Boreal caribou population trend results for Naosap-Reed, Wabowden, The Bog and Charron Lake 2015-2019

Dr. Neil Arnason, University of Manitoba

Dr. Micheline Manseau & Samantha McFarlane, Environment and Climate Change Canada & Trent University

Dr. Paul Wilson, Trent University

Mark-Recapture Analysis of scat data

- Scat samples analyzed using 9 microsatellite loci
- Caribou-specific Zfx/Zfy primers used for sex id.
- Samples clustered into genotypes and encounter history built
- Encounter histories as formatted for MR analysis by program MARK

```
/* JNP Tonquin  2006-13 K=17 Nhist=156 G=Female Male  */

10000100010011000  0 1;    /* PCID= 7 */
10000000000000000  1 0;    /* PCID= 10 */
00000000110000000  0 1;    /* PCID= 100 */
00000101110110011  1 0;    /* PCID= 120 */
```

Encounter history — 2006 07 08 ….

Group counts — 13 F M

Demographic Parameters

Parameter of interest is realised annual growth rate:

$\lambda_i = N_{i+1} / N_i$ **and trends in** λ

Other important demographic parameters are:

N_i = abundance (at survey time in year i)

ϕ_i = (net) survival rate from year i to i+1

f_i = (net) fecundity rate

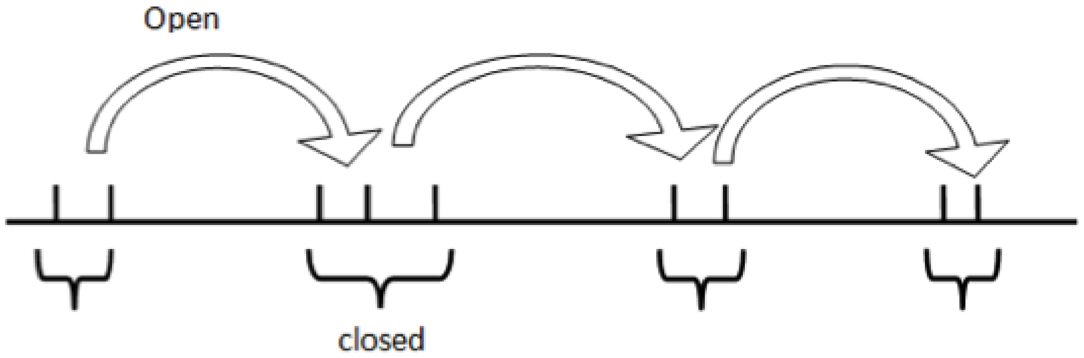
(female calf recruits to N_{i+1} per female in N_i)

Parameter estimates for each sex.

Note that $\lambda_i = \phi_i + f_i$

Robust Design Models (RD)

- Annual (primary) sampling occasions involving multiple within-year surveys (secondary samples)



- Population assumed "open" among years (subject to recruitment and losses)
- Population assumed closed across secondary samples and samples independent
  - Note trade-off: if 2ndary samples too close in time, sighting independence fails; if too far apart, closure fails

RD parameter estimation

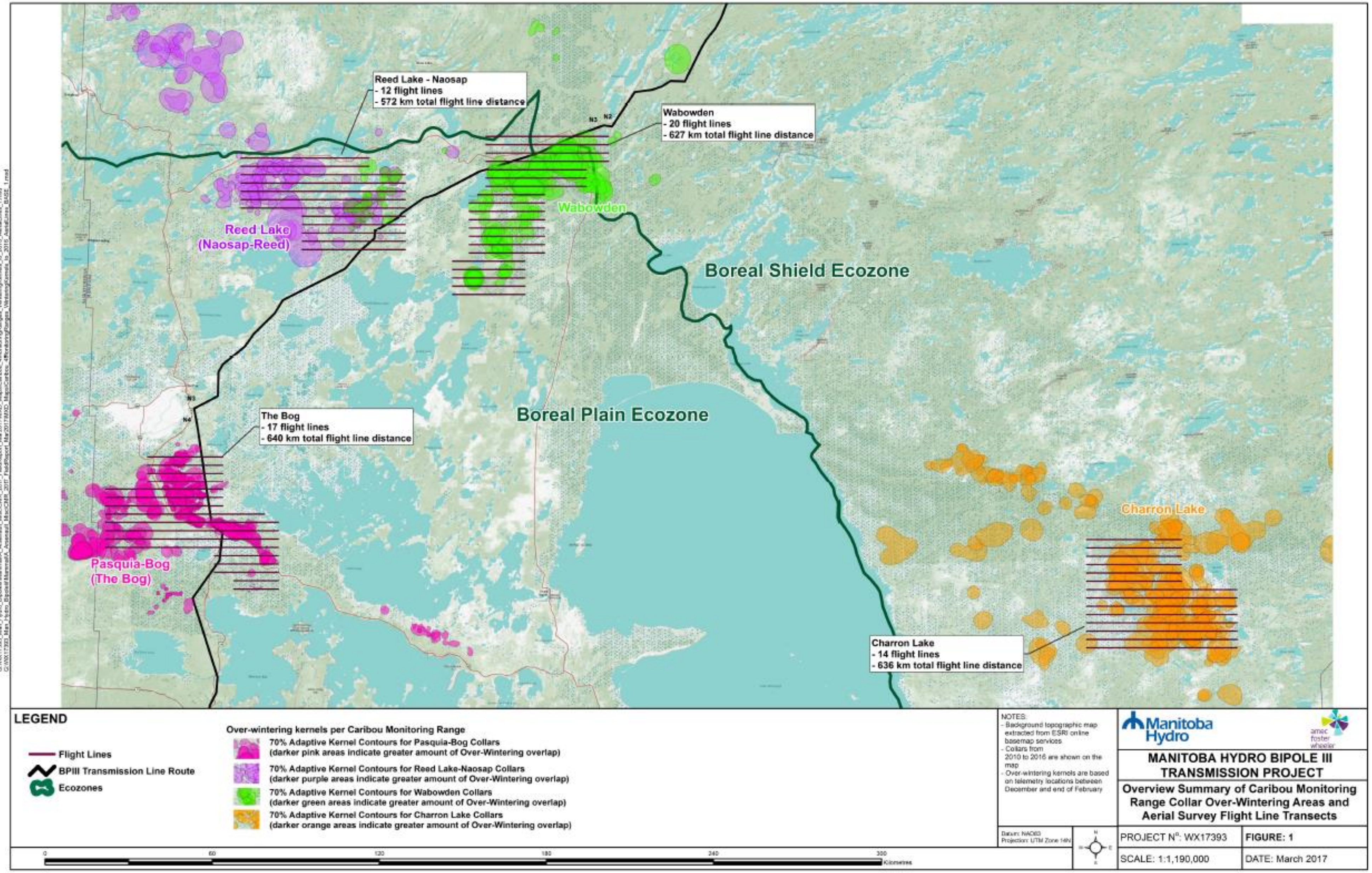
- Requires a minimum of 2 secondary samples per primary
- Pradel models (Pradel 1996, Cooch and White 2015) applied to primary intervals:
  - Provides estimates of λ_i, ϕ_i, f_i
  - All rates are normalized to annual rates by providing deltas (δ_i = t_{i+1} - t_i) in years; Allows for unequal δ_i
- Closed models applied to secondary samples
  - Provides estimates of N_i
  - If only 2 secondaries per primary, model choices are (Otis et al. 1978)

    M_0 , M_t , M_b ("behavioural" model: marked status affects capture rate)
- Capture rate (nuisance parameter p_i) estimated from all data
  - Importance of reducing number of p_i by using constraints and/or covariates.
- CJS models (ignoring RD structure) can be used to model p and ϕ and are used to test closure, judge constraints on p and ϕ

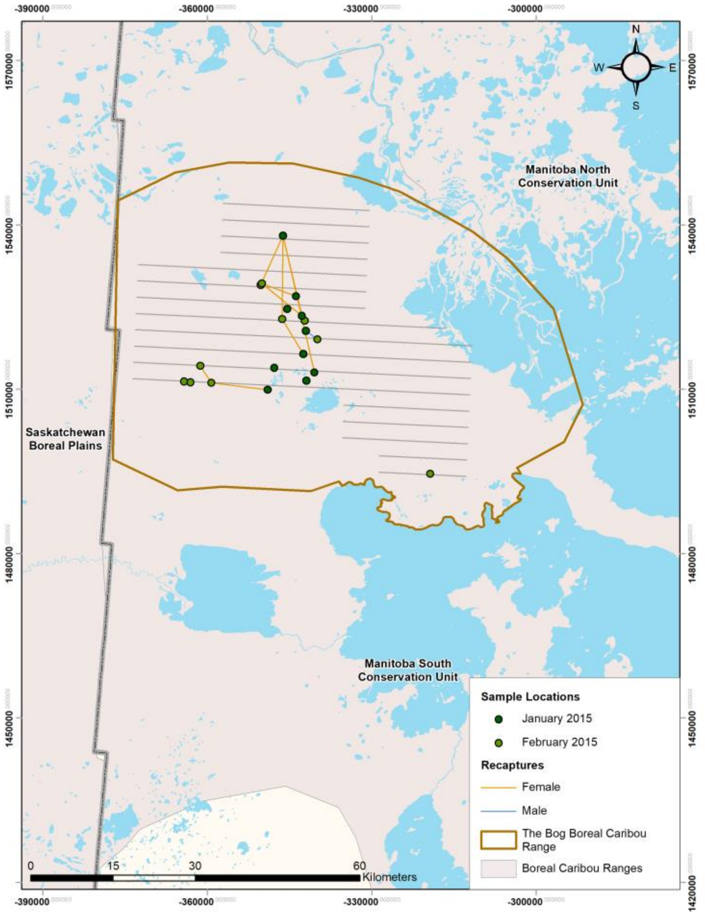
RD analyses in MARK

- Fit and rank systematic battery of models: Pradel primary + Closed (Otis) secondary models.
  - ϕ: $(g \times t)$, (g), (t), $(\cdot)$
  - λ: $(g \times t)$, (g), (t), $(\cdot)$
  - p: $(g \times t)$, (t), $(g \times \text{effort})$
  - c: $(g \times t)$, (t), $\{c=p_2\}$ (no within-year capture effect)
  - F_0: $(g \times t)$ (number of never-sited animals; note that N is a derived parameter)
- Obtain model averaged estimates for N, λ, ϕ. Top models weighted by AICc (a score combining GOF with number of model parameters).
- Fit constrained models with $\lambda(g)$, $\lambda(t)$, *and* $\lambda(\cdot)$ to estimate sex, time, and overall rate of change (these models may not be among highest ranked models but provide best estimates of average λ over these subsets).

Manitoba Hydro CMR scat collection 2015-2019

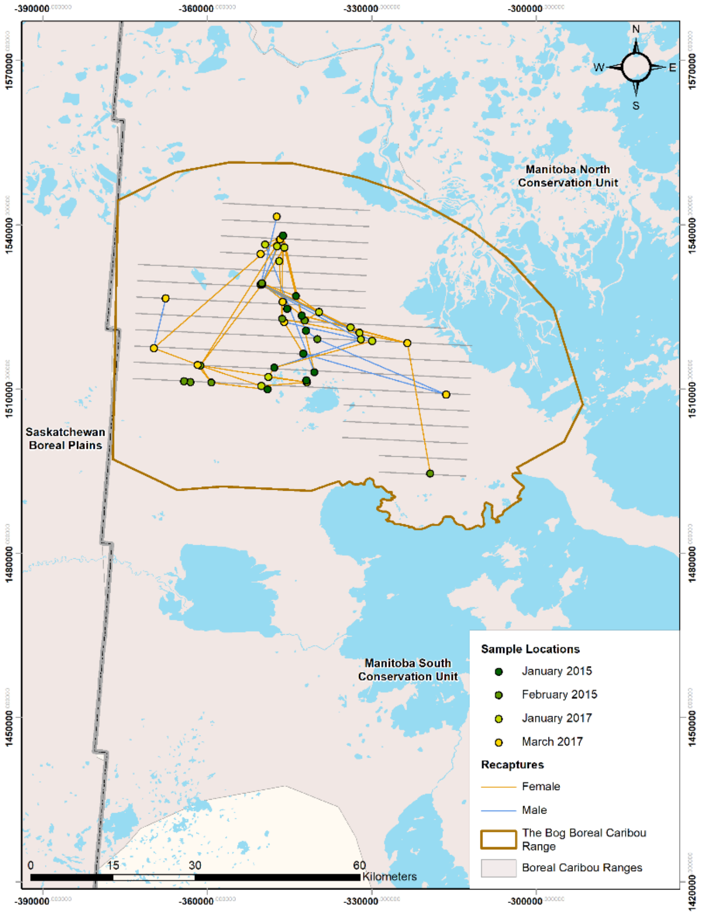


The Bog Scat Collection – 2015, 2017 & 2019



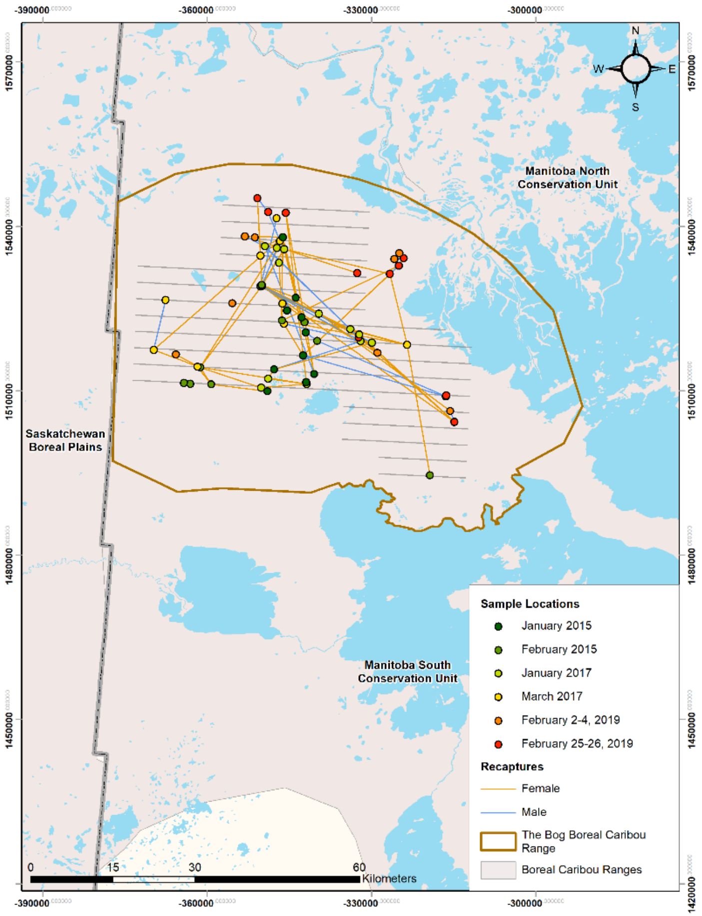
- 183 samples successfully profiled
  - Occasion 1 – 81 samples, Occasion 2 – 102 samples
- 88 unique genotypes – 72 females, 16 males
  - Occasion 1 – 47 genotypes, Occasion 2 – 41 genotypes
- 16/41 (39%) genotypes recaptured between January and February

2015



- 243 samples successfully profiled
  - Occasion 3 – 110 samples, Occasion 4 – 133 samples
- 97 unique genotypes – 62 females, 35 males
  - Occasion 3 – 56 genotypes, Occasion 4 – 41 genotypes
- 10/41 (24%) genotypes recaptured between January and March

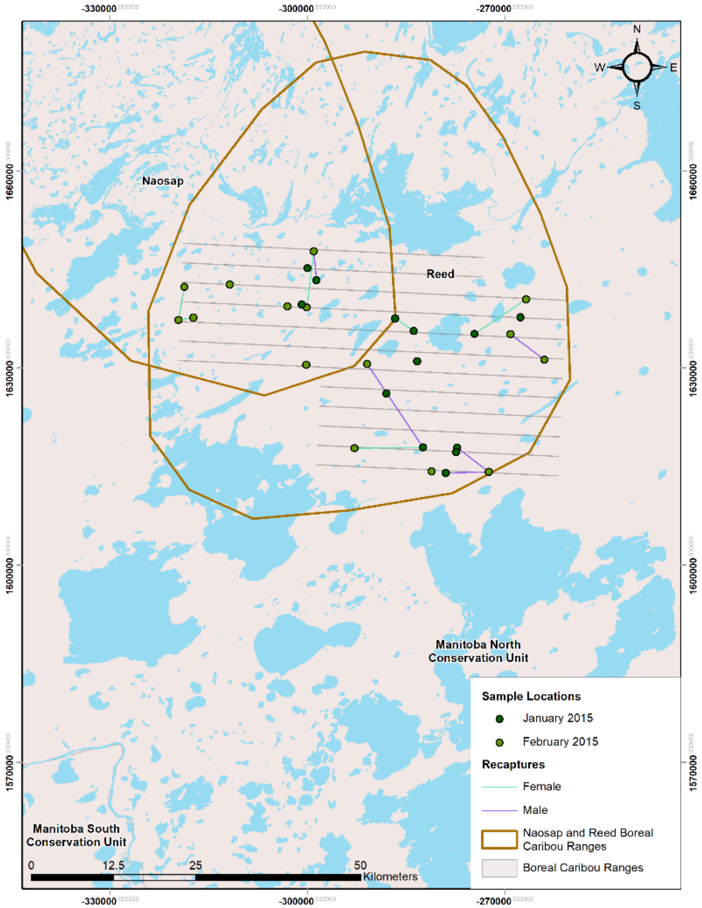
2017



- 203 samples successfully profiled
  - Occasion 5 – 95 samples, Occasion 6 – 108 samples
- 60 unique genotypes – 40 females, 20 males
  - Occasion 5 – 25 genotypes, Occasion 6 – 35 genotypes
- 11/35 (31%) genotypes recaptured between early and late February

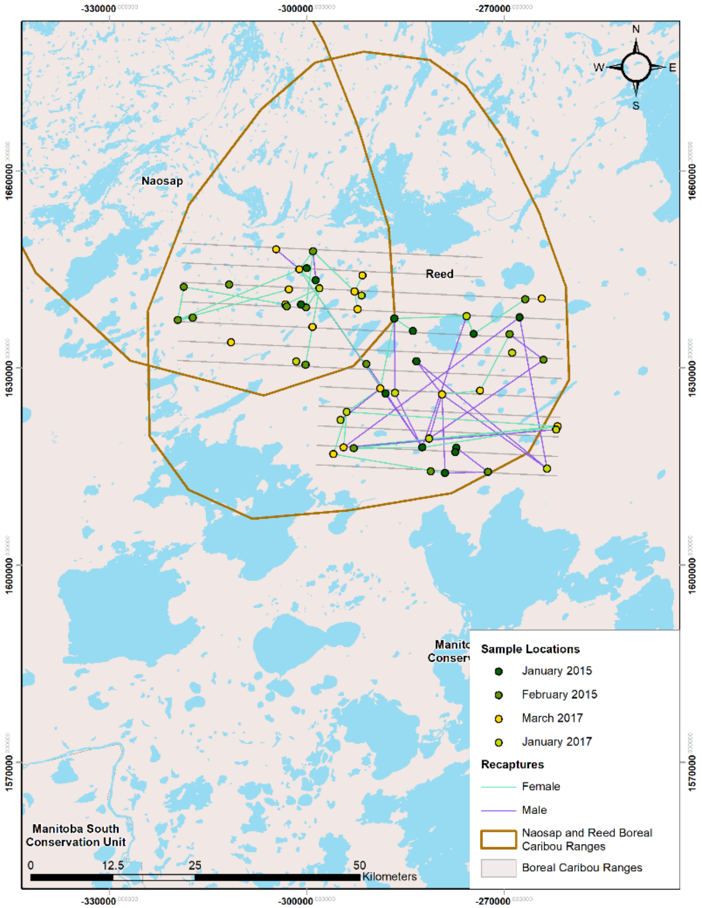
2019

The Naosap-Reed Scat Collection – 2015, 2017 & 2019



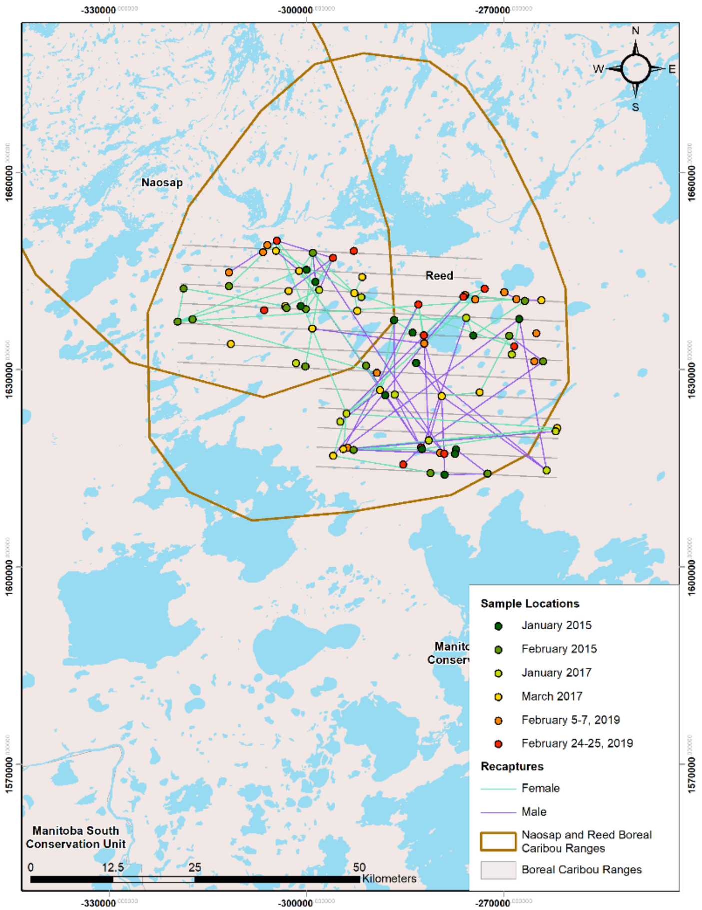
- 225 samples successfully profiled
  - Occasion 1 – 91 samples, Occasion 2 – 134 samples
- 109 unique genotypes – 57 females, 52 males
  - Occasion 1 – 49 genotypes, Occasion 2 – 60 genotypes
- 10/60 (17%) genotypes recaptured between January and February

2015



- 298 samples successfully profiled
  - Occasion 3 – 86 samples, Occasion 4 – 212 samples
- 143 unique genotypes – 82 females, 61 males
  - Occasion 3 – 50 genotypes, Occasion 4 – 93 genotypes
- 13/93 (14%) genotypes recaptured between January and March

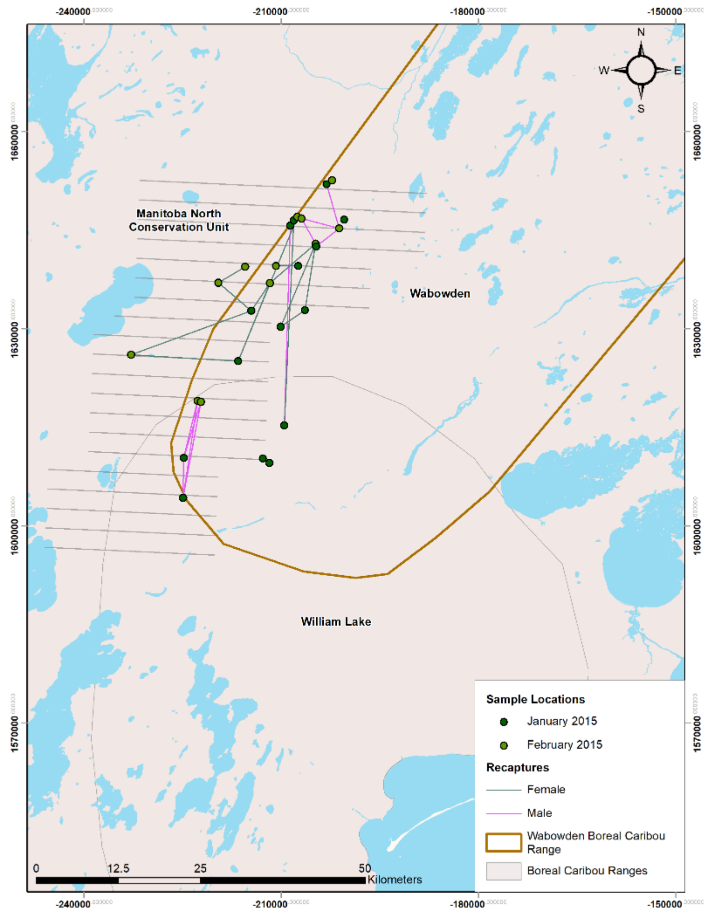
2017



- 225 samples successfully profiled
  - Occasion 5 – 91 samples, Occasion 6 – 134 samples
- 118 unique genotypes – 75 females, 43 males
  - Occasion 5 – 58 genotypes, Occasion 6 – 60 genotypes
- 20/60 (33%) genotypes recaptured between early and late February

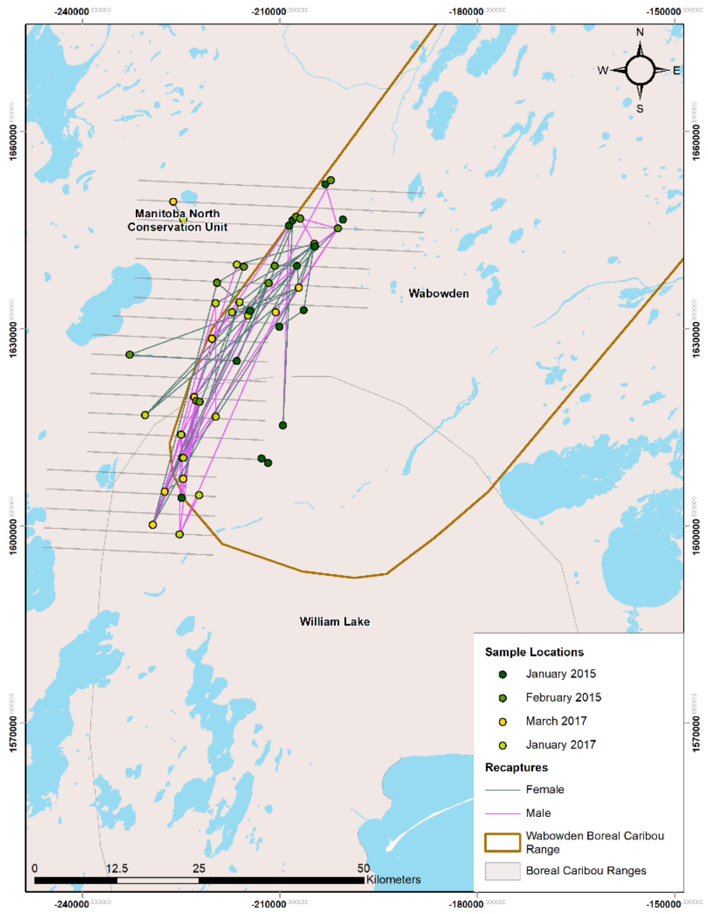
2019

Wabowden Scat Collection – 2015, 2017 & 2019



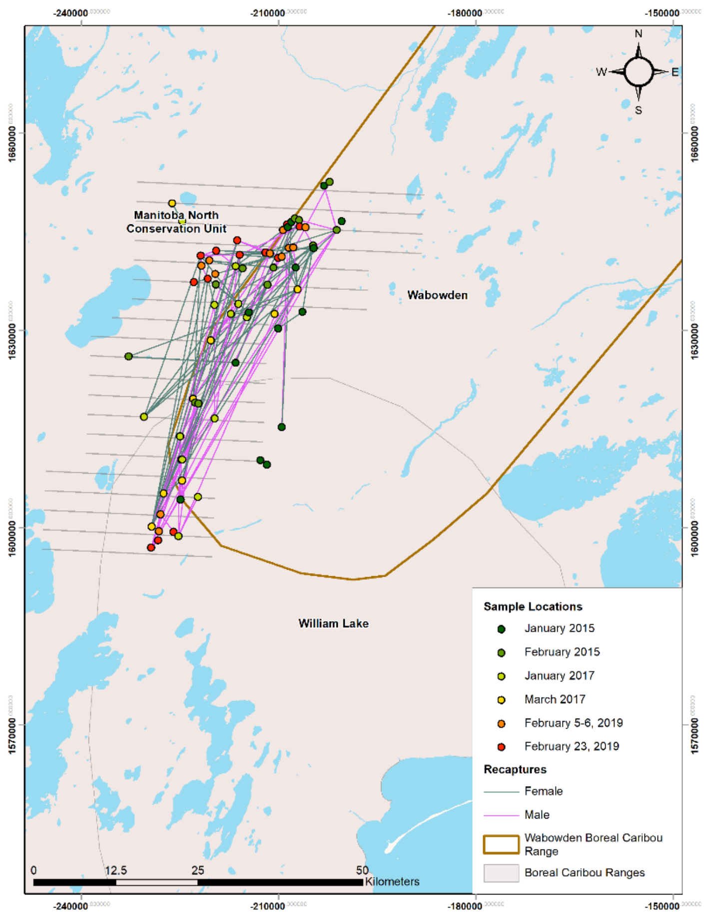
- 208 samples successfully profiled
  - Occasion 1 – 120 samples, Occasion 2 – 88 samples
- 108 unique genotypes – 64 females, 44 males
  - Occasion 1 – 64 genotypes, Occasion 2 – 44 genotypes
- 26/44 (59%) genotypes recaptured between January and February

2015



- 208 samples successfully profiled
  - Occasion 3 – 83 samples, Occasion 4 – 125 samples
- 98 unique genotypes – 55 females, 43 males
  - Occasion 3 – 47 genotypes, Occasion 4 – 51 genotypes
- 15/51 (29%) genotypes recaptured between January and March

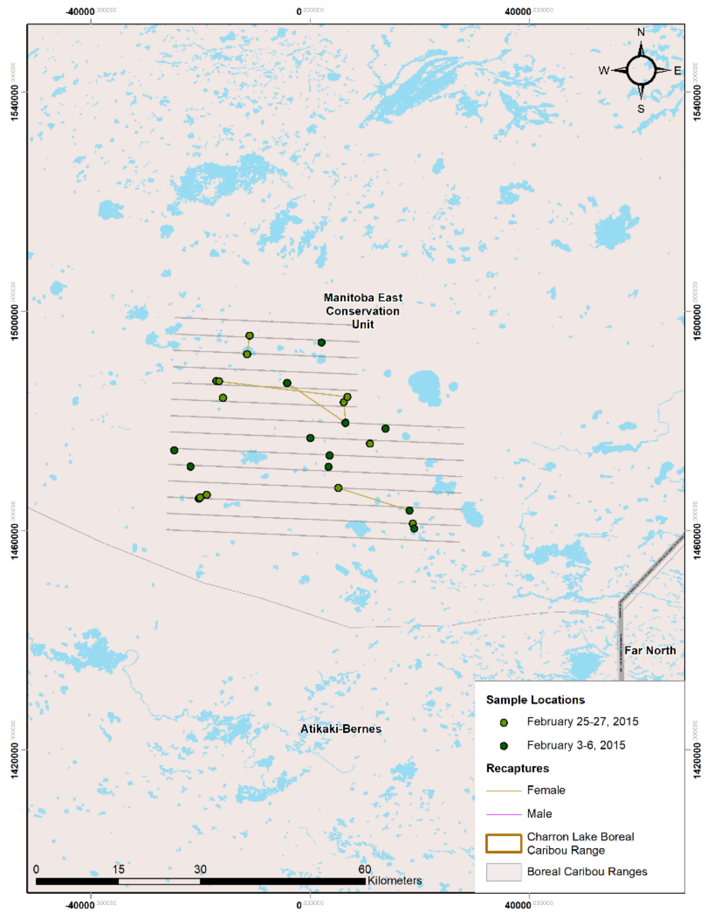
2017



- 230 samples successfully profiled
  - Occasion 5 – 102 samples, Occasion 6 – 128 samples
- 97 unique genotypes – 52 females, 45 males
  - Occasion 5 – 39 genotypes, Occasion 6 – 58 genotypes
- 18/58 (31%) genotypes recaptured between early and late February

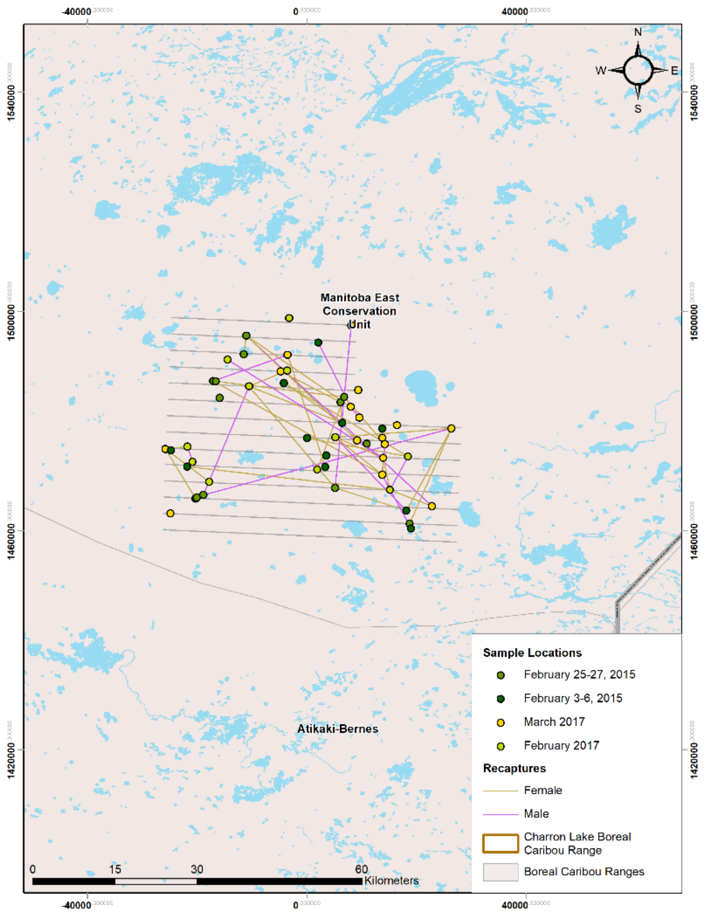
2019

Charron Lake Scat Collection – 2015, 2017 & 2019



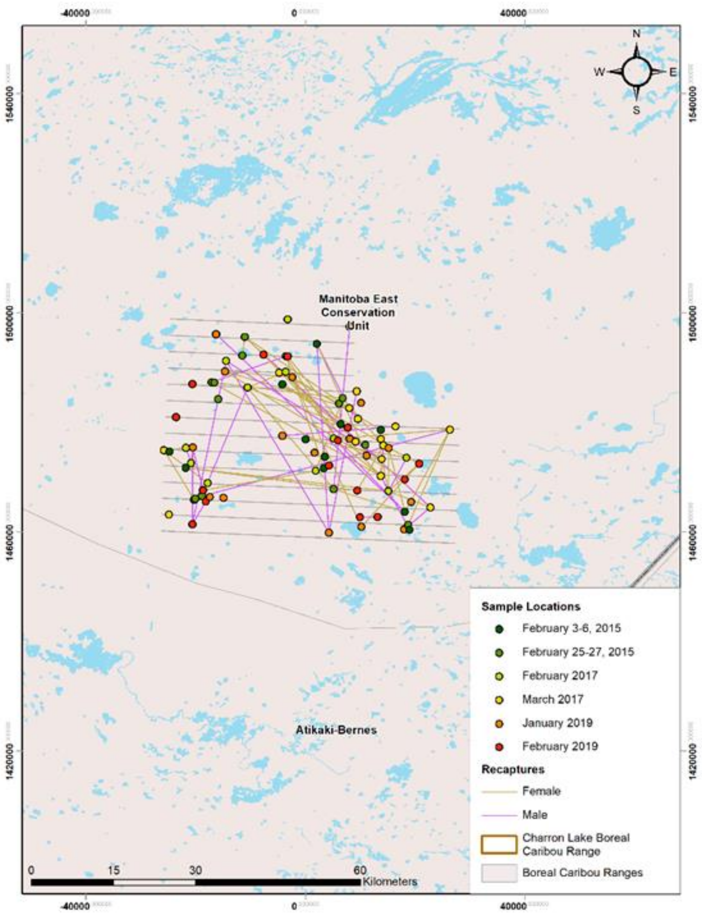
- 225 samples successfully profiled
  - Occasion 1 – 126 samples, Occasion 2 – 99 samples
- 131 unique genotypes – 98 females, 33 males
  - Occasion 1 – 77 genotypes, Occasion 2 – 54 genotypes
- 5 (9%) genotypes recaptured between early and late February

2015



- 279 samples successfully profiled
  - Occasion 3 – 147 samples, Occasion 4 – 132 samples
- 177 unique genotypes – 163 females, 64 males
  - Occasion 3 – 91 genotypes, Occasion 4 – 86 genotypes
- 9/86 (10%) genotypes recaptured between February and March

2017



- 271 samples successfully profiled
  - Occasion 5 – 125 samples, Occasion 6 – 146 samples
- 170 unique genotypes – 111 females, 59 males
  - Occasion 5 – 76 genotypes, Occasion 6 – 94 genotypes
- 6/94 (6%) genotypes recaptured between January and February

2019

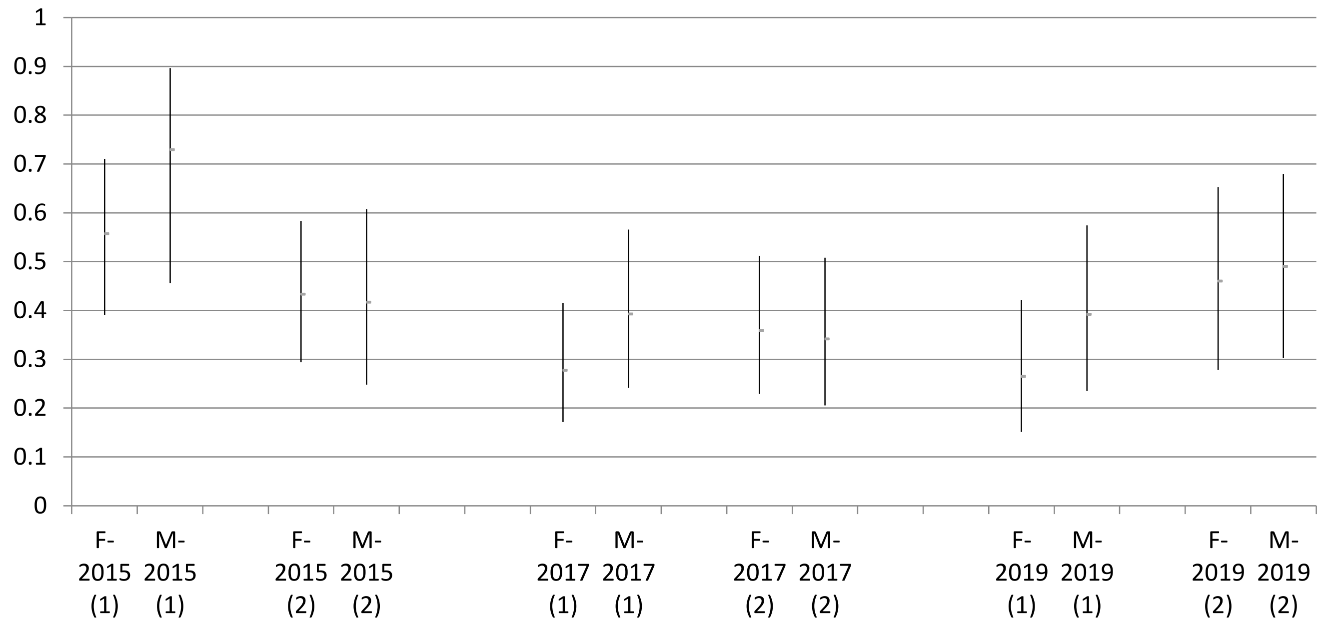
Model Fits Wabowden 2015-2019

- Considerable variation in effort over sample times and logit(p) was well explained by a linear model in effort.
- With a more general *p* model, it appeared that both Phi and Lam also show time trends. Both Phi and Lam show a decrease from 2015-17 to 2017-19 and this is consistent with a constant recruitment as most of the decline in Lam is explained by the decline in survival Phi
- The declines are not big enough to be statistically significant given the estimation uncertainty and both Lam confidence intervals overlap 1.0.

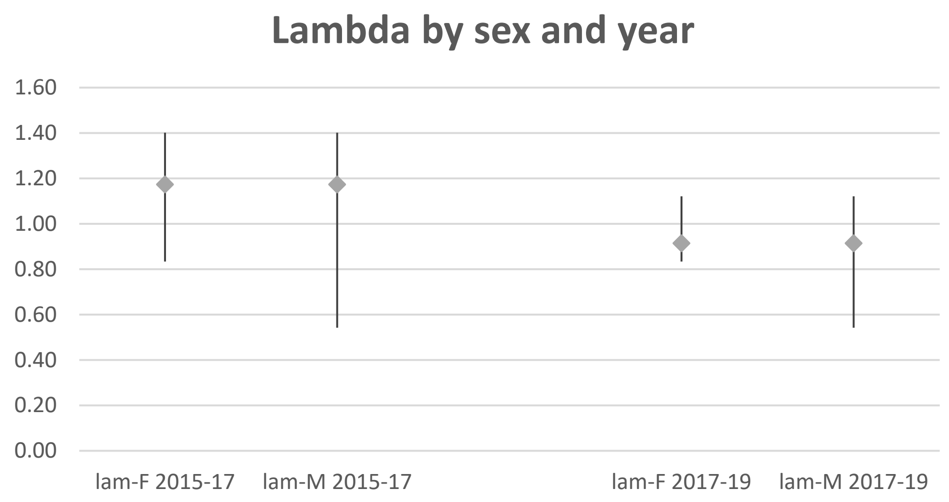
#	Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
1	{Phi(.) Lam(.) p(t) p=c PIM}	-152.603	0	0.32413	1	14	-1241.01
2	{Phi(.) Lam(t) p(t) p=c PIM}	-151.606	0.9977	0.19682	0.6072	15	-1242.23
3	{Phi(t) Lambda(t) p(a +bEFF) c=p f0(g*t) DM}	-150.831	1.7722	0.13363	0.4123	12	-1234.86
4	{Phi(t) Lam(t) p(t) p=c PIM}	-150.475	2.1288	0.11181	0.3449	16	-1243.33
5	{Phi(t) Lambda(t) p(t) c=p f0(g*t) DM}	-150.475	2.1288	0.11181	0.3449	16	-1243.33
6	{Phi(t) Lam(.) p(t) p=c PIM}	-150.394	2.2093	0.10739	0.3313	15	-1241.02
7	{Phi(.) Lam(.) p(g) p=c}	-145.202	7.4009	0.00801	0.0247	10	-1224.91
8	{Phi(g*t) Lam(g*t) p(t) p=c PIM}	-142.335	10.2681	0.00191	0.0059	20	-1244.26
9	{Phi(t) Lam(t) p(g*t) p=c PIM}	-141.697	10.9068	0.00139	0.0043	22	-1248.26
10	{Phi(g) Lam(g) p(g) p=c}	-141.648	10.9555	0.00135	0.0042	12	-1225.67
11	{Phi(t) Lam(t) p(g) p=c}	-141.431	11.1726	0.00122	0.0038	12	-1225.46
12	{Phi(t) Lam(g*t) p(g*t) p=c PIM}	-138.847	13.7567	0.00033	0.001	24	-1250.11
13	{Phi(g*t) Lam(t) p(g*t) p=c PIM}	-137.438	15.1658	0.00017	0.0005	24	-1248.7
14	{Phi(g*t) Lam(g*t) p(g*t) p=c PIM}	-134.11	18.4932	0.00003	0.0001	26	-1250.15
15	{Phi(t) Lam(t) p(t) c(t) PIM fail}	40.6855	193.2888	0	0	19	0
16	{Phi(t) Lambda(t) p(t) c(t) f0(g*t) DM fail }	40.6855	193.2888	0	0	19	0

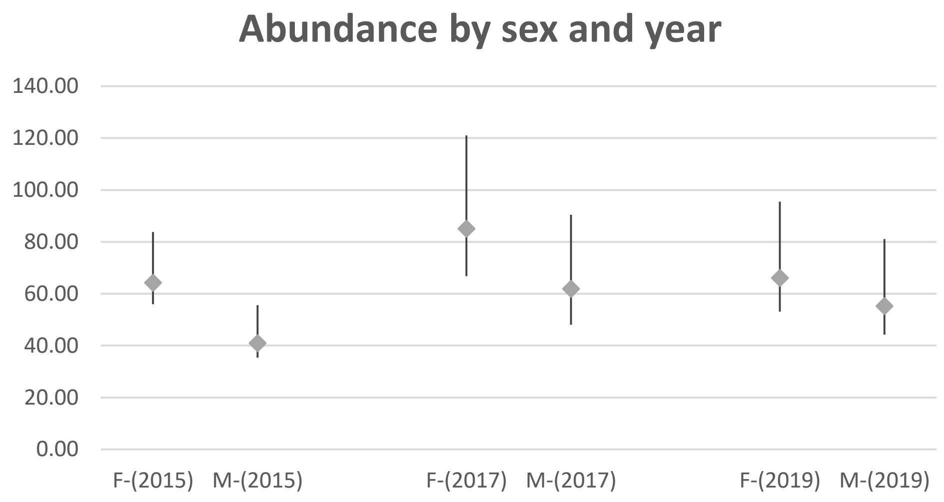
- In fact, the top model (#1 on Models tab) supports no time effects on Phi or Lambda, but there is no biological reason why this restriction should apply and the #1 model is too restrictive. To avoid bias, the more general model (#4) {Phi(t) Lam(t) p(t) p=c} was adopted as the best model for forming estimates.

Results Wabowden: Capture rate



Results Wabowden: Abundance and lambda





For both sexes, populations rose between 2015 and 17 and declined between 2017 and 19. This is also reflected in the lambda values which are above 1 for 2015-17 and below 1 for 2017-19. All estimates overlapped 1.0. Survival rates were 0.77 (0.06) in 2015-17 and 0.66 (0.07) in 2017-2019. Pregnancy rates (from hormones analysis) averaged 0.78 (0.86 (2015), 0.80 (2017), 0.70 (2019)).

With the more general best model the precision of the *N* estimates from RD analysis are much the same as from the Peterson estimates within years and sexes.

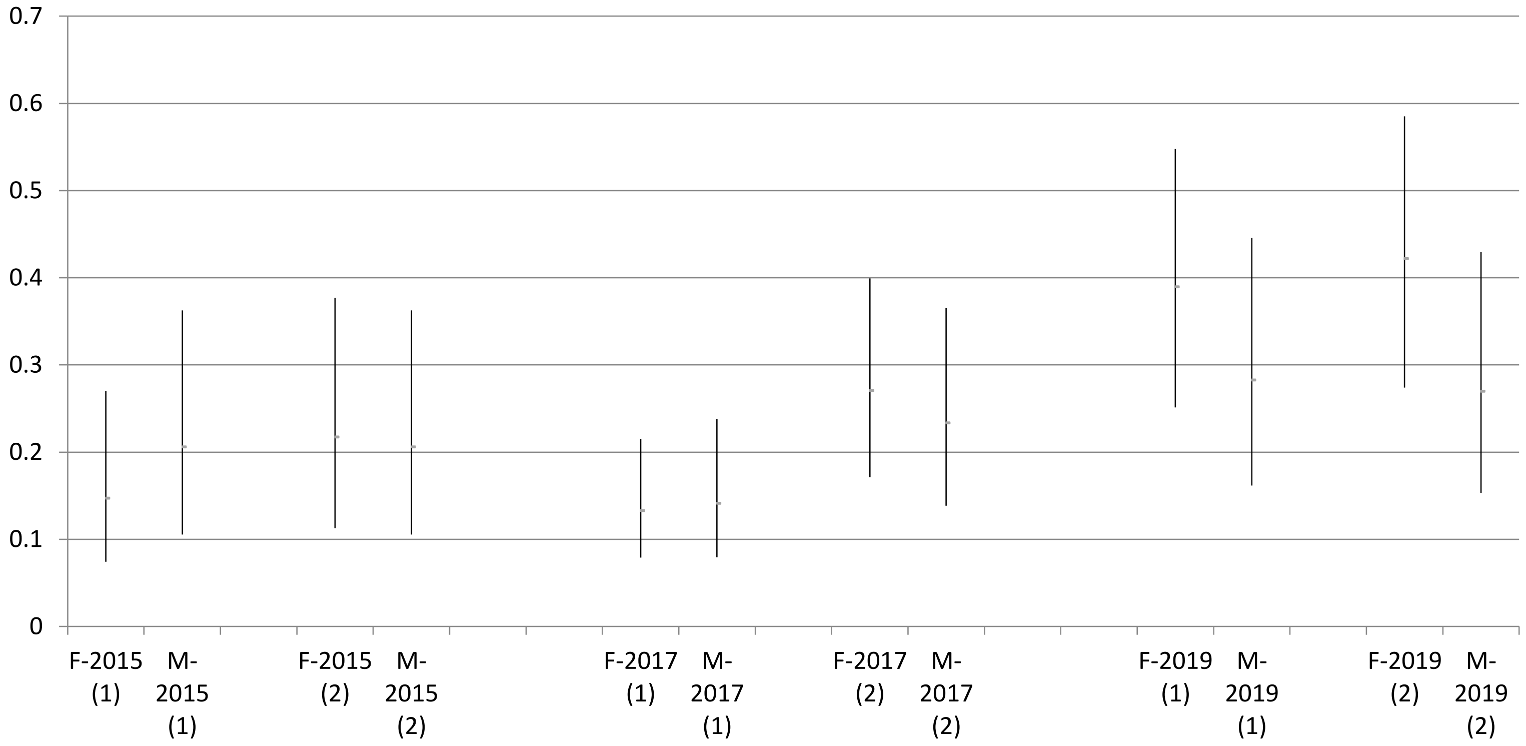
Model Fits Naosap-Reed 2015-2019

- Model conclusions are similar to Wabowden although this population is doing much more poorly. CJS analyses support a time effect on *p* but no group (sex) effect on Phi or *p*.

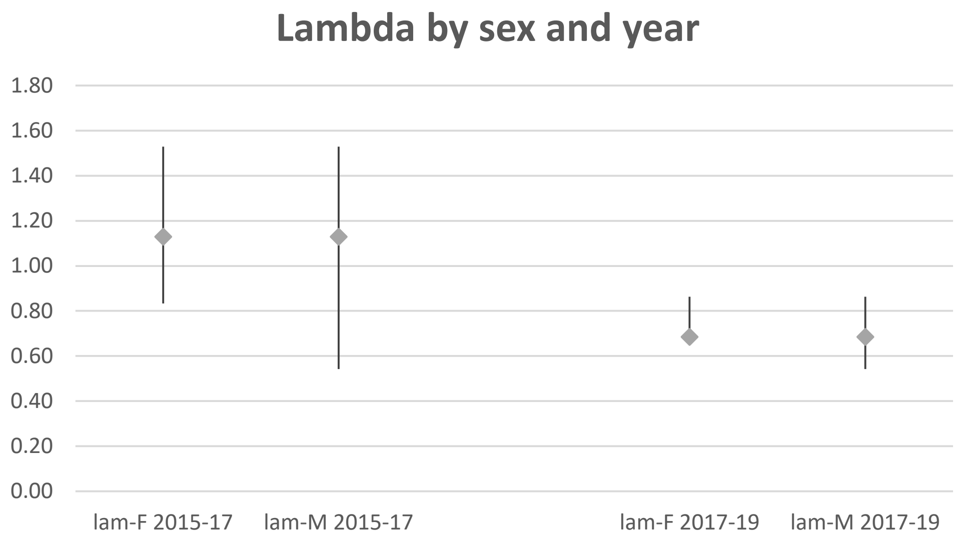
- RD analyses support a constant Phi(.) and/or Lam(.) but opted for Phi(t) Lam(t) p(t) as the best model to get a better idea of time trends. The more restrictive Phi(.) and/or Lam(.) models are supported only because there isn't sufficient precision to rule them out.

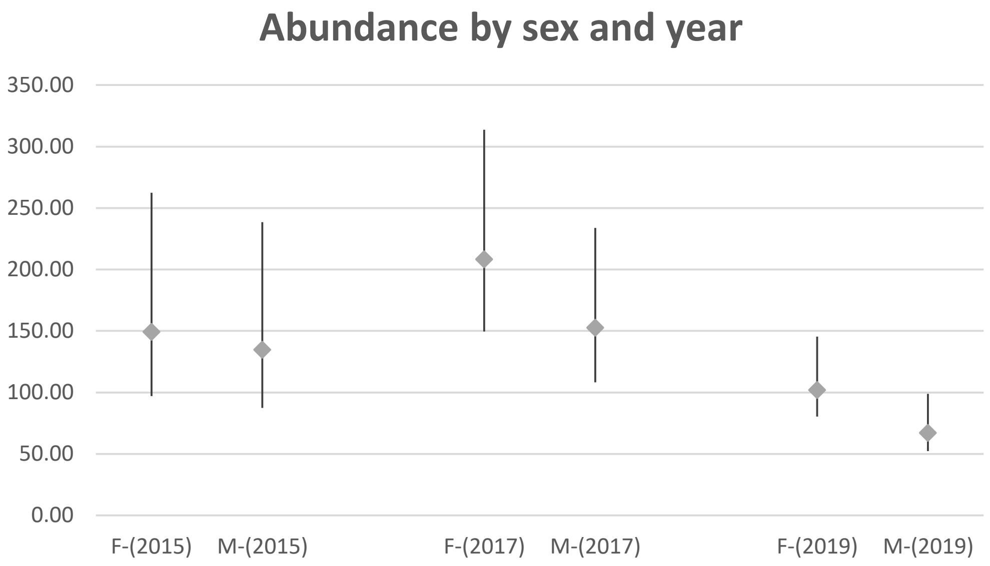
Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{Phi(.) Lam(.) p(t) p=c PIM}	-456.958	0	0.91309	1	8	-1873.33
{Phi(.) Lam(.) p(g) p=c}	-451.239	5.7193	0.05231	0.0573	4	-1859.32
{Phi(t) Lam(t) p(t) p=c PIM}	-448.959	7.9991	0.01673	0.0183	16	-1882.47
{Phi(t) Lam(.) p(t) p=c PIM}	-448.7	8.2586	0.0147	0.0161	14	-1877.85
{Phi(t) Lam(t) p(g) p=c}	-444.359	12.5993	0.00168	0.0018	12	-1869.2
{Phi(.) Lam(t) p(t) p=c PIM}	-442.438	14.5207	0.00064	0.0007	15	-1873.76
{Phi(t) Lam(t) p(g*t) p=c PIM}	-441.273	15.6852	0.00036	0.0004	22	-1888.16
{Phi(g*t) Lam(g*t) p(g*t) p=c PIM}	-440.206	16.7519	0.00021	0.0002	25	-1893.96
{Phi(g*t) Lam(t) p(g*t) p=c PIM}	-440.167	16.7913	0.00021	0.0002	24	-1891.62
{Phi(t) Lam(g*t) p(g*t) p=c PIM}	-436.912	20.0467	0.00004	0	24	-1888.36
{Phi(g) Lam(g) p(g) p=c}	-436.602	20.3568	0.00003	0	12	-1861.45
{Phi(t) Lam(t) p(t) c(t) PIM fail}	40.1714	497.1297	0	0	19	0

Results Naosap-Reed: Capture rate



Results Naosap-Reed: Abundance and λ





Estimates for N change substantially in the Phi(.) and/or Lam(.) models so it is better to go with the more general model as it is likely to be less biased.

CV's for N estimates mostly around 30% for N-Reed whereas they were around 15% for Wabowden. Same trend as with Wabowden: numbers for both sexes seem to increase between 2015 and 2017 and then decline between 2017 and 2019.

Lam>1 in first interval and Lam<1 in second. Big decline in survival in second interval leading to big drop in Lam: Phi(2015-17)= 0.89 (0.08), Phi(2017-19)=0.55 (0.06). Lam(2017-19) is significantly below 1. Large drop in Lam is not entirely accounted for by decline in Phi so there must have been recruitment failure too. Pregnancy rates (from hormones analysis) averaged 0.72 over the 3 years; being lower in 2017 (0.79 (2015), 0.65 (2017), 0.71 (2019)).

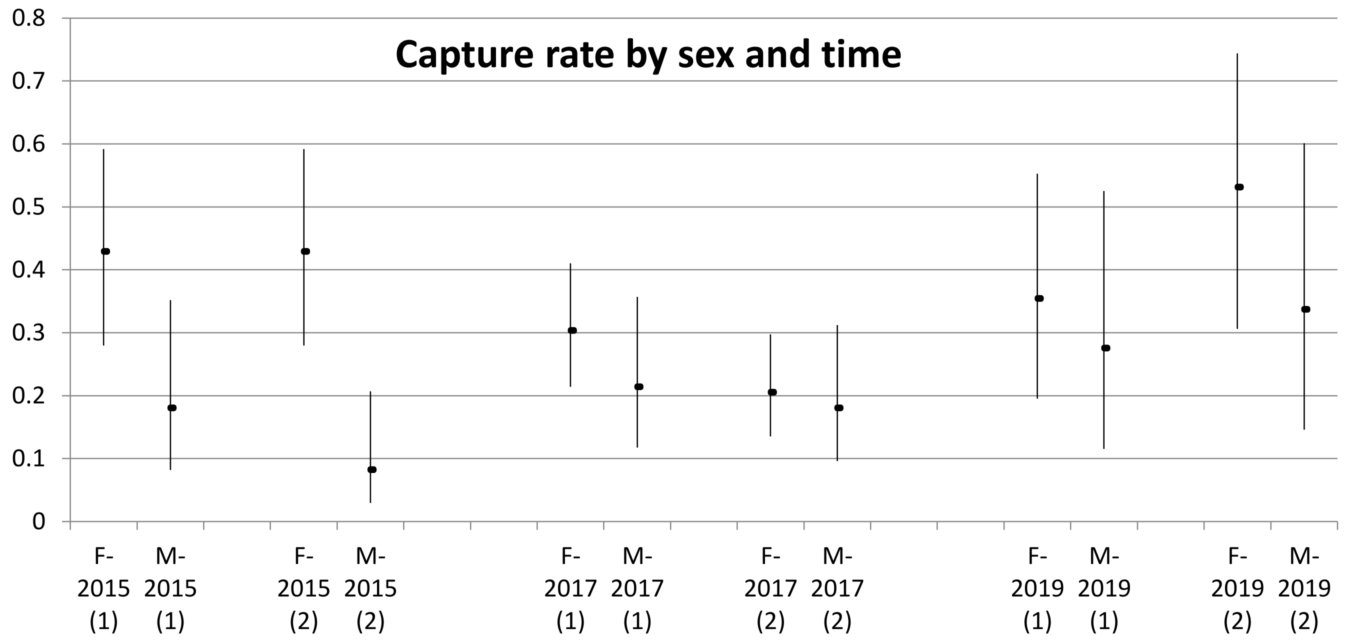
Model Fits The Bog 2015-2019

- The models used were the same as for Naosap-Reed and results are generally similar though specifically less “clean” and precise.
- The CJS models showed a group and time effect on *p* and a time effect but no group effect on Phi (the top 4 models were all Phi(t); models with Phi(g) or Phi(g*t) had AIC weights below 5%). The group effect on *p* is almost solely due to very low capture rates of males relative to females in 2015.
- Males show a consistently lower capture rate relative to females in all years.

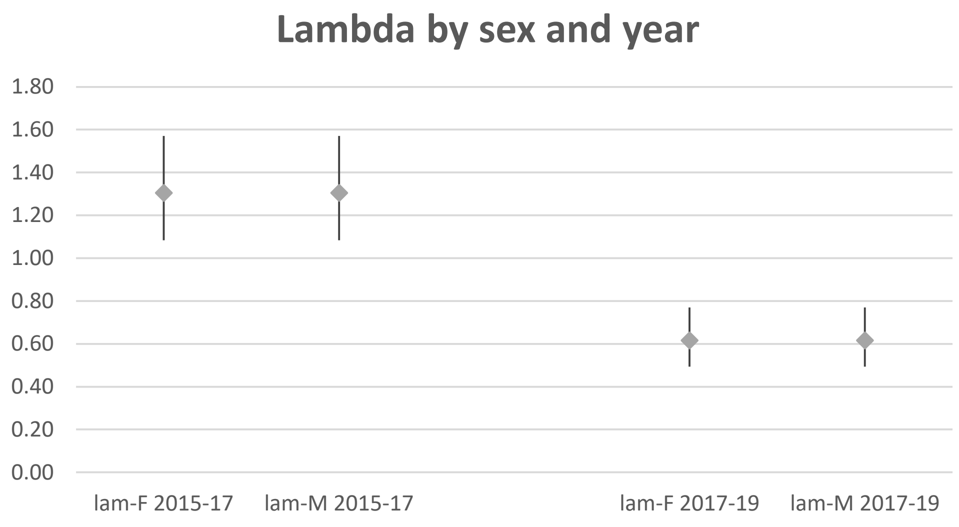
#	Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance	-2log(L)
1	{Phi(t) Lam(t) p(g*t) p=c PIM}	-131.28	0.00	0.61	1.00	21.00	-1019.15	-177.43
2	{Phi(g*t) Lam(t) p(g*t) p=c PIM}	-128.87	2.42	0.18	0.30	23.00	-1021.58	-179.87
3	{Phi(t) Lam(g*t) p(g*t) p=c PIM}	-127.76	3.53	0.10	0.17	23.00	-1020.47	-178.75
4	{Phi(t) Lam(t) p(t) p=c PIM}	-126.87	4.41	0.07	0.11	15.00	-1000.69	-158.97
5	{Phi(g*t) lam(g*t) p(g(*t) c=p F0(g*t) PIM}	-124.17	7.12	0.02	0.03	25.00	-1021.82	-180.10
6	{Phi(t) Lam(t) p(g) p=c}	-123.39	7.89	0.01	0.02	12.00	-990.46	-148.74
7	{Phi(g) Lam(g) p(g) p=c}	-121.17	10.11	0.00	0.01	12.00	-988.23	-146.52
8	{Phi(.) Lam(.) p(t) p=c PIM}	-114.41	16.87	0.00	0.00	14.00	-985.96	-144.24
9	{Phi(.) Lam(t) p(t) p=c PIM}	-113.88	17.41	0.00	0.00	15.00	-987.69	-145.97
10	{Phi(t) Lam(.) p(t) p=c PIM}	-113.53	17.75	0.00	0.00	15.00	-987.35	-145.63
11	{Phi(.) Lam(.) p(g) p=c}	-110.61	20.67	0.00	0.00	10.00	-973.27	-131.55

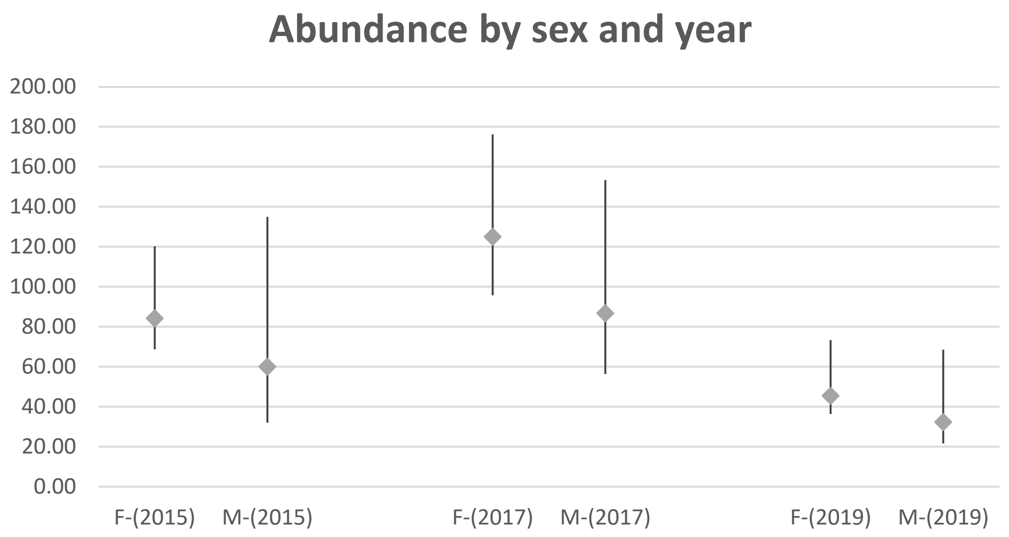
- All top models in both the CJS models and RD models support a time effect on Phi but no sex effect. However, all models gave an estimate of Phi(2015 to 2017) of 1.0 and this parameter had to be fixed at 1.0 to avoid convergence problems. Similarly, there was support for a strong time effect on Lambda but no sex effect. So the top model {Phi(t) Lam(t) p(g*t) p=c} was chosen for all the estimates.

Results The Bog: Capture rate



Results The Bog: Abundance and λ





As with N-Reed, Lambda is high over 2015-17 and then crashed to less than half the value over 2017-19.

There is a large decrease in Phi as well: Phi(2015-17)= 1.0; Phi(2017-19)=0.54 (0.07), but again as with N-Reed, not enough to fully explain the decline in Lambda, so some recruitment failure is implied. Pregnancy rates (from hormones analysis) averaged 0.74; being higher in 2017 (0.68 (2015), 0.80 (2017), 0.72 (2019)).

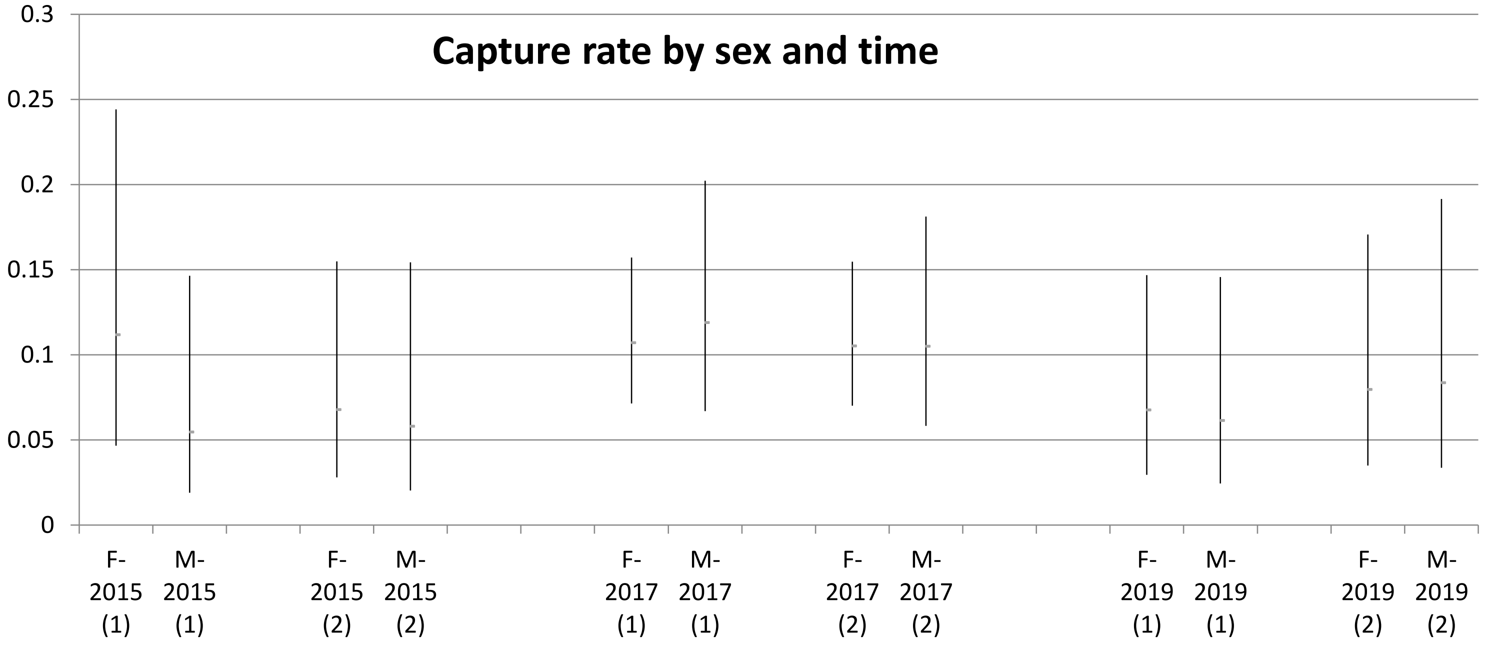
Lambda Confidence intervals do not overlap 1.0 in either time interval so Lambda >1 in 2015-17 and Lambda<1 in 2017-19 are both significantly different from stable rates of change (Lambda=1).

Model Fits Charron Lake 2015-2019

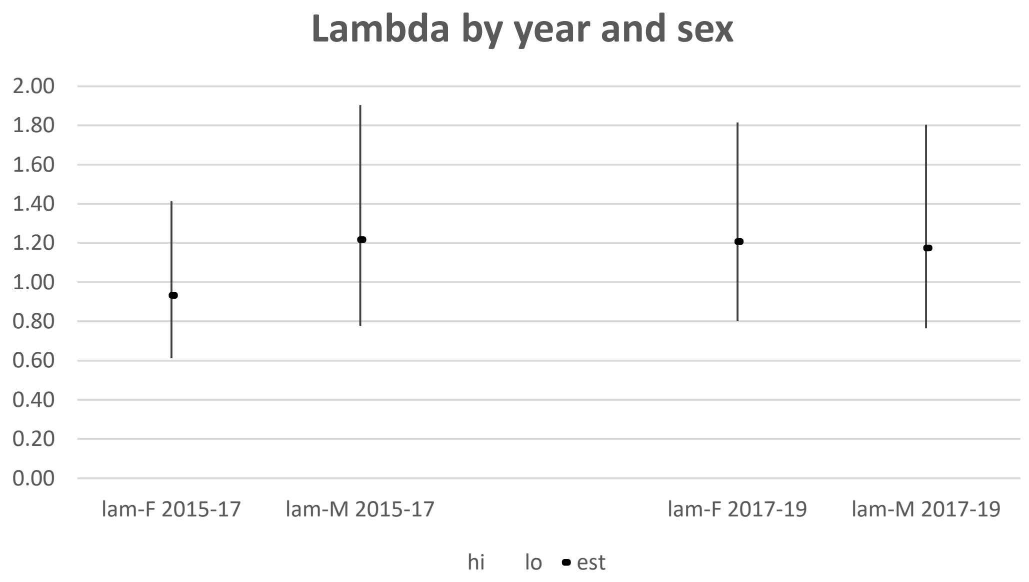
- Models used were as for the Bog with some additional models to explore time and sex effects on Phi and Lambda. Both the CJS and RD models support a time effect on *p* but no sex effect and the highest ranking model is Phi(t) Lam(t) *p*(t).
- There is visual and model weight support for no time or sex effect on Lambda. There was very little variation in sampling effort over sample times and so effort was not a good explanatory covariate for *p*.

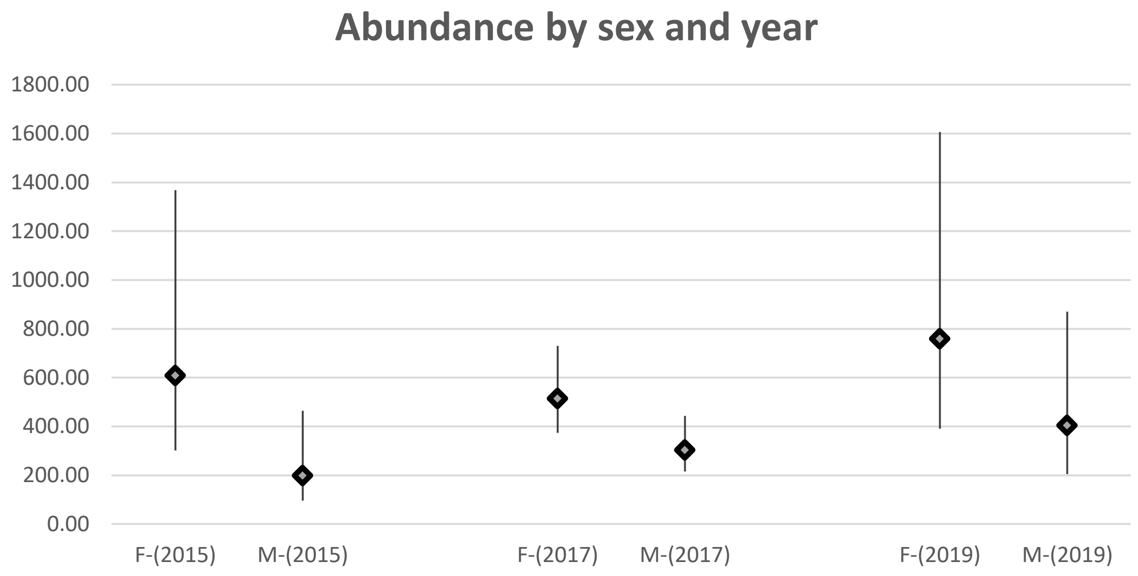
#	Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance	-2ln(L)
1	{Phi(t) Lam(t) p(t) p=c PIM}	-1181.8	0.00	0.67	1.00	9	-3031.7	-1200.2
2	{Phi(t) Lam(.) p(t) p=c PIM}	-1179.5	2.39	0.20	0.30	10	-3031.4	-1199.9
3	{Phi(g*t) Lam(g*t) p(t) p=c PIM}	-1176.0	5.83	0.04	0.05	15	-3038.5	-1207.0
4	{Phi(t) Lam(g*t) p(t) p=c PIM}	-1175.5	6.33	0.03	0.04	15	-3038.0	-1206.5
5	{Phi(t) Lam(t) p(g*t) p=c PIM}	-1174.8	7.07	0.02	0.03	16	-3039.4	-1208.0
6	{Phi(t) Lam(g*t) p(g*t) p=c PIM}	-1174.6	7.28	0.02	0.03	17	-3041.3	-1209.9
7	{Phi(g*t) Lam(t) p(g*t) p=c PIM}	-1173.2	8.59	0.01	0.01	17	-3040.0	-1208.6
8	{Phi(g*t) Lam(g*t) p(g*t) p=c PIM}	-1172.6	9.28	0.01	0.01	18	-3041.5	-1210.1
9	{Phi(t) Lam(t) p(g) p=c}	-1172.0	9.83	0.00	0.01	10	-3023.9	-1192.5
10	{Phi(.) Lam(.) p(t) p=c PIM}	-1168.8	13.09	0.00	0.00	11	-3022.7	-1191.3
11	{Phi(.) Lam(t) p(t) p=c PIM}	-1158.4	23.41	0.00	0.00	11	-3012.4	-1181.0
12	{Phi(.) Lam(.) p(g) p=c}	-1156.9	24.96	0.00	0.00	9	-3006.7	-1175.3
13	{Phi(g) Lam(g) p(g) p=c}	-1156.5	25.29	0.00	0.00	11	-3010.5	-1179.1
14	{phi(g*t) lam(g*t) p(g*t) c(g*t) F0(g*t)} PIM fail}	2.0	1183.85	0.00	0.00	1	0.0	0.0
15	{phi(t) lam(t) p(t) c(t) F0(g*t)} PIM fail}	2.0	1183.85	0.00	0.00	1	0.0	0.0

Results Charron Lake: Capture rate



Results Charron Lake: Abundance and lambda





As with the Bog, the first survival rate estimate Phi(2015-17) had to be fixed at 1.0. In the following interval (2017-19) the survival rate fell dramatically: phi(2017-19) = 0.58 (0.14)

Yet the Lambda stayed around 1.0 throughout (the estimate of overall Lambda from Model #2 is Lam(.) = 1.1 (0.14) with a. 95% CI of (0.86, 1.41)) so recruitment must have been good in the latter interval to compensate for low survival. Pregnancy rates average 80% over the 3 years; being higher in 2017 (0.76 (2015), 0.87 (2017), 0.78 (2019)).

Conclusions

- Population sizes vary greatly among ranges, with Wabowden (Y1=105, Y2=147, Y3=121) and The Bog (Y1=144, Y2=211, Y3=78) being the smallest, Naosap-Reed (Y1=284, Y2=360, Y3=170) and Charron Lake (Y1=806, Y2=818, Y3=1160) being the largest.

- The ratio of M:F varied among populations from 0.6 to 0.9, with Charron Lake presenting a lower ratio (0.3-0.5).

- All populations except for Charron Lake, showed an increasing trend over the 2015-2017 period and a decreasing trend over the 2017-2019 period. Large drops in Lambda are not entirely accounted for by a decline in survival so there must have also been recruitment failures. Does this mean something global to all populations is happening, as opposed to specific environmental effects within individual populations.