Draft indicators of risk for Southern Resident Killer Whales

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Data used to inform metrics

At the 07/23/2019 meeting, we discussed using 3 metrics related to SRKW:

- Demographic rates (survival, fecundity)
- Occurrence of peanut head whales
- Increasing trends of SRKW abundance

Starting with the demographic rates, we will estimate these using previous described methods in Hilborn et al. (2012) and Ward et al. (2013).

Fecundity rates

First, the estimated fecundity rates for a 20 year old female. All other ages have the same approximate shape, but we'll use 20 because fecundity is thought to peak in the early 20s.

population	year	age	fec_rate
SRKW	1976	20	0.212
SRKW	1977	20	0.161
SRKW	1978	20	0.126
SRKW	1979	20	0.107
SRKW	1980	20	0.103
SRKW	1981	20	0.112
SRKW	1982	20	0.135
SRKW	1983	20	0.166
SRKW	1984	20	0.200
SRKW	1985	20	0.224
SRKW	1986	20	0.231
SRKW	1987	20	0.221
SRKW	1988	20	0.202
SRKW	1989	20	0.182
SRKW	1990	20	0.168
SRKW	1991	20	0.162
SRKW	1992	20	0.164
SRKW	1993	20	0.170
SRKW	1994	20	0.174
SRKW	1995	20	0.173
SRKW	1996	20	0.165
SRKW	1997	20	0.151
SRKW	1998	20	0.138
SRKW	1999	20	0.129
SRKW	2000	20	0.128
SRKW	2001	20	0.136
SRKW	2002	20	0.154

population	year	age	fec_rate
SRKW	2003	20	0.178
SRKW	2004	20	0.203
SRKW	2005	20	0.222
SRKW	2006	20	0.229
SRKW	2007	20	0.223
SRKW	2008	20	0.210
SRKW	2009	20	0.196
SRKW	2010	20	0.187
SRKW	2011	20	0.184
SRKW	2012	20	0.186
SRKW	2013	20	0.188
SRKW	2014	20	0.181
SRKW	2015	20	0.161
SRKW	2016	20	0.129
SRKW	2017	20	0.092
SRKW	2018	20	0.060

Survival rates

Survival rates are estimated by stage, because of uncertainty in some of the ages. But we can similarly estimate the year effect as a smooth term, and have the population and stage effects as estimated fixed effects offsets. Ward et al. (2013)

First, the estimated survival rate for a young reproductive female. All other ages have the same approximate shape, with offests (population, stage).

population	year	stage	surv_rate
SRKW	1976	young_female	0.997
SRKW	1977	young_female	0.996
SRKW	1978	young_female	0.995
SRKW	1979	young_female	0.993
SRKW	1980	young_female	0.991
SRKW	1981	young_female	0.990
SRKW	1982	young_female	0.989
SRKW	1983	young_female	0.989
SRKW	1984	young_female	0.989
SRKW	1985	young_female	0.990
SRKW	1986	young_female	0.990
SRKW	1987	young_female	0.991
SRKW	1988	young_female	0.991
SRKW	1989	young_female	0.992
SRKW	1990	young_female	0.991
SRKW	1991	young_female	0.991
SRKW	1992	young_female	0.989
SRKW	1993	young_female	0.987
SRKW	1994	young_female	0.985
SRKW	1995	young_female	0.981
SRKW	1996	young_female	0.977
SRKW	1997	young_female	0.972
SRKW	1998	young_female	0.970

population	year	stage	surv_rate
SRKW	1999	young_female	0.969
SRKW	2000	young_female	0.971
SRKW	2001	young_female	0.974
SRKW	2002	young_female	0.978
SRKW	2003	young_female	0.982
SRKW	2004	young_female	0.984
SRKW	2005	young_female	0.986
SRKW	2006	young_female	0.986
SRKW	2007	young_female	0.985
SRKW	2008	young_female	0.984
SRKW	2009	young_female	0.982
SRKW	2010	young_female	0.979
SRKW	2011	young_female	0.977
SRKW	2012	young_female	0.976
SRKW	2013	young_female	0.977
SRKW	2014	young_female	0.978
SRKW	2015	young_female	0.980
SRKW	2016	young_female	0.983
SRKW	2017	young_female	0.986
SRKW	2018	young_female	0.988

Occurrence of peanut head whales

The data on peanut head whales was discussed in the Hilborn et al. report as an indicator of killer whale mortality Hilborn et al. (2012). As a follow up, Durban and Ellifrit (2019 pers. comm.) have updated the more recent instances of peanut head whales: L73 (died 2010), J28 (died 2016), J54 (died 2016), J52 (died 2017), J50 (died 2018), J17 (missing 2019).

The breakdown by year looks like this,

year	n_peanut
1994	2
1995	3
1996	2
1997	1
2002	1
2005	1
2006	1
2008	2
2010	1
2016	2
2017	1
2018	1
2019	1

To model the occurrence of peanut head syndrome, we could either use the raw data as an indicator, or the predicted response (using a Poisson GAM).

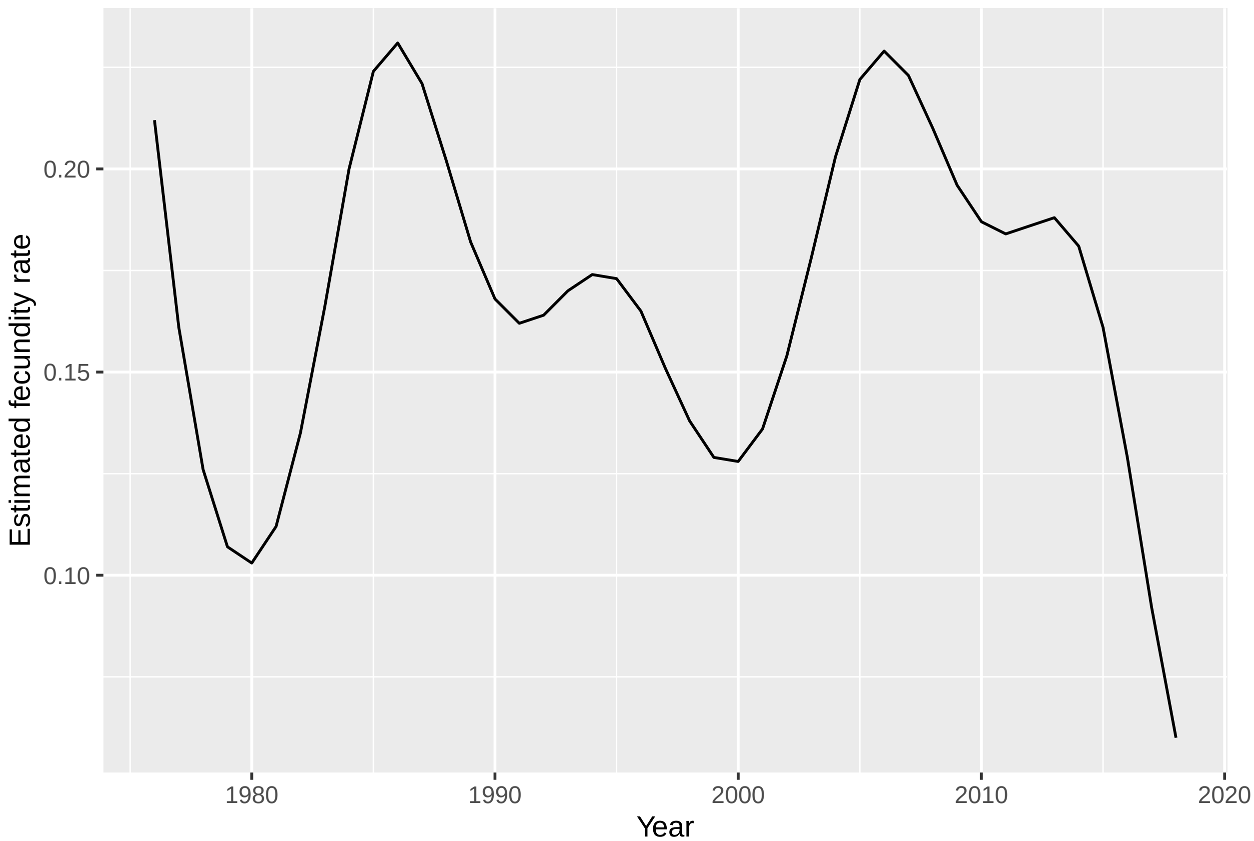

Figure 1: Estimated fecundity rate for age 20 SRKW female

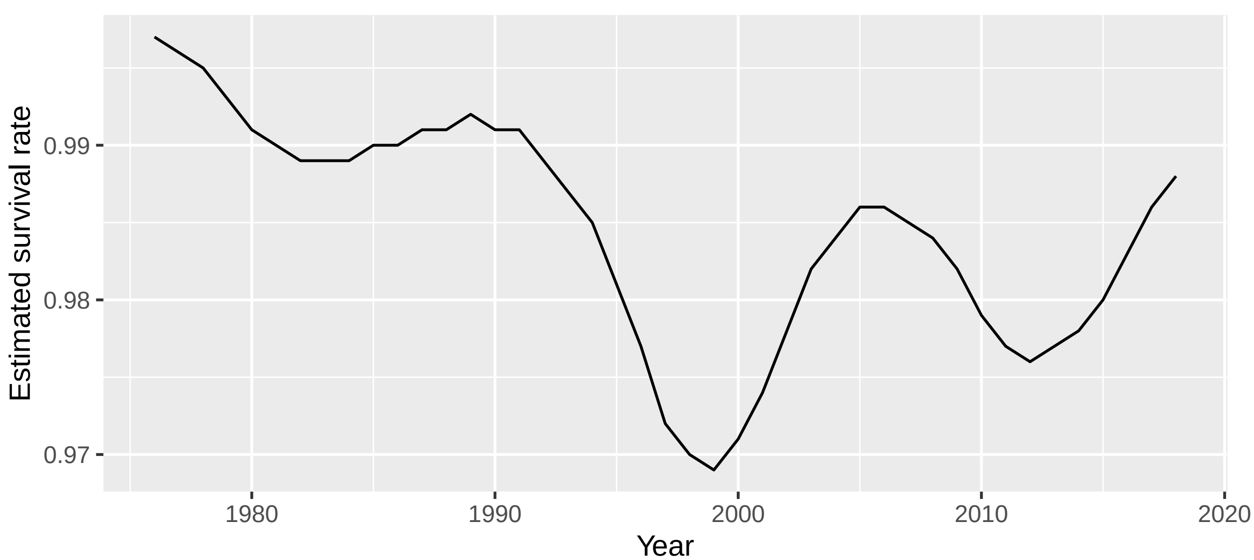

Figure 2: Estimated survival rate for a young reproductive aged SRKW female

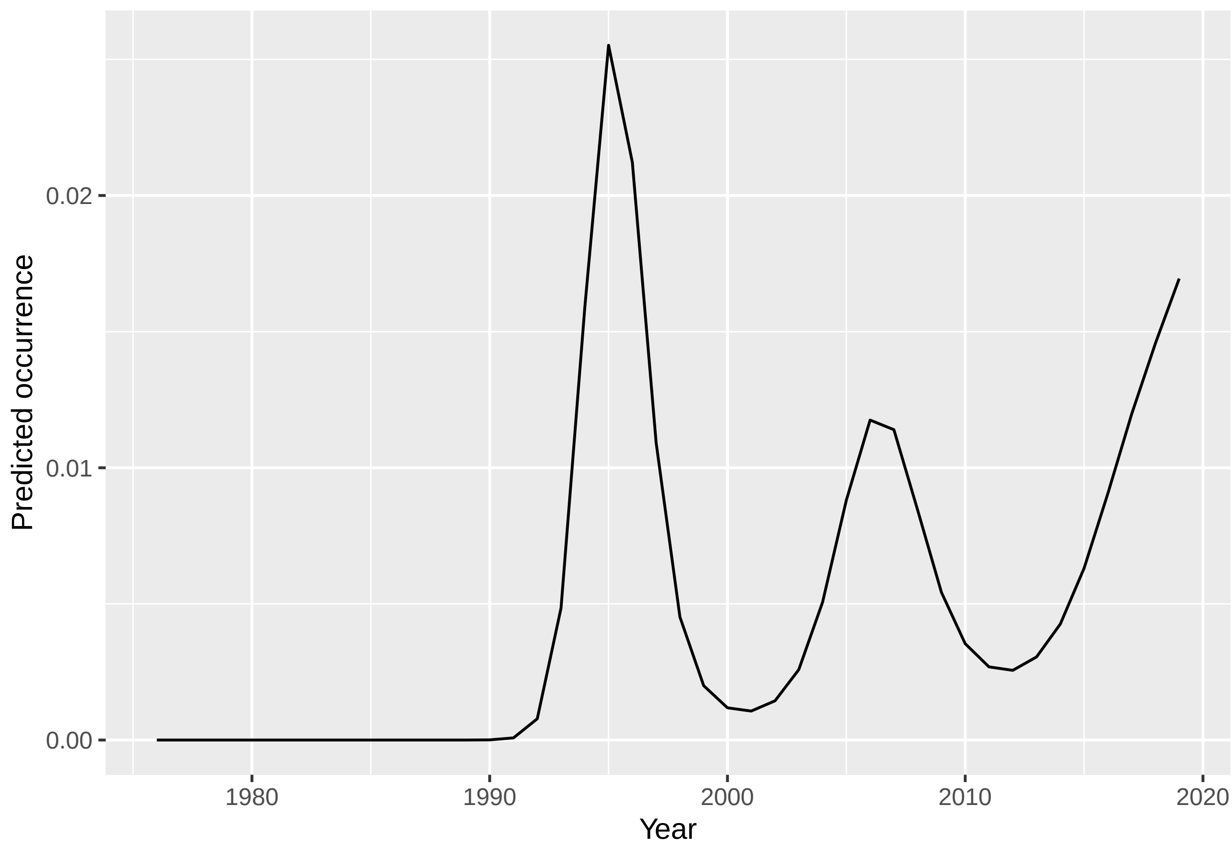

Figure 3: Estimated occurrence of peanut head whales

Increases in SRKW population size

As we discussed at the 07/23/2019 meeting, there's a number of reasons why a declining SRKW population might not be informative with respect to prey. A small population is subject to variation because of demographic stochasticity (random chance), and other factors including disease, ship strikes and other human disturbance, and other factors.

As an indicator, we can coarsely bin the time series of SRKW data into periods when the population was increasing (indicator = 1) or not (indicator = 0). Data here is taken from the Center for Whale Research's annual census.

year	total
1976	71
1977	80
1978	80
1979	82
1980	84
1981	82
1982	79
1983	76
1984	74
1985	77
1986	81
1987	84
1988	85
1989	85
1990	88
1991	92
1992	91
1993	97
1994	96
1995	98
1996	97
1997	92
1998	89
1999	85
2000	82
2001	78
2002	79
2003	82
2004	83
2005	88
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2014	78
2015	81
2016	83
2017	77

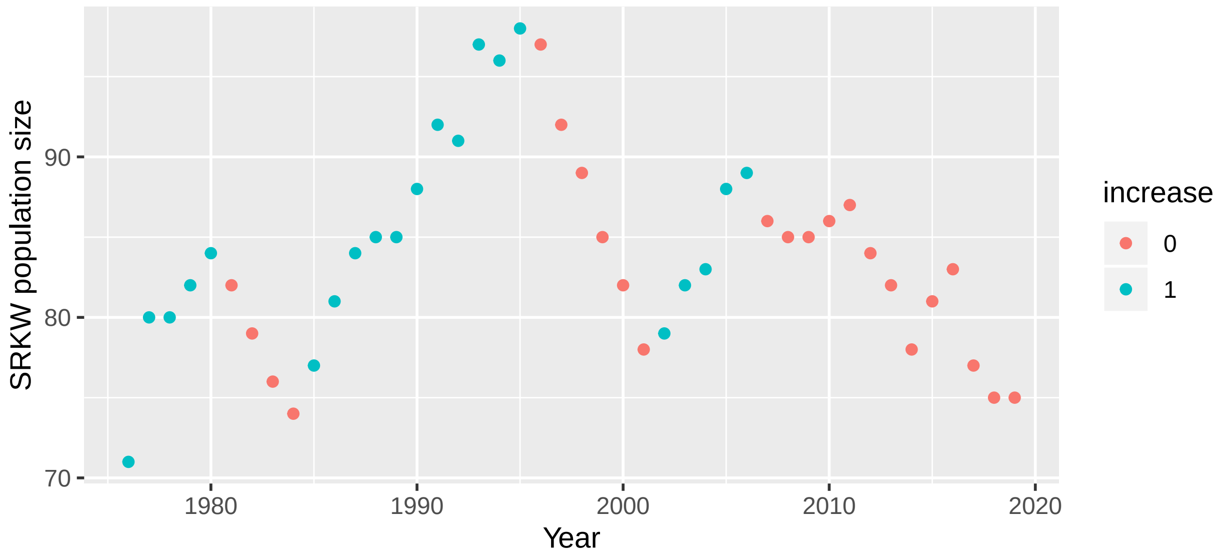

Figure 4: Indicator of SRKW population growth

year	total
2018	75
2019	75

Aggregating metrics

We can start by creating a data frame from the 4 metrics above: fecundity rates, survival rates, occurrence of peanut head whales.

year	fec_rate	surv_rate	peanut_rate	increase
1976	0.212	0.997	2.220446e-16	1
1977	0.161	0.996	2.220446e-16	1
1978	0.126	0.995	2.220446e-16	1
1979	0.107	0.993	2.220446e-16	1
1980	0.103	0.991	4.462297e-16	1
1981	0.112	0.990	4.997984e-15	0
1982	0.135	0.989	5.559651e-14	0
1983	0.166	0.989	5.815147e-13	0
1984	0.200	0.989	5.543858e-12	0
1985	0.224	0.990	4.873247e-11	1
1986	0.231	0.990	4.177929e-10	1
1987	0.221	0.991	3.791184e-09	1
1988	0.202	0.991	3.914522e-08	1
1989	0.182	0.992	4.706515e-07	1
1990	0.168	0.991	6.232470e-06	1
1991	0.162	0.991	7.896024e-05	1
1992	0.164	0.989	7.809630e-04	1
1993	0.170	0.987	4.848190e-03	1
1994	0.174	0.985	1.588854e-02	1
1995	0.173	0.981	2.552118e-02	1

year	fec_rate	surv_rate	peanut_rate	increase
1996	0.165	0.977	2.122002e-02	0
1997	0.151	0.972	1.091932e-02	0
1998	0.138	0.970	4.521171e-03	0
1999	0.129	0.969	1.996213e-03	0
2000	0.128	0.971	1.182963e-03	0
2001	0.136	0.974	1.063923e-03	0
2002	0.154	0.978	1.439938e-03	1
2003	0.178	0.982	2.585670e-03	1
2004	0.203	0.984	5.060086e-03	1
2005	0.222	0.986	8.806674e-03	1
2006	0.229	0.986	1.175171e-02	1
2007	0.223	0.985	1.139874e-02	0
2008	0.210	0.984	8.443292e-03	0
2009	0.196	0.982	5.423702e-03	0
2010	0.187	0.979	3.538308e-03	0
2011	0.184	0.977	2.686805e-03	0
2012	0.186	0.976	2.559278e-03	0
2013	0.188	0.977	3.051588e-03	0
2014	0.181	0.978	4.260147e-03	0
2015	0.161	0.980	6.309109e-03	0
2016	0.129	0.983	9.054685e-03	0
2017	0.092	0.986	1.196960e-02	0
2018	0.060	0.988	1.457231e-02	0

Clustering this kind of data is a little complicated because of mixed types; all variables are continuous, but the population increase is a categorical variable. One option is to use the R package 'clustMixType' for clustering mixed type data.

We'll try applying this with 2:4 clusters.

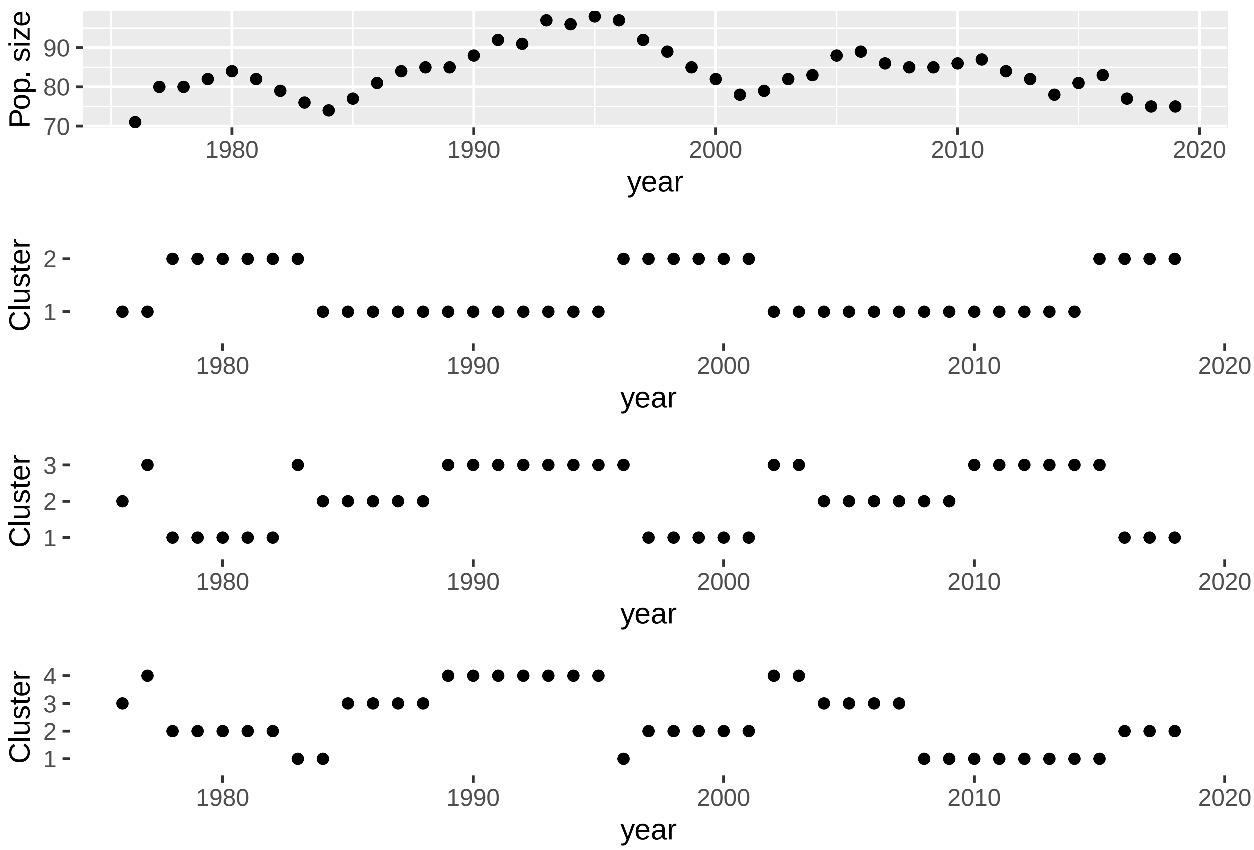

Figure 5: Results from clustering with 2:4 clusters and all years