Appendix C

Norton Sound Red King Crab Summer Commercial Fishery Discard Estimation

Formal methodologies have not been established for estimating Red King Crab discards by Norton Sounds Summer commercial fishery from observer data. Here, I describe a few methods and discuss pros and cons of each method.

Data source and description of survey protocols

Norton Sound Summer Commercial fishery observer survey started in 2009 as a potential feasibility project, and formal data collection started since 2012. The observer survey in Norton Sound is voluntary. Due to small boat size, the boat that can take a fishery observer is limited. Fishery observer often work as a crew member. During the fishery, an observe inspect every pots. All lengths/shell condition/sex of red king crab in the pots were measured, and the fisherman sorts out discards that are noted. **Observed discarded crab are deemed accurate.** However, it is uncertain whether fishing behaviors of the volunteer fishermen are the same as other unobserved fishermen. Observed fishermen tend to have large boat and catcher and sellers. Here are possible concerns:

1. The observed fishermen may go to better fishing grounds with more legal crab and less sub-legals: **higher legal retain CPUE and lower discards CPUE than unobserved (lower discards proportion)**
2. The observed fishermen may not mind sorting out crab and may choose areas: **higher legal retain CPUE and higher discards CPUE than unobserved (higher discards proportion)**
3. The observed fishermen may keep more legal crab that are not accepted by NSEDC: **lower discard CPUE than unobserved (lower discard proportion)**

Data Source & Cleaning

From 2012 to 2018, crab catches of 3-4 volunteer crab fishing vessels were observed. Annual observed pots ranged 69 to 199 and total observed crab ranging from 2200 to 5300 (Table 1). All observed data were combined.

Estimation Methods

Every estimation method is based on expanding observed discards

Observer survey data	Fish Ticket data
Sublegal crab discards (n_{sub})	*NA*
Legal crab discards (n_{ld})	*NA*

Legal crab retained (n_{lr})	Total Legal crab retained (N_{LR})
Pot lifts (p_l)	Total Pot lifts (P_L)
Total discards ($n_d = n_{sub} + n_{ld}$)	*NA*: Total Discards (D)
Total catch ($n_t = n_{sub} + n_{ld} + n_{lr}$)	*NA*: Total Catch (N_T)

LNR method

LNR method simply **expands observed discards CPUE (cp_d)** to total pot lifts. This method assumes **accurate discarded crab** and observed discards CPUE (cp_d) is representative of all fishermen.

$$cp_d = \frac{(n_{sub} + n_{ld})}{p_l} \qquad D_{LNR} = cp_c \cdot P_L$$

LNR2 method

Observer bias corrected LNR method (LNR2) acknowledges that observed discards CPUE may not be representative of all fishermen, so that observed discards CPUE needs to be adjusted. However because the data are not directly available, the correction is approximated by taking retained CPUE by observed fishermen to all fishermen as follows:

$$CP_{obs} = \frac{N_{LR.obs}}{P_{L.obs}} \qquad CP = \frac{N_{LR}}{P_L}$$

Where $N_{LR.obs}$ and $P_{L.obs}$ are total number of retained crab and pot lifts of the observed fishermen from the fish ticket database, and N_{LR} and P_L total number of crab and pot lifts by all fishermen.

$$D_{LNR2} = \left(\frac{CP}{CP_{obs}} \right) \cdot D_{LNR}$$

Subtraction method

Subtraction method expands **total catch CPUE** and subtracts total retained catch. This method does **NOT** assume **accurate discarded crab** but assume **accurate total catch crab**

$$cp_t = \frac{n_t}{p_l} \qquad D_{Sub} = cp_t \cdot P_L - N_{LR}$$

Subtraction2 method

Similar to LNR2, bias corrected Subtraction method is simply bias corrected total catch minus retained catch

$$D_{Sub2} = \left(\frac{CP}{CP_{obs}} \right) \cdot cp_t \cdot P_L - N_L$$

Ratio method

The ratio method expands observed ratio of discards to retained to total retained. This method assumes observed discards to retained ratio is accurate and representative.

$$D_{prop} = \frac{n_d}{n_{lr}} N_{LR}$$

Methods	Estimation methodology	Assumption	Issue
LNR	Estimate total discards from observed discards CPUE	Accurate observed discards & CPUE	Observer may not know true discards.
Subtraction	Estimate total catch from observed total catch CPUE **and then subtract observed retained**	Accurate observed total catch & CPUE	Discards can be < 0, when total catch CPUE is underestimated.
Ratio	Estimate total discards from observed discard/retained ratio.	Accurate discards/retained ratio.	Discards/retained ratio may differ greatly among fishermen

Table

Results

While general annual discard trends were similar among the 3 methods, the number of discards differed (Table 2). Overall, the Subtraction method estimated the highest and the ratio method estimated the lowest. Bias correction method (LNR2, Sub2) reduced discard estimates during 2013-2017 (Table 3).

Discussion

The CPUE method assumes that observed CPUE would represent total CPUE or that there is no difference in **CPUE** between observed and unobserved fishermen. Difference between LNR and Subtraction method is that LNR method assumes that **observed discards are accurate** whereas subtraction method assumes that **observed discards are biased but observed total catches are accurate.** On the other hand, the proportional method assumes that observed discard proportions would represent total proportion or that **every fisherman has a similar crab composition**.

In Norton Sound observer survey, discarded crab are more likely accurate because separation of retained vs discards are often done in cooperation with the fishermen. However, fishermen and timing of observation are limited to convenience of volunteer fishermen who have larger boats (so that observer can be on board) and are also high catchers. They would be more efficient in catching legal crab with fewer discards than those with small boats. They would also take observers when they expect higher catch. In fact, season total retained legal crab CPUE by observed fishermen were generally higher than other unobserved fishermen (Table 2). Furthermore, their CPUE was generally higher during the periods when observers were on board. Observed fishermen appeared to go different fishing area from those of all fishermen (Table 4). Those suggest that subtraction method would probably overestimate discards. Direction of bias for LNR and proportional methods are difficult to evaluate. If the observed fishermen tend to better avoid catching sublegal crab (e.g., lower sublegal proportion), the proportional method would underestimate discard catch. But, as they have higher catch CPUE, their discard catch CPUE could still be higher than those of unobserved fishermen. Then, discard catch estimate by LNR method could overestimate as well as underestimate.

Table 1. Observed pot lifts, catch, and total pot lifts and catch from 2012 to 2018

	Observer Survey					Fish Tickets	
	Pot lifts	Sublegal	Legal retained	Legal discards		pot lifts	Retained
Year	p_l	n_{sub}	n_{lr}	n_{ld}	Female	P_L	N_{LR}
2012	78	898	1055	177	152	10041	161113
2013	199	2775	2166	258	123	15058	130603
2014	147	1504	1838	341	104	10127	129656
2015	69	969	1676	577	224	8356	144224

2016	67	264	1700	169	878	8,009	138997
2017	110	432	2174	122	373	9440	135322
2018	78	547	1096	10	574	8797	89613
2019	28	123	142	1	89	5436	24913

Table 2. Retained Crab CPUE between observed during the observer survey, and season total CPUE between observed and unobserved fishermen derived from fish ticket data.

Year	CP_{obs}	CP
2012	13.53	16.05
2013	10.88	8.67
2014	12.50	12.80
2015	24.29	17.26
2016	25.37	17.36
2017	19.76	14.33
2018	14.05	10.19
2019	5.07	4.58

Table 3. The number of discarded crab estimated by 5 methods and model.

Year	LNR	LNR2	Sub	Sub2	Prop	Model
2012	138386	150043	113084	136182	164167	94564
2013	229502	173750	262797	167229	182880	120486
2014	127104	104697	124070	79340	130150	147066
2015	187223	135910	245965	139023	133037	88430
2016	51760	32965	115976	23394	35403	50228
2017	47543	34870	98790	36384	34484	46441
2018	62820	60714	96816	90566	45542	45848
2019	24074	23362	26729	24203	21755	28887

Table 4. Average legal crab proportion caught by 2012-2018 trawl survey and Summer commercial harvest proportion in major fishing stat area

	Catch proportion	
STAT Area	All fishermen	Observed Fishermen
666401	15%	7%
656401	21%	18%
646401	19%	46%
636401	33%	19%

626401	15%	2%

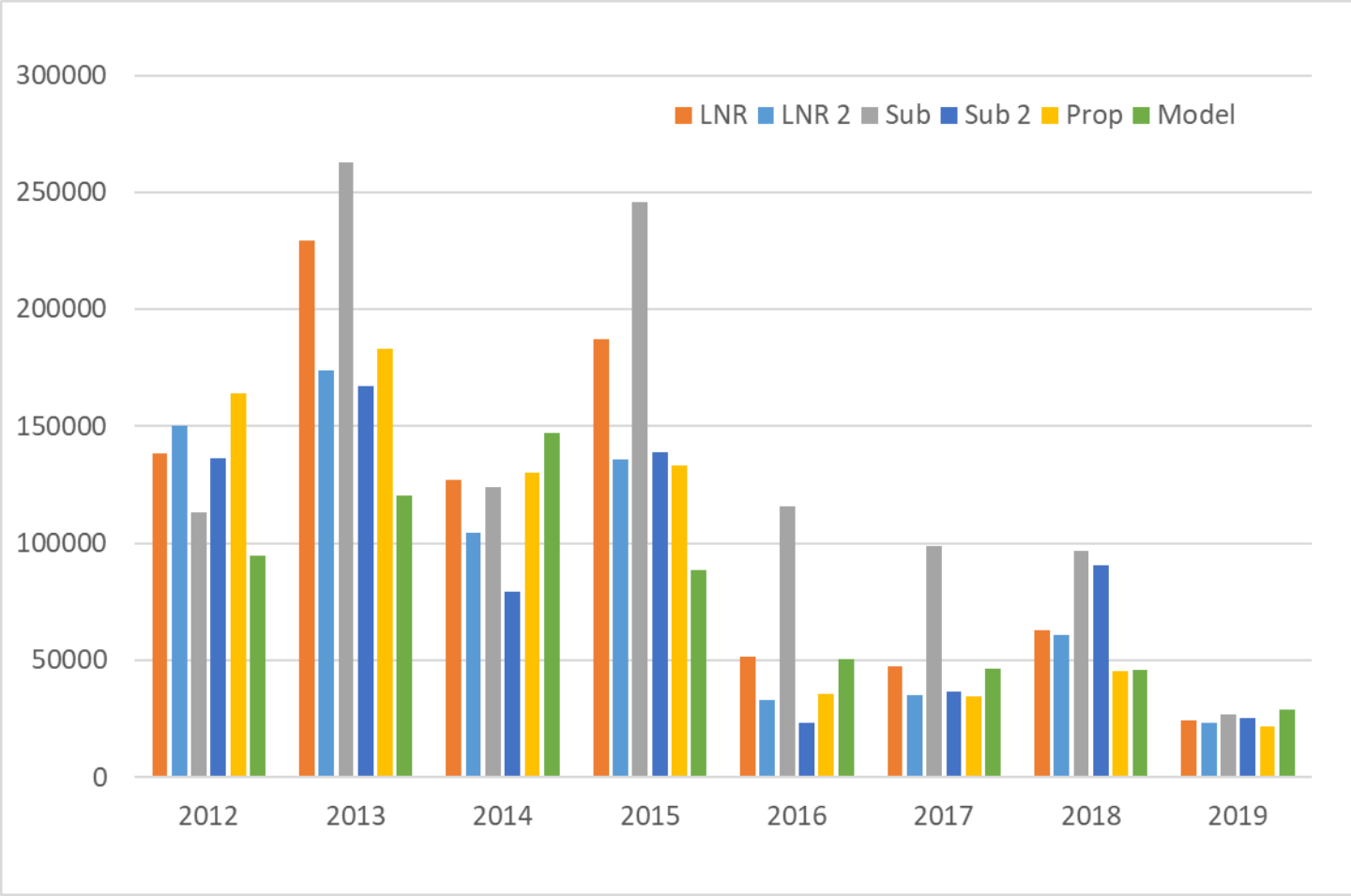

Figure 1. The number of discarded crab estimated by 3 methods.

Discards Estimate without observer survey

Norton Sound red king crab fishery observer program was terminated in 2020, while NSRKC OFL is total OFL (i.e. sum retained and discard OFL). Such that total discards need to be estimated. Given that the NSRKC observer survey and estimation of discards are <u>*ad hoc*</u>, developing a method for estimating discards biomass is also *ad hoc* and highly speculative.

Here I present an intended method for estimating discards mortality biomass when observer data are available. This method can also be used for estimation of discards when the data are not available.

When an observer survey is conducted and observer discards and the size distribution are available, discards abundance and biomass can be estimated as follows:

1. Estimate the number of discarded crab (D_n) using the ratio method.

$$D_n = \frac{n_d}{n_{lt}} N_{LR} = r_{dis} \cdot N_{LR}$$

2. Estimate biomass of discarded crab (D_b)

$$D_b = D_n \sum_l p_{dis,l} \cdot wm_l = D_n \cdot w_{dis}$$

where $p_{dis,l}$ is the length (l) proportions of observed discarded crab, wm_l is the average weight of each length class (l) and w_{dis} is a discard biomass unit per discarded crab.

Combine the above two equations, and discarded crab biomass is expressed as

$$D_b = r_{dis} \cdot w_{dis} \cdot N_{LR}$$

Applying discards mortality of 0.2, **unretained catch biomass can be estimated as $0.2 \cdot D_b$, or $0.2 \cdot r_{dis} \cdot w_{dis} \cdot N_{LR}$,** is a discard mortality biomass unit per retained crab (*Mort lb*).

Mean Mort lb method

Mort lb method is applying mean observed Mort lb to observed Total retained catch, or

$$\textit{Unretained catch biomass} = \textit{mean(Mort lb)} \cdot N_{LR} = 0.252 \cdot N_{LR}$$

During the 2012-2019 periods, discarded crab size proportions, r_{dis}, w_{dis}, and *Mort lb* are calculated as follows.

Size class	2012	2013	2014	2015	2016	2017	2018	2019	Average	Weight wm (lb)
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.09
44	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.18
54	0.07	0.11	0.01	0.00	0.01	0.02	0.04	0.18	0.06	0.32
64	0.11	0.30	0.04	0.02	0.04	0.10	0.09	0.24	0.12	0.54
74	0.07	0.25	0.10	0.08	0.05	0.16	0.18	0.10	0.12	0.81
84	0.12	0.13	0.27	0.18	0.17	0.14	0.36	0.12	0.19	1.17
94	0.24	0.14	0.43	0.47	0.53	0.30	0.30	0.27	0.34	1.72
104	0.19	0.04	0.13	0.21	0.18	0.26	0.02	0.02	0.13	2.35
114	0.14	0.00	0.01	0.03	0.02	0.01	0.00	0.00	0.03	3.02
124	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	3.71
134	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.30
$_{wdis}$	1.75	0.90	1.51	1.72	1.65	1.54	1.22	0.94	1.40	
r_{dia}	1.96	1.40	1.02	0.92	0.25	0.25	0.50	0.87	0.90	
$r_{dis} \cdot w_{dis}$	3.43	1.27	1.53	1.58	0.42	0.39	0.61	0.82	1.26	
Mort lb	0.686	0.254	0.306	0.316	0.084	0.078	0.122	0.164	0.252	

Mort lb ranged from 0.078 to 0.786, with the mean of 0.252. In the absence of observer data, unretained crab mortality can be estimated as $0.252N_{ret}$. However, this also indicates that applying the mean would overestimate unretained catch by 3.2 times (0.252/0.078) or underestimate it by 0.38 times (0.252/0.686).

Trawl Survey adjusted method

Trawl survey adjusted method uses **trawl survey length proportion data as a proxy for true length proportions.** The model estimated trawl survey selectivity is 1.0 for all lengths, which indicates that trawl survey length composition equals NSRKC length proportion.

Discards length proportion $p_{dis,l}$ can be estimated by multiplying model estimated fishery selectivity (S_l) and 1- retention probability ($S_{ret,l}$)

$$p_{dis,l} = p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret.l}\right)$$

Then calculate discards-retained ratio (r_{dis}) as

$$r_{dis} = \frac{\sum_l p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret,l}\right)}{\sum_l p_{twl,l} \cdot S_l \cdot S_{ret,l}}$$

The discard biomass unit (w_{dis}) is

$$w_{dis} = \frac{\sum_l p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret,l}\right) \cdot wm_l}{\sum_l p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret,l}\right)}$$

During the 2012-2019 periods, trawl survey occurred in 2014, 2017, 2018, and 2019. The table below shows trawl survey length proportion, and model estimated selectivity and retention probability from the 2021 assessment model.

Size class	2014	2017	2018	2019	Selectivity (2021)	Retention (2021)	lb
34	0.01	0.11	0.02	0.00	0.00	0.00	0.09
44	0.00	0.02	0.33	0.00	0.01	0.00	0.18
54	0.01	0.01	0.42	0.02	0.04	0.00	0.32
64	0.01	0.06	0.08	0.13	0.12	0.00	0.54
74	0.07	0.12	0.05	0.47	0.33	0.00	0.81
84	0.14	0.11	0.02	0.26	0.64	0.00	1.17
94	0.25	0.06	0.02	0.04	0.86	0.07	1.72
104	0.27	0.09	0.01	0.02	0.96	0.88	2.35
114	0.14	0.13	0.01	0.01	0.99	1.00	3.02
124	0.06	0.23	0.01	0.02	1.00	1.00	3.71
134	0.02	0.07	0.02	0.03	1.00	1.00	4.30
w_{dis}	1.56	1.28	0.92	1.04			
r_{dis}	0.75	0.35	1.53	4.72			
$r_{dis} \cdot w_{dis}$	1.18	0.45	1.41	4.92			
Mort lb	0.236	0.090	0.282	0.984			
% Deviation	-22.9	+15.4	-56.7	+500			

Among the 4 years, the model estimated *Mort lb* multiplier ranged from 0.090 to 0.984. Comparing the model with observed, the model deviation ranged from -22% to +500%. The deviation was greater in 2018 and 2019.

The major difficulty is inferring the amount and length composition of **unobserved and discarded crabs. Retained catch has no information about the proportion of sublegal crab that are discarded and never observed.** Mean Mort lb method ignores the annual variations. Alternative models attempts to estimate annual variations with model estimated selectivity and retention probability; however, this also generates highly variable estimates.