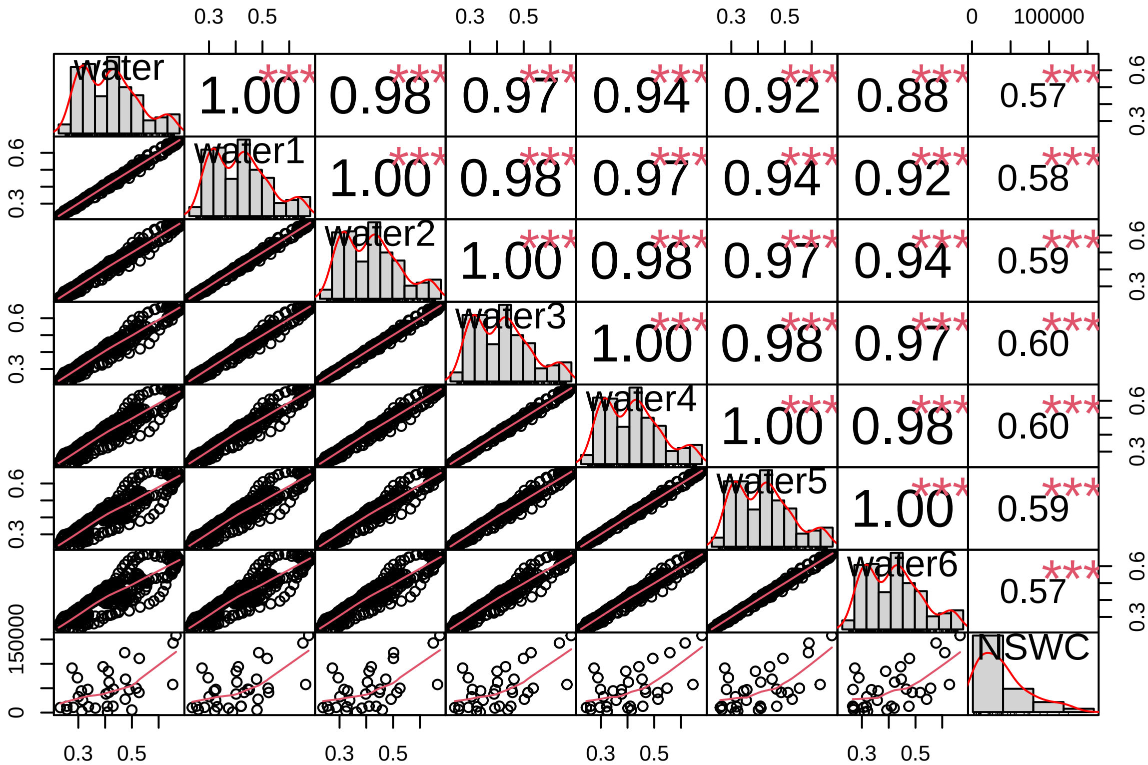

water
water1
water2
water3
water4
water5
water6
NSWC
0.99
0.98
0.97
0.95
0.94
0.92
0.50
0.48
0.49
0.51
0.53


```
##
##
##  MDB
##
```

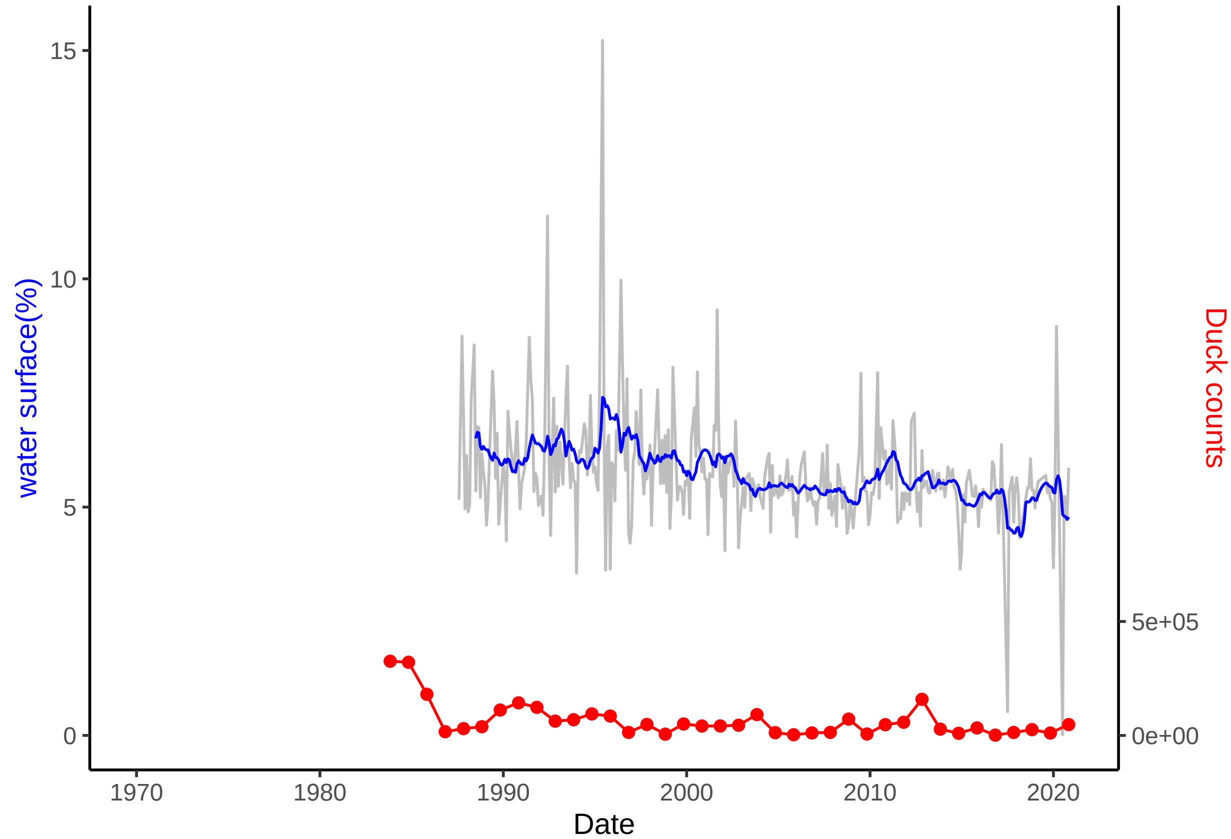


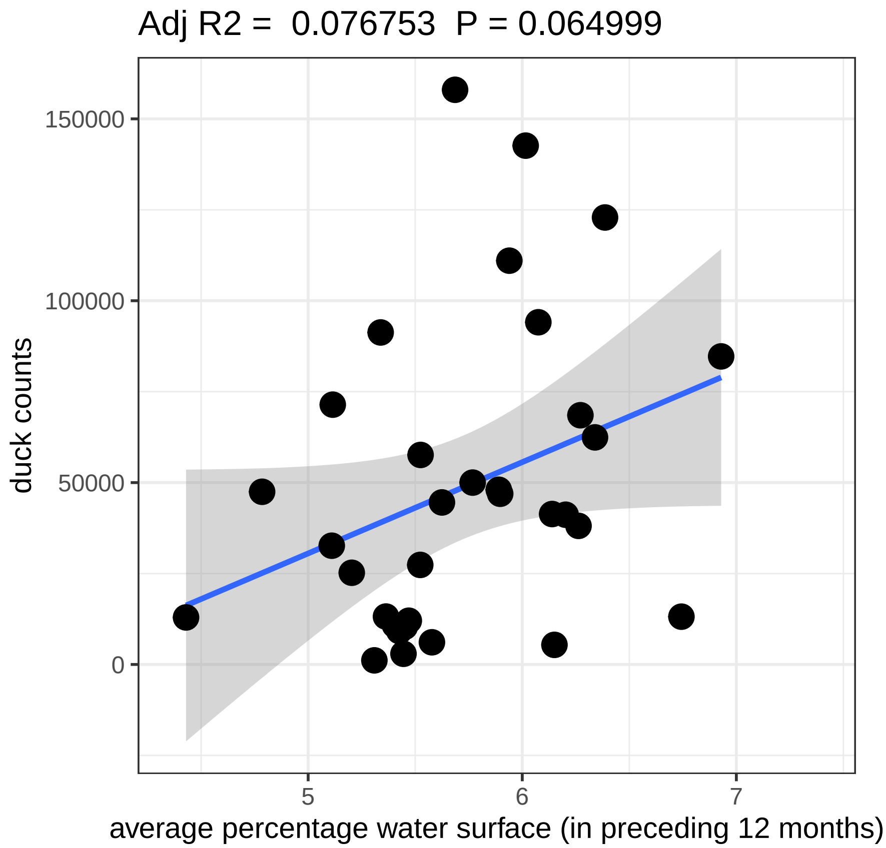
water surface(%)
Duck counts
Date
1.5
1.0
0.5
0.0
0
1970
1980
1990
2000
2010
2020

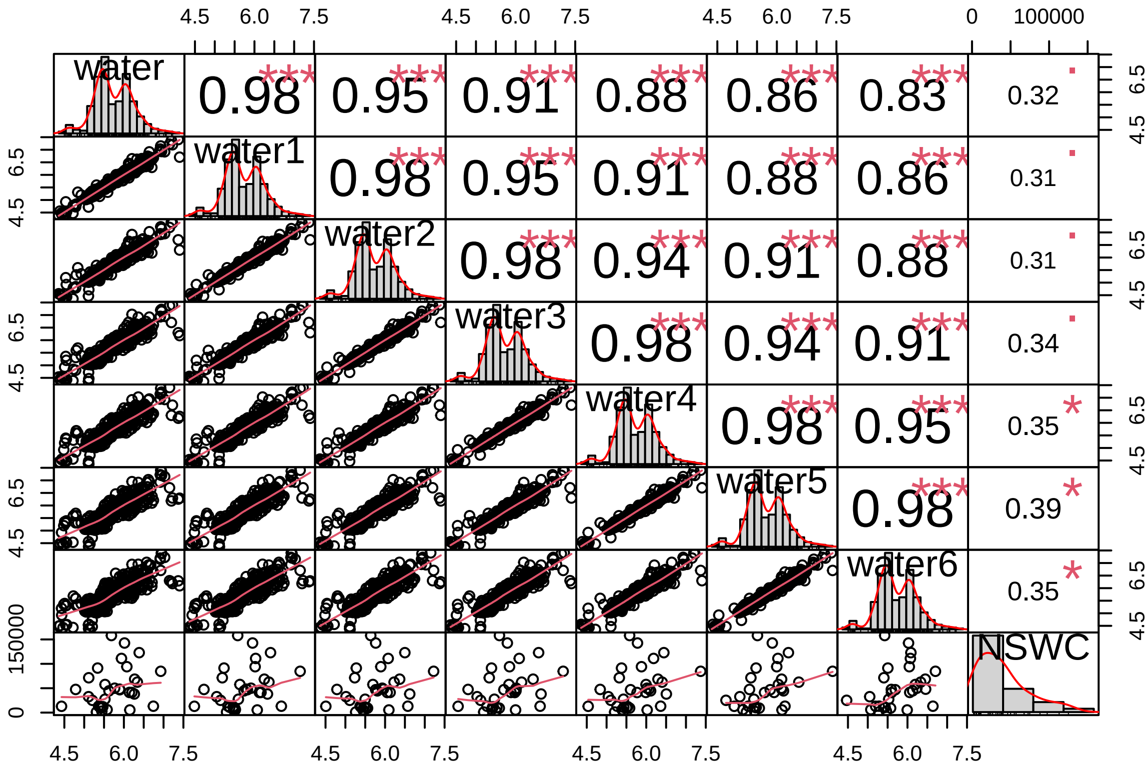

Adj R2 = 0.29979 P = 0.00057798
150000
100000
50000
0
duck counts
0.3
0.4
0.5
0.6
0.7
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
NSWC
1.00
0.98
0.97
0.94
0.92
0.88
0.57
0.58
0.59
0.60
***
0.3
0.5
0.6
0
100000
150000

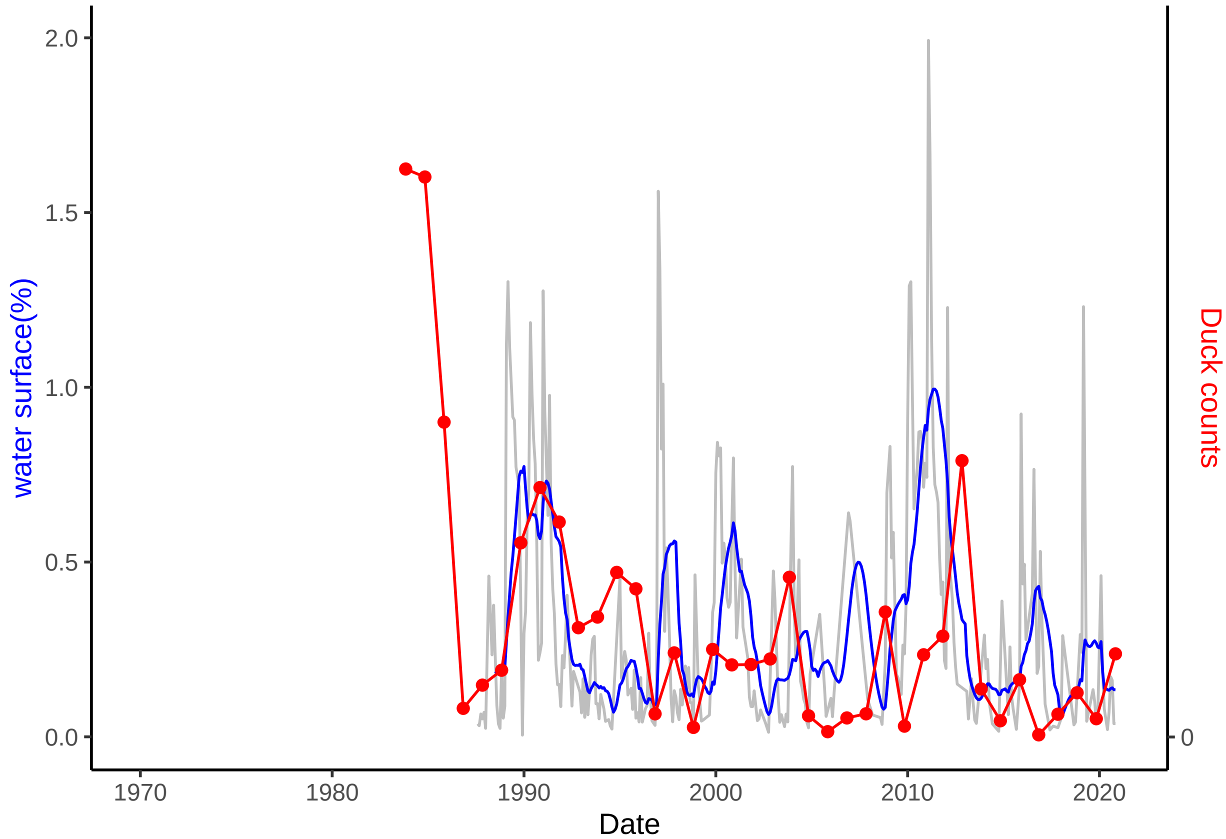
```
##
##
## SEDB
##
```

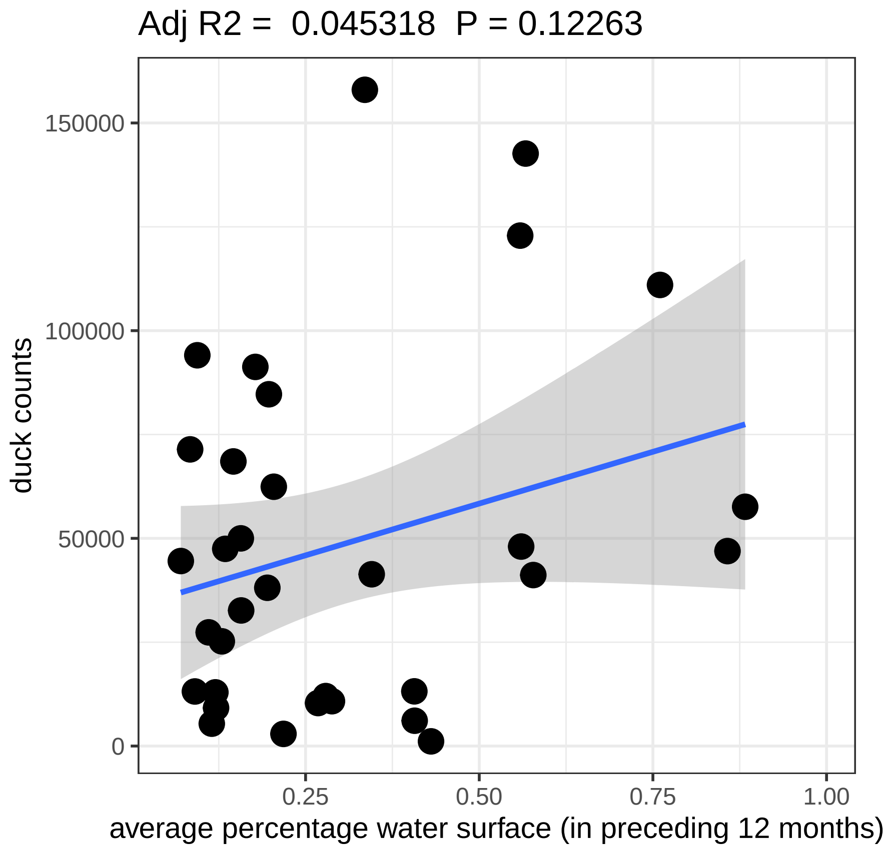

water surface(%)
Duck counts
Date
15
10
5
0
5e+05
0e+00
1970
1980
1990
2000
2010
2020


Adj R2 = 0.076753 P = 0.064999
150000
100000
50000
0
duck counts
5
6
7
average percentage water surface (in preceding 12 months)

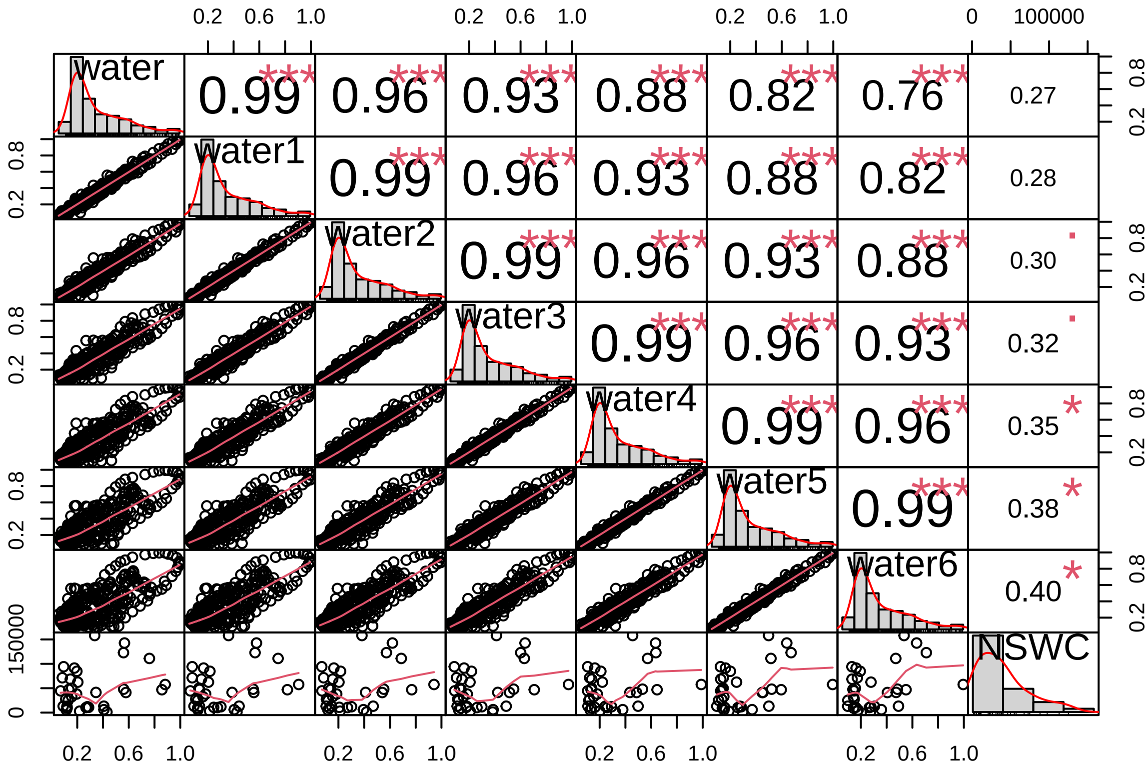

water
water1
water2
water3
water4
water5
water6
NSWC
0.98
0.95
0.91
0.88
0.86
0.83
0.32
0.31
0.34
0.94
0.35
0.39
***
4.5
6.0
7.5
6.5
0
100000
150000

```
##
##
##  LEB
##
```

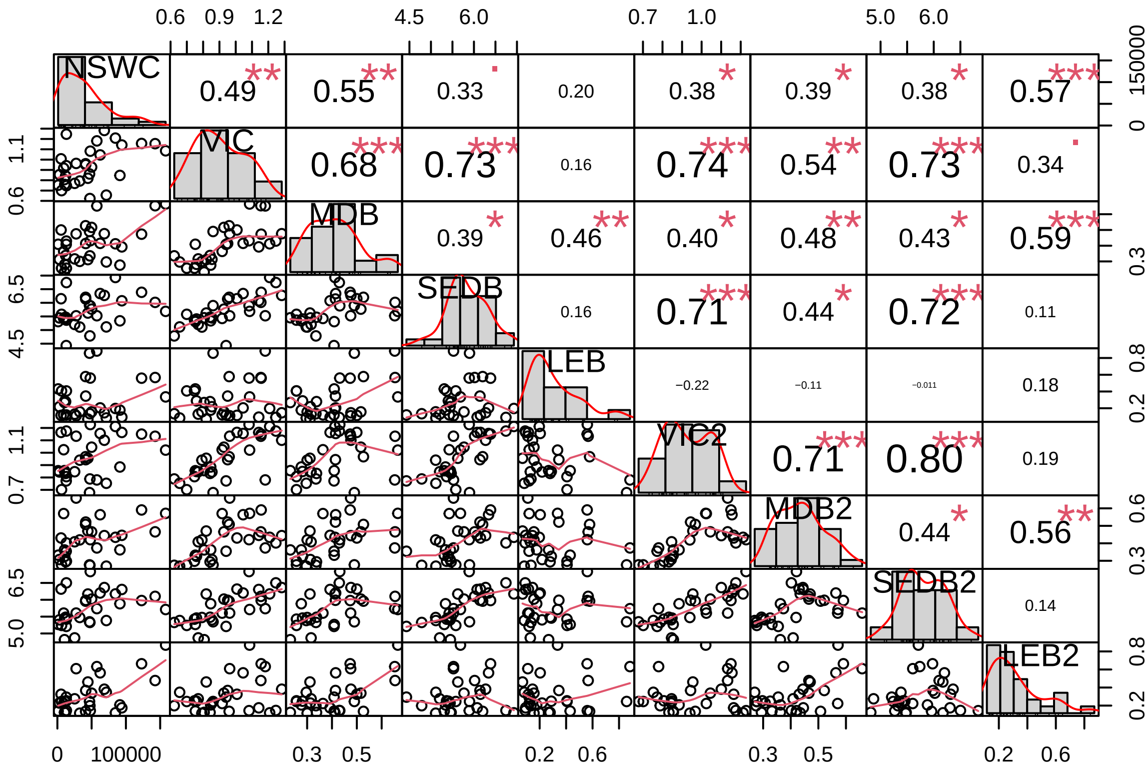

2.0
1.5
1.0
0.5
0.0
water surface(%)
Duck counts
0
1970
1980
1990
2000
2010
2020
Date



Adj R2 = 0.045318 P = 0.12263
150000
100000
50000
0
duck counts
0.25
0.50
0.75
1.00
average percentage water surface (in preceding 12 months)


water
water1
water2
water3
water4
water5
water6
NSWC
0.99
0.96
0.93
0.88
0.82
0.76
0.27
0.28
0.30
0.32
0.35
0.38
0.40

8.1 Predictive models



(Intercept)	LEB	LEB2	MDB	MDB2	SEDB	SEDB2	VIC	VIC2	adjR^2	df	delta	weight	AllSignif
-54758	NA	99745	NA	NA	NA	NA	75224	NA	0.4211	4	0.0000	0.079706	TRUE
-138407	NA	115070	NA	NA	NA	26000	NA	NA	0.4158	4	0.2811	0.069255	TRUE
-56469	NA	112609	NA	NA	NA	NA	NA	71103	0.4029	4	0.9559	0.049423	FALSE
-107869	NA	117850	NA	NA	20717	NA	NA	NA	0.3986	4	1.1805	0.044172	FALSE
-25305	NA	82483	114222	NA	NA	NA	NA	NA	0.3930	4	1.4680	0.038258	FALSE
-124805	NA	91736	69721	NA	NA	19963	NA	NA	0.4363	5	2.0335	0.028835	FALSE
8172	NA	124173	NA	NA	NA	NA	NA	NA	0.3247	3	2.1233	0.027569	TRUE
-62266	NA	143344	NA	-124869	NA	NA	NA	121260	0.4340	5	2.1626	0.027032	FALSE
-75473	34766	103452	NA	NA	NA	NA	NA	83257	0.4338	5	2.1743	0.026876	FALSE
-108994	NA	104150	NA	NA	NA	13849	46729	NA	0.4331	5	2.2114	0.026381	FALSE
-64547	NA	86048	80354	NA	NA	NA	NA	54083	0.4322	5	2.2568	0.025789	FALSE
-54816	NA	87728	47744	NA	NA	NA	58567	NA	0.4283	5	2.4732	0.023144	FALSE
-144970	20444	110730	NA	NA	NA	26334	NA	NA	0.4272	5	2.5299	0.022497	FALSE
-63912	NA	101598	NA	NA	NA	NA	55288	28413	0.4268	5	2.5535	0.022234	FALSE
-99323	NA	90862	78657	NA	15075	NA	NA	NA	0.4255	5	2.6232	0.021471	FALSE
-56049	11799	97855	NA	NA	NA	NA	73540	NA	0.4248	5	2.6593	0.021088	FALSE
-80010	NA	102975	NA	NA	6972	NA	58726	NA	0.4248	5	2.6609	0.021071	FALSE
-51181	NA	106463	NA	-28385	NA	NA	81764	NA	0.4239	5	2.7066	0.020595	FALSE
-147559	NA	114874	NA	NA	8744	18936	NA	NA	0.4222	5	2.7991	0.019664	FALSE
-121679	NA	113242	NA	NA	NA	18678	NA	27001	0.4198	5	2.9265	0.018451	FALSE
-141974	NA	122282	NA	-25487	NA	28074	NA	NA	0.4181	5	3.0185	0.017621	FALSE
-95732	NA	113476	NA	NA	11323	NA	NA	44524	0.4141	5	3.2334	0.015826	FALSE
-31647	NA	NA	193077	NA	NA	NA	NA	NA	0.2997	3	3.2496	0.015698	TRUE
-79130	31763	132343	NA	-114162	NA	NA	NA	128064	0.4595	6	3.8337	0.011722	FALSE
-106890	11196	115730	NA	NA	20085	NA	NA	NA	0.4020	5	3.8681	0.011522	FALSE
-69317	NA	116607	74259	-115967	NA	NA	NA	101956	0.4588	6	3.8693	0.011515	FALSE
-109697	NA	123482	NA	-19489	22152	NA	NA	NA	0.3999	5	3.9724	0.010937	FALSE
-29564	NA	78589	110827	16481	NA	NA	NA	NA	0.3941	5	4.2703	0.009423	FALSE
-25665	-5046	81639	119390	NA	NA	NA	NA	NA	0.3935	5	4.3010	0.009280	FALSE

3981	18323	120389	NA	NA	NA	NA	NA	NA	0.3339	4	4.3478	0.009065	FALSE
-5568	NA	110747	NA	43106	NA	NA	NA	NA	0.3330	4	4.3877	0.008886	FALSE
-66948	NA	NA	165868	NA	NA	NA	NA	48314	0.3312	4	4.4738	0.008512	FALSE
-67223	NA	129994	NA	-105761	NA	NA	43416	80063	0.4479	6	4.4872	0.008455	FALSE
-105658	NA	NA	166745	NA	NA	14743	NA	NA	0.3240	4	4.8055	0.007211	FALSE
-56270	NA	NA	142489	NA	NA	NA	48205	NA	0.3239	4	4.8109	0.007191	FALSE
-110805	NA	91641	50261	NA	NA	14295	28275	NA	0.4410	6	4.8723	0.006974	FALSE
-47764	NA	NA	164105	67088	NA	NA	NA	NA	0.3224	4	4.8803	0.006946	FALSE
-92260	NA	141944	NA	-116456	8763	NA	NA	97313	0.4405	6	4.9027	0.006869	FALSE
-75240	26186	99117	NA	NA	NA	NA	33116	54687	0.4404	6	4.9063	0.006856	FALSE
-73598	22486	90780	48123	NA	NA	NA	NA	68771	0.4404	6	4.9070	0.006854	FALSE
-115310	29710	105197	NA	NA	NA	12203	NA	52678	0.4403	6	4.9126	0.006835	FALSE
-109088	NA	90234	69031	NA	NA	13084	NA	25588	0.4400	6	4.9325	0.006767	FALSE
-132463	NA	93091	65239	NA	6480	15116	NA	NA	0.4398	6	4.9431	0.006732	FALSE
-117939	15978	102175	NA	NA	NA	15686	40667	NA	0.4398	6	4.9432	0.006731	FALSE
-128559	NA	99377	70575	-28012	NA	22168	NA	NA	0.4391	6	4.9781	0.006615	FALSE
-111241	NA	114476	NA	-41087	NA	15744	52294	NA	0.4389	6	4.9913	0.006571	FALSE
-98476	NA	138821	NA	-105031	NA	10636	NA	88180	0.4387	6	5.0041	0.006529	FALSE
-129761	8582	93690	58440	NA	NA	21080	NA	NA	0.4378	6	5.0522	0.006374	FALSE
-66321	NA	87524	57796	NA	NA	NA	30030	35674	0.4370	6	5.0976	0.006231	FALSE
-89536	NA	89134	72739	NA	7428	NA	NA	38261	0.4368	6	5.1084	0.006198	FALSE
-83025	NA	NA	174117	NA	10374	NA	NA	NA	0.3156	4	5.1895	0.005951	FALSE
-84571	32089	104391	NA	NA	3046	NA	NA	75171	0.4344	6	5.2401	0.005803	FALSE
-114328	NA	105034	NA	NA	2667	12744	42690	NA	0.4335	6	5.2857	0.005672	FALSE
-105817	NA	104184	NA	NA	NA	12422	44418	7476	0.4333	6	5.2967	0.005641	FALSE
-84278	NA	90388	52143	NA	8133	NA	37788	NA	0.4333	6	5.2998	0.005632	FALSE
-51702	NA	94144	45472	-24694	NA	NA	65049	NA	0.4304	6	5.4554	0.005210	FALSE
-150728	17789	111153	NA	NA	6314	21190	NA	NA	0.4304	6	5.4582	0.005203	FALSE
-81254	NA	112365	NA	-36522	8586	NA	63321	NA	0.4294	6	5.5131	0.005062	FALSE
-55358	5029	88730	40564	NA	NA	NA	60354	NA	0.4288	6	5.5450	0.004982	FALSE
-78675	NA	103363	NA	NA	4534	NA	48171	23266	0.4282	6	5.5781	0.004900	FALSE
-79166	10858	100976	NA	NA	6411	NA	58504	NA	0.4280	6	5.5899	0.004871	FALSE
-146181	19358	114113	NA	-11139	NA	27223	NA	NA	0.4276	6	5.6075	0.004829	FALSE
-101407	NA	97276	79559	-23264	16724	NA	NA	NA	0.4274	6	5.6195	0.004800	FALSE
-154410	NA	125179	NA	-36546	10402	20570	NA	NA	0.4268	6	5.6529	0.004720	FALSE
-53321	9343	102866	NA	-19509	NA	NA	78385	NA	0.4260	6	5.6945	0.004623	FALSE
-99235	-3038	90319	81915	NA	15013	NA	NA	NA	0.4257	6	5.7124	0.004582	FALSE
-32435	-13452	NA	204704	NA	NA	NA	NA	NA	0.3037	4	5.7202	0.004564	FALSE
-134814	NA	113681	NA	NA	7281	15209	NA	18102	0.4239	6	5.8107	0.004362	FALSE
-56846	NA	NA	NA	NA	NA	NA	110657	NA	0.2357	3	5.9603	0.004048	TRUE
-16082	24405	100890	NA	58574	NA	NA	NA	NA	0.3483	5	6.5327	0.003040	FALSE
-77308	20196	119971	45487	-112608	NA	NA	NA	113761	0.4654	7	6.8600	0.002581	FALSE
-107895	9931	118727	NA	-9540	20859	NA	NA	NA	0.4022	6	6.9535	0.002463	FALSE

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	-80031	60600	62237	1.286	0.1985
LEB2	106285	35259	36699	2.896	0.0038
VIC	75224	34845	36417	2.066	0.0389
SEDB2	26000	12443	13005	1.999	0.0456
VIC2	71103	37121	38796	1.833	0.0668
SEDB	20717	11169	11673	1.775	0.0760
MDB	114222	64357	67261	1.698	0.0895

```
##                       LEB2 VIC  SEDB2 VIC2 SEDB MDB
## Sum of weights:       1.00 0.28 0.25  0.18 0.16 0.14
## N containing models:     5    1    1     1    1    1
```

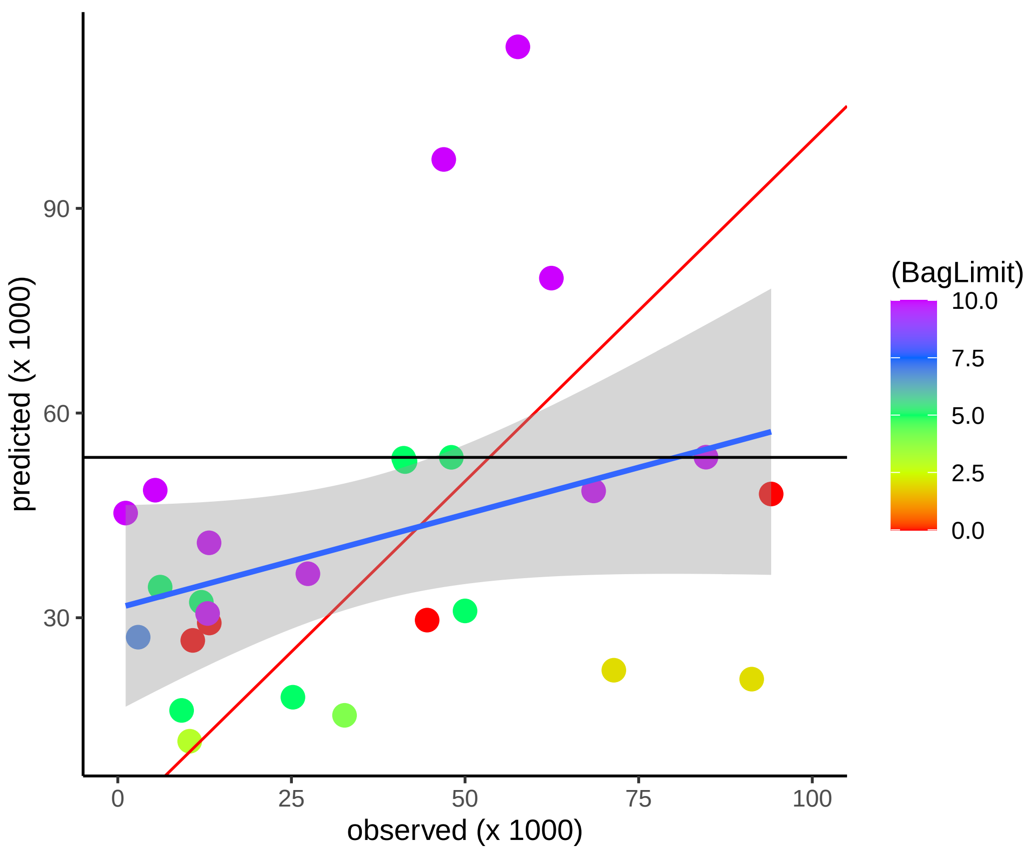
The above results are based on 31 cases.

8.2 Predicted versus observed

```
##
```

```
##    The preferred model selected: 1 with a threshold number of 53500
##
##
##


##
## Call:
## lm(formula = NSWC ~ LEB2 + VIC + 1, data = Jc)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -51060 -16971  -8347  20358  62916
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   -54758      31303   -1.75   0.0912 .
## LEB2           99745      33315    2.99   0.0057 **
## VIC            75224      34845    2.16   0.0396 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 32700 on 28 degrees of freedom
## Multiple R-squared:  0.421,  Adjusted R-squared:  0.38
## F-statistic: 10.2 on 2 and 28 DF,  p-value: 0.000475
```



9 Summary of predictive models

Generally, there are very good fits between the four proxies for duck numbers and water in the landscape in the preceding 12 months, notably so for the percentage of water surface area in Victoria and across the entire MDB. Modest time shifts of up to 6 months (i.e. using average water surface areas calculated from 0-12 months prior to the estimate of the dependant variable up to 6-18 months prior) did not generally impact the fits, somewhat supporting an approach where decision-making on annual duck hunting arrangements is made based on environmental indicators a few months prior to the actual hunting season.

When conducting more sophisticated model analyses using 3 years of surface water availability across all 4 geographic areas, the following preferred models were selected (with adjR^2 in brackets):

BagSize ~ MDB + 1 (0.230) (section 3)

Game ~ MDB2 + VIC + 1 (0.366) (section 4)

PGame ~ VIC + 1 (0.198) (section 6) (Game counts limited to frequently counted wetlands across years)

VicC ~ LEB2 + VIC + 1 (0.530) (section 6)

NSWC ~ LEB2 + VIC + 1 (0.380) (section 7)

For bag size, although measured during opening weekend in Victoria, it may be somewhat surprising that the preferred model contains water availability over the previous year in MDB rather than Victoria. However, it should be considered that water surface area in the MDB is highly correlated with water surface area in Victoria ($r = 0.65$, $n=25$, $P< 0.01$). Moreover, the number of ducks in Victoria and thus the ease of shooting them, is not only dependent on conditions in Victoria itself, but also further afield. That notion is also supported by how game counts in Victoria relate to water availability over the previous year in Victoria and the two years preceding that in the MDB, which at the same time stresses the longer-term positive effects of water in the landscape on duck numbers. The aerial counts for Victoria and NSW likewise support that notion, although there it appears that notably the water availability in the landscape across the Lake Eyre basin, 2-3 years prior to the counts, appears influential on duck numbers. Yet, also here it should be borne in mind that correlations between LEB2 and MDB2 ($r = 0.61$, $n=30$, $P< 0.01$) and VIC and MDB ($r = 0.69$, $n=30$, $P< 0.01$) are high.

10 From predictive models to duck population indices

10.1 Calculation of the indices

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

In doing so, we opted not to use BagSize predictions from water surface area (section 3) as an index of duck numbers since BagSize was biased by hunting bag limits. Using linear modelling across hunting bag data from unrestricted seasons only, dramatically reduced sample size (n=13) and yielded no meaningful insights (i.e. insignificant relationships only).

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 years predominantly, but not always, had bag limits imposed; see figures in sections 4.2, 5.2, 6.2 and 7.2). These threshold values were 242000, 64000, 56000 and 53000, respectively.

These threshold values were used to calculate five duck population indices:

iGame: index of game counts using the predictive model from section 4.2 divided by the game count threshold

iPGame: index of game counts limited to some priority wetlands using the predictive model from section 5.2 divided by the game count threshold

iVicC: index of aerial survey for Victoria using the predictive model from section 6.2 divided by the threshold for these counts

iNSWC: index of aerial survey for NSW using the predictive model from section 7.2 divided by the threshold for these counts

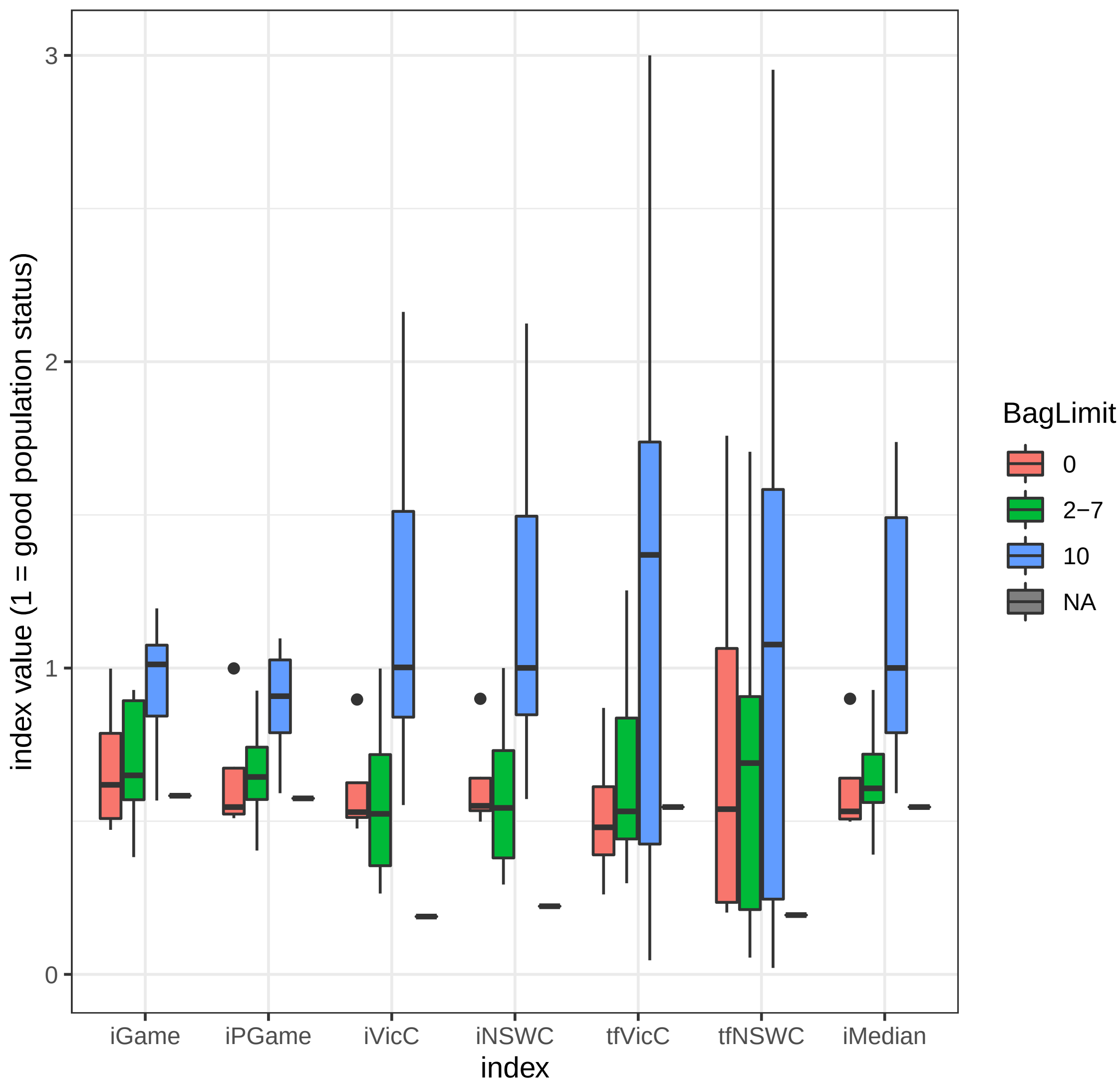
tfVicC: index of aerial survey for Victoria using actual counts divided by the threshold for these counts

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

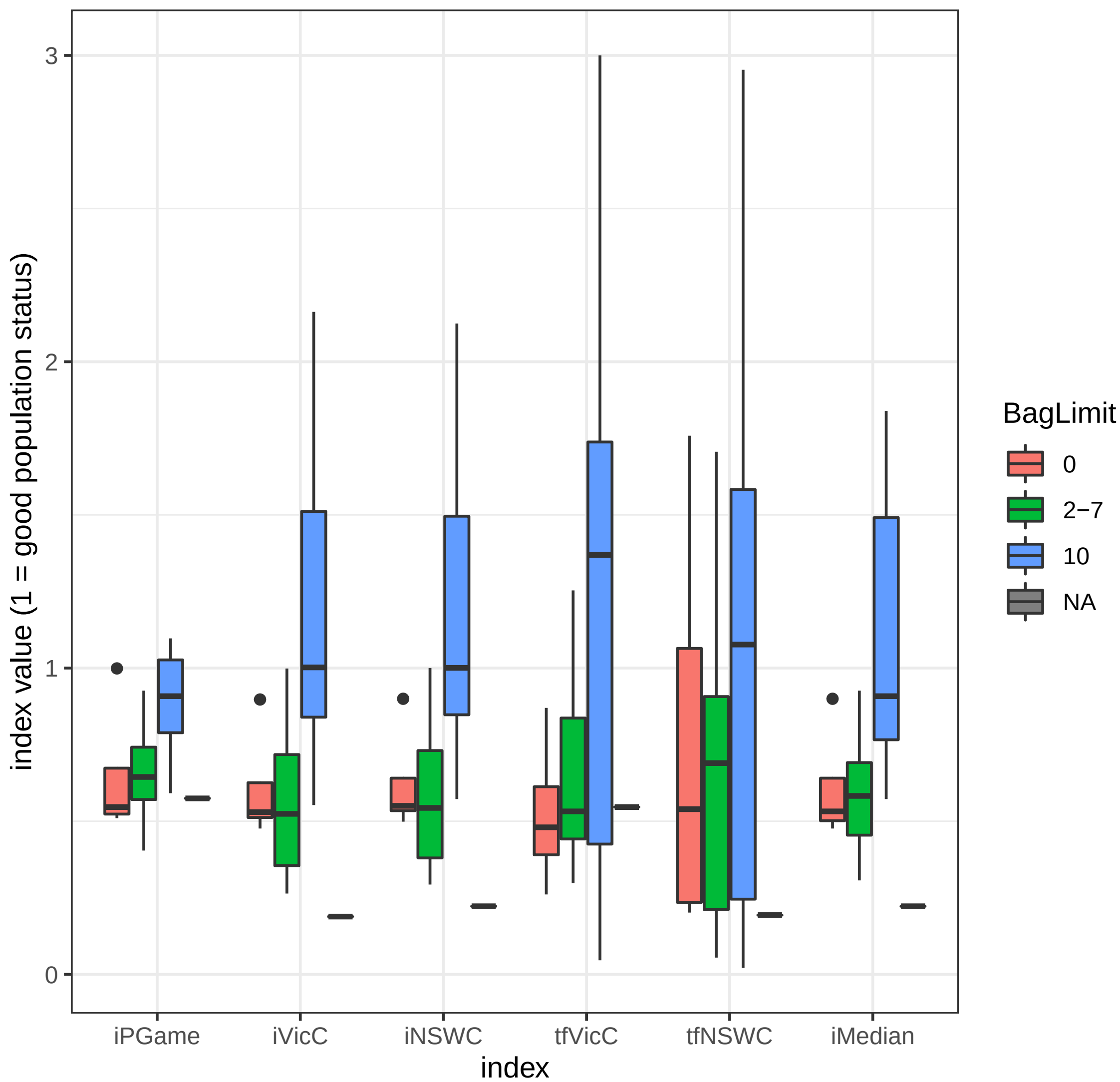
Index values higher than 1 indicate a good to excellent population status of ducks, while values lower than 1 indicate a poor to good population status.

11 Past performance of the indices

Below boxplots (depicting minimum, 25 percentile, median, 75 percentile and maximum) are presented for the six duck-population indices as well as their median for unrestricted hunting seasons (bag limit = 10, blue) cancelled hunting season (bag limit = 0, pink) and hunting seasons with restrictions (bag limit = 2-7, green; values are not considering opening weekend and species-specific regulations).



The same but now without iGame:



In the table below the six post-dicted duck population indices for the years 1991-2020 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 based on all duck population indices except for **iGame** in each year.

As can be seen from the table, **iGame** and **iPGame** are highly correlated 0.8794. Given that **iPGame** is supposedly less biased than **iGame**, we give preference to the use of the former over the latter in our calculation of the duck-population valuation.

same table but without iGame

		using water surface				using aerial counts		
Year	BagLimit	iGame	iPGame	iVicC	iNSWC	tfVicC	tfNSWC	aPS
2007	0	0.52	0.53	0.48	0.50	0.43	0.20	1
2008	0	0.47	0.51	0.52	0.55	0.26	0.25	3
2003	0	0.72	0.56	0.53	0.55	0.53	0.83	5
1995	0	1.00	1.00	0.90	0.90	0.87	1.76	7
2009	2	0.38	0.40	0.39	0.42	0.30	1.34	2
2004	2	0.64	0.67	0.37	0.39	0.76	1.71	4
2020	3	0.58	0.57	0.19	0.22	0.55	0.19	2
2016	4	0.66	0.59	0.26	0.29	0.40	0.61	2
2019	5	0.63	0.52	0.32	0.34	0.86	0.47	2
2005	5	0.56	0.64	0.59	0.60	0.46	0.22	3
2015	5	0.89	0.65	0.28	0.31	0.93	0.17	3
2010	5	0.43	0.47	0.63	0.64	1.25	0.11	4
2000	5	0.84	0.74	0.56	0.58	0.32	0.93	5
2001	5	0.93	0.77	1.00	1.00	0.50	0.77	6
2002	5	0.92	0.76	0.98	0.99	0.56	0.77	7
1998	5	0.92	0.93	1.00	1.00	0.51	0.90	8
2006	7	0.57	0.62	0.49	0.51	0.83	0.05	3
2017	10	0.57	0.59	0.84	0.85	0.05	0.02	3
2018	10	0.73	0.73	0.55	0.57	1.01	0.24	5
1999	10	0.84	0.80	0.90	0.91	0.09	0.10	5
2011	10	0.63	0.78	1.84	1.82	0.35	0.88	6
1997	10	1.00	1.10	0.76	0.77	1.79	0.25	6
2014	10	1.09	0.79	0.67	0.68	0.93	0.51	6
1994	10	1.05	1.09	0.91	0.91	0.43	1.28	8
2012	10	0.95	0.98	2.16	2.12	1.74	1.08	10
1996	10	1.01	1.07	1.00	1.00	1.37	1.58	10
1991	10	1.05	1.03	1.87	1.84	1.66	2.67	10
1993	10	1.07	0.91	1.51	1.49	1.59	1.17	10
2013	10	1.12	0.91	1.48	1.47	3.00	2.95	10
1992	10	1.19	1.01	1.51	1.50	2.45	2.30	10

		using water surface			using aerial counts		
Year	BagLimit	iPGame	iVicC	iNSWC	tfVicC	tfNSWC	aPS
2007	0	0.53	0.48	0.50	0.43	0.20	1
2008	0	0.51	0.52	0.55	0.26	0.25	3
2003	0	0.56	0.53	0.55	0.53	0.83	5
1995	0	1.00	0.90	0.90	0.87	1.76	7
2009	2	0.40	0.39	0.42	0.30	1.34	2
2004	2	0.67	0.37	0.39	0.76	1.71	4
2020	3	0.57	0.19	0.22	0.55	0.19	2
2016	4	0.59	0.26	0.29	0.40	0.61	2
2019	5	0.52	0.32	0.34	0.86	0.47	2
2005	5	0.64	0.59	0.60	0.46	0.22	3
2015	5	0.65	0.28	0.31	0.93	0.17	3
2010	5	0.47	0.63	0.64	1.25	0.11	4
2000	5	0.74	0.56	0.58	0.32	0.93	5
2001	5	0.77	1.00	1.00	0.50	0.77	6
2002	5	0.76	0.98	0.99	0.56	0.77	7
1998	5	0.93	1.00	1.00	0.51	0.90	8
2006	7	0.62	0.49	0.51	0.83	0.05	3
2017	10	0.59	0.84	0.85	0.05	0.02	3
2018	10	0.73	0.55	0.57	1.01	0.24	5
1999	10	0.80	0.90	0.91	0.09	0.10	5
2011	10	0.78	1.84	1.82	0.35	0.88	6
1997	10	1.10	0.76	0.77	1.79	0.25	6
2014	10	0.79	0.67	0.68	0.93	0.51	6
1994	10	1.09	0.91	0.91	0.43	1.28	8
2012	10	0.98	2.16	2.12	1.74	1.08	10
1996	10	1.07	1.00	1.00	1.37	1.58	10
1991	10	1.03	1.87	1.84	1.66	2.67	10
1993	10	0.91	1.51	1.49	1.59	1.17	10
2013	10	0.91	1.48	1.47	3.00	2.95	10
1992	10	1.01	1.51	1.50	2.45	2.30	10

12 From indices to proposed bag limits

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.