Supplementary Material

# Results for the two best-fitting CJS models

Here, we present the full results of the two best-fitting CJS models (Table S1). The second-best fitting CJS model had a very similar AICc to the best model (ΔAICc = 0.6) and consisted of transient and time-varying apparent survival (both *Φ*0 and *Φ*1+); and detection probability (*p*) varying with effort. The only difference between the two models is that *Φ*1+ is constant in the best-fitting model and time-varying in the second model. The second model produced very similar estimates of detection, survival, transient rate and abundance, compared with the final model (Table S1, Figure S1).

**Table S1.** Parameter maximum likelihood estimates (MLE) and 95% confidence intervals (CI) for the two best-fitting CJS models: *p.effort, Φ.time:transient* (*p* varies with effort, transient *Φ,* time-varying *Φ*0, constant *Φ*1+) and *p.effort, Φ.time+transient* (as before but *Φ*1+ is time-varying)*. p* denotes detection probability; *Φ*0 denotes survival following the first sighting; *Φ*1+ denotes survival following subsequent sightings; *NR* denotes the number of non-transient animals; *NT* denotes the number of transient animals; and *Ntot* denotes the total number of animals. Parameter types are separated by dashed lines and season-specific values are given for time-varying parameters.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameter** | **Season** | ***p.effort, Φ.time:transient*** | | | ***p.effort, Φ.time+transient*** | | |
| **MLE** | **Lower CI** | **Upper CI** | **MLE** | **Lower CI** | **Upper CI** |
| *p* | 2011 | 0.12 | 0.09 | 0.16 | 0.11 | 0.08 | 0.15 |
| *p* | 2012 | 0.16 | 0.13 | 0.22 | 0.16 | 0.11 | 0.21 |
| *p* | 2013 | 0.15 | 0.12 | 0.21 | 0.15 | 0.11 | 0.2 |
| *p* | 2014 | 0.1 | 0.08 | 0.14 | 0.1 | 0.07 | 0.13 |
| *p* | 2015 | 0.15 | 0.12 | 0.21 | 0.15 | 0.11 | 0.2 |
| *p* | 2016 | 0.11 | 0.09 | 0.15 | 0.11 | 0.08 | 0.14 |
| *p* | 2017 | 0.12 | 0.1 | 0.17 | 0.12 | 0.09 | 0.16 |
| *p* | 2018 | 0.11 | 0.08 | 0.14 | 0.11 | 0.08 | 0.14 |
| *p* | 2019 | 0.2 | 0.15 | 0.28 | 0.2 | 0.14 | 0.28 |
| *p* | 2020 | 0.05 | 0.03 | 0.08 | 0.05 | 0.03 | 0.07 |
| *Φ*0 | 2010 | 0.5 | 0.35 | 0.7 | 0.47 | 0.33 | 0.65 |
| *Φ*0 | 2011 | 0.46 | 0.32 | 0.64 | 0.45 | 0.31 | 0.62 |
| *Φ*0 | 2012 | 0.33 | 0.22 | 0.47 | 0.33 | 0.22 | 0.47 |
| *Φ*0 | 2013 | 0.32 | 0.21 | 0.47 | 0.31 | 0.2 | 0.47 |
| *Φ*0 | 2014 | 0.35 | 0.19 | 0.53 | 0.34 | 0.18 | 0.54 |
| *Φ*0 | 2015 | 0.25 | 0.13 | 0.38 | 0.25 | 0.13 | 0.4 |
| *Φ*0 | 2016 | 0.26 | 0.1 | 0.47 | 0.27 | 0.1 | 0.5 |
| *Φ*0 | 2017 | 0.2 | 0.06 | 0.38 | 0.21 | 0.06 | 0.43 |
| *Φ*0 | 2018 | 0.07 | 0.03 | 0.17 | 0.08 | 0 | 0.18 |
| *Φ*0 | 2019 | 0.72 | 0.18 | 0.9 | 0.75 | 0.23 | 1 |
| *Φ*1+ | constant | 0.97 | 0.91 | 0.98 | - | - | - |
| *Φ*1+ | 2011 | - | - | - | 0.99 | 0.97 | 1 |
| *Φ*1+ | 2012 | - | - | - | 0.98 | 0.95 | 1 |
| *Φ*1+ | 2013 | - | - | - | 0.98 | 0.95 | 1 |
| *Φ*1+ | 2014 | - | - | - | 0.99 | 0.94 | 1 |
| *Φ*1+ | 2015 | - | - | - | 0.98 | 0.91 | 1 |
| *Φ*1+ | 2016 | - | - | - | 0.98 | 0.92 | 1 |
| *Φ*1+ | 2017 | - | - | - | 0.97 | 0.88 | 1 |
| *Φ*1+ | 2018 | - | - | - | 0.92 | 0.76 | 1 |
| *Φ*1+ | 2019 | - | - | - | 1 | 0.97 | 1 |
| *T* | 2011 | 0.5 | 0.31 | 0.64 | 0.53 | 0.37 | 0.66 |
| *T* | 2012 | 0.6 | 0.44 | 0.69 | 0.6 | 0.48 | 0.7 |
| *T* | 2013 | 0.56 | 0.4 | 0.65 | 0.57 | 0.44 | 0.67 |
| *T* | 2014 | 0.53 | 0.34 | 0.65 | 0.52 | 0.37 | 0.66 |
| *T* | 2015 | 0.64 | 0.5 | 0.74 | 0.64 | 0.51 | 0.75 |
| *T* | 2016 | 0.58 | 0.39 | 0.72 | 0.57 | 0.38 | 0.72 |
| *T* | 2017 | 0.61 | 0.45 | 0.73 | 0.6 | 0.44 | 0.73 |
| *T* | 2018 | 0.8 | 0.69 | 0.86 | 0.78 | 0.69 | 0.87 |
| *T* | 2019 | 0.2 | 0.04 | 0.64 | 0.19 | 0 | 0.6 |
| *NR* | 2011 | 443 | 276 | 719 | 427 | 264 | 708 |
| *NR* | 2012 | 409 | 260 | 646 | 408 | 266 | 674 |
| *NR* | 2013 | 457 | 300 | 695 | 450 | 302 | 750 |
| *NR* | 2014 | 479 | 290 | 760 | 489 | 302 | 809 |
| *NR* | 2015 | 426 | 248 | 670 | 424 | 258 | 726 |
| *NR* | 2016 | 330 | 183 | 543 | 345 | 208 | 579 |
| *NR* | 2017 | 387 | 227 | 605 | 397 | 246 | 682 |
| *NR* | 2018 | 284 | 169 | 471 | 310 | 178 | 504 |
| *NR* | 2019 | 864 | 347 | 1092 | 872 | 407 | 1460 |
| *NT* | 2011 | 449 | 278 | 547 | 478 | 347 | 639 |
| *NT* | 2012 | 620 | 432 | 730 | 624 | 460 | 841 |
| *NT* | 2013 | 573 | 406 | 698 | 585 | 431 | 793 |
| *NT* | 2014 | 529 | 348 | 670 | 539 | 384 | 730 |
| *NT* | 2015 | 746 | 549 | 909 | 753 | 567 | 1008 |
| *NT* | 2016 | 456 | 293 | 571 | 454 | 311 | 634 |
| *NT* | 2017 | 601 | 424 | 746 | 603 | 435 | 815 |
| *NT* | 2018 | 1100 | 802 | 1330 | 1099 | 846 | 1512 |
| *NT* | 2019 | 216 | 35 | 704 | 204 | 0 | 720 |
| *Ntot* | 2011 | 892 | 675 | 1118 | 906 | 711 | 1257 |
| *Ntot* | 2012 | 1028 | 779 | 1317 | 1032 | 788 | 1433 |
| *Ntot* | 2013 | 1030 | 772 | 1290 | 1035 | 801 | 1429 |
| *Ntot* | 2014 | 1008 | 751 | 1268 | 1028 | 802 | 1415 |
| *Ntot* | 2015 | 1171 | 878 | 1483 | 1177 | 904 | 1619 |
| *Ntot* | 2016 | 786 | 593 | 964 | 799 | 625 | 1063 |
| *Ntot* | 2017 | 988 | 738 | 1219 | 1001 | 781 | 1365 |
| *Ntot* | 2018 | 1384 | 1040 | 1710 | 1409 | 1109 | 1961 |
| *Ntot* | 2019 | 1081 | 777 | 1388 | 1076 | 784 | 1539 |
| *Ntot* | 2020 | 1434 | 924 | 1908 | 1501 | 1031 | 2244 |

Chart

Description automatically generated

**Figure S1.** Seasonal estimates for detection probability (*p*), transient rate (*T*), abundance of non-transients (N­­R), abundance of transients (NT), and total abundance (Ntot), with 95% confidence intervals (CI, shaded regions) derived from a stratified bootstrap (1000 replicates), for the second best-fitting model (effort-dependent *p*, transient *Φ*, time-dependent *Φ*0 and *Φ*1+)*.* The weighted linear trend (non-significant) for total abundance is denoted by the dashed red line.

# Sensitivity analysis of *p* specification

Although it was considered reasonable in this study to modify effort by long-term intra-seasonal sighting rates, there were reservations about using the data twice in model fitting, in terms of capture-recapture data and applying an availability weighting to the catch-effort covariate. Therefore, we conducted a sensitivity analysis by visually comparing abundance estimates from CJS models with three different specifications of *p*: time-varying; linked to unmodified effort (number of survey days); and linked to modified effort (survey days corrected for intra-seasonal variability in sighting rates). Figure S2 demonstrates that, despite some differences in estimates and inter-seasonal variability, all specifications show similar trends and 95% confidence intervals (CI) are largely overlapping.

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**Figure S2.** A comparison of seasonal abundance estimates from CJS models with three different specifications of detection (*p*): time-varying; linked to unmodified effort (number of survey days); and linked to modified effort (survey days corrected for intra-seasonal variability in sighting rates). In each case, in line with the best-fitting CJS model, we specified transient *Φ,* in which *Φ*0 was time-varying and *Φ*1+ was constant. Lines denote abundance estimates from the full model and shading denotes 95% confidence intervals (CI) derived from a stratified bootstrap (1000 replicates).

# Results for candidate JSSA model

Initially, we considered both Jolly-Seber-Schwarz-Arnason (JSSA) and Cormack-Jolly-Seber (CJS) model frameworks. CJS was selected because there were identifiability issues with time-varying JSSA models (primarily identified through inspection of beta estimates). Nevertheless, the range of estimates given by JSSA models was comparable to CJS and encouraging. Here, we provide model outputs for the best-fitting JSSA model without identifiability issues, with transient apparent survival (*Φ*), detection (*p*) linked to effort, and constant probability of entry (*pent*; Table S2, Figure S3). This JSSA model yielded two survival estimates: survival following the first sighting (*Φ*0) and survival following subsequent sightings (*Φ*1+). Due to the way in which seasonal abundance is derived from the super-population abundance parameter estimate, transience rates and the separate numbers of transients and non-transients could not be provided (Félix et al. 2011, Schleimer et al. 2019). The model was fit as a POPAN model in *RMark*.

**Table S2.** Parameter maximum likelihood estimates (MLE) and 95% confidence intervals (CI) for a candidate JSSA model (effort-dependent *p*, transient *Φ*, constant *pent*)*. p* denotes detection probability; *Φ*0 denotes survival following the first sighting; *Φ*1+ denotes survival following subsequent sightings; *pent* denotes probability of entry; *Nsuper* denotes super-population abundance (the total number of animals present across all occasions); and *Nyear* denotes derived seasonal abundance. Season-specific values are given for time-varying parameters.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Season** | **MLE** | **Lower CI** | **Upper CI** |
| *p* | 2010 | 0.07 | 0.05 | 0.09 |
| *p* | 2011 | 0.11 | 0.08 | 0.14 |
| *p* | 2012 | 0.14 | 0.10 | 0.18 |
| *p* | 2013 | 0.14 | 0.10 | 0.18 |
| *p* | 2014 | 0.10 | 0.07 | 0.13 |
| *p* | 2015 | 0.14 | 0.10 | 0.18 |
| *p* | 2016 | 0.10 | 0.07 | 0.14 |
| *p* | 2017 | 0.11 | 0.08 | 0.15 |
| *p* | 2018 | 0.10 | 0.07 | 0.13 |
| *p* | 2019 | 0.17 | 0.12 | 0.22 |
| *p* | 2020 | 0.05 | 0.04 | 0.07 |
| *Φ*1+ | constant | 0.99 | 0.94 | 1 |
| *Φ*0 | constant | 0.34 | 0.29 | 0.46 |
| *pent* | constant | 0.05 | 0.04 | 0.06 |
| *Nsuper* | constant | 2140 | 1932 | 2673 |
| *N­year* | 2010 | 979 | 751 | 1411 |
| *Nyear* | 2011 | 1085 | 854 | 1519 |
| *N­year* | 2012 | 1188 | 951 | 1617 |
| *N­year* | 2013 | 1287 | 1034 | 1716 |
| *N­year* | 2014 | 1386 | 1112 | 1817 |
| *N­year* | 2015 | 1487 | 1181 | 1924 |
| *N­year* | 2016 | 1580 | 1232 | 2032 |
| *N­year* | 2017 | 1680 | 1307 | 2140 |
| *N­year* | 2018 | 1777 | 1367 | 2247 |
| *N­year* | 2019 | 1870 | 1412 | 2355 |
| *N­year* | 2020 | 1956 | 1435 | 2451 |

Chart, line chart

Description automatically generated

**Figure S3.** Seasonal estimates (black lines) and 95% confidence intervals (shaded areas), derived from a stratified bootstrap (1000 replicates), for detection probability (*p*)and derived abundance (*Nyear*) for a candidate JSSA (POPAN) model (effort-dependent *p*, transient *Φ*, constant *pent*)*.*