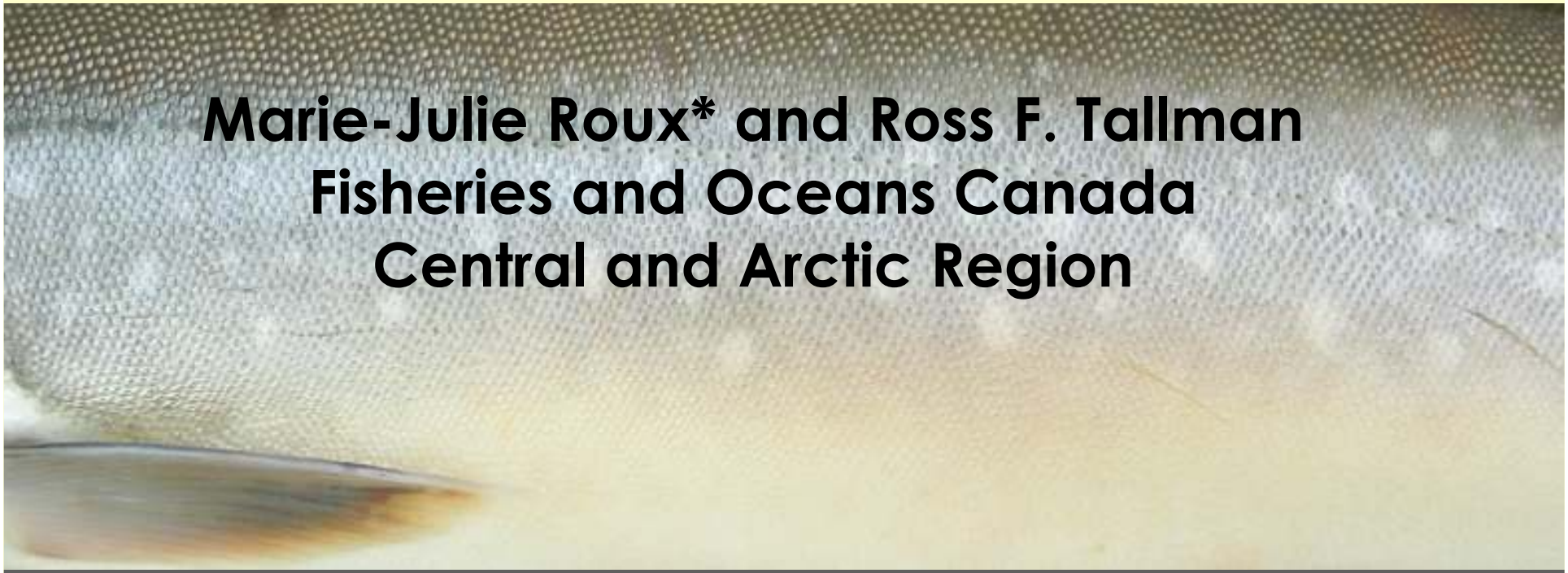
A productivity-susceptibility risk analysis for the effects of fishing on Arctic Char (*Salvelinus alpinus*) stocks from the Nunavut Territory



Marie-Julie Roux* and Ross F. Tallman
Fisheries and Oceans Canada
Central and Arctic Region

***Present address :Current Address: National Institute of Water and Atmospheric Research , 301 Evans Bay Parade, Greta Point, Wellington, New Zealand**

Problems

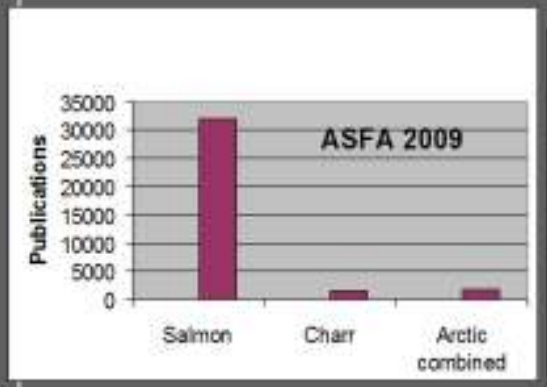
(…) “what needs to be done to address priority gaps”

paucity of data

too large a place

too many stocks

Background

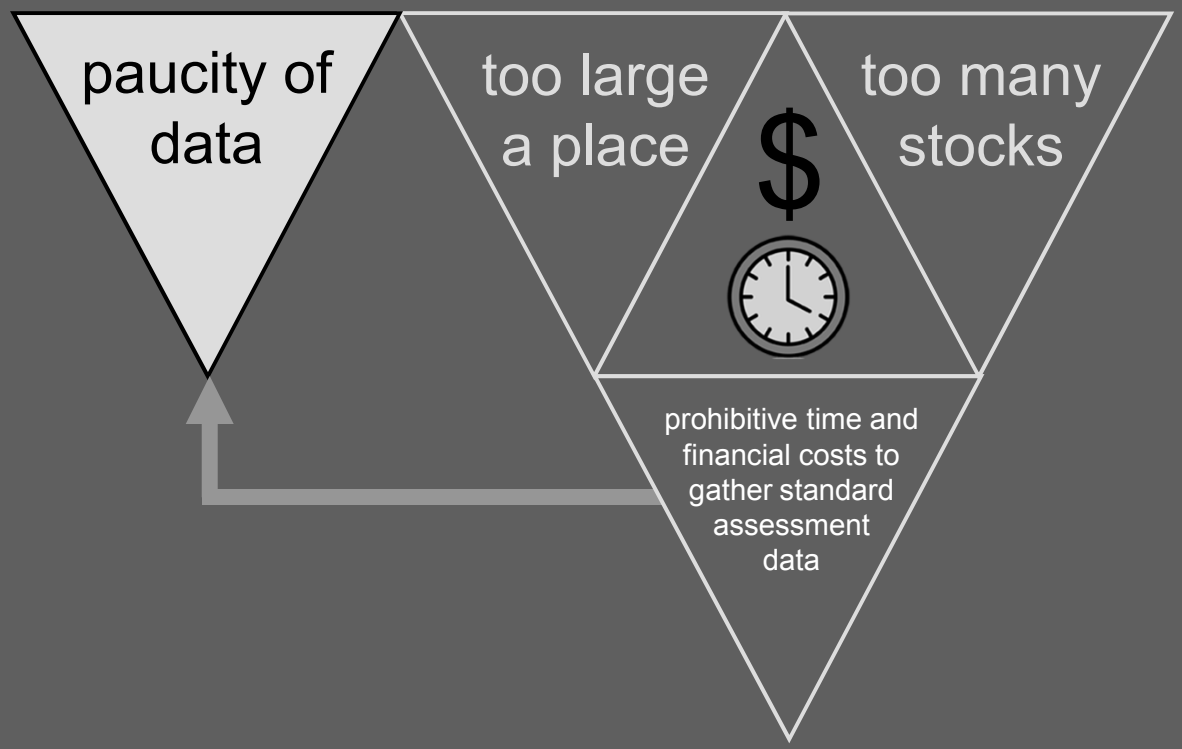


195 Arctic Char
350 FW and Anadromous

Problems

Background

(…) “what needs to be done to address priority gaps”



Problems

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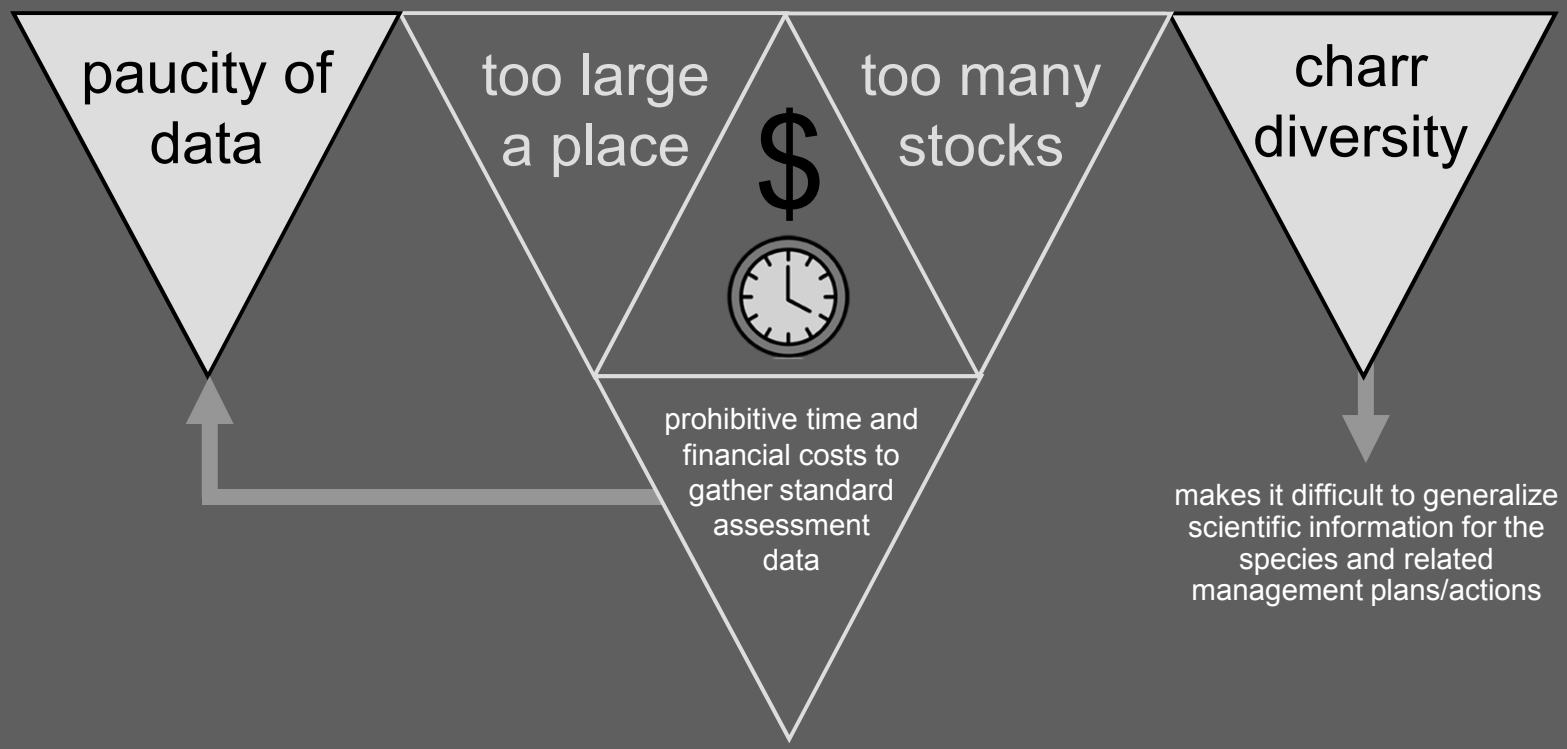


from Gaps to Solutions

Objective

solutions ~~gaps~~ for the scientific understanding and management of Arctic charr fisheries

charr modelling

charr diversity

Life history traits determine stock productivity

Conceptual approach

life history traits

age at maturity (**R**)
fecundity (**R**)
growth rate (**G**)
survival (**M**)

elements of productivity

R = reproductive capacity
G = growth
M = mortality = 1-survival

(productivity ≈ resilience)

Life history traits determine stock productivity

Conceptual approach

life history traits

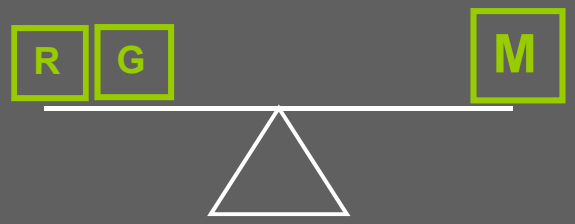
age at maturity (**R**)
fecundity (**R**)
growth rate (**G**)
survival (**M**)

elements of productivity

R = reproductive capacity
G = growth
M = mortality = 1-survival

stable population:

R + G = M



population trend = nil (0)

traits are in balance and the population persists

(productivity ≈ resilience)

Charr modelling using life history traits

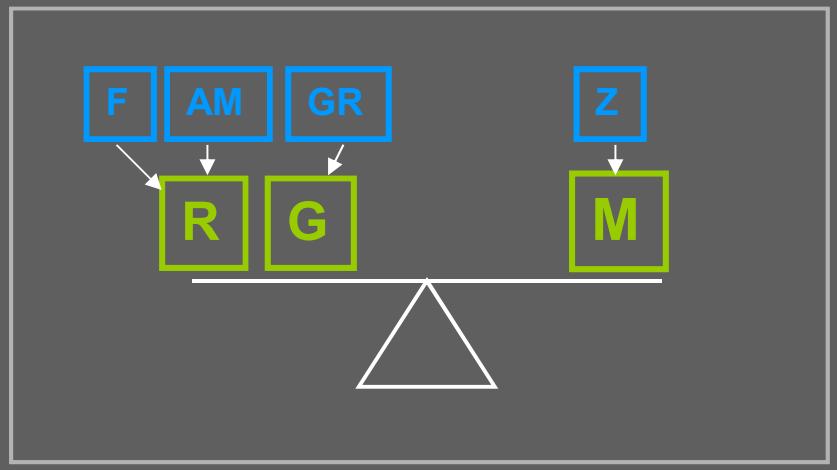
Conceptual approach

life history traits

AM = age at maturity
F = fecundity
GR = growth rate
Z = instantaneous mortality

elements of productivity

R = reproductive capacity
G = growth
M = mortality



Charr modelling using life history traits

Conceptual approach

life history traits

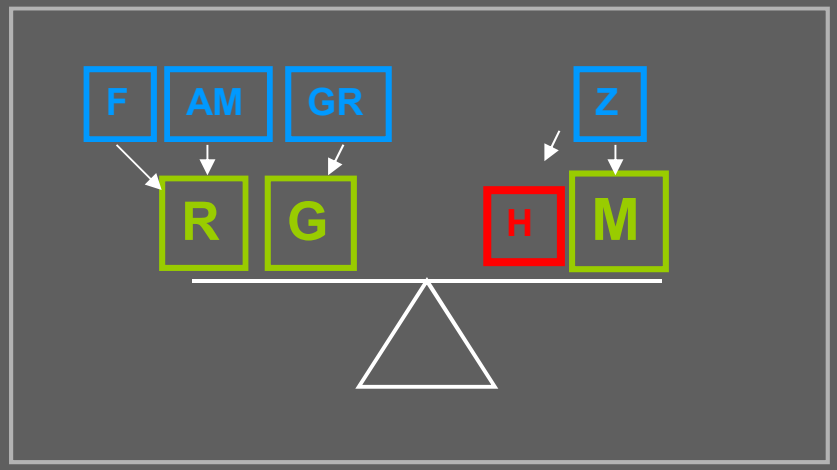
AM = age at maturity
F = fecundity
GR = growth rate
Z = instantaneous mortality

elements of productivity

R = reproductive capacity
G = growth
M = mortality

H = harvest rate

(management history and population response information)



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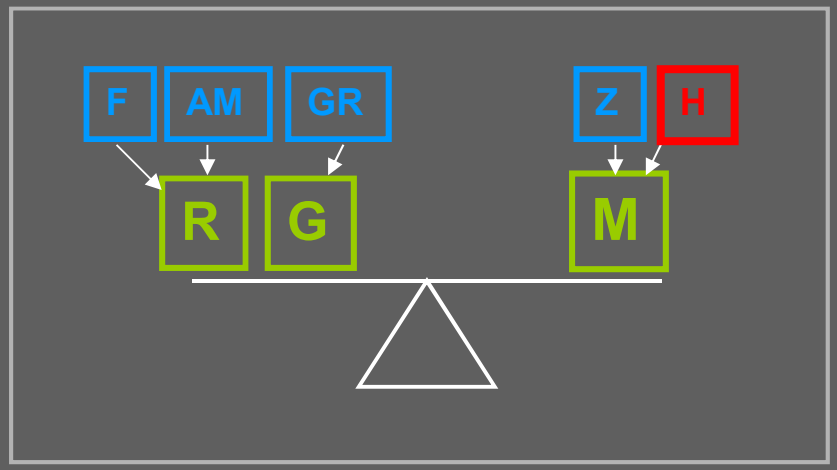


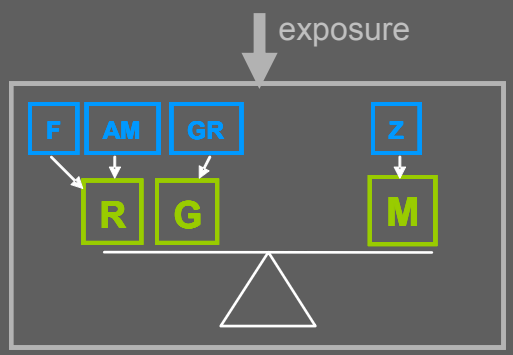
a model using life history traits and harvest rates as input parameters to predict population trends

explore and identify sustainable **H** range

R + **G** – **M** > 0

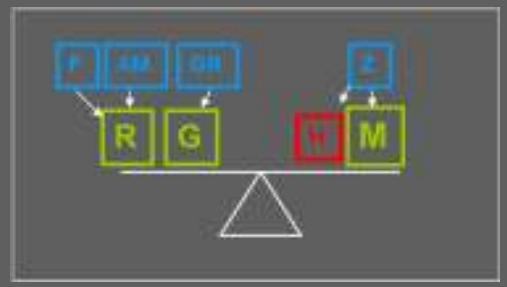
Charr modelling using life history traits

Conceptual approach



phase 1 :

• demonstrate the extent of inter-population variability in life-history traits and how this can be used for evaluating the relative vulnerability of Arctic charr stocks to fishing activities (SEMI-QUANTITATIVE RISK ANALYSIS)



phase 2 :

• model development and testing (FULL QUANTITATIVE ANALYSIS)

Risk assessment using life history traits

PSA introduction

- a relative (as opposed to absolute) risk assessment method
- based on the principle that population vulnerability to fishing activities depends on:
  - its ability to recover from increased mortality (productivity≈resilience) (more productive = less vulnerable)
  - the extent of the impacts due to fishing activities (susceptibility≈exposure) (more exposed = more vulnerable)

PSA

Productivity-Susceptibility Analysis

Risk assessment using life history traits

PSA introduction

not a new method:

•Australian Northern Prawn fishery by-catch spp.
(see Stobutzki et al. 2001)

• recently proposed as a semi-quantitative step in a hierarchical ecological risk assessment for the effects of fishing (ERAEF) framework by the **Marine Stewardship Council** (MSC eco-certification body) (see Hobday et al. 2007)

• currently being evaluated for use in determining the vulnerability of U.S. fisheries by NOAA (see Patrick et al. 2009)

…but has never been experimented on a single-species basis

PSA

Productivity-Susceptibility Analysis

Productivity-Susceptibility risk assessment

PSA methods

STEP 1: define and estimate productivity and susceptibility attributes

Productivity
attributes

Susceptibility
attributes

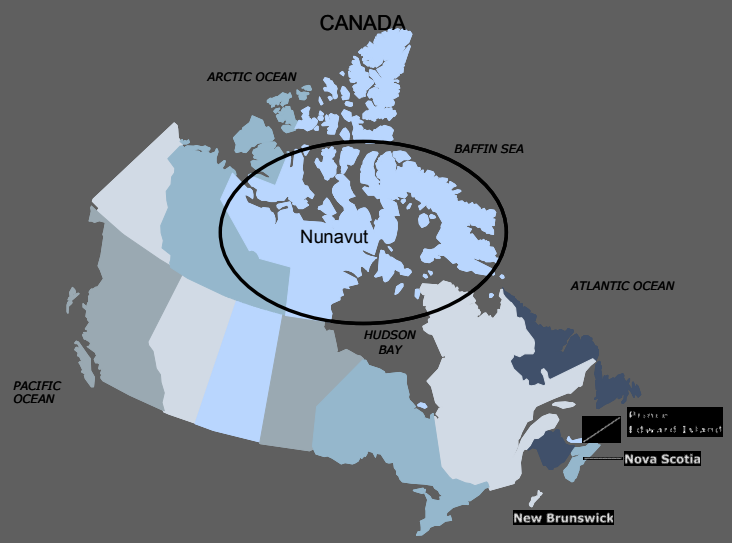
Productivity-Susceptibility risk assessment

PSA methods

STEP 1: define and estimate productivity and susceptibility attributes

Productivity
attributes

Susceptibility
attributes



historical data base for charr from across Nunavut (1971-2003)

97 anadromous stocks
(5.5” (139.7 mm) gillnet studies)

Productivity-Susceptibility risk assessment

PSA methods

STEP 1: define and estimate productivity and susceptibility attributes

Productivity attributes	estimation
age at first maturity younger age at first maturity = more productive	first age group with mature fish (all data pooled) or approximated from a linear model using max age as predictor
individual growth rate faster growth = more productive	Brody (K) growth coefficient calculated by fitting von Bertalanffy growth curves to fully recruited age groups* (all 139.7mm gillnet data pooled)
lifespan short-lived = more productive	maximum age observed in the sample (all 139.7mm gillnet data pooled)
mortality higher mortality = more productive	annual mortality estimated from catch curves (catch at age plots) (all 139.7mm gillnet data pooled)

Productivity-Susceptibility risk assessment

PSA methods

STEP 1: define and estimate productivity and susceptibility attributes

estimation	Susceptibility attributes
distance from nearest human community	**encounterability** likelihood that the stock will encounter fishing gear
ranked high for anadromous stocks	**availability** overlap between fishing effort and stock distribution
ratio of mean fork length over mesh size (in mm)	**selectivity** potential for the gear to capture/retain fish

Productivity-Susceptibility risk assessment

PSA methods

STEP 2: rank individual productivity attributes for data quality

data quality scores = a measure of uncertainty

Data Quality Score	Conditions
1	- sample size is large (≥300).
	- All conditions *a priori* determined for the estimate to be reliable are met.
	- Data is recent and is likely to reflect current state environmental conditions.
2	- sample size is large (≥300).
	- All conditions a priori determined for the estimate to be reliable are met.
	- Data is not recent and unlikely to reflect current state environmental conditions.
3	- Sample size is <300 but >100
	OR – sample size is >300 BUT other conditions *a priori* determined for an estimate to be reliable are not met.
4	- Sample size is <100
	OR – Sample size is >100 BUT other conditions *a priori* determined for an estimate to be reliable are not met.
5	Sample size is <100 AND other conditions *a priori* determined for an estimate to be reliable are not met.
	Estimate was approximated using life-history information.

Productivity-Susceptibility risk assessment

PSA methods

STEP 3: rank productivity and susceptibility attributes into tiers corresponding to different levels of risk

*DQ

Productivity
attributes
age at first maturity
individual growth rate
lifespan
mortality

Susceptibility
attributes
encounterability
availability
selectivity

→ determine a range of values for each attribute

→ divide this range into thirds:

Productivity

1=Low	2=Moderate	3=High
1=High	2=Moderate	3=Low
	Risk	

Susceptibility

1=Low	2=Moderate	3=High
1=Low	2=Moderate	3=High
	Risk	

Productivity-Susceptibility risk assessment

PSA methods

STEP 3: rank productivity and susceptibility attributes into tiers corresponding to different levels of risk

*DQ Productivity attributes

Attribute	Observed Range		Productivity Tiers and Scores		
	Min	Max	LOW = 1	MODERATE = 2	HIGH = 3
Age at first maturity	3	12	9-12	6-8	3-5
Growth rate (K)	0.028	0.175	0.028-0.079	0.080-0.127	0.128-0.175
Lifespan (Age_{max})	12	31	24-31	18-23	12-17
Mortality	0.17	0.66	0.17-0.34	0.35-0.50	0.51-0.66

*only stocks with values corresponding to data quality scores ≤3 were used to define the observed range

Productivity-Susceptibility risk assessment

PSA methods

STEP 3: rank productivity and susceptibility attributes into tiers corresponding to different levels of risk

Susceptibility
attributes

encounterability scores

Encounterability scores	3 = High	2.5	2 = Mod	1.5	1 = Low
Distance from community (km)	≤ 10	51-60	101-110	151-160	≥ 201

Productivity-Susceptibility risk assessment

PSA methods

STEP 3: rank productivity and susceptibility attributes into tiers corresponding to different levels of risk

Susceptibility
attributes

selectivity scores

Observed range (mean FL)		Observed range (Mean FL / Mesh size)		**Gear Selectivity Tiers and Scores**		
MIN	MAX	MIN	MAX	**LOW = 1**	**MODERATE=2**	**HIGH=3**
501	772	3.60	5.55	3.60-4.25	4.26-4.90	4.91-5.55

Productivity-Susceptibility risk assessment

PSA methods

STEP 3: rank productivity and susceptibility attributes into tiers corresponding to different levels of risk

Susceptibility
attributes

availability scores

Availability tiers and scores		
low=1	**moderate=2**	**high=3**
anadromous - large lake fishery	anadromous - medium size lake fishery	anadromous - river mouth fishery
lacustrine -large lake fishery	lacustrine -medium size lake fishery	

Productivity-Susceptibility risk assessment

PSA methods

STEP 4: plot average productivity-susceptibility scores and estimate vulnerability as the Euclidean distance from the origin

*DQ Productivity attributes

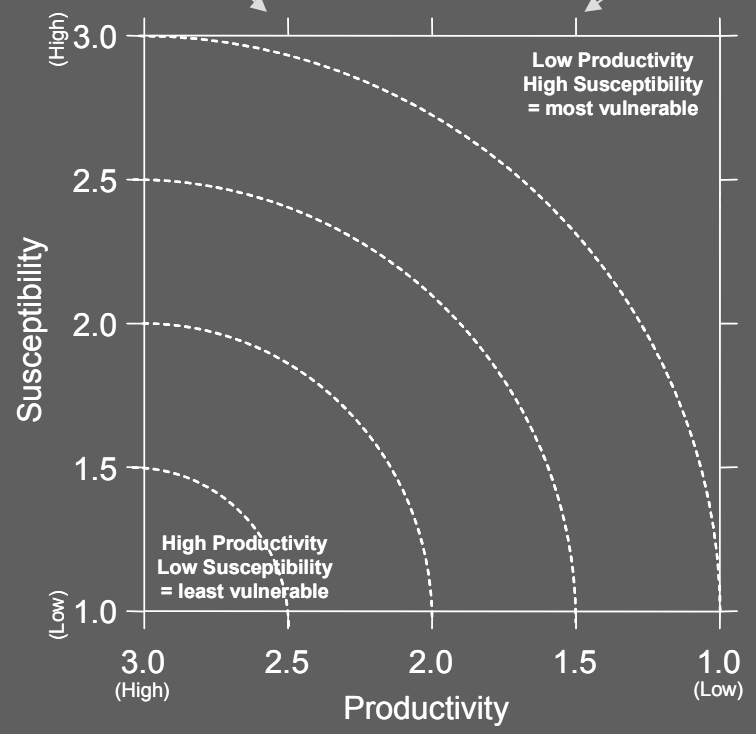
Productivity
1=Low 2=Moderate 3=High
1=High 2=Moderate 3=Low
Risk

Susceptibility attributes

Susceptibility
1=Low 2=Moderate 3=High
1=High 2=Moderate 3=Low
Risk

average Productivity score (P)

average Susceptibility score (S)



Vulnerability (V)

(Euclidean distance from origin)

$$V = \sqrt{(P - 3)^2 + (S - 1)^2}$$

Productivity-Susceptibility risk assessment

PSA methods

STEP 5: average data quality scores into a data quality index

*DQ

Productivity attributes

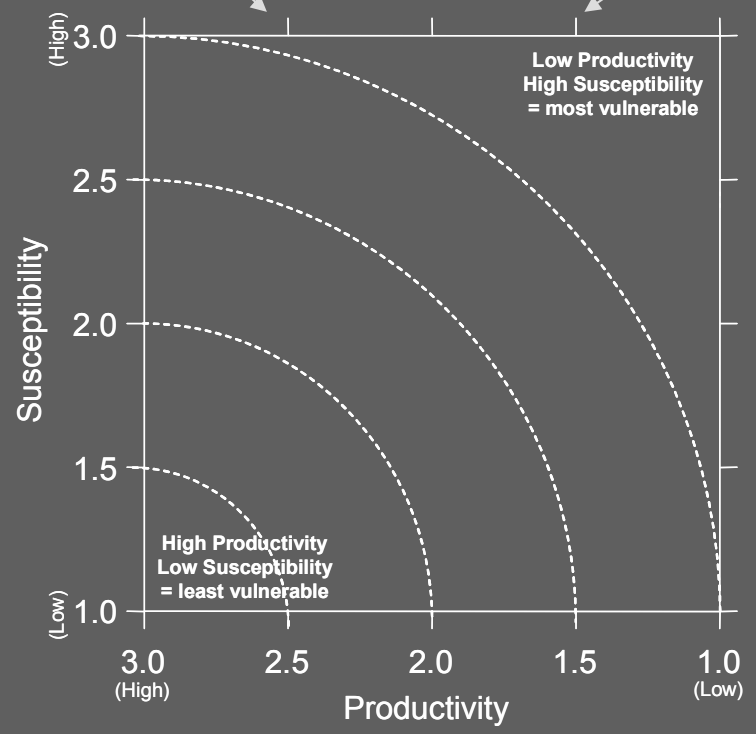
Productivity
1=Low 2=Moderate 3=High
1=High 2=Moderate 3=Low
Risk

Susceptibility attributes

Susceptibility
1=Low 2=Moderate 3=High
1=High 2=Moderate 3=Low
Risk

average Productivity score (P)

average Susceptibility score (S)

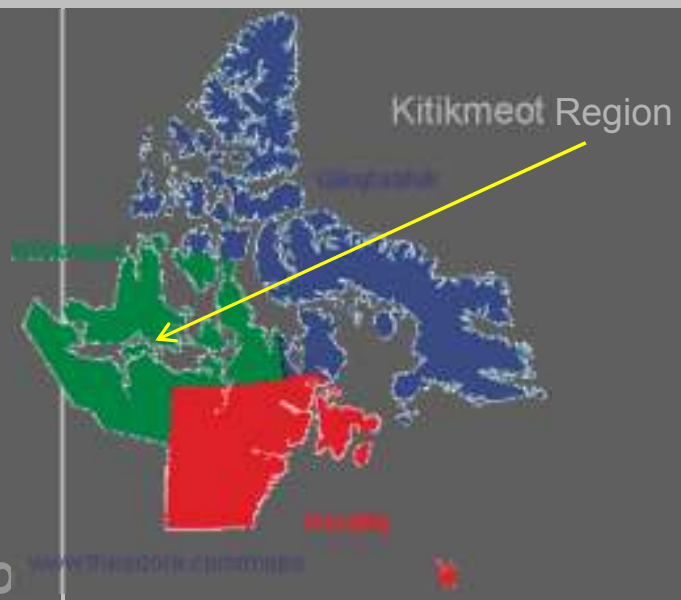


overall DATA QUALITY Index		
LOW (L)	MEDIUM (M)	HIGH (H)
≥3.6	2.1-3.5	≤2

- High data quality
- Medium data quality
- Low data quality

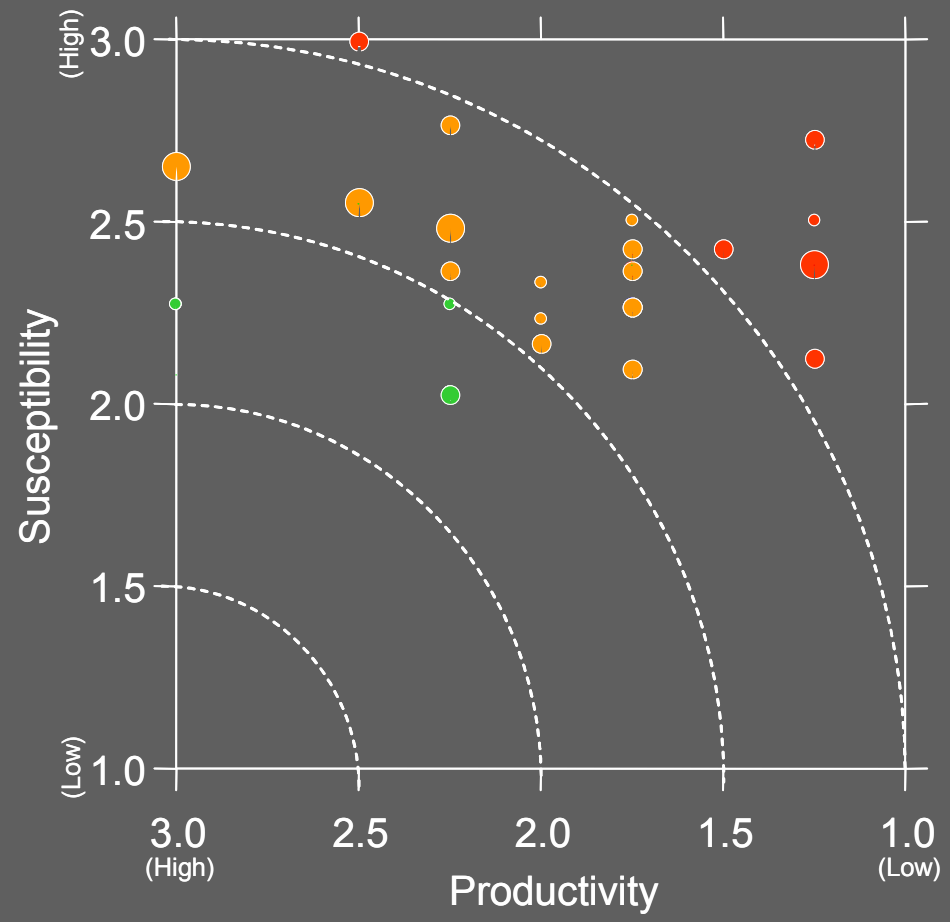
Productivity-Susceptibility risk assessment

PSA results



- More Vulnerable stocks
- Vulnerable stocks
- Less Vulnerable stocks

- High data quality
- Medium data quality
- Low data quality



Less Vulnerable

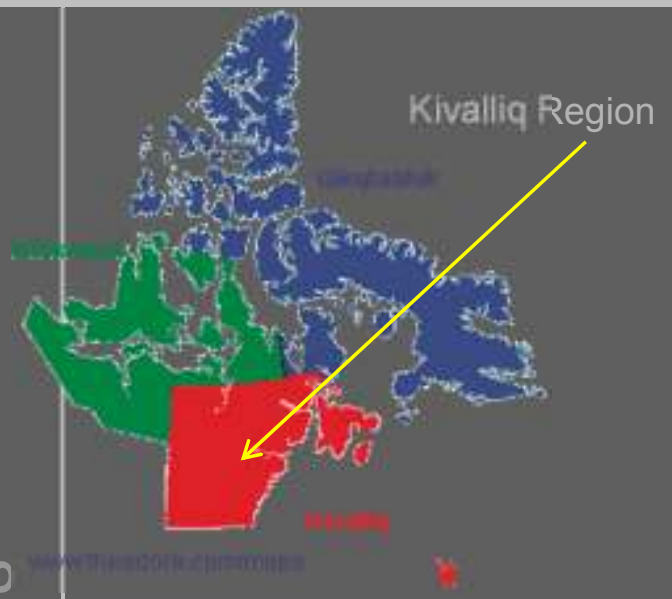
(1.27) Arrowsmith River
(1.27) Kellett River
(1.28) Nakyoktok River
(1.28) Perry River
(1.47) Becher River

More Vulnerable

(2.06) Freshwater Creek
(2.07) Paliryuak River
(2.08) Hayes River
(2.24) Jayco River
(2.30) Abernethy River
(2.46) Lord Lindsay Lake

Productivity-Susceptibility risk assessment

PSA results



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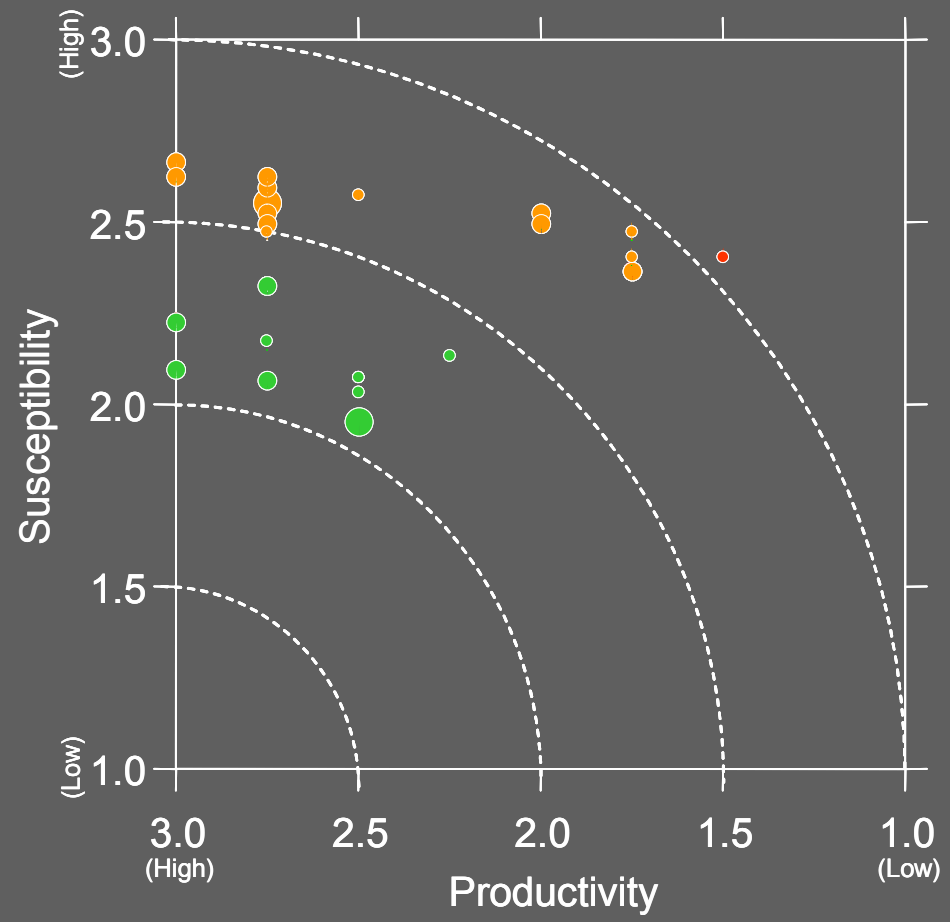


Less Vulnerable

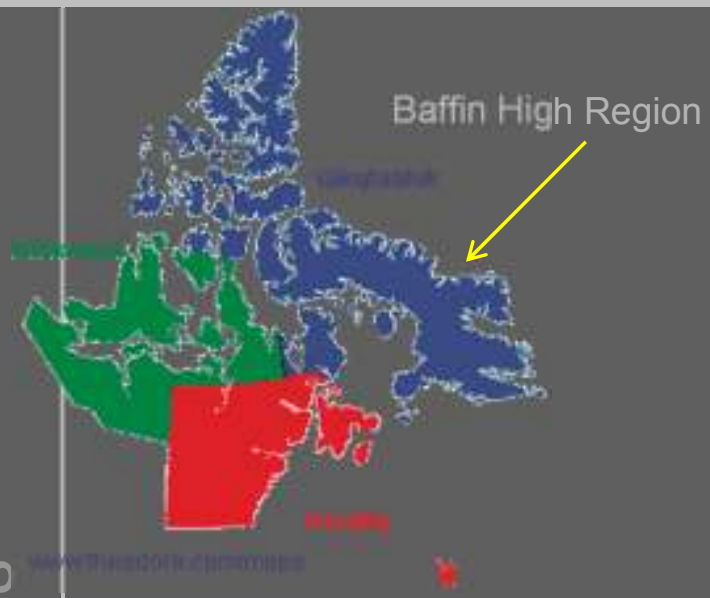
(1.09) Stony Point Area
(1.10) Barbour Bay
(1.10) Robinhood Bay
(1.15) Lorillard River
(1.18) Gore Bay Area
(1.18) Hanway River
(1.19) Steep Bank Bay
(1.23) Pistol Bay
(1.36) Chesterfield Inlet
(1.36) Rankin Inlet Area
(1.36) Ranger Seal Bay

More Vulnerable

(2.05) Ross Inlet

Productivity-Susceptibility risk assessment

PSA results



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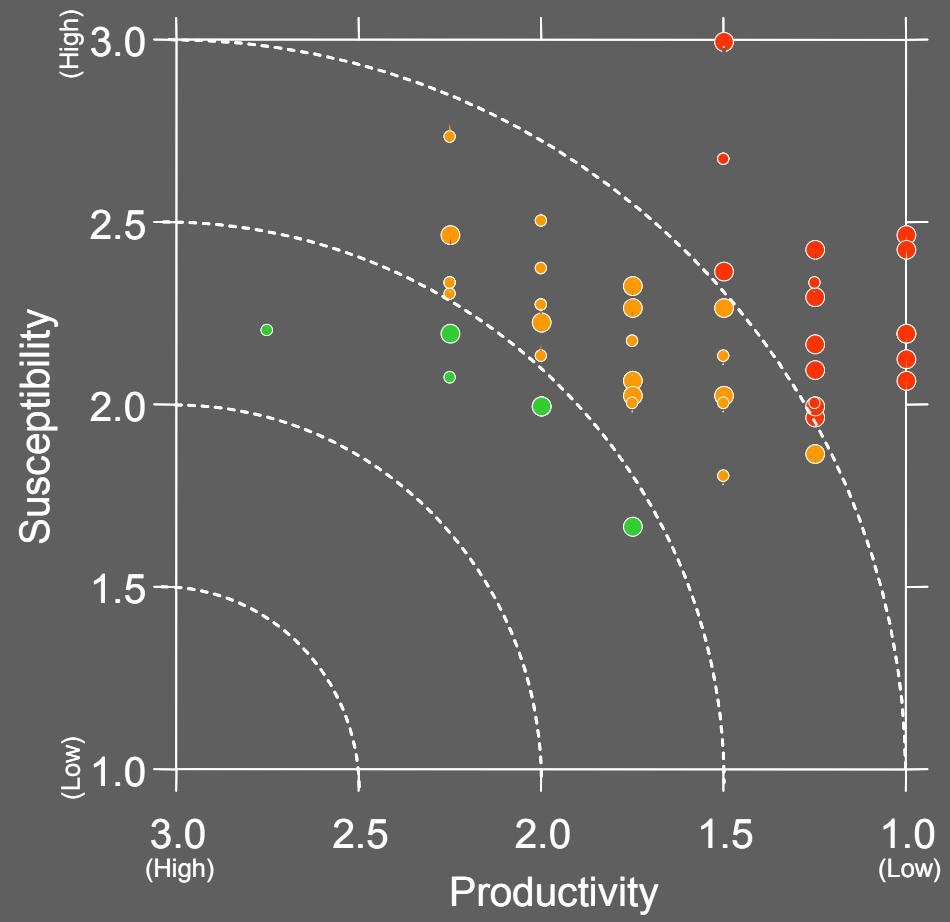


Less Vulnerable

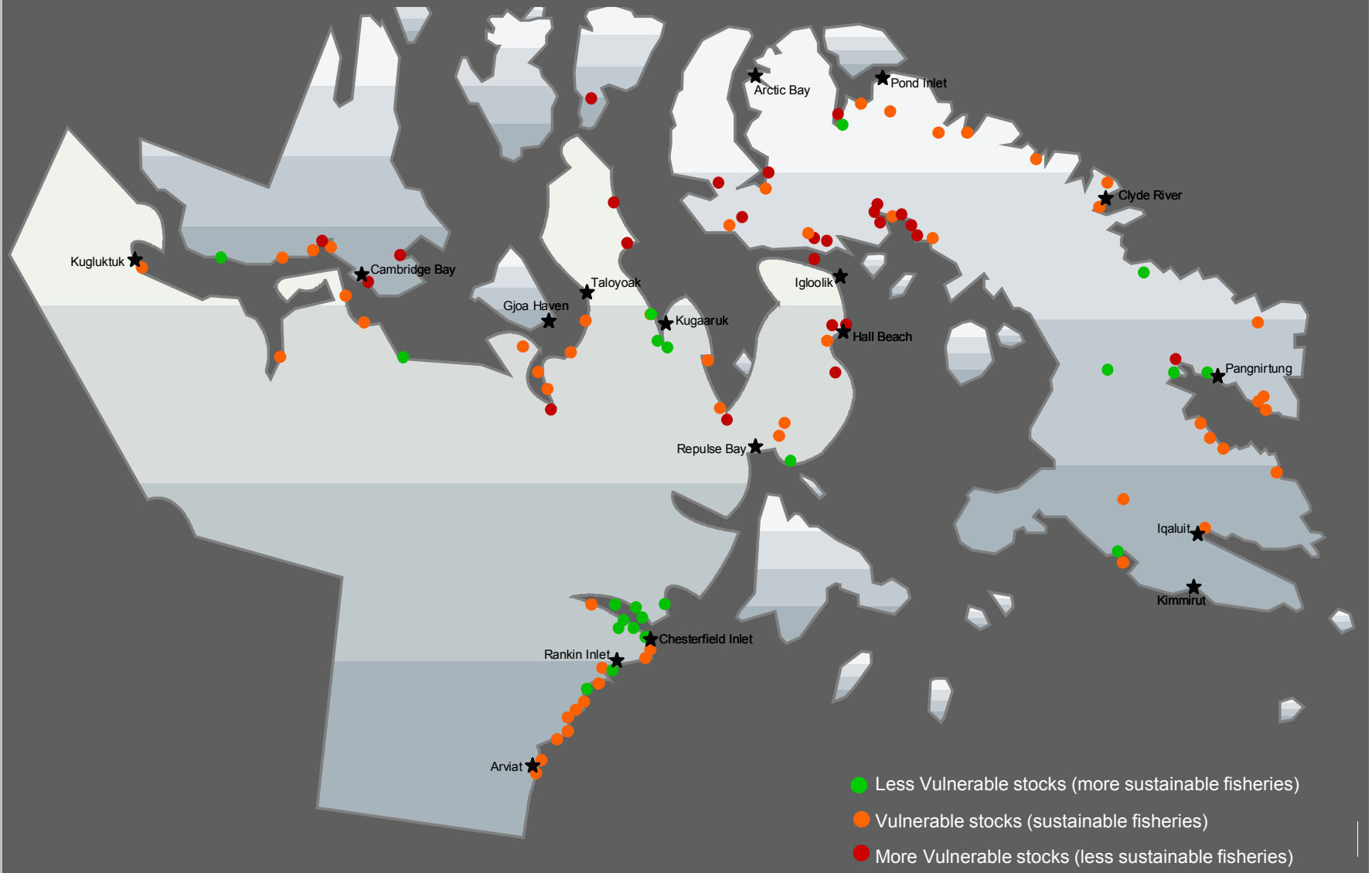
(1.23) Ikalukjuaq Lake and River
(1.30) Tasirululik Lake
(1.41) Kipisa Lake
(1.41) Tugaat River
(1.42) Ava Inlet
(1.42) Nettilling Lake

More Vulnerable

(2.14) Ijaruvung Lake
(2.14) Kukaluk River
(2.15) Ikikeesarjuq Lake
(2.15) Stanwell-Fletcher Lake
(2.20) Tarsiujuak Arm
(2.23) Magda River
(2.29) Gifford River
(2.30) Ivisarak Lake
(2.30) Koluktoo Bay
(2.30) Naulingiavik Lake
(2.35) Hall Lake
(2.39) Rowley River
(2.41) Ikpikiturjuaq Lake
(2.44) Neergaard Lake
(2.44) Ravn River
(2.50) Hall Beach Area
(2.55) Windless River
(2.56) Fury and Hecla Strait

Productivity-Susceptibility risk assessment

PSA results

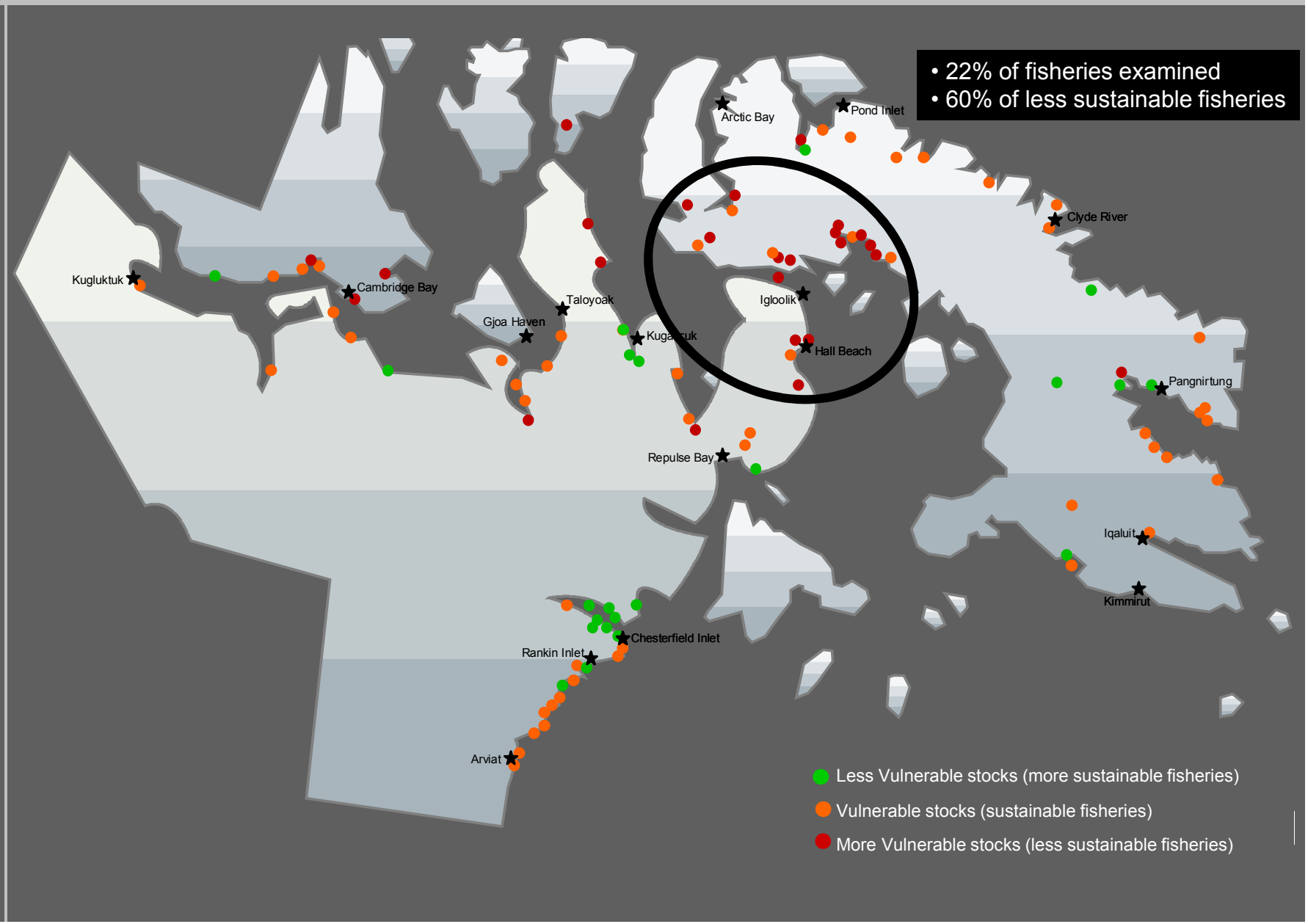


Productivity-Susceptibility risk assessment

PSA results

Productivity-Susceptibility risk assessment

PSA results



Productivity-Susceptibility risk assessment

PSA implications

over a broad geographic landscape:

- PSA analysis allows us to distinguish between regions characterized predominantly by less or more vulnerable Arctic charr populations

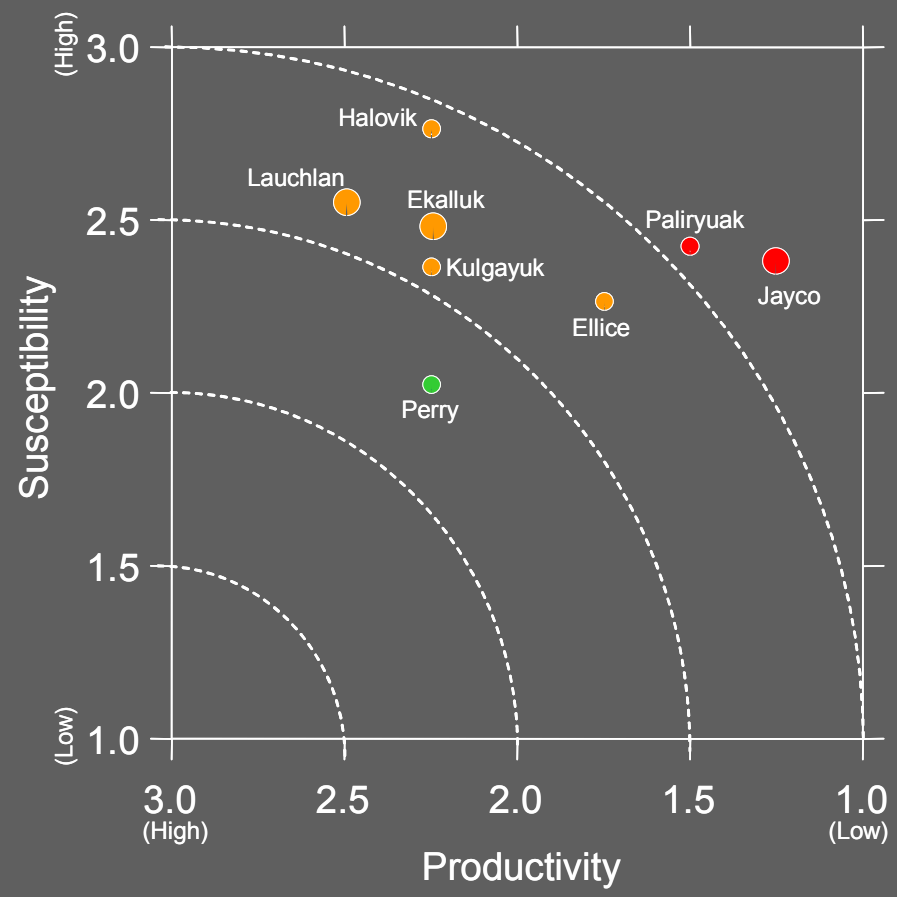
prevalence of more vulnerable stocks = greater risk of overfishing
prevalence of less vulnerable stocks = lower risk of overfishing

Regional differences
in stock vulnerability

Productivity-Susceptibility risk assessment

PSA results

Cambridge Bay Area



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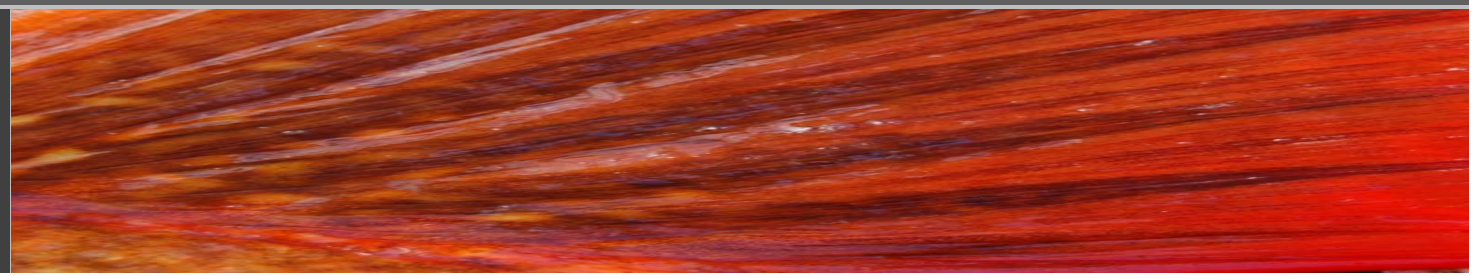


Yield Calculations

$\log L_\infty = 0.044 + 0.9841 \log L_{max}$ (Froese & Binohlan 2000)

$K = -\ln(1 - L_m/L_\infty) / (t_m - t_0)$ (Froese & Binohan 2003)

$M = 1.5K$ $F = Z - M - Z$ calculated from catch curve (Jensen 1996)

Biomass = Yield/F

Max Sustainable Production = 0.33 x Z x Biomass

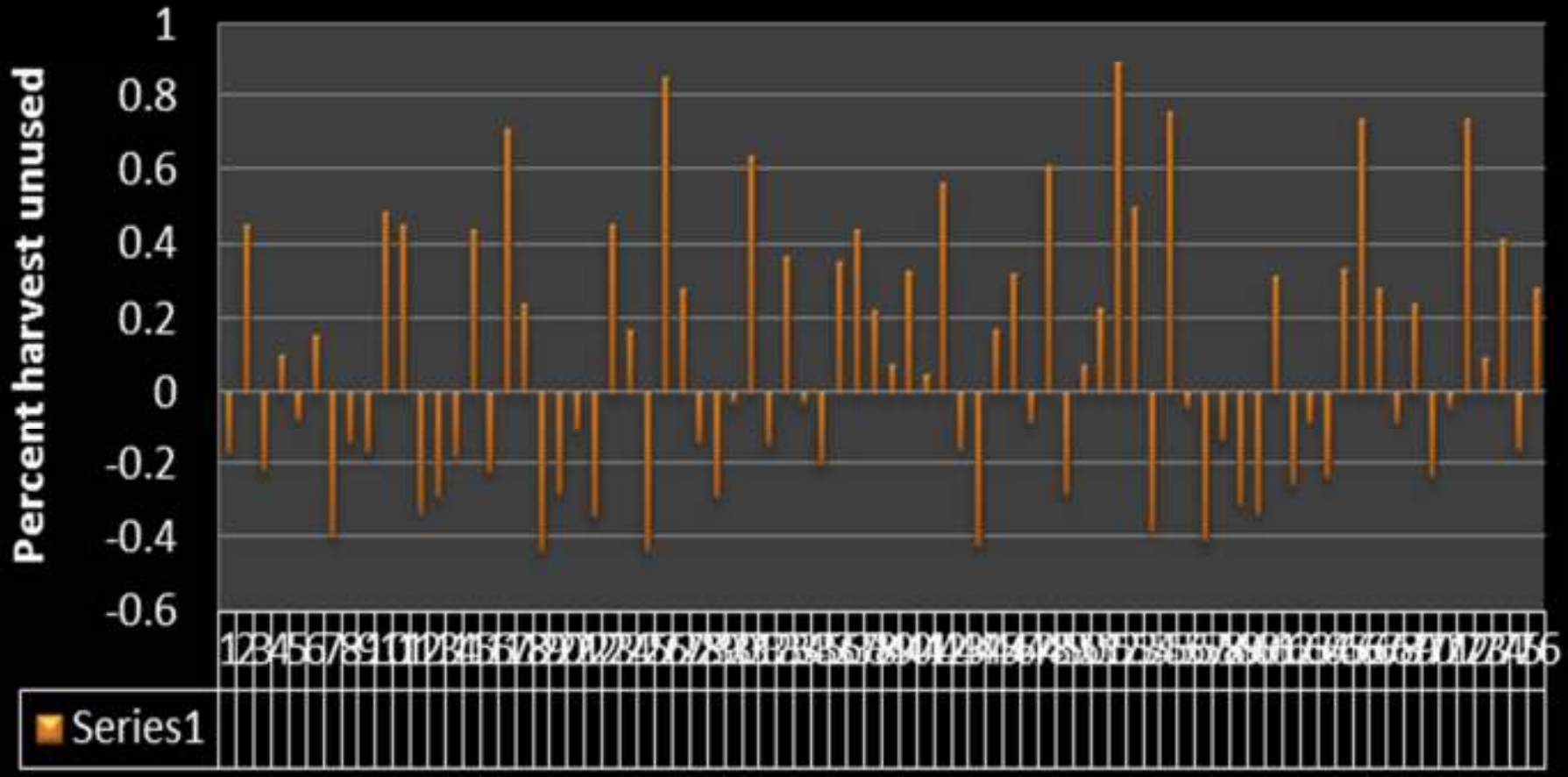
Estimation of Maximum Sustainable Production

Stock (harvestable unit)	Location Lat (oN)	Long (oW)	sample size (length)	sample size (age)	Max FL (mm)	Max Age (yr)	Mean FL (mm)	Age full recr.	Z	P	S	V	Linf	K	M	F	Yield	Biomass	MSP	Over/Und	CCH	PA
Ajakutalik Lake	68.23	82.33	193	140	865	18		15	0.6	1.33	2.63	2.33	859.6419	0.166667	0.25	0.35	373.4	1066.857	320.0571	-0.16667	0.31	Cautious
Amadjuak Lake	65	71	283	179	814	23	426	15	0.27	1.33	1.67	1.76	809.7398	0.130435	0.195652	0.074348	9100	122397.7	16523.68	0.449275	0.76	Healthy
Anaktuvvuit	65.17	64.05	230	148	867	22		17	0.52	1	2.43	2.46	861.5978	0.136364	0.204545	0.315455	623.5	1976.513	513.8934	-0.21929	0.28	Cautious
Angujaatutit Lake	65.05	63.42	200	153	788	20		17	0.41	1.67	1.87	1.59	784.2836	0.15	0.225	0.185	1500	8108.108	1662.162	0.097561	0.62	Healthy
Arrowsmith River	68.23	90.17	460	137	725	11	588	8	0.88	3	2.27	1.27	722.5346	0.272727	0.409091	0.470909	1476.896	3136.265	1379.957	-0.07025	0.65	Healthy
Arviat Area	61.07	94.04	427	347	750	11	668	7	0.71	2.67	2	1.05	747.0468	0.272727	0.409091	0.300909	2360.673	7845.137	2785.024	0.152369	1	Healthy
Ava Inlet	63.49	71.55	507	449	731	17	527	13	0.87	1.67	2.17	1.77	728.4187	0.176471	0.264706	0.605294	519	857.4344	372.984	-0.39148	0.28	Cautious
Back River	67.15	95.15	746	297	895	19	611	13	0.55	2.67	1.53	0.63	888.974	0.157895	0.236842	0.313158	2028.86	6478.713	1781.646	-0.13876	1.2	Healthy
Baker Foreland Lake	62.55	90.48	981	815	752	14	606	8	0.77	3	1.73	0.73	749.0072	0.214286	0.321429	0.448571	2682.487	5980.067	2302.326	-0.16512	1	Healthy
Barbour Bay	63.35	92.14	130	118	664	11		6	0.55	2	2	1.41	662.6674	0.272727	0.409091	0.140909	496.8743	3526.205	969.7062	0.487603	0.98	Healthy
Brown Inlet	69.29	67.2	259	207	785	20		14	0.41	2.67	1.67	0.75	778.588	0.15	0.225	0.185	1529.837	17998.09	2699.713	0.461619	1.6	Healthy
Chesterfield Inlet (Fish Bay)	63.19	90.45	903	768	750	13	597	9	1.03	2	1.83	1.3	747.0468	0.230769	0.346154	0.683846	2580.29	3784.901	1949.224	-0.32786	0.44	Cautious
Clyde Area	70.27	68.36	316	269	768	18	508	14	0.7	2.33	2.67	1.8	764.6875	0.166667	0.25	0.45	700	1555.556	544.4444	-0.28571	0.34	Cautious
Coppermine River	67.49	115.04	1039	735	913	14	663	8	0.78	2.67	2.47	1.5	906.5657	0.214286	0.321429	0.458571	617.8	1347.227	525.4187	-0.17582	0.48	Cautious
Coppermeedie River	61.52	93.37	266	208	747	11	648	7	0.57	2.67	1.9	0.96	744.106	0.272727	0.409091	0.160909	1099.327	6831.976	1947.113	0.435407	1.39	Healthy
Corbett Inlet	62.28	92.2	1422	1242	803	14	647	8	0.82	2	2.37	1.69	798.9702	0.214286	0.321429	0.498571	2287.522	4588.153	1881.143	-0.21603	0.4	Cautious
Curtis River (Committee Bay)	67.12	87.28	809	171	794	17	604	13	0.31	2.67	2.63	1.67	790.1569	0.176471	0.264706	0.045294	712.1462	15722.71	2437.02	0.70778	0.96	Healthy
Diana River	62.5	92.23	627	141	806	13	704	8	0.96	1.67	2.5	2.01	801.9076	0.230769	0.346154	0.213846	6763.6	31628.35	8855.937	0.236264	0.56	Healthy
Ekaluk River	69.25	106.17		2802	878	21	604	13	0.75	2	2.27	1.61	872.3544	0.142857	0.214286	0.535714	14473.03	27016.32	10131.12	-0.42857	0.29	Cautious
Ellice River	68.03	104		3279	885	18	632	9	0.69	2	2.53	1.83	879.1984	0.166667	0.25	0.44	8154.043	18531.92	6393.511	-0.27536	0.34	Cautious
Ferguson River	62.03	93.2	2309	1377	863	16	663	8	0.63	1	2.63	2.58	857.6858	0.1875	0.28125	0.34875	4902.423	14057.13	4427.995	-0.10714	0.31	Cautious
Gifford River	70.19	83.03	346	268	858	23		18	0.99	1.67	2.33	1.89	852.7954	0.130435	0.195652	0.394348	4034.987	10232.05	3018.455	-0.33677	0.3	Cautious
Hall Beach Area	68.46	81.13	197	152	838	23		12	0.27	1.67	2.1	1.73	833.2291	0.130435	0.195652	0.074348	1943.096	24135.21	3528.253	0.449275	0.78	Healthy
Hall Lake	68.41	82.17	551	450	838	22	558	11	0.35	1.67	2.77	2.21	833.2291	0.136364	0.204545	0.145455	5608.928	38561.38	6748.242	0.168831	0.48	Cautious
Halovik River	69.1	107.04		2358	880	20	611	13	0.79	2	2.13	1.51	874.3099	0.15	0.225	0.565	7407.27	13110.21	5178.534	-0.43038	0.31	Cautious
Hayes River	67.08	95.17	202	166	794	18	611	11	0.27	2.33	2.5	1.64	790.1569	0.166667	0.25	0.02	2470	123500	16672.5	0.851852	1.06	Healthy
Iqaluvung Lake	66.43	67.46	300	196	703	18	527	13	0.39	2.33	1.63	0.92	700.9527	0.166667	0.25	0.14	1546.713	11047.95	2154.35	0.283051	1.28	Healthy
Ikaluit Lake	65.02	67.07	151	130	733	18		14	0.58	2	1.9	1.35	730.3799	0.166667	0.25	0.33	1181.4	3580	1038.2	-0.13793	0.56	Healthy
Ikaluit River	71.58	79.15	1427	878	809	19		13	0.66	2	2.37	1.69	804.8448	0.157895	0.236842	0.423158	635.45	1501.685	495.5562	-0.2823	0.36	Cautious
Ikkeesarjuk Lake	71.12	87.22	700	425	867	22	542	14	0.42	1.33	2	1.94	861.5978	0.136364	0.204545	0.215455	1547.652	7183.195	1508.471	-0.02597	0.45	Cautious
Ikpikturjuao Lake	70.21	78.24	373	154	800	25		18	0.22	1.33	1.8	1.85	796.0326	0.12	0.18	0.04	1240.5	31012.5	3411.375	0.636364	0.83	Healthy
Iqaluijuaq Fjord	65.43	64.51	308	271	714	17	524	11	0.62	2.33	1.8	1.04	711.745	0.176471	0.264706	0.355294	1795.306	5053.014	1566.434	-0.14611	0.72	Healthy
Isortoq River	70	75.59	400	127	788	22		15	0.3	1.33	2.09	1.96	784.2836	0.136364	0.204545	0.095455	1263.5	13236.67	1985.5	0.363636	0.64	Healthy
Ivisarak Lake	70.34	86.2	341	199	877	25		20	0.37	1	2	2.24	871.3766	0.12	0.18	0.19	2010.246	10580.24	1957.345	-0.02703	0.39	Cautious
Jayco River	69.34	103.21		2239	830	25	578	15	0.45	1.33	2.4	2.18	825.4005	0.12	0.18	0.27	12374.25	45830.56	10311.88	-0.2	0.32	Cautious

Estimation of Maximum Sustainable Production

Jungersen River	71.23	84.37	302	213	846	19	628	12	0.35	2	2.07	1.46	841.0565	0.157895	0.236842	0.113158	1350.395	11933.72	2088.402	0.353383	0.85	Healthy
Keel River	71.12	75.07	164	129	762	19		12	0.33	2	2.03	1.44	758.808	0.157895	0.236842	0.093158	308	3306.215	545.5254	0.435407	0.92	Healthy
Keith Bay	68.15	88.15	966	395	740	18	537	10	0.41	2	1.43	1.09	737.2436	0.166667	0.25	0.16	664.6874	4154.296	851.6307	0.219512	1.02	Healthy
Kellett River	68.21	90.07	422	116	752	11	519	8	0.76	2.67	2.27	1.31	749.0072	0.272727	0.409091	0.350909	3735.944	10646.47	4045.66	0.076555	0.74	Healthy
Kingark River	68.01	94.5	295	129	811	20		13	0.34	2	2.43	1.75	806.9028	0.15	0.225	0.115	804.04	6991.652	1188.581	0.323529	0.7	Healthy
Koluktoo Bay	72.05	80.3	144	122	907	22		18	0.39	1	2.33	2.4	900.7024	0.136364	0.204545	0.185455	2714.703	14638.1	2854.43	0.048951	0.39	Cautious
Kukaluk River	70.13	81.57	300	221	844	24		14	0.24	1.67	2.37	1.91	839.0998	0.125	0.1875	0.0525	4046.941	77084.99	9250.151	0.5625	0.76	Healthy
Kulgayuk River (Dease Point)	68.16	105.09	419	318	805	15	638	10	0.71	2	2.37	1.69	800.9285	0.2	0.3	0.41	3670.738	8963.02	3178.322	-0.15493	0.44	Cautious
Lauchlan River (Byron Bay)	68.56	108.3		2657	908	21	633	13	0.73	1.67	2.57	2.06	896.7932	0.142857	0.214286	0.515714	7080.008	13746	9017.29	-0.41292	0.23	Cautious
Lord Lindsay Lake	70.1	92.25	437	206	811	22		14	0.35	1.67	2.4	1.93	806.9028	0.136364	0.204545	0.145455	2678.516	18414.8	3222.59	0.158831	0.55	Healthy
Magda River	71.39	84.37	407	310	775	19	609	11	0.36	2	2.17	1.54	771.546	0.157895	0.236842	0.123158	2883.171	23410.36	4213.865	0.315789	0.79	Healthy
Magusa River	61.17	94.03	653	525	731	11	627	7	0.89	3	2.63	1.63	728.4187	0.272727	0.409091	0.430909	2026	4212.854	1874.72	-0.08069	0.5	Cautious
Mangles Bay	67.28	95.25	366	119	805	18	590	14	0.31	2	1.57	1.15	800.9285	0.166667	0.25	0.06	727.5	12125	1879.375	0.612903	1.31	Healthy
Markham Bay	63.3	71.48	494	441	706	18		12	0.69	2.33	1.6	0.9	702.9152	0.166667	0.25	0.44	621	1411.364	486.9206	-0.27534	0.69	Healthy
Murchison River	68.35	93.3	1078	458	830	20	573	11	0.42	2	2.37	1.69	825.4005	0.15	0.225	0.195	3233.74	16583.28	3482.489	0.071429	0.57	Healthy
Nakyoktok River	68.37	110.52	140	106	747	15	590	12	0.49	2	2.03	1.44	744.106	0.2	0.3	0.19	995.75	5240.789	1283.993	0.22449	0.78	Healthy
Naulinavik Lake	65.13	63.5	230	146	854	25		18	0.19	1	2.33	2.4	848.8827	0.12	0.18	0.01	2218.449	221844.9	21075.27	0.894737	0.75	Healthy
Neergaard Lake	70.24	79.35	301	148	762	25		16	0.24	1.33	1.87	1.88	758.808	0.12	0.18	0.06	797.75	13298.83	1585.5	0.5	0.67	Healthy
Nettilling Lake	66.3	70.55	3102	3612	733	20	515	11	0.72	2.33	1.33	0.75	730.3799	0.15	0.225	0.485	8347.24	16863.11	6070.72	-0.375	0.51	Healthy
Opingivik Lake	65.14	67.22	200	130	785	19		13	0.27	2	1.93	1.37	781.3421	0.157895	0.236842	0.033158	900.4448	27156.27	3666.097	0.754386	1.1	Healthy
Padle Fjord	66.47	63.47	250	133	851	17		12	0.55	1.67	2.4	1.93	845.548	0.176471	0.264706	0.285294	4245.044	14879.54	4091.872	-0.03743	0.36	Cautious
Palirvuak (Surrey) River	69.27	106.4		2563	860	21	620	13	0.72	1.67	2.77	2.21	854.7516	0.142857	0.214286	0.505714	7947.639	15715.67	8657.641	-0.40476	0.15	Critical
Perry River	67.43	102.1	516	353	790	17	580	11	0.61	2	2.03	1.44	786.2394	0.176471	0.264706	0.345294	5065.107	14668.96	4474.094	-0.13211	0.42	Cautious
Pistol Bay	62.28	92.44	802	716	754	12	623	8	1.08	2.67	1.57	0.66	750.9675	0.25	0.375	0.705	1230.754	1745.75	942.7052	-0.30556	0.65	Healthy
Qaisgyat	64.37	66.19	192	159	731	16		14	0.84	2.33	1.77	1.02	728.4187	0.1875	0.28125	0.55875	1108.904	1984.616	833.5386	-0.33036	0.4	Cautious
Ranger Seal Bay	63.45	91.42	221	192	694	14	575	8	0.49	3	1.8	0.8	692.1207	0.214286	0.321429	0.168571	798.5	4736.864	1160.532	0.311953	1.31	Healthy
Rankin Inlet Area	62.45	92.05	1361	1144	789	14	620	8	0.86	2.67	1.67	0.75	785.26	0.214286	0.321429	0.538571	2380.066	4419.221	1900.265	-0.25249	0.65	Healthy
Rawn River	70.28	79.3	1399	470	792	20		18	0.35	1.33	2.2	2.05	788.1982	0.107143	0.160714	0.189286	5564.015	29394.8	5144.089	-0.08163	0.32	Cautious
Robinhood Bay	63.45	92.02	322	267	734	13	626	9	0.9	3	1.77	0.77	731.3605	0.230769	0.346154	0.553846	266.4346	481.0625	216.4791	-0.23077	0.66	Healthy
Rowley River	70.15	77.47	382	209	776	25		15	0.27	1.33	2.07	1.98	772.5257	0.12	0.18	0.09	605.75	6730.556	908.625	0.333333	0.54	Healthy
Sandy Point	61.44	93.15	260	210	808	14	711	7	0.37	2.67	1.83	0.9	803.8657	0.214286	0.321429	0.048571	1838.36	37848.59	7001.989	0.737452	1.64	Healthy
Steep Bank Bay	63.36	91.37	171	150	682	13	571	8	0.54	3	1.83	0.83	680.3419	0.230769	0.346154	0.193846	647.25	3338.988	901.5268	0.282051	1.23	Healthy
Stony Point Area	63.51	92.48	644	573	777	15	616	9	0.65	2.33	1.63	0.92	773.9064	0.2	0.3	0.35	2300.805	6830.871	2220.083	-0.07692	0.72	Healthy
Swan Lake/Burnside Inlet	66.47	108.1	248	207	757	13	649	10	0.56	2.33	2.33	1.49	753.0849	0.230769	0.346154	0.213846	373.8	1747.986	489.436	0.236264	0.65	Healthy
Tagoknitak River/Lake	68.15	102.05	629	342	757	22		16	0.53	1.33	1.97	1.93	753.9078	0.136364	0.204545	0.325455	938.6803	2884.213	764.3165	-0.2813	0.26	Cautious
Tanujuak Arm	70.36	79.03	240	195	755	24		16	0.39	1.33	1.77	1.83	751.9476	0.125	0.1875	0.2025	661.75	3267.901	637.2407	-0.03846	0.38	Cautious
Tern Lake	67.48	97.02	273	121	739	14	602	10	0.37	2.67	2	1.05	736.263	0.214286	0.321429	0.048571	407.05	8380.441	1550.382	0.737452	1.4	Healthy
Tinitqavuk	68.55	90.34	282	163	817	15	602	9	0.55	2.33	2	1.2	812.6765	0.2	0.3	0.25	478.925	1915.7	526.8175	0.090909	0.42	Cautious
Wallace River	61.37	93.41	206	193	792	11	673	7	0.58	2.67	2.5	1.54	788.1982	0.272727	0.409091	0.170909	673.2857	3939.438	1542.437	0.410668	0.53	Healthy
Wilson Bay	62.18	92.53	1343	1127	789	13	638	8	0.82	2.67	2.27	1.31	785.26	0.230769	0.346154	0.473846	3545.815	7483.051	3068.051	-0.15572	0.1	Critical
Windless River	70.06	77.38	284	167	811	26		19	0.27	1.33	2.43	2.2	806.8028	0.115385	0.173077	0.096923	1020	10623.81	1430.714	0.282051	0.26	Cautious

Average Harvest relative to Maximum Sustainable Production



Charr modelling using life history traits

General conclusion

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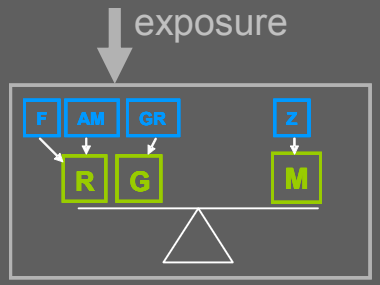

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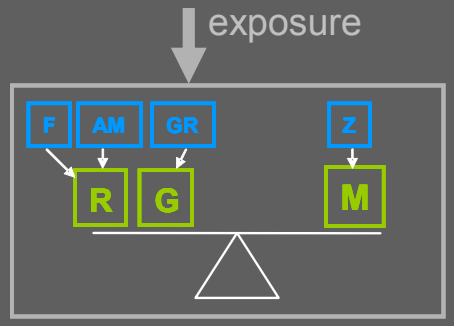
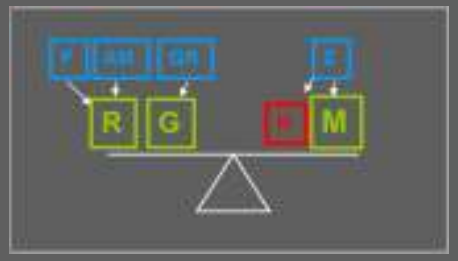


soon:

- Life history traits can be used in a quantitative model to explore and identify sustainable harvest rates for a stock and thereby facilitate the formulation of scientific advice for arctic charr in the CNA region.



Gaps → Solutions

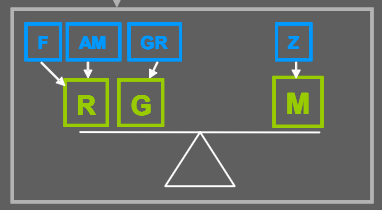
General conclusion

solutions ~~gaps~~ for the scientific understanding and management of Arctic charr fisheries

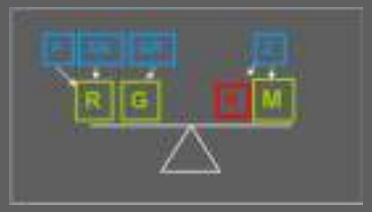
life history traits

charr diversity

exposure



relative risk assessment



full quantitative analysis

Questions ?

Acknowledgments

Theresa Carmicheal DFO

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Nunavut Wildlife Management Board