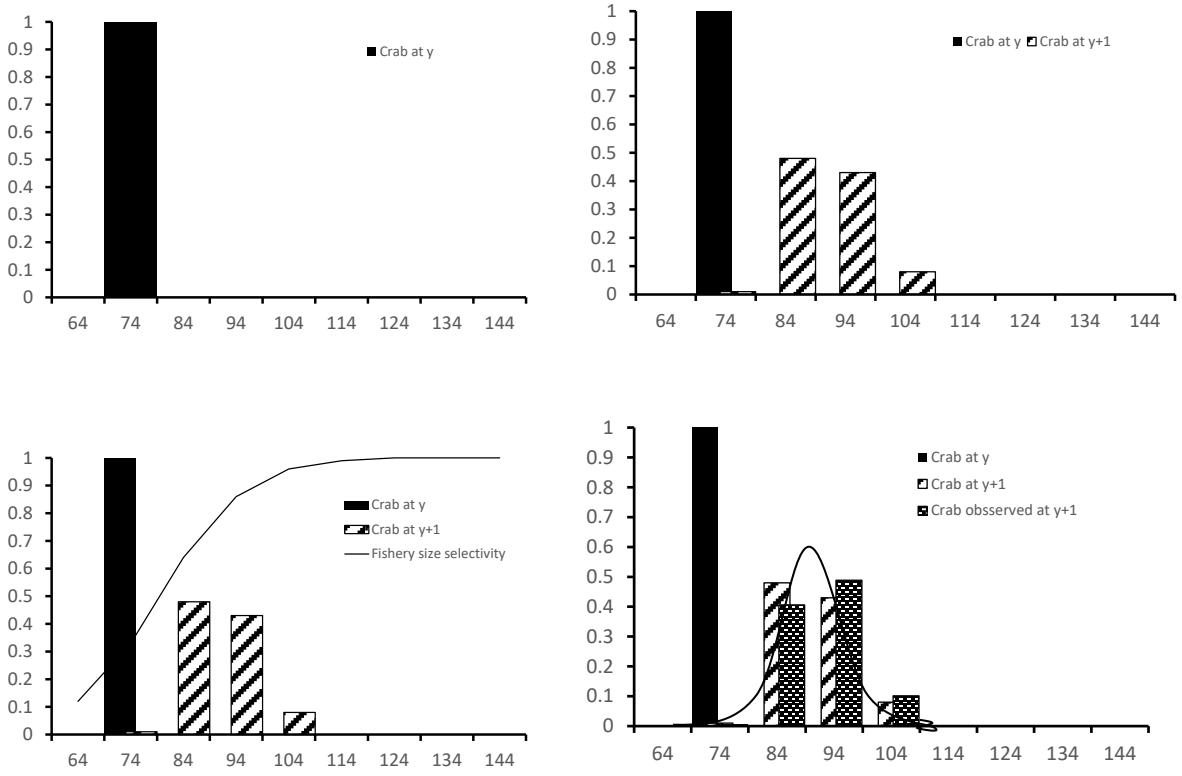
Appendix C

Norton Sound Red King Crab tag recovery data.

In the Norton Sound red king crab assessment model tag-recovery size distribution data are used to estimate size-transition matrix that is a probability distribution of each size class at year **y** to transitioning to other size classes at year **y+1**. The size transition matrix is a combined probability of 1) probability of crab did not molt and 2) conditional probability of post-molt growth given that the crab is molted.

As illustrated in Figure 1, crab of a size class tagged and released at year y will transition to multiple size classes at year y+1 (size transition probability). **The crab that remained in the same size class in year y+1 are either (1) crab did not molt, or molted but small growth.** The crabs will be captured by fishery that has size selectivity probability. Size distribution of the recovered tagged crab at year y+1 is a combination of both size transition matrix and fishery size selectivity. For estimating size transition matrix, probability of post-molt size distribution was fitted to a normal distribution and molt probability is estimated from observed proportion of new-old shell from commercial catch and trawl survey data.

Figure 1: Tag recovery process



Assembly of tag recovered data.

In Norton Sound, tag-recovery operations were conducted largely in 3 periods:1980-1985, 1986-2010, and 2012-2015. The first period was conducted as a part of mark-recapture experiment during summer commercial fishery period. The second periods were conducted as a part of winter pot survey. And the third was conducted as a part of migration study.

Table 1: NSRKC Tag-recovery data

Year		n	Tagged size (CL mm)
1980-1985	Summer Mark-Recapture	281	64-140
1986-2010	Winter Pot Survey	475	67-133
2012-2015	NPRB tagging	2170	71-145

All tagged crabs were recovered from by commercial or subsistence fisheries. The recovered crabs (if brought by a fishermen) were measured. **Shell condition (New vs Old) at the time of tagging and recovery were not always recorded, especially before 2012.** All tagged crabs were recovered from 0 to 6 years

Table 2: The number of crab recovered years at large.

Years liberty	n
0	850
1	1112
2	549
3	269
4	107
5	30
6	7

Data Cleaning and processing

The data were cleaned as follows

1. Convert each tagging and recovered length to 8 length classes

2. Remove data that were captured within a year (0 year at liberty).
   Tagging occurred in winter-summer and recovery occurred in summer. NSRKC molts in late fall, so that molting does not occur if they were recovered within the same year.

3. Separate tag recovery data pre and post 1993 to reflect changes of fishery (large boat to small boat fishery).

This was done under the assumption that fishery size selectivity curve (i.e., recapture probability) differ between the two fishery periods. However, because the assessment model estimate only 1 selectivity for summer commercial fishery, the data were later combined.

4. Remove data recovered size class was smaller than tagged size class (Table 3)
   Assumed that crab does not shrink.

5. Calculate proportion by size class (Table 4)

Table 3. The number of tagged data released and recovered after 1 year – 6 year during 1980-1992 and 1993-2019 periods. Bold numbers indicate crab with smaller recovery size (and thus removed).

Year: 1980-1992: Year at liberty 1

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	1	1	0	0	0	0	0
74-83	0	0	0	0	0	0	0	0
84-93	0	0	0	5	10	0	0	0
94-103	0	0	0	3	31	26	2	0
104-113	0	0	0	**1**	16	34	7	0
114-123	0	0	0	0	0	16	26	5
124-133	0	0	0	0	0	0	15	10
>134	0	0	0	0	0	0	0	15

Year: 1980-1992: Year at liberty 2

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	1	0	0	0	0
74-83	0	0	0	0	2	0	0	0
84-93	0	0	0	0	2	1	0	0
94-103	0	0	0	0	1	1	0	0
104-113	0	0	0	0	0	13	6	0
114-123	0	0	0	0	0	2	9	1
124-133	0	0	0	0	0	0	0	4
>134	0	0	0	0	0	0	0	6

Year: 1980-1992: Year at liberty 3

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	0	0	0	0	0
74-83	0	0	0	0	0	2	0	0
84-93	0	0	0	0	0	1	0	0
94-103	0	0	0	0	1	3	1	0
104-113	0	0	0	0	0	0	3	0
114-123	0	0	0	0	0	0	1	0
124-133	0	0	0	0	0	0	0	2
>134	0	0	0	0	0	0	0	1

Year: 1980-1992: Year at liberty 4

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	0	1	1	0	0
74-83	0	0	0	0	0	0	0	0
84-93	0	0	0	0	1	1	1	0
94-103	0	0	0	0	0	0	1	0
104-113	0	0	0	0	0	0	1	1
114-123	0	0	0	0	0	0	0	1
124-133	0	0	0	0	0	0	0	0
>134	0	0	0	0	0	0	0	0

Year: 1980-1992: Year at liberty 5

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	0	0	0	0	0
74-83	0	0	0	0	0	2	0	0
84-93	0	0	0	0	0	0	1	0
94-103	0	0	0	0	0	0	0	1
104-113	0	0	0	0	0	0	0	0
114-123	0	0	0	0	0	0	0	0
124-133	0	0	0	0	0	0	0	0
>134	0	0	0	0	0	0	0	0

Year: 1993-2021: Year at liberty 1

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	3	0	0	0	0	0
74-83	0	0	21	22	4	0	0	0
84-93	0	0	0	42	81	7	1	0
94-103	0	0	**1**	7	165	82	0	1
104-113	0	0	0	0	59	109	15	0
114-123	0	0	0	0	**4**	72	72	19
124-133	0	0	0	0	0	**7**	41	15
>134	0	0	0	0	**1**	0	0	11

Year: 1993-2021: Year at liberty 2

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	1	5	4	0	0	0
74-83	0	0	0	12	94	5	0	0
84-93	0	0	0	5	34	69	3	0
94-103	0	0	0	2	33	38	19	0
104-113	0	0	0	0	7	64	18	0
114-123	0	0	0	0	**2**	9	38	6
124-133	0	0	0	0	0	**1**	9	12
>134	0	0	0	0	0	0	0	2

Year: 1993-2021: Year at liberty 3

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	0	11	11	0	0
74-83	0	0	0	0	19	46	6	0
84-93	0	0	0	2	14	27	9	0
94-103	0	0	0	0	2	32	13	0
104-113	0	0	0	0	0	9	18	4
114-123	0	0	0	0	0	0	10	3
124-133	0	0	0	0	0	0	1	7

>134	0	0	0	0	0	0	0	0

Year: 1993-2021: Year at liberty 4

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	0	3	5	1	0
74-83	0	0	0	0	4	17	11	1
84-93	0	0	0	0	1	9	12	2
94-103	0	0	0	0	0	3	5	1
104-113	0	0	0	0	0	3	9	1
114-123	0	0	0	0	0	0	1	4
124-133	0	0	0	0	0	0	0	1
>134	0	0	0	0	0	0	0	0

Year: 1993-2021: Year at liberty 5

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	0	1	1	0	2
74-83	0	0	0	0	1	2	3	0
84-93	0	0	0	0	0	3	4	1
94-103	0	0	0	0	0	0	1	1
104-113	0	0	0	0	0	1	1	1
114-123	0	0	0	0	0	0	1	0
124-133	0	0	0	0	0	0	0	0
>134	0	0	0	0	0	0	0	0

Year: 1993-2021: Year at liberty 6

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134
64-73	0	0	0	0	1	0	1	0
74-83	0	0	0	0	0	1	2	0
84-93	0	0	0	0	0	0	0	0
94-103	0	0	0	0	0	0	0	1
104-113	0	0	0	0	0	0	0	1
114-123	0	0	0	0	0	0	0	0

124-133	0	0	0	0	0	0	0	0
>134	0	0	0	0	0	0	0	0

Table 4: Observed transition size distribution fitted by the assessment model
Year at liberty 1

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134	n
64-73	0	0.2	0.8	0	0	0	0	0	5
74-83		0	0.44	0.47	0.09	0	0	0	47
84-93			0	0.32	0.62	0.05	0.01	0	146
94-103				0.03	0.62	0.34	0.01	0.00	317
104-113					0.31	0.59	0.09	0	241
114-123						0.42	0.47	0.11	210
124-133							0.69	0.31	81
>134								1	26

Year at liberty 2

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134	n
64-73	0	0	0.09	0.55	0.36	0	0	0	11
74-83		0	0	0.11	0.85	0.04	0	0	113
84-93			0	0.04	0.32	0.61	0.03	0	114
94-103				0.02	0.36	0.41	0.20	0	94
104-113					0.06	0.71	0.22	0	108
114-123						0.17	0.72	0.11	65
124-133							0.36	0.64	25
>134								1	8

Year at liberty 3

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134	n
64-73	0	0	0	0	0.5	0.5	0	0	22
74-83		0	0	0	0.26	0.66	0.082	0	73
84-93			0	0.04	0.26	0.53	0.17	0	53

94-103				0	0.06	0.67	0.27	0	52
104-113					0	0.26	0.62	0.12	34
114-123						0	0.79	0.21	14
124-133							0.1	0.9	10
>134								1	1

Estimates of tag recovery

The observed proportion of released tagged length class *l'* crab recovered after *t-th* year with length class of *l* by a fishery of *s-th* selectivity (S_l) was assumed to be proportional to the growth matrix, catch selectivity, and molting probability (m_l) as

$$\hat{P}_{l',l,t,s} = \frac{S_l \cdot [X^t]_{l',l}}{\sum_{l=1}^{n} S_l \cdot [X^t]_{l',l}} \tag{1}$$

where X is a molting probability adjusted growth matrix with each component consisting of

$$X_{l',l} = \begin{cases} m_{l'} \cdot G_{l',l} & \text{when } l' \neq l \\ m_l \cdot G_{l',l} + (1\text{-}m_i) & \text{when } l' = l \end{cases} \tag{2}$$

Where growth matrix $G_{l',l}$ (the expected proportion of crab molting from length class l' to length class l) was μ

assumed to be normally distributed:

$$G_{l',l} = \begin{cases} \dfrac{\int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2) dL}{\sum_{l=1}^{n} \int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2) dL} & \text{when } l \geq l' \\ 0 & \text{when } l < l' \end{cases} \tag{3}$$

Where

$$N(x \mid \mu_{l'}, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(L - \mu_{l'})^2}{\sigma^2} \right)$$

$$lm_l = L_1 + st \cdot l$$

$$\mu_l = L_1 + \beta_0 + \beta_1 \cdot l$$

Note

It should be noted that transition probability is based on size classes of both **molted and unmolted (without shell condition)**. Transition matrix does not include shell conditions. In the assessment model, molting probability is estimated by observed shell condition of trawl survey and commercial catch. **Individual crab growth increments was NOT calculated** in the above operation. At individual crab level, there were many crabs with growth increment of+/- 3mm that could be **umolted, molted but small growth, or measurement error**. Whether or not considering them as unmolted (i.e growth = 0) does not change size distribution unless crabs of the length are at the border between two size classes. In that case, growth increments of +/- 3mm will put the crab to adjacent class size. However, almost all of those crabs remain in the same size class, so that correction is unnecessary.

In model fitting, mean growth (μ) is should be considered as *ad hoc* mean growth mean that were conventionally estimated to fit the observed size distribution. Thus, μ does not necessarily indicate mean molting growth.