Energy requirements and salmon consumption by Southern Resident killer whales in their summer range

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[Noren 2011; Hanson, Ward, and Noren (in prep); Williams *et al.* 2011]

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Purpose

1) Describe two methods of estimating SRKW daily prey energy requirements (Noren 2011, Williams *et al.* 2011)

2) Describe two methods of estimating SRKW Chinook salmon consumption, relative to Chinook abundance, in the SRKW summer range (Williams *et al.* 2011, Hanson *et al.* in prep)

3) Assess the potential for Chinook salmon abundance to impact SRKWs

Noren 2011 Approach to Calculating DPER

1) Estimated SRKW field metabolic rates (FMR: 5-6X Kleiber predicted BMR)

-Based on several published values from otariids and delphinids

-Validated by FMRs calculated from activity budgets, swim speeds (Ford 1989, D. Noren unpub. data), and published NRKW COT equations (Williams and Noren 2009)

Noren 2011 Approach to Calculating DPER

Table 1. FMRs for adult male and female Northern Resident killer whales calculated from daily activity budgets.

Activity state[a] (% of 24 h day engaged in activity, mean swimming speed during activity)	Daily adult male (4,434 kg) FMR[b]	Daily adult female (3,338 kg) FMR[c]
Foraging (66.5%, 1.7 m/s)	780.7 MJ (186,585.8 kcal)	428.7 MJ (102,462.8 kcal)
Travelling (4.2%, 2.9 m/s)	50.4 MJ (12,038.8 kcal)	27.5 MJ (6,575.9 kcal)
Resting (13.2%, 0.8 m/s)	150.4 MJ (35,936.6 kcal)	83.2 MJ (19,883.7 kcal)
Socializing (11.6%, 1.1 m/s)	133.8 MJ (31,985.5 kcal)	73.8 MJ (17,641.3 kcal)
Beach-rubbing (4.5%, speed not available but assumed to be 0.8 m/s [speed for resting], since beach rubbing whales do not move through the area very quickly and rubbing behavior was often accompanied by resting among nearby animals ([Ford 1989]).	51.3 MJ (12,251.1 kcal)	28.4 MJ (6,778.5 kcal)
Total daily energy budget (24 h)	1,166.5 MJ (278,797.8 kcal)	641.6 MJ (153,342.2 kcal)
Daily energy budget relative to Kleiber (1975) predicted basal metabolic rate (BMR) values	7.3× Kleiber	5.0× Kleiber

[a]Percentage of time Northern Resident killer whales were observed in five activity states and mean swimming speed during each activity from Ford (1989). Ford (1989) reported percentages based on 416 total h of observations collected on 93 d. For this illustration, these percentages were also assumed to apply to a 24 h activity budget.

[b]Energy expenditure was calculated using the speed for each activity state from Ford (1989) and the cost of swimming at that speed (calculated from the *COT* regression equation for adult males from Williams and Noren 2009), with the assumption that whales maintained a constant swimming speed during the entire period they were engaged in each activity state.

[c]Energy expenditure was calculated using the speed for each activity state from Ford (1989) and the cost of swimming at that speed (calculated from the *COT* regression equation for adult females without calves from Williams and Noren 2009), with the assumption that whales maintained a constant swimming speed during the entire period they were engaged in each activity state.

Table 2. FMRs for adult male and female Southern Resident killer whales calculated from daily activity budgets.

Activity state[a] (% of 24 h day engaged in activity, mean swimming speed during activity)	Daily adult male (4,434 kg) FMR[b]	Daily adult female (3,338 kg) FMR[c]
Foraging (21%, 1.1 m/s)	242.3 MJ (57,904.7 kcal)	133.6 MJ (31,936.9 kcal)
Travelling (70.4%, 2.2 m/s)	835.0 MJ (199,576.1 kcal)	457.4 MJ (109,314.2 kcal)
Resting (6.8%, 0.8 m/s)	77.5 MJ (18,512.8 kcal)	42.9 MJ (10,243.1 kcal)
Socializing (1.8%, 0.3 m/s)	19.7 MJ (4,711.9 kcal)	11.0 MJ (2,632.8 kcal)
Total daily energy budget (24 h)	1174.5 MJ (280,705.5 kcal)	644.9 MJ (154,126.9 kcal)
Daily energy budget relative to Kleiber (1975) predicted basal metabolic rate (BMR)	7.4× Kleiber	5.0× Kleiber

[a]Percentage of scan samples collected on a 10-min interval ($n = 571$ sampling intervals) that Southern Resident killer whales were observed in four activity states (Noren *et al.* 2009, D. Noren, unpublished data). The mean swimming speed for each activity state was calculated from speeds of individual male and female focal whales recorded during each state (D. Noren, unpublished data). Data were collected during daylight hrs only, but for this illustration, it is assumed that the percentages approximate percentages of a 24 h activity budget.

[b]Energy expenditure was calculated using the speed for each activity state (D. Noren, unpublished data) and the cost of swimming at that speed (calculated from the *COT* regression equation for adult males from Williams and Noren 2009), with the assumption that whales maintained a constant swimming speed during the entire period they were engaged in each activity state.

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From Noren (2011)

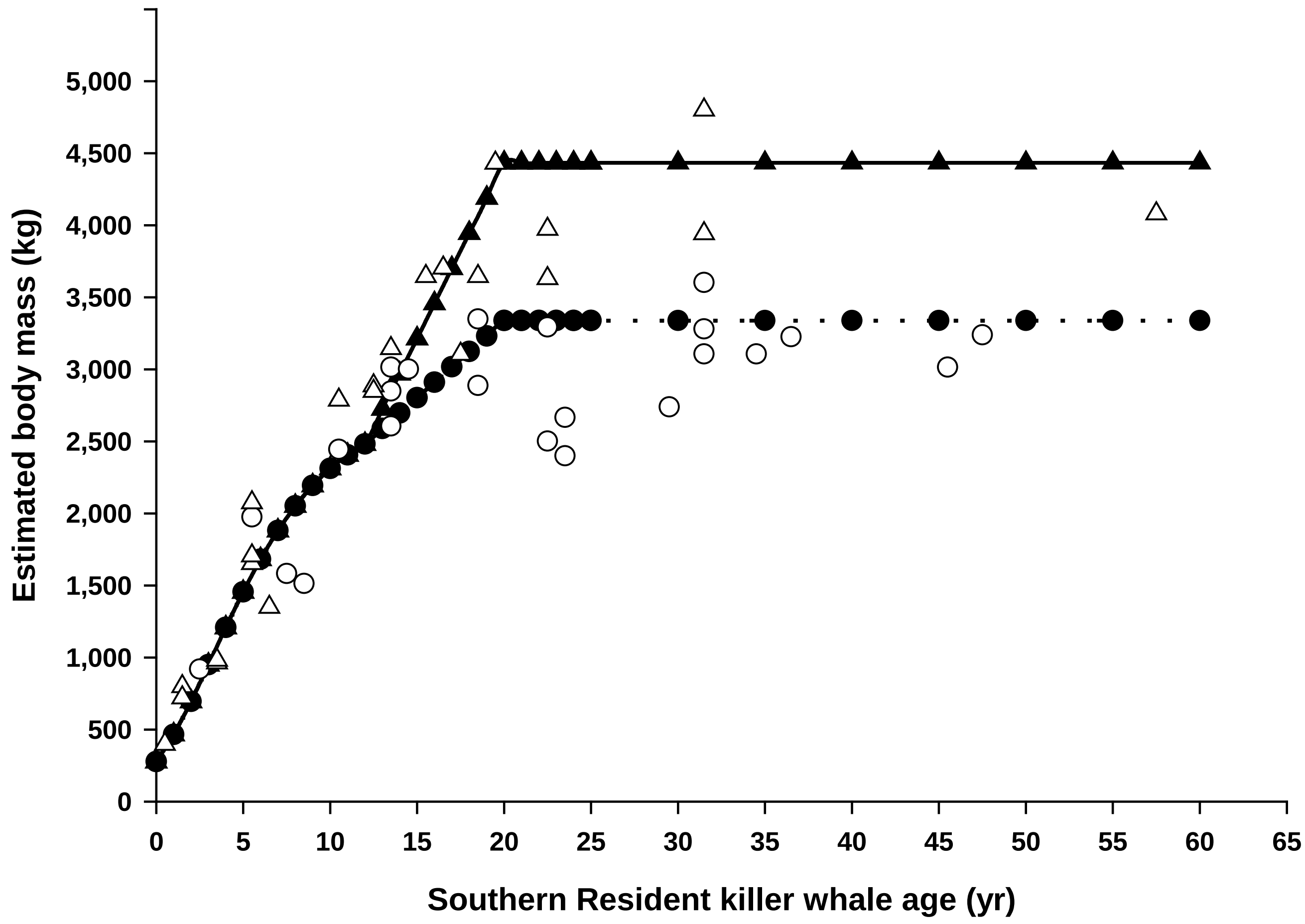
Noren 2011 Approach to Calculating DPER

2) Estimated male and female SRKW body mass across all ages ≥1 year

-Based on kw growth patterns and mass at length curves (Bigg and Wolman 1975; Bigg 1982; Christensen 1988; Clark *et al.* 2000; Kastelein *et al*. 2000, 2001, 2003)

-Validated from body lengths and estimated mass (Bigg and Wolman 1975) of known individual SRKWs measured by photogrammetry (Fearnbach *et al.* 2011)

Noren 2011 Approach to Calculating DPER



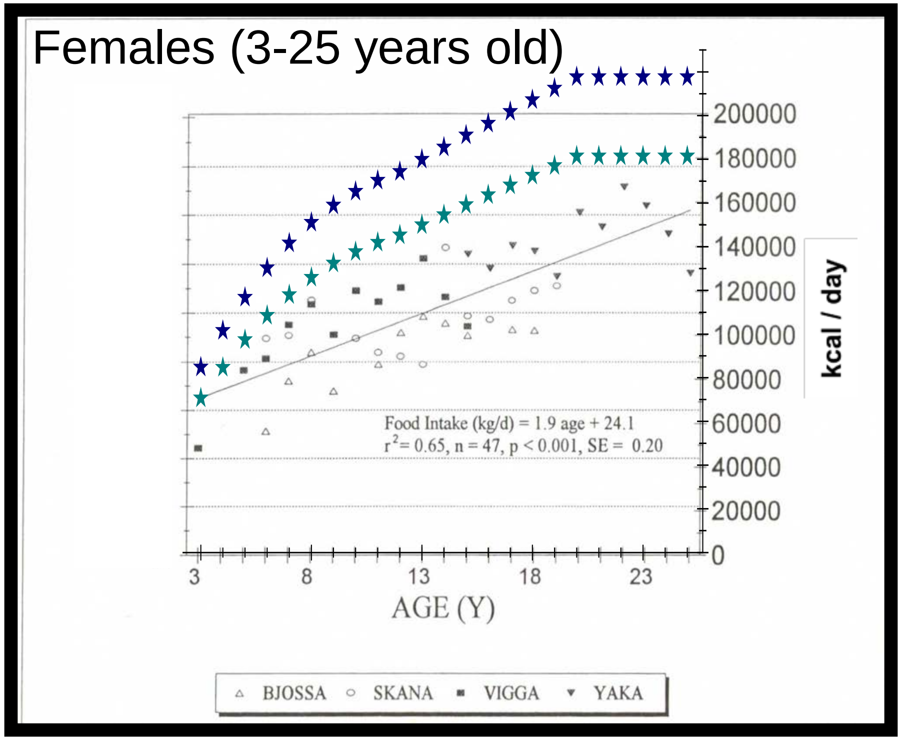
Corresponding open symbols represent masses estimated by max lengths measured by Fearnbach *et al.* (2011) using the equation from Bigg and Wolman (1975).

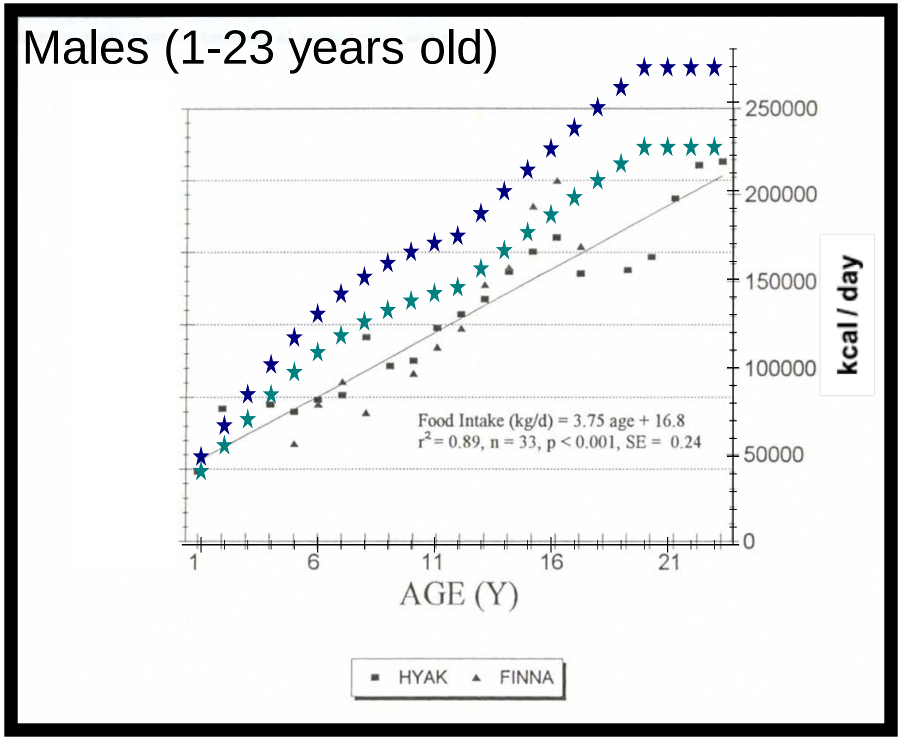
Noren 2011 Approach to Calculating DPER

3) Estimated min. and max. DPERs from body mass and FMRs (assumes DE=84.7%, Williams *et al.* 2004)

-Validated by comparing DPERs to male and female kw DPE consumption rates in captivity (Kriete 1995)

Noren 2011 Approach to Calculating DPER





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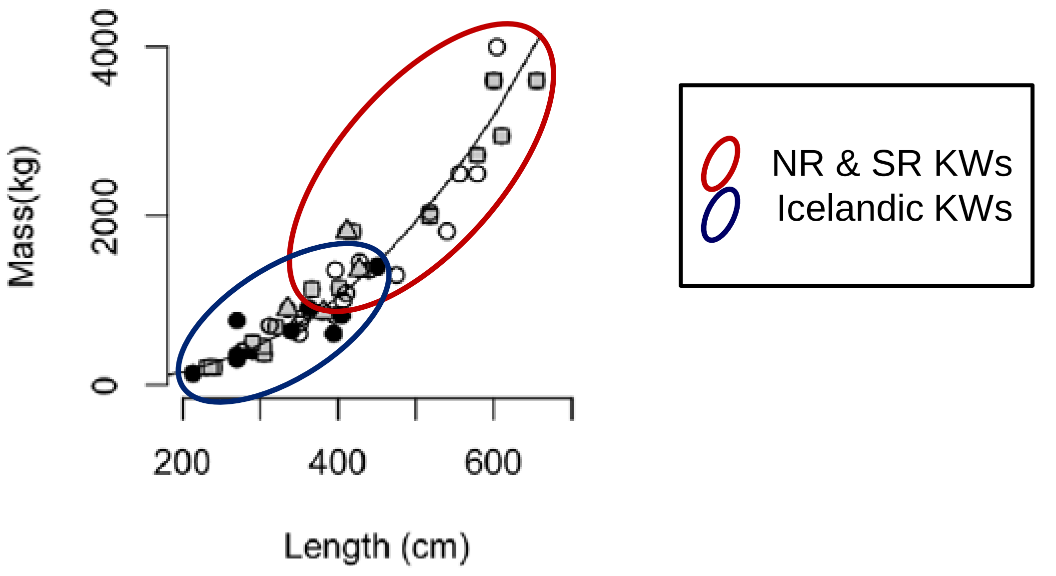
Noren 2011 Approach to Calculating DPER

-Estimated DPERs were slightly greater than captive kw DPE consumption rates
(max DPERs equivalent to ~0-3 Chinook day^{-1} greater)
-Differences likely due to significant differences in body size across kw ecotypes and sedentary lifestyle of captive whales



From Williams *et al.* (2011)

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Williams *et al.* 2011 Approach to Calculating DPER

1) Estimated length at age from time-series data collected from 30 captive kws (Sea World)

- asymptotic length differed by sex
- asymptotic length of captive kws less than those estimated for SRKWS

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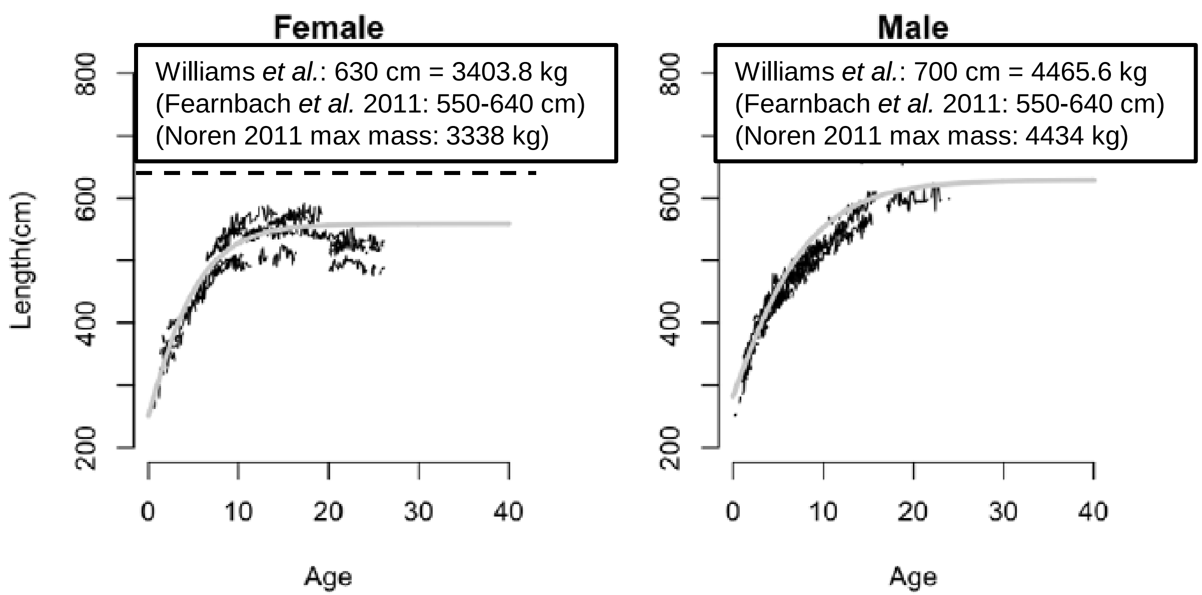

Dashed line designates best estimate of asymptotic length of SRKWs (80th percentile of the distribution of body lengths of kws taken from Northeast Pacific IWC records)

Figure 1. Length at age plots (dots represent each monthly measurement), with model predictions (grey line) for male and female captive whales from SeaWorld records. Males achieve a greater asymptotic length than females.

From Williams *et al.* (2011)

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Williams *et al.* 2011 Approach to Calculating DPER

2) Modeled gross energy requirements (DPERs) from body length from food consumption records of captive kws (Sea World)

-males, females at several reproductive states

- -lactation is associated with large increase in energy consumption (42% increase for one female)

Williams *et al.* 2011 Approach to Calculating DPER

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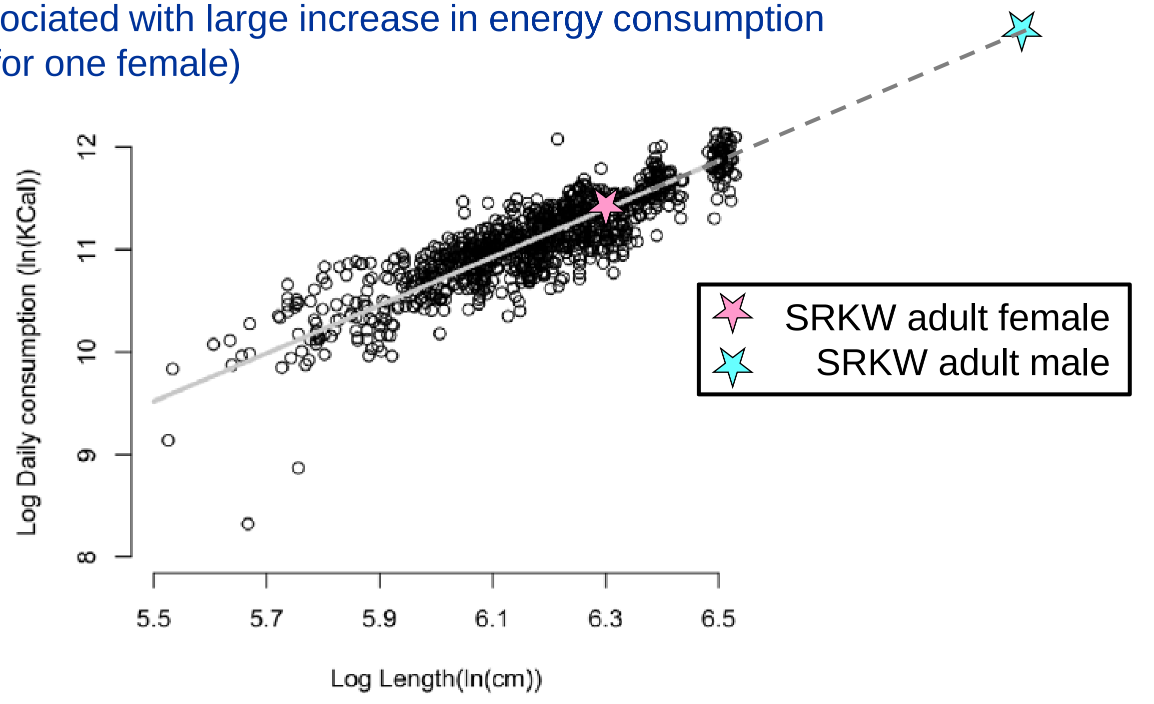

Figure 3. Estimated daily energy consumption (Kcal) at length (cm) on natural log scale, predicted from captive male killer whale records. Parameters are −3.4 for the intercept and 2.35 for the slope.

From Williams *et al.* (2011)

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Williams *et al.* 2011 Approach to Calculating DPER

3) Applied models to the 2009 SRKW population (87 individuals) using data on age, sex, and reproductive status (Center for Whale Research) as inputs to predict lengths, weights, and DPERs of SRKWs

-Ran several scenarios - assumed 80th percentile of length distribution in the North Pacific IWC whaling records was best estimate of asymptotic body length for SRKWs

Williams *et al.* 2011 Approach to Estimating Salmon Consumption – Only Chinook from Fraser River in summer (May-September)

Inputs

SRKW daily length-based age and sex specific caloric requirements
Williams *et al.* 2011

↓

SRKWs present in summer core habitat 79% of days in May-Sept.
(Hauser *et al.* 2007)

↓

SRKW total caloric requirements in summer core habitat in May-Sept.

Fraser River Chinook caloric content: 16,386 kcal fish^{-1}
(average adult Chinook from Fraser River; O'Neill unpubl. data, reported in Noren 2011)

** Estimated upper and lower bounds of caloric content of SRKW preferred Chinook :
18,700 kcal fish^{-1} (Osborne 1999)
10,869 kcal fish^{-1} (Logerwell and Schaufler 2005)

83% of SRKW diet is Chinook, 90% of Fraser River origin
Hanson *et al.* 2010

↓

SRKW Fraser River Chinook requirements in summer core habitat in May-Sept.

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Table 1. Daily and annual energetic requirements in kcal and number of Chinook salmon (based on a hypothetical 16,386 kcal salmon, [34]) for the current size of the southern resident killer whale (SRKW) population, considering various levels of asymptotic length and mass attained by killer whales in the population.

Body Length Scenario (Source)	Male Asymptotic Length (cm)	Male Asymptotic Mass (kg)	Female Asymptotic Length (cm)	Female Asymptotic Mass (kg)	Total Energy Requirement kcal ($\times 10^6$) (per day)	Total Energy Requirement kcal ($\times 10^9$) (per year)	Total Chinook Requirement "100%" fish (per day)	Total Chinook Requirement "100%" fish $\times 10^3$ (per year)	Total Chinook Requirement "Summer" Fish $\times 10^3$ (per year)
IWC NP Max	820	9655	780	8393	17.8	6.5	1088	397	98
IWC NP 99th	804	9137	742	7298	16.2	5.9	988	361	89
IWC NP 95th	770	8096	710	6451	14.4	5.3	880	321	79
IWC NP 80th	**700**	**6199**	**630**	**4616**	**10.8**	**4.0**	**662**	**242**	**59**
SeaWorld Max	685	5835	626	4534	10.5	3.8	[illegible]	[illegible]	57
SeaWorld 99th	678	5669	620	4413	10. 2	3.7	[illegible]	[illegible]	56
SeaWorld 95th	651	5059	598	3989	9.2	3.3	[illegible]	[illegible]	50
SeaWorld 80th	604	4102	560	3319	7.7	2.8	468	[illegible]	[illegible]

Our best estimate of body size in SRKW is based on the 80th percentile of body lengths from the IWC catch records from the Nor… scenario is hypothetical and illustrative: it naively converts caloric requirement to units of fish, assuming that the diet is comp… "Summer" scenario only estimates prey requirements from May–September, based on the proportion (83%) of the diet that is est… in summer [17,18]. Note that a 'recovered' population refers here to 155 animals in 2029 (one scenario calculated from the 20… estimated average annual growth of 2.3 percent over the succeeding 28 years, [31]). A recovered population will require at least 75% more energy than the values predicted here.

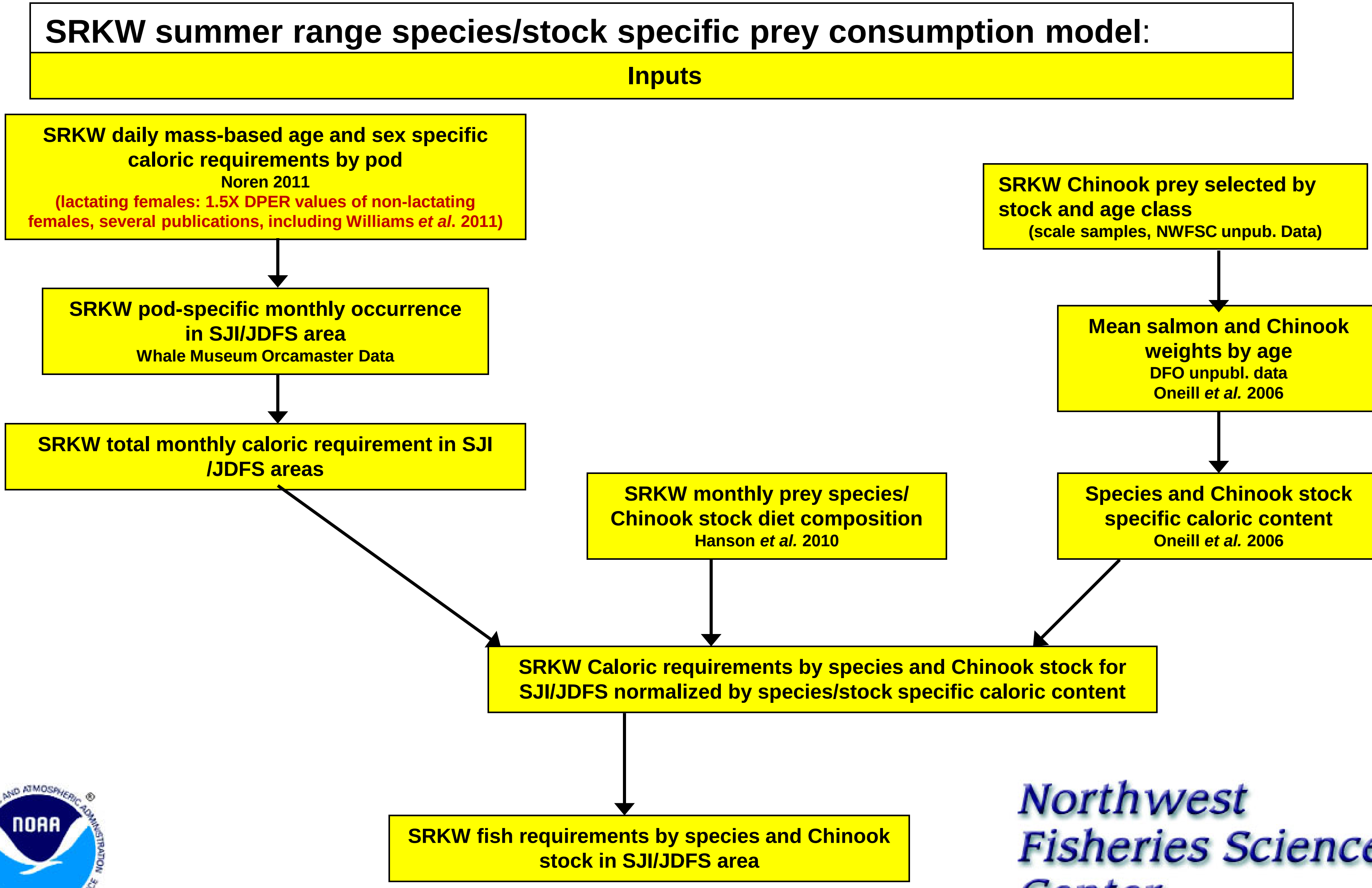
doi:10.1371/journal.pone.0026738.t001

289-347X10^3
(Noren 2011)

12-23% available
Fraser River Chinook
(Wiliams *et al.* 2011)

Williams R, Krkošek M, Ashe E, Branch TA, *et al.* (2011) Competing Conservation Objectives for Predators and Prey: Estimating Killer Whale Prey Requirements for Chinook Salmon. PLoS ONE 6(11): e26738. doi:10.1371/journal.pone.0026738
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0026738

Hanson *et al.* Approach to Estimating Salmon Consumption



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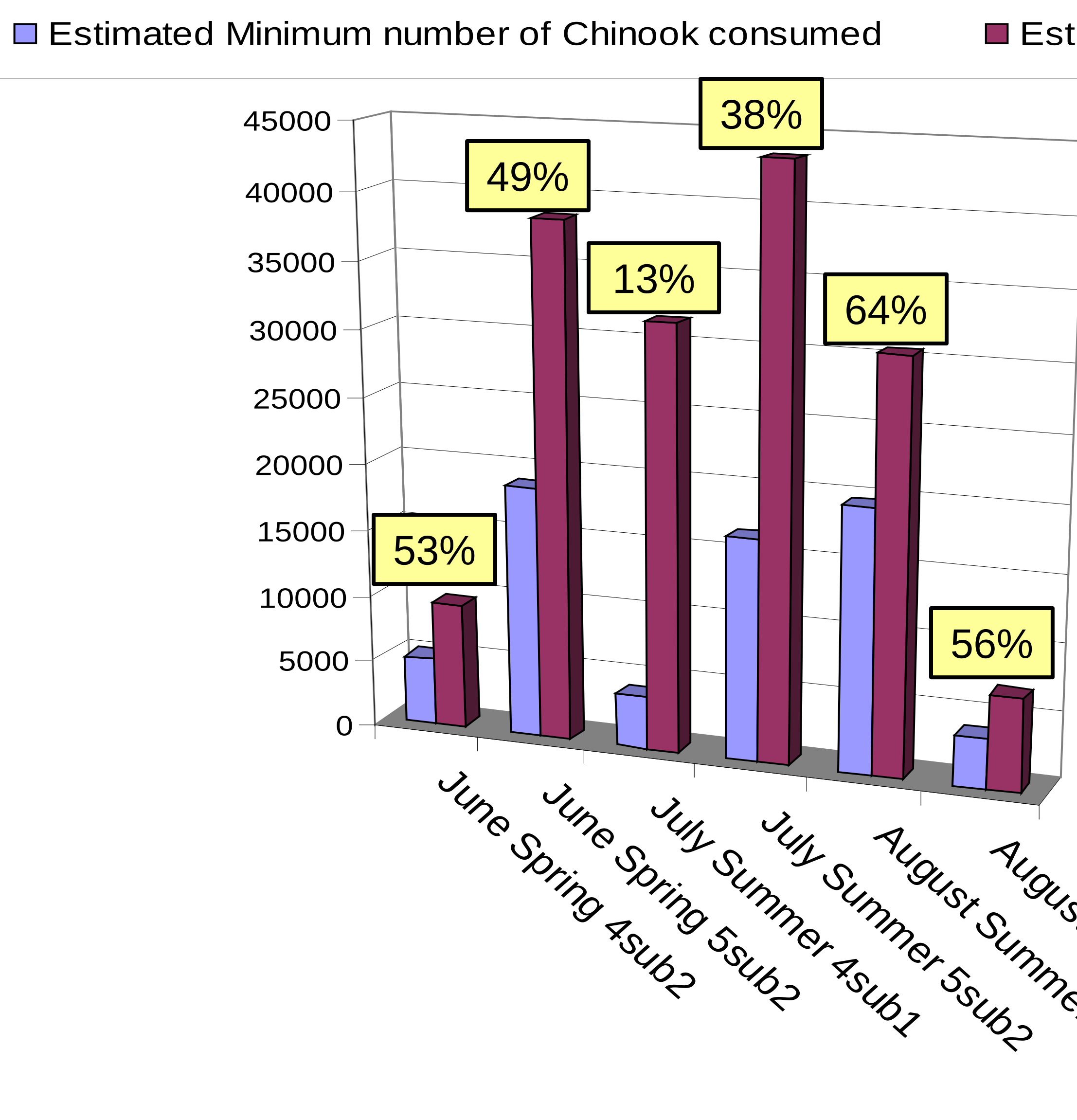
Estimated min. monthly SRKW Chinook stock specific consumption versus estimated monthly availability of Fraser River Chinook stocks



Spring 4_2 - North, South and Lower Thompson, age: 4 yrs

Spring 5_2 - Upper, Mid- and lower Fraser, North and South Thompson, age: 5 yrs

Summer 5_2 - Mid-Fraser and North Thompson, age: 5 yrs

Summer 4_1 - South Thompson and Lower and Fraser (English et al. 2007), age: 4 yrs

Hanson *et al.* in prep

Conclusions

1) Two approaches to determine SRKW DPERs yield similar results

2) Two approaches to determine consumption of Fraser River Chinook in summer yield slightly different results

-Williams et al. 2011: 52,000-89,500 FR Chinook consumed during 5 months (May-Sept.)

-Hanson *et al.:* 95,810-115,090 FR Chinook consumed during 4 months (June-Sept.)

-Difference mainly due to caloric values of fish used

3) Both approaches demonstrate that a high proportion of available Fraser River Chinook are consumed by SRKWs

-Williams *et al.* 2011: 12-23% generic available Chinook consumed during 5 months

-Hanson *et al.*: min. 13-64% available "preferred" Chinook consumed during 3 months

Prey requirements of "recovered" population (155 animals) could be 75% higher (Williams *et al.* 2011)

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Conclusions

SRKWs may consume a significant proportion of Fraser River Chinook during summer months

Chinook availability may be inadequate to support SRKW population growth to recovered status


GUARANTEED
WHALE WATCHING TOURS
ISLAND EXPLORER II

Result: DPERs for Individual SRKWs

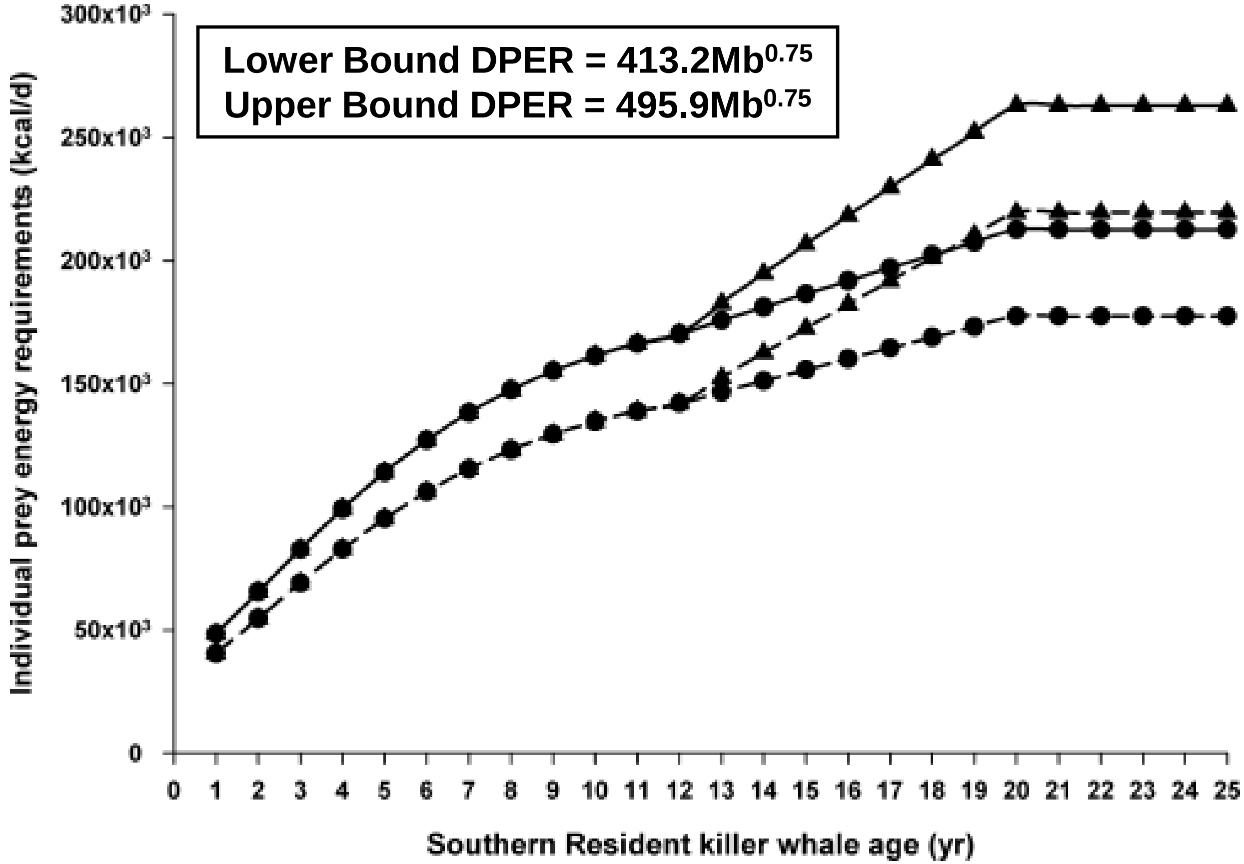

Figure 2. Relationship between daily prey energy requirements (DPERs) and age in years for male and female killer whales. Lower bound (broken lines) and upper bound (solid lines) estimates of DPERs (kcal/d) are presented for male (▲) and female (•) killer whales.

From Noren (2011)

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