Proposal for commercial harvesting of pinnipeds in British Columbia

For submission to the Department of Fisheries and Oceans under the New Emerging Fisheries Policy as an exploratory fishery

Proposal prepared by the Pacific Balance Pinnipeds Society (PBPS)
Submitted October 2018, Revised April 2019

TARGET SPECIES:	BC Pinnipeds: 1. Harbour seal; 2. California sea lion; 3. Stellar sea lion
FISHING AREA(S):	North Coast; West Coast Vancouver Island (WCVI); Strait of Georgia
FISHING METHOD(S):	-clubbing on all haulout sites (the traditional First Nations method) -shooting (rifles, shotguns with slugs) in remote areas -harpoons with retrieval line, shot from cross-bows. (in accordance with established marine mammal regulations under the fisheries act – SOR/93-56)

SUMMARY

First Nations people have harvested marine mammals including pinnipeds (harbour seals, sea lions) along the British Columbia coast for thousands of years. Current estimates of abundance from aerial surveys indicate that there has been a massive increase in pinniped abundance since the species were largely protected in the early 1970s (Olesiuk 2010, 2018; Majewski and Ellis 2016), to levels probably much higher than were present during pre-contact times.

This proposal is to initiate redevelopment of that long-standing fishery, as an “exploratory” fishery type. The basic objectives of the fishery would be to (1) provide commercial incomes to First Nations and other license holders through the sale of valuable products (skins, oil, meat), and (2) to reduce population sizes (seals) or prevent further population growth (sea lions) so as to reduce predation impacts on chinook and coho salmon (and possibly other species like steelhead and rockfish) and allow development of healthier fisheries for these species at least in the Georgia Strait region. Reductions in Steller sea lion abundance are not recommended since this species is listed as a Species of Special Concern by SARA and COSEWIC. Harvesting would be allowed all along the coast, but with particular emphasis on reducing seal abundances in the Georgia Strait where declines in first-ocean year survival rates of chinook and coho salmon have been most severe. Harvesting would take place mainly in winter when hides are most valuable and where interference with ocean uses like ecotourism would be minimal.

It is envisioned that the fishery would develop in three phases over the next decade. In Phase I (years 1-2), limited harvesting would demonstrate whether the fishery is technically feasible (hunting methods, humane harvesting) and economical for harvesters (processing and marketing).. In Phase II (years 3-6), the fishery would develop rapidly so as to stabilize the sea lion populations at current levels and reduce the harbour seal population by about 50%, to near the levels expected to produce MSY. In Phase IIII (years 7 ff) the fishery would be managed to sustain yields near MSY for the foreseeable future. Data

gathered during Phases I-II would be reviewed by DFO with a decision made about whether to proceed to the next phase.

For long term management (Phase III), the fishery would be managed through assignment of individual species-area quotas or permits to license holders, with the licensing (or at least the allocation process) to be administered by DFO with assistance in license allocation by the Pacific Balance Pinnipeds Society (PBPS). Quotas would be issued on an annual basis, with priority to First Nations applicants, and the quota allowed for each permit would be varied over time in response to changes in assessments of abundance so as to insure long term sustainability at current sea lion abundances and at harbour seal abundances approximately half of present levels. PBPS recommends a format for the permits that would provide detailed logbook information on the spatial locations of each animal harvested, with PBPS assuming costs for analysis of the logbook data to provide DFO with improved information for varying species-area quotas as needed. For phases I-II, the proposal presents an option for simplified harvest management involving a derby fishery approach, with simpler and more widely available harvest permits and fishery closures imposed as needed by DFO based on monitoring of processing plant deliveries and commercial sales slip information on species and location (statistical area) of harvests.

PBPS recommends that the In terms of the objective of reducing impact on chinook and coho populations, it would be best to reduce the seal population as rapidly as possible, from current levels of around 100,000 seals coastwide (40,000 in the Georgia Strait) to around 50,000 (20,000 in the Georgia Strait). As harvesting proceeds, PBPS and DFO would conduct collaborative aerial surveys annually, following Olesiuk's protocols, with PBPS funding plane and pilot time and DFO providing observers and analysis of photographs of pinnipeds on haulout sites.

Costs for managing the fishery are not likely to exceed $100,000 per year during years of peak harvests (Phase II), with the bulk of those costs being for seal and sea lion surveys, license administration, logbook record keeping, and compliance monitoring. These costs could easily be recovered from modest voluntary contributions by purchasers of tidal sport licenses or a modest increase in the salmon Conservation Stamp price, along with minor grants from other institutions.

The fishery would likely produce only modest direct benefits in terms of net incomes for fishermen and processors, totaling less than $3 million per year during the peak harvest phase. But there are much larger potential economic benefits for at least two components of the salmon fishery. Expenditures by sport anglers in the Georgia Strait region could increase by $22 million or more as higher fishing efforts are attracted by increased chinook and coho abundance. Incomes to West Coast Vancouver Island commercial trollers could increase by as much as $11 million, due to relaxation in chinook fishing restrictions aimed at protecting interior Fraser coho, if survival rates of those coho improve substantially as predicted. Other potential benefits from increased chinook abundance would be reduced costs or lost fishing opportunities due to measures aimed at improving food supplies for southern resident killer whales.

The following sections provide more detailed information on expected harvests, impacts on the marine ecosystem, assessment monitoring, licensing and catch reporting, harvesting methods, marketing and processing, compliance with CFIA inspection requirements, management costs and benefits, and public consultation. There are important uncertainties in each of these areas that will need to be resolved through consultation with DFO and the public.

An alternative proposal by sport fishing groups has been to cull "problem" seals in order to improve salmon survivals (see www.srkw.org). Addendum A to this proposal explains why that would be a lose-lose policy, i.e. would involve controversial seal killing without substantial benefit to salmon abundance.

This proposal draft includes two additional Addenda to address specific issues raised by DFO staff. Addendum B discusses possible impacts of seal harvesting on transient killer whales, and Addendum C discusses possible impacts on marine ecotourism.

SCIENCE

This section provides a variety of data analyses in support of the proposal. All data used in these analyses are available as Excel spreadsheets with names indicated below the graphs and in text. These spreadsheets are available at the Dropbox link:
https://www.dropbox.com/sh/a86vojnytd02nrp/AAD45U3kED9n9d5VA059Pc9Ia?dl=0
Questions about them can be addressed to Carl Walters, UBC (c.walters@oceans.ubc.ca).

Life Histories/Species Overview

Harbour seals (*Phoca vitulina*) are abundant in northern oceans around the world, with several recognized subspecies. The B.C. population exhibited rapid population growth from the early 1970s until 2000, and has now stabilized at around 100,000 animals. They exhibit obligate haulout behavior that has made them relatively easy to census. Pupping occurs through the summer months in B.C. Juveniles grow rapidly, with females reaching maturity at 2-5 years of age and males maturing at ages 5-6. Based on observed population growth rates, most mature females must produce a pup every year. They live to maximum ages of around 20 years for males and 20-25 years for females (http://marinebio.org/species.asp?id=158).

Steller sea lions (*Eumetopias Jubatus*) are distributed around the north Pacific, with highest abundances in the Gulf of Alaska. The B.C. population has grown rapidly in recent years, to a total abundance of around 35,000 animals in 2013. They also exhibit obligate haulout behavior. Pupping occurs in summer, mainly in a relatively small number of large rookeries scattered in outside waters along the B.C. coast; in winter, animals spread widely to utilize haulouts in both inside (Georgia Strait) and outside waters. Juveniles grow rapidly to much larger sizes than harbour seals. Females reach maturity over a wide range of ages, from 3-8, and males from ages 3-7. Based on observed population growth rates much lower than for harbour seals, it is likely that females do not produce pups every year. They live to maximum ages of around 30 years (http://www.dfo-mpo.gc.ca/species-especes/profiles-profils/stellersealion-otarieSteller-eng.htmlrs ()).

California sea lions (*Zalophus californianus*) were first recorded in B.C. waters in the 1950s, as the population expanded from its core distribution off Mexico and California. Animals found in B.C. are likely mainly from the California breeding rookeries, moving into B.C. during fall and winter months to forage; the overall California breeding population has grown from around 75,000 animals in 1975 to 275,000 in 2012, and is showing signs of stabilizing (Laake et al. 2018). There is very limited information on life history and abundance in B.C. from unpublished surveys (Yamanaka et al. 2011). They likely haul out much less frequently than seals, spending up to two weeks at sea foraging between haulout periods. Their pupping season is similar to Steller sea lions, and they have life history characteristics (ages at maturity, longevity) similar to Steller sea lions.

Stock assessment: sustainable harvests and abundances

Table 1 summarizes estimated current population sizes (from Olesiuk 2010,2018 and Yamanaka et al. 2011) and proposed yields by fishery development phase for the three pinniped species. It is likely that there will be enough applicants for licenses to reduce population sizes within a few years to the balanced levels associated with MSY, but this prediction is uncertain because marketing and processing schemes have not yet been tested.

Table 1. Estimated current population sizes and proposed annual harvests for the Georgia Strait and outside (West Coast Vancouver Island, North Coast) areas. Phase III yields for harbour seals are MSY estimates based on logistic population growth models fitted to historical data. Source: Carl Walters, UBC), and harvests needed to stabilize population size for the sea lion species

CURRENT POPULATION SIZES

Species	Georgia Strait	Outside Waters
Harbour seal	40000	60000
Steller sea lion	1500	27200
California sea lion	3000	15000

PHASE I DEMONSTRATION FISHERY ANNUAL HARVESTS (1-2 YEARS)

Species	Georgia Strait	Outside Waters
Harbour seal	1000	1000
Steller sea lion	72	300
California sea lion	150	150

PHASE II STOCK REDUCTION FISHERY ANNUAL HARVESTS (4-5 YEARS)

Species	Georgia Strait	Outside Waters
Harbour seal	4000	6000
Steller sea lion	72	1300
California sea lion	150	700

PHASE III SUSTAINABLE FISHERY ANNUAL HARVESTS (LONG TERM)

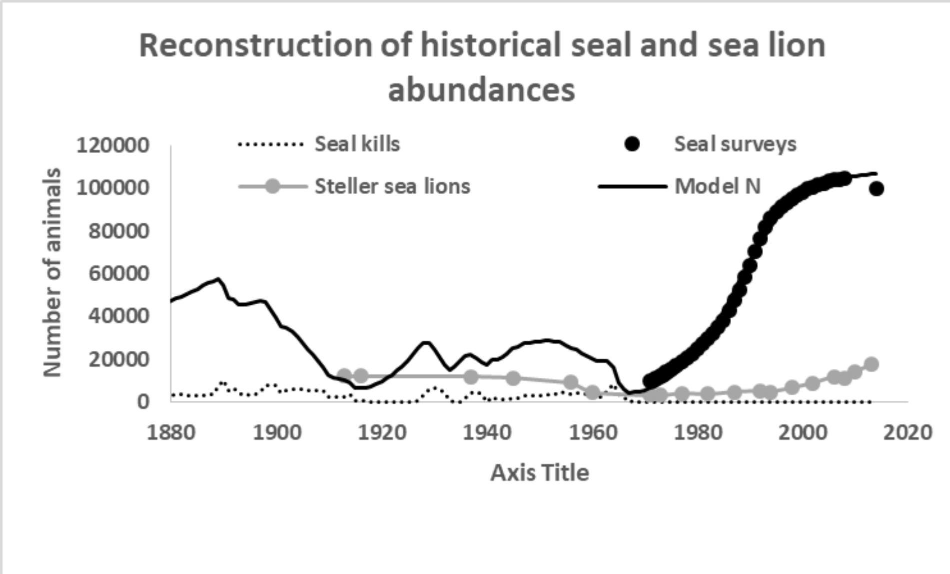
Species	Georgia Strait	Outside Waters
Harbour seal	1800	2000
Steller sea lion	72	1300
California sea lion	150	700

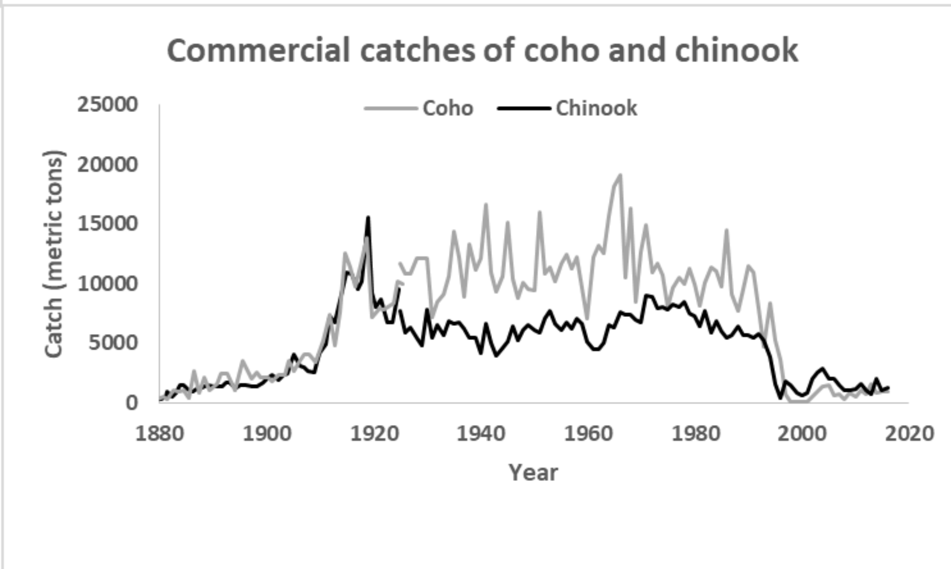
Note in Table 1 that the sustainable yield estimates for sea lions are based on holding populations at current sizes, with yield estimated from recent population growth rates. The following sections provide more information by species about how the estimates in Table 1 were derived, along with recommended area-specific allowable harvests for seals and Steller sea lions.

Harbour seal assessments

Long term reconstructions of seal abundance using the methods in Olesiuk (2010) show that the seal population in the late 1800's was roughly half of what it is today, near the end of the long period of intense First Nations harvesting (Figure 1). Based on information from middens, pinnipeds were important to First Nations people of coastal B.C., particularly harbour seals in the southern Georgia Strait (McKechnie and Wigen, 2011). As the seal population grew after harvests ended, there was a severe decline in coastwide catches of chinook and coho salmon, particularly when exploitation rates were reduced during the 1990s in response to observations of declining abundance.

Figure 1. Top panel: reconstruction of seal abundances from historical kill statistics in Olesiuk (2010) using a logistic model fit, recent seal estimates prepared by Olesiuk for Yamanaka et al. (2011), and Steller sea lion abundances from Olesiuk (2018). Bottom panel: total B.C. commercial catches of chinook and coho, from NPAFC.org and Argue and Shepard (2005).





(long term seal abundance SRA repaired.xlsx)

Aerial surveys since the early 1970s provide considerable information on population growth rates and (for seals) equilibrium population sizes without harvesting. By fitting logistic population models to these data, it is simple to estimate population sizes that would produce maximum sustainable yield, and MSY. To obtain the MSY and MSY abundance estimates, the logistic model for numbers N(t) over time

$$N(t+1) = N(t) + rN(t)[1-N(t)/K] \qquad (1)$$

was propagated forward over time from 1972 to the present, with r, K, and N(1972) varying so as to find the values that minimized a simple sum of squared differences between observed and predicted N(t). Then the reference points for harvest management were calculated as

$MSY=rK/4$ (2) (maximum sustainable yield)

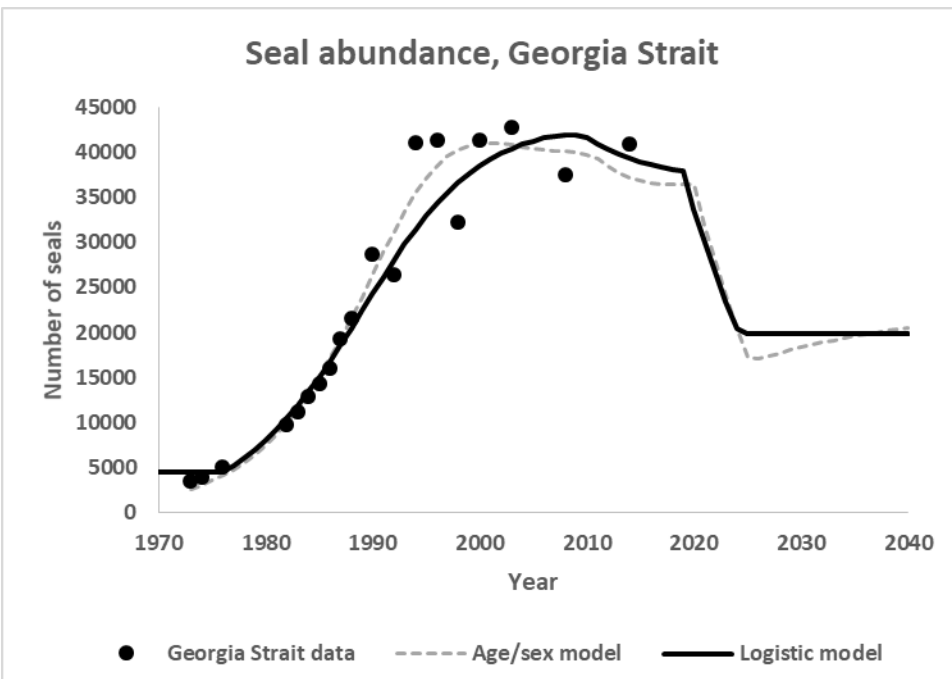
$Fmsy = r/2$ (3) (annual harvest rate leading to MSY)

$Bmsy = K/2.$ 4) (equilibrium stock size that produces MSY)

Since there are observations over a wide range of abundances, and these observations are close to the predicted values, statistical uncertainty in the reference point estimates is quite low for the Georgia Strait, with K being more uncertain for areas outside the Strait.

Figure 2 shows the results of the logistic model fitting for harbour seals in the Georgia Strait, for which the data indicate a maximum population growth rate (population "r") of close to 18%/year, and an MSY of around 1800 seals at a sustainable exploitation rate of 9% on a balanced population size of around 20000. As indicated in Figure 2, projections of abundance decrease under harvesting indicate a rapid approach to the balanced level for MSY. Since some biologists are concerned about possible effects of population structure, a fully age-sex structured model was fit to the data using survival rate estimates from Olesiuk (1998); reference point estimates (e.g. MSY) for this model were slightly more optimistic than for the logistic model (MSY=2000 vs 1800 for the logistic model), so the more conservative estimates for the logistic model were used for policy development.

Figure 2. Historical and predicted abundances of harbour seals in the Georgia Strait, using data from Olesiuk (2010) and Majewski et al. (2016). Fitted logistic growth model used to project reduction under harvesting after 2019. This projection includes predicted impact of transient killer whale predation; seal decline begins in 2008 due to assumed growth in kills by transient killer whales, growing to 1000/year by 2012 and remaining at that level afterward. Source: Carl Walters and Ben Nelson, UBC. Dotted line shows fit to fully age-sex structured model.



(harbour seal age sex model fitted to georgia strait.xlsx)

Similar calculations for areas outside the Georgia Strait indicate lower population growth rates for seals, around 12% per year implying MSY harvest rate of 6% per year.

To provide further assessments of uncertainty in the reference point estimates (MSY, etc.), Murdoch McAllister analyzed the data using a full Bayesian state space logistic model similar to one he has used in other assessments (Yamanaka et al. 2011, McAllister et al. 2010). The state space model accounts for both process (population growth rate variation) and measurement error (random effects and persistent bias in scaling from counts to total abundances), and provides posterior probability distributions for the important reference points. Plots of McAllister's posterior distributions for the Georgia Strait and Outside seal data from Olesiuk (2010) are provided in Appendix B.

The reconstructed seal abundances for 1886-1972 shown in Figure 1 were obtained by solving the logistic model backward in time while accounting for historical kills estimated by Olesiuk (2010), using the population r,K estimated for the more recent data. That is, the logistic model was written as

$$N(t+1) = R(t)N(t) - C(t) \qquad (5)$$

where C(t) is estimated kill and R(t)=1+r[1-N(t)], approximated by R(t)=1+r[1-N(t+1)/K] because N changes were slow. Solving eq. (5) for N(t) gives the backward or "stock reduction analysis" equation

$$N(t) = [N(t+1)+C(t)]/R(t) \qquad (6).$$

Olesiuk (2010) used this same basic approach but with constant R, and also used a forward prediction approach to obtain N(1886) by simulating eq. (5); that approach is numerically difficult to implement, and apparently did not work properly for him.

The main uncertainty in the sustainable yield estimates for seals in Table 1 is about future impacts of predation by transient killer whales in the Georgia Strait region, which could make the historical population growth pattern unreliable as a predictor of future population r,K values. Transients specifically target pinnipeds, and there is clear evidence that more of them have been moving into the Strait in recent years (Houghton et al. 2015, Shields et al. 2018), so their predation impacts are likely to grow. This means that it is critical to closely monitor pinniped population sizes as the fishery develops, as proposed below. It is recommended that the fishery simply be closed if population sizes drop below 40% of the current levels shown in Table 1 (see also Fig. 4a); unless there is really substantial growth in transient killer whale abundance, these limit reference points should insure rapid recovery (see population growth rates evident in Fig. 2, showing doubling in abundance every five years when population size has been low) to levels that can again sustain harvesting (at perhaps lower exploitation rates than currently estimated to be optimal for MSY).

There is also modest uncertainty in the absolute abundance estimates. These estimates are the product of three factors: (actual aerial count)(expansion for proportion hauled out at count time)(expansion for proportion of shoreline surveyed). The expansion factor for proportion hauled out (1.6-1.7) is uncertain due to variation in haulout patterns with tide, etc. and in the baseline estimates from dive monitoring tagging (details in Olesiuk, 2010). The whole shoreline has been surveyed in recent years for the Georgia Strait, but not for outside areas for which the expansion for proportion of shoreline surveyed has been 3.0-3.1.

If DFO requires that harvesting permits be issued on an area-specific basis rather by the two regions in Table 1, recommended harbour seal harvests by seal census region (as defined by Olesiuk, 2010) are provided in Table 2. These estimates for the Georgia Strait sub-regions are based on 2014 census data, and on earlier census data from Olesiuk (2010) for areas outside the Georgia Strait (outside area estimates could be updated if more recent census data were provided by DFO).

Table 2. Recommended harbour seal allowable harvests by census area. Estimates for the Georgia Strait from 2014 census, and from Olesiuk (2010) for outside areas. BC statistical areas corresponding to the census areas shown in parentheses. Phase II recommended harvests assume

50% reduction in abundance over 4 years, MSY estimates based on region-specific estimates of population growth rates (Umsy=r/2). (Estimates from Recommended HS harvests Georgia Strait subregions.xlsx)

Census area (statistical area)	**Most recent census**	**2014 N (K)**	**Nmsy**	**Phase II annual harvest**	**MSY**
Georgia Strait census regions					
BBAY (29)	2014	1122	561	83	50
FRASERR (29)	2014	1588	794	117	71
GULFISL (18)	2014	10492	5246	772	472
HOWESD (29)	2014	644	322	47	29
NEGULF (15,16)	2014	12900	6450	949	580
NWGULF (14)	2014	4515	2258	332	203
SGULF (19)	2014	8690	4345	639	391
Outside census regions					
SWVI (21)	2007	1594	797	199	48
Barkley (22)	2007	1741	870	218	52
MWVI (23)	2007	2590	1295	324	78
NMWVI (24)	2007	2820	1410	353	85
NWVI (25)	1996	1777	889	222	53
SQCSTR (11)	1989	2055	1027	257	62
NEQSTR (11)	2004	2234	1117	279	67
Broughton (12)	2004	2023	1012	253	61
Discovery Pass (12)	2003	4550	2275	569	137
CC 51 (7)	2006	249	124	31	7
CC 52 (8)	2006	1625	813	203	49
CC 53 (9)	2006	66	33	8	2
CC 54 (10)	2004	1142	571	143	34
NC 62 (3)	2005	457	228	57	14
Skeena (4)	2005	3193	1596	399	96
NC 63 (4)	2005	2294	1147	287	69
NC 64 (5)	2005	1752	876	219	53
NC 65 (6)	2005	1122	561	140	34
NEQCI 72 (2)	2008	4360	2180	545	131
SEQCI 71 (2)	2008	5423	2711	678	163
SQCI 73 (2)	2008	350	175	44	10
SWQCI 74 (2)	2008	424	212	53	13
SWQACI (2)	2008	1748	874	219	52

Steller sea lion assessment

The data in Olesiuk (2018) shown in Figure 1 indicate that the Steller sea lion population is still growing exponentially, at an average annual rate since 1982 of 4.8%. This growth rate implies that the population would be stabilized (prevented from further increase) by a harvest rate equal to the population growth rate, i.e. 4.8%/year. As for harbour seals, there is some uncertainty in the absolute abundance estimates due to limited information about the proportion of sea lions hauled out at the times of aerial survey counts.

Since it is impossible with available data to predict when the population will stop growing absent harvesting, no estimate of MSY can be provided. The harvest rate for MSY should be near ½ of the intrinsic growth rate, i.e. 2.4%/year, but it is recommended that the higher rate of 4.8% be used to prevent further population growth with attendant growth in impacts on salmon populations.

Note that Steller sea lions are listed as a Species of Special Concern under SARA and COSEWIC. The reasons for this listing are entirely unclear considering that the population is large and growing rapidly. Nevertheless, the response in this proposal is to avoid harvests that would cause decline in the population, i.e. would simply stabilize it at current abundance.

The abundances and yield estimates reported in Table 1 are based on Olesiuk's (2018) direct counts for fall 2012 and assumed population growth rate 4.8%. This means that the estimates are certainly very conservative, i.e. do not account for population growth since 2012 and for the proportion of animals not hauled out at the times when survey counts were made.

Specification of area-specific harvest goals for Steller sea lions is complicated because the population in summer is concentrated at 10 breeding sites, from which the animals disperse widely in winter to utilize haulout sites mainly along the mainland coast during the period when winter harvesting would be concentrated. Most likely the winter haulout sites have some mixing or interspersion of animals from different breeding sites, and are variable from year to year due to changes in the distributions of key winter prey types like Pacific herring. Thus it does not make sense to think of the winter/harvesting haulout sites as distinct reproductive populations as may be the case for harbour seals, or to specify area-specific harvests at as fine a scale as for seals in Table 2. However, it does make sense to have at least regional harvest quotas or limits. Recommended regional quotas are provided in Table 3, based on Olesiuk's (2018) regional aggregation of the Steller sea lion population data.

Table 3. Minimum estimates of current Steller sea lion abundance (fall 2012 actual counts) and sustainable harvest (assuming 4.8% annual population growth) for the winter population distribution of Steller sea lions estimated by Olesiuk (2018). It is not recommended to utilize smaller areas for quota setting due to mixing of animals from breeding sites and probable interannual variation in haulout patterns. Estimates from Recommended SSL harvests.xlsx.

Region	**Fall 2012 Abundance**	**Sustainable Yield**
Georgia Strait	1499	72
West Coast Vancouver Island	8838	424
Scott Islands	1250	60
Johnstone and Queen Charlotte Straits	4244	204

Central Mainland Coast	4459	214
North Mainland Coast	3849	185
Haida Gwaii	4538	218

California sea lion assessment

Olesiuk has summarized rough population estimates for California sea lions in Appendix F of Yamanaka et al. (2011), and he indicates that the population has apparently not been growing since 1980 despite the rapid growth in potential numbers reaching B.C. reported in Laake et al. (2018). Recent unpublished survey observations suggest a much larger current abundance (Olesiuk and Majewski, pers. comm.). Since the maximum population growth rate for this species is expected to be similar to that for Steller sea lions, around 4%-5%/year (Laake et al. estimated the overall population r=0.07, with lower growth rates in recent years), it is likely that the "sustainable" yield estimate in Table 1 will cause at least some reduction in the population size. If it occurs, this reduction should not be a serious management concern considering that the overall (from California north) population is healthy, remains protected over most of its range, and in any case is a recent "invader" to B.C. waters.

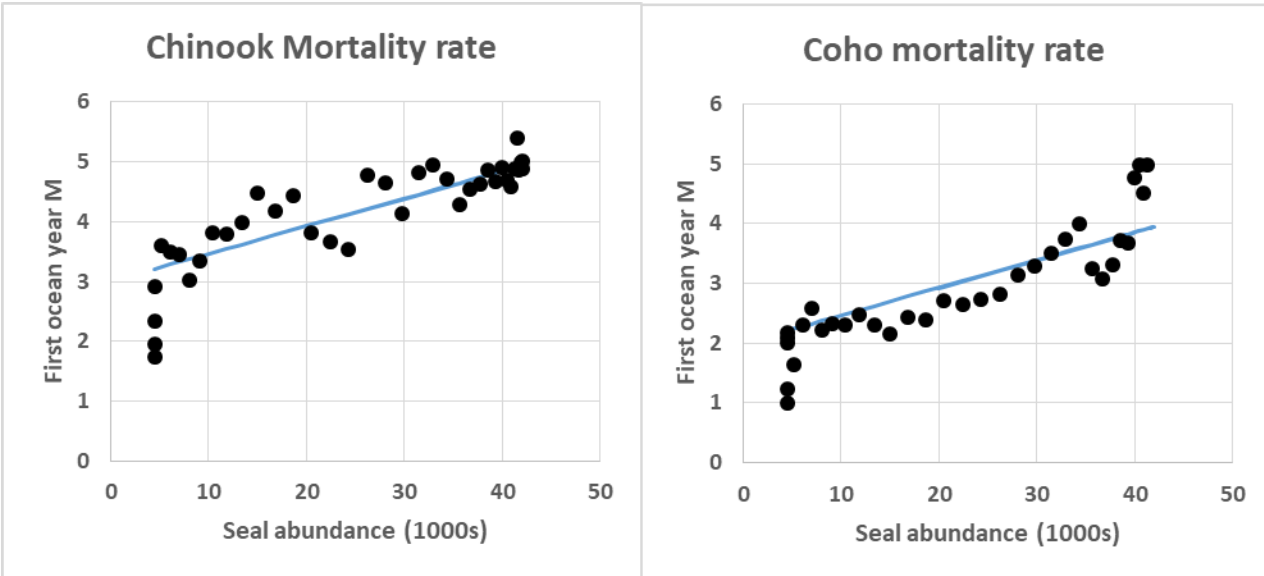
No area-specific harvest limits are recommended for California sea lions. This is partly because there is probably no need for any limits on this invasive species, and partly because area-specific abundance estimates have not been made available for use in this proposal.

Impact on the marine ecosystem, particularly chinook and coho salmon

Pinnipeds currently consume large tonnages of fish along the B.C. coast, on order 0.7 (seals) to 5-6 (sea lions) tons of fish per individual per year (Yamanaka et al. 2011, Appendix F), so that abundance reductions due to fishing will doubtless have substantial impact on a variety of fish populations. Some populations like hake in the Georgia Strait (Saunders and MacFarlane 2000; Guan et al. 2017) have declined considerably as seals increased, while others (like herring in the Georgia Strait) have increased since the 1970s. Most importantly, the Georgia Strait sport fishery for chinook and coho salmon has declined drastically since the late 1970s (Riddell et al. 2013).

Recent publications have estimated larger impacts of pinniped consumption on chinook salmon abundance than fisheries impacts (Chasco et al. 2017). But the most dramatic changes apparently due to pinniped predation have been in the first-ocean year survival rates of chinook and coho salmon in the Georgia Strait (Nelson et al. 2018; Nelson et al. in prep.), measured by recovery of coded wire tags. When measured as instantaneous annual mortality rates, averages of these rates over Georgia Strait indicator stocks have increased by about 2.0 since 1970, implying roughly a 90% decline in first year survival (Figure 3). Further details on the estimation of marine mortality rates and how they have varied among indicator stocks are provided in Appendix C; for chinooks there has been considerable variation among stocks in apparent impact of seal abundance, implying more uncertainty about the overall chinook response to reduction in seal abundance than is apparent from the strong regression relationship in Fig. 3.

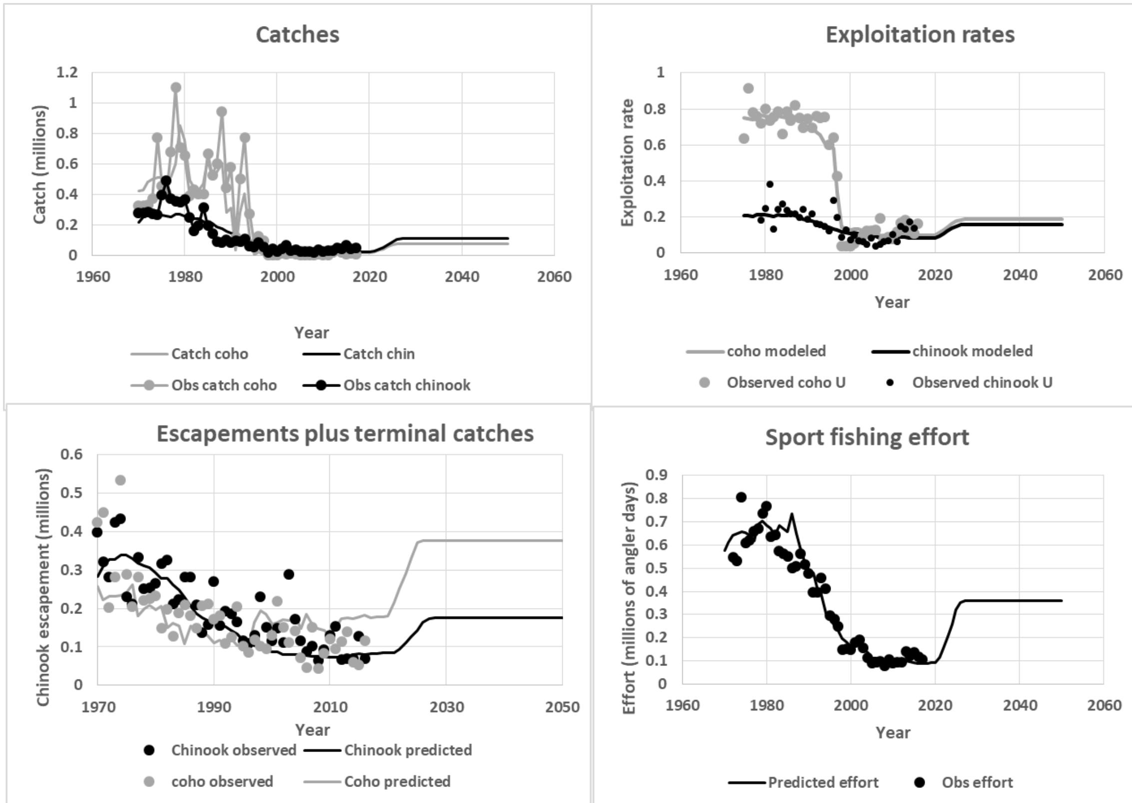
Figure 3. Regression relationship between first year ocean mortality rate of Georgia Strait indicator stocks and seal abundances estimated from fitted logistic models. Mortality rate estimated as –log(survival rate from CWT data). Regression parameters used to predict increases in survival rate and declines in abundance shown in Fig. 4. Source: Carl Walters (UBC)



(georgia strait sport model.xlsx, chinook marine survival rates from CWT data.xlsx)

The mortality relationships in Figure 3 have been used in conjunction with wild and hatchery smolt abundance estimates to predict recovery of chinook and coho abundance if seals were reduced by the recommended 50% (Figure 4).

Figure 4. Reconstructed historical abundances of chinook and coho salmon in the Georgia Strait, and predictions of recovery using the mortality regressions in Figure 3 and the seal abundance pattern predicted in Figure 2. Model reconstructions and predictions shown as solid lines compared to observed indicator statistics for the Georgia Strait sport fishery. From Georgia Strait policy model under development by Carl Walters, Ben Nelson, and Villy Christensen for the Pacific Salmon Foundation's Salish Sea Marine Survival Project.



(Georgia strait sport model.xlsx)

As indicated in Figure 4, seal reduction to balanced levels of around 20,000 seals would not likely result in full recovery of chinook and coho to peak levels of the 1970s and 1980s when positive effects of enhancement (hatcheries) were largest. But abundances should at least double, with attendant benefits particularly for the Georgia Strait sport fishery and coastal communities that derive considerable economic benefits from that fishery.

Increases in chinook and coho survival rates, particularly for threatened interior Fraser coho stocks, would have additional indirect benefits. Current restrictions on West Coast Vancouver Island and Fraser River fisheries because of interior Fraser coho concerns could largely be eliminated, with substantial benefits for WCVI commercial fishing and Fraser River pink and chum fishing.

Importantly, the predictions shown in Figure 4 indicate that availability of chinook salmon to southern resident killer whales would at least double, especially if seal populations in the Puget Sound are also reduced through US management initiatives. These predictions imply higher availability even after allowing for substantial increases in Georgia Strait sport fishing effort and chinook catch, implying that seal reduction would have a much larger positive effect on food availability to southern resident killer whales than any fisheries restrictions now in place or contemplated to make more chinooks available to the whales.

Korman et al. (2019) estimate increases in total life cycle mortality rate for interior Fraser steelhead of about the same magnitude as shown in Fig. 3, i.e. a total mortality rate increase of 1.5-2.0 as measured in their analysis by decreases in the Ricker stock-recruitment “a” parameter. They also have found seal abundance to be a better predictor of mortality changes than other (oceanographic) factors used to explain the increase.

However, it must be admitted that there is considerable debate about the seal-mortality relationship in Fig. 3; scientists involved in the Pacific Salmon Foundation's Salish Sea Marine Survival Project are evaluating a wide range of hypotheses for the mortality rate increase, and no clear consensus was reached in Riddell et al. (2013) about that same range of hypotheses. In particular, sea surface temperatures have increased over the same historical period so that temperature and seal abundance changes have been highly correlated (R^2=0.62). This means that even though the increase in M estimated either from the regression or from seal abundance and diet data agree (i.e. even if scientists agree that seals have been the proximate cause of mortality increase), we cannot rule out the possibility that seals have been selectively consuming smolts that have been made vulnerable to prediction by some stress factor(s) related to temperature (e.g. disease expression, food availability) that would have killed them even if seals had not increased. Put another way, mortality rates caused by seals and other (temperature-related) factors may be not be additive, leading to a weaker mortality response than predicted from Fig. 3 if seal numbers are reduced (Walters and Christensen, ms. In review).

An "ecosystem model" developed by DFO and PSC scientists (Araujo et al. 2013) used a multivariate statistical approach to explain changes in Georgia Strait coho marine survival rates. That study claimed to examine influences of a wide variety of explanatory variables (e.g. PDO, Fraser River flow, temperatures, etc.), including seal abundance. But the pairwise correlations that they presented between survival and the variety of factors included in their final model did not even include seal abundance; they gave no explanation for that omission.

Ecosystem modeling studies using dynamic models like Ecopath/Ecosim have indicated at least some risk of net negative impacts on chinook and coho survival due to increases in other species (particularly hake) that are also predators of juvenile salmon (Yodzis 2001; Martell et al. 2002; Lessard et al. 2005; Li et al. 2010). However, the Georgia Strait model scenarios in Martell et al., Lessard et al. and Li et al. that showed high hake impacts on herring and salmon involved much more severe reductions in seal abundance than are proposed here, and had a grossly incorrect parameter setting for hake feeding. The models assumed hake feeding rates to be about 4-5 times higher than is realistic based on hake body growth data. Also, hake diet compositions in those models included juvenile salmon proportions that are higher than can be supported with available diet data (e.g. McFarlane and Beamish 1985 found no juvenile salmon in examination of 10,000 hake stomachs from the Georgia Strait).

But such modeling studies are not really needed, because there is substantial empirical information about how the B.C. marine ecosystem has responded to changes in seal abundance. Based on that experience, the much more likely scenario is that various species like hake will simply recover to levels seen before the pinniped increase, and at those levels the survival rates of chinook and coho were much higher. That is, if there were substantial negative impacts of seal reduction on the marine ecosystem, those impacts should already have been seen during the period between 1920 and 1980 when seal populations were at historical lows, and more particularly during the 1965-75 period when seals were at their lowest.

Ecosystem studies also indicate a risk that recovery of survival rates may also be limited by environmental changes (e.g. ocean temperatures) that have apparently occurred due to climate change.

These risks imply that it is critical to continue monitoring survival rates (through the CWT programs) as any management plan for chinook and coho is implemented.

There may also be negative impacts of seal reduction on their main predator, transient killer whales. A more detailed analysis of this risk is provided in Addendum B, where transient killer whale foraging and abundance information is used to show that the number of transients using the B.C. coast may decline as much as 50% following seal reduction, but is more likely not to be affected at all since the transients utilize a variety of mammalian prey and are not that dependent (from a bioenergetics perspective) on seals in the first place.

It is quite possible that reductions in seal abundance would have beneficial effects for rockfish. Yamanaka et al. (2011) estimated pinniped predation rates high enough to possibly prevent recovery of yelloweye rockfish (Sebastes ruberrimus, SARA and COSEWIC listed as a species of Special Concern). Quillback rockfish (Sebastes maliger, COSEWIC listed as Threatened), which pinnipeds also consume, have been a key target species in development of an extensive network of Rockfish Conservation Areas. Olesiuk et al. (1990) estimated that 112 t per year of rockfish were consumed in the Georgia Strait, well before the seal population reached its current abundance.

Pinnipeds visibly target spawning aggregations of Pacific herring (Clupea pallasii) and spawning salmon at stream mouths. But there is no clear evidence that such targeting has had substantial impacts on either herring or salmon recruitment. Spawning abundances are increasing for the main BC herring stocks DFO (2018), and recruitment reconstructions for Georgia Strait chinook and coho do not indicate that spawning numbers have been low enough to impair recruitment of smolts (see Addendum A below). However, pinnipeds could be having biodiversity impacts by exerting relatively high impacts on very small spawning runs of both herring and salmon, perhaps even causing localized extinctions of very small spawning stocks.

From the general standpoint of marine ecosystem management in B.C., the pinniped harvesting proposal would represent a major experiment in adaptive management. Considering debates that have occurred over the years about causes of salmon declines in at least southern B.C., such an experiment would have lasting impact on scientific understanding about causes of salmon population variation, whether or not there is the recovery predicted in the Figures above.

Species at risk (SARA) implications

As noted in the section above, there are some potentially beneficial effects of pinniped harvesting for fish stocks that are listed by COSEWIC, in particular rockfishes and interior Fraser coho salmon.

The proposal calls for stabilization, but not reduction, in the abundance of Steller sea lions. DFO staff have indicated that “there is a legal obligation to continue to ensure that anthropogenic impacts from Canadian sources, including a potential fishery, do not cause unsustainable population declines for this species, or contraction of current range or number of breeding sites in Canada. Primary threats to SSL as identified in the Management Plan include prey reduction, environmental contaminants, and physical and acoustic disturbance. The Management Plan also identifies predator control programs and harvesting of SSL as threats to the conservation of this species.” There is no intention in the proposal to cause “unsustainable population declines” or to eradicate sea lions from any breeding site. Winter harvesting, when the sea lions have dispersed widely from their breeding sites (Olesiuk, 2018), should help insure against severe differential harvesting of animals from any one breeding site. Maps in Olesiuk

(2010) show 10 main breeding sites in B.C., and it would be relatively inexpensive to conduct aerial surveys every few years to at least determine trends at each of these sites and to introduce local harvesting closures if necessary for the most likely wintering areas for animals from any sites that show downward trends; it is unclear whether pinniped harvesters should be required to bear the costs of such surveys, since surveys will be needed in any case as part of the DFO Management Plan.

As noted in Addendum B, the number of transient killer whales using the B.C. coast has increased in parallel with seal population increases, at population growth rates higher than expected from killer whale reproductive biology and longevity. Transient killer whales consume a wide variety of marine mammals, and harbour seals are a high proportion of their diets by prey numbers but not by weight of prey consumed; Steller sea lions likely make up a larger proportion of the diet by weight. So if the transients respond directly to seal abundance in choosing where to concentrate, there could be a decrease in numbers using the B.C. coast regularly. But it is very unlikely that there would be any decrease in the overall transient population size, due to high availability of alternative prey. The most reasonable scenario would be that they simply spend more time in more southerly (e.g. California) and northerly (southeast Alaska) foraging areas.

Precautionary approach

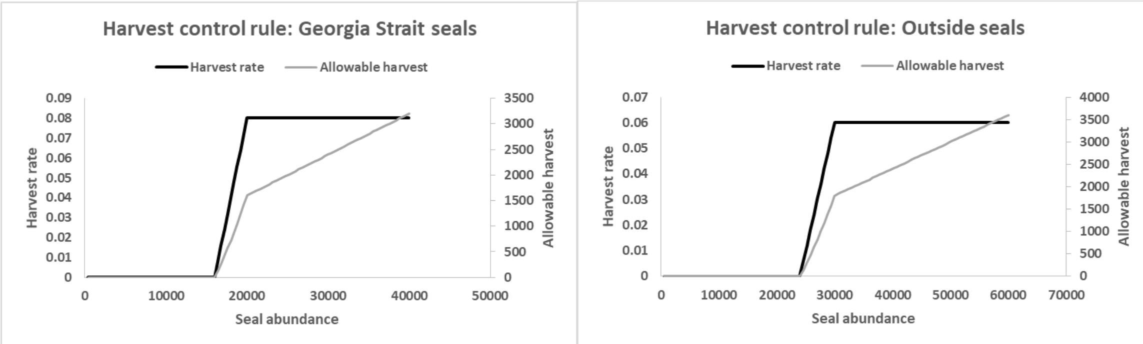
This proposal should be largely compliant with the Precautionary Approach for Canadian Fisheries (http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precaution-back-fiche-eng.htm). It provides for maintaining pinniped stock sizes at relatively high levels (no less than 50% of current) as an upper stock reference point, includes an abundance monitoring program to insure that harvests do not reduce abundances below target levels i.e. to below a limit reference point also set at 40% of current stock size, and includes georeferenced catch reporting to guard against localized depletion of abundances. But it does not call for limitation of initial harvests to an MSY removal reference point because one aim of the fishery is to reduce abundances rapidly so as to promote the earliest possible recovery of chinook and coho stocks.

MSY estimates (coastwide) for the three species are shown in Table 1, along with current abundances. The MSY estimates are based on harvest rates of 9%/year for seals in the Georgia Strait and 6% for seals in outside areas, and 4.8%/year for sea lions, aimed for the sea lions at preventing further population growth rather than achievement of MSY population levels. MSY estimates for local spatial areas are provided in Tables 2-3, based on the regional harvest rate estimates and on seal census data by area.

No species would be managed with a fixed catch quota, rather quotas would be adjusted to maintain harvest rates no higher than the MSY rates for seals and population stabilization rates for Steller sea lions, except as noted for harbour seals where the hope is to initially reduce the population more rapidly than would occur under a 9% exploitation rate cap, during management phase II.

Proposed precautionary harvest control rules for harbour seals are shown in Fig. 4a. Control rules for sea lions are not proposed at this time since the harvest management objective is simply to prevent those population sizes from growing. In any case a control rule for Steller sea lions cannot be estimated with the data available, since there is no indication as yet of slowing in population growth that would permit estimation of population carrying capacity (K) needed for calculation of population size reference points.

Figure 4a. Proposed precautionary harvest control rules for long term management of harbour seals. These rules cap annual harvest rate at the MSY rate, which allows catches above MSY at high population sizes.



(harvest control rules for seals.xlsx)

In keeping with the precautionary approach, it is recommended that the fishery development proceed in the following three phases:

1. Phase I (years 1-2), limited harvesting would demonstrate whether the fishery is technically feasible (hunting methods, humane harvesting) and economical for harvesters (processing and marketing). During this phase, harvests would be compared to population estimates expected from the 2018 DFO survey.
2. Phase II (years 3-5), the fishery would develop rapidly so as to stabilize the sea lion populations at current levels and reduce the harbour seal population by about 50%, to near the levels expected to produce MSY. During this phase, annual population estimates would be obtained and compared to the harvest data using a collaborative survey approach (see below).
3. Phase IIII (years 6 ff) the fishery would be managed to sustain yields near MSY for the foreseeable future. For the long term, impacts of the fishery would be determined by comparison of harvests to ongoing DFO surveys likely to be conducted only once every several years. But harvest rates during this phase should be low enough that annual surveys and assessments are not necessary.

Data gathered during Phases I-II would would be reviewed by DFO with a decision made about whether to proceed to the next phase.

For developing fisheries on long-lived species, there is generally an issue about whether to allow harvests far higher than MSY initially, i.e. initial "overcapitalization" to reduce the accumulated stock to most productive levels. That issue does not apply in this case, since harvesters will largely be existing First Nations and commercial fishermen who will not need to make a large capital commitment to the harvesting process. It remains to be seen whether processing capacity can be mobilized to utilize high initial harvests economically.

MANAGEMENT OBJECTIVES

The basic objectives of the fishery would be to:

1. provide commercial incomes to First Nations and other license holders through the sale of valuable products (skins, oil, meat), and

2. to reduce population sizes (seals) or prevent further population growth (sea lions) so as to reduce predation impacts on chinook and coho salmon and allow development of healthier fisheries for these species at least in the Georgia Strait region.

MANAGEMENT ISSUES

In examining the management plan recommended below, it is important to recognize at the outset that there are several issues that could prevent development past Phase I of the plan:

1. There may be strong public opposition, particularly from ENGOs, to killing marine mammals in general, expressed in various ways such as public protests and attempts to interfere with harvesters on the fishing grounds (as occurred with harp seal harvesting off Newfoundland).
2. There may be public concern about whether the proposed killing methods (clubbing, shooting) are really humane, and more particularly about whether there is likely to be large unreported kill due to shooting, where there is at least some chance of not retrieving each kill.
3. It may turn out that harvesting costs are too high to attract harvesting license applicants, relative to expected earnings, due for example to a finding that the most valuable product (seal oil) has unacceptably high contaminant concentrations.
4. Harvesting may be concentrated in just a few locations (haul out sites) where seals and sea lions are most concentrated, such that there is localized depletion but not a substantial reduction in overall abundance as desired under objective 2 above.

MANAGEMENT PLAN COMPONENTS

Monitoring plan

In developing fisheries, there is typically not a substantial initial commitment to assessment monitoring (abundance indices, size-age and species composition data). The lack of such information then causes serious problems later for scientific stock assessments that attempt to reconstruct pre-harvest abundances as key assessment reference points for long term management. Management strategy simulation studies for fisheries developing under quota management indicate that it is critical to initiate abundance monitoring right from the start of each new fishery (Walters, 1998), and the pinniped case is nearly unique in having considerable pre-fishery abundance data.

It is proposed to closely monitor abundance changes as the fishery develops, using a collaborative implementation of Olesiuk's aerial survey approach. There would be a lower number of flights each year than DFO has used in the past and with those flights concentrated on obtaining counts mainly for the larger haulout sites, so as to minimize the expansion factors need to account for abundances at non-monitored sites (in the 2014 seal data, about 80% of the seals were found on the largest 40 haulout sites). Time(s) of year for the survey would be as recommended by DFO based on past survey experience.

This plan assumes that DFO will be conducting a coastwide pinniped survey in 2018 so as to provide updated abundance estimates (the last DFO survey was in 2014) that might result in some adjustment of at least the Georgia Strait seal abundance and MSY estimates before initiation of Phase I of the fishery development.

It is proposed that PBPS seek funding to cover at least part of the annual survey cost. An experienced volunteer pilot would be used if possible. DFO would provide an experienced observer to take pictures of haulout sites as in past surveys, and experienced DFO staff and DFO image processing software would be used to obtain counts from the photographs. It is anticipated about 60 hrs of floatplane time would be needed each year for surveys (20 hrs for seals, 40 hrs for Steller sea lions due to flying time to offshore haulout sites).

Licensing and catch reporting

Based on meetings all along the coast with First Nations and other fishermen, there will likely be a substantial number of applicants for licenses in the fishery. Assuming that management utilizes a quota allocation system, three main issues will need to be addressed: (1) how many licenses to issue, given that the quota per license holder will have to be smaller if more licenses are allowed; (2) priority to First Nations applicants, with allocation to other fishermen only of the surplus not requested by First Nations applicants; and (3) whether to issue quota shares that are restricted by harvesting area (Georgia Strait, WCVI, north coast) and species.

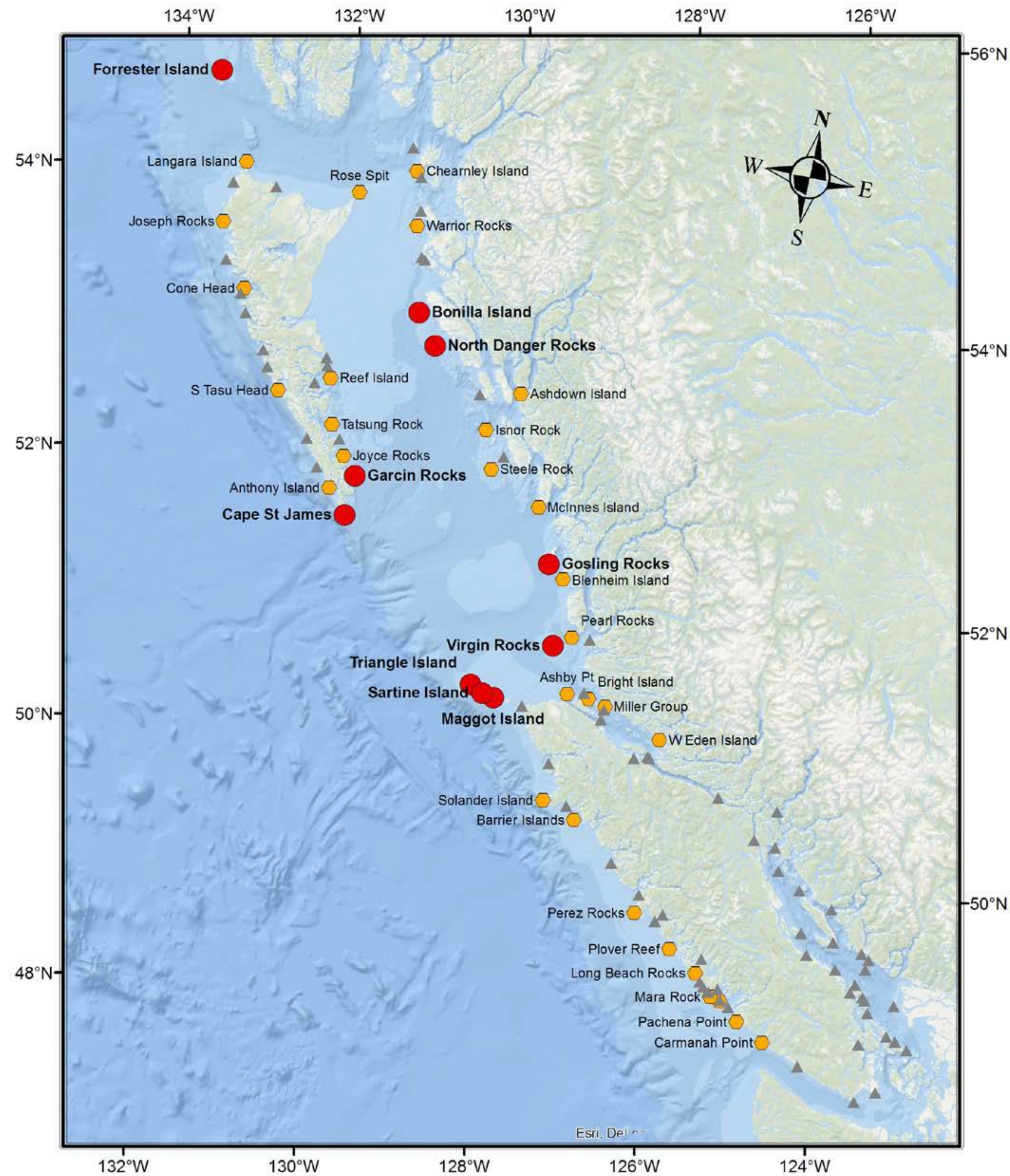
The simplest option would be to initially issue licenses to all applicants, with each applicant given an aggregate (over pinniped species) annual quota to be taken wherever the applicants choose. Applicants would then be allowed to transfer quota shares (i.e. an "ITQ" approach). If this simple option is used initially, it will very likely be found that at least regional and species quotas will need to be implemented later in the development as populations in some local areas are depleted. To avoid local depletion, the harbour seal recommended harvests in Table 2 and the Steller sea lion harvests in Table 3 could be used to set area-specific quotas or permits.

Quota shares would be issued each year as a specific number of animals to be harvested for each share, and for each share the license holder would be provided with a simple logbook with a record line for each animal harvested (similar to the way sports fishermen are required to report each chinook salmon harvested on their licenses); a proposed format for the logbook is provided as Appendix A below. Each individual record would be required to have the date, species, and specific location of the kill recorded as the DFO monitoring code or site name for the haul out site nearest to where the animal was killed (e.g. H001 for a seal, haulout name for a sea lion). License holders would be provided the maps from Olesiuk (2010, 2018) showing the location code numbers for seals and site names for sea lions, as in Figure 4. These maps would also provide fishermen with information on historical abundance patterns to help them find the best hunting locations. For at least the Georgia Strait, maps would also be provided to show areas where juvenile salmon face the highest predation risk (Figure 5) as estimated with individual-based models developed at the University of British Columbia.

DFO may wish to provide each quota share with a tag for each animal included in the share. These tags could be used for catch reporting independent of the logbook, and for traceability/enforcement of each quota limit. Should DFO require this in addition to the logbook as described above, any costs associated with producing and distributing the tags should be borne by DFO as an enforcement cost component.

It is envisioned that logbook reporting would be on an annual basis, at the end of each harvesting season. If necessary, an in-season hail system could be developed where a sample of licensed harvesters would be contacted by phone every month or two, and required to report the number of animals so far recorded for that year in their logbooks.

Figure 4. Location maps for reporting individual harvests. Top map shows sea lion locations, bottom map shows haulout codes for the Gulf Islands area, one of many maps for harbour seals in Olesiuk (2010).



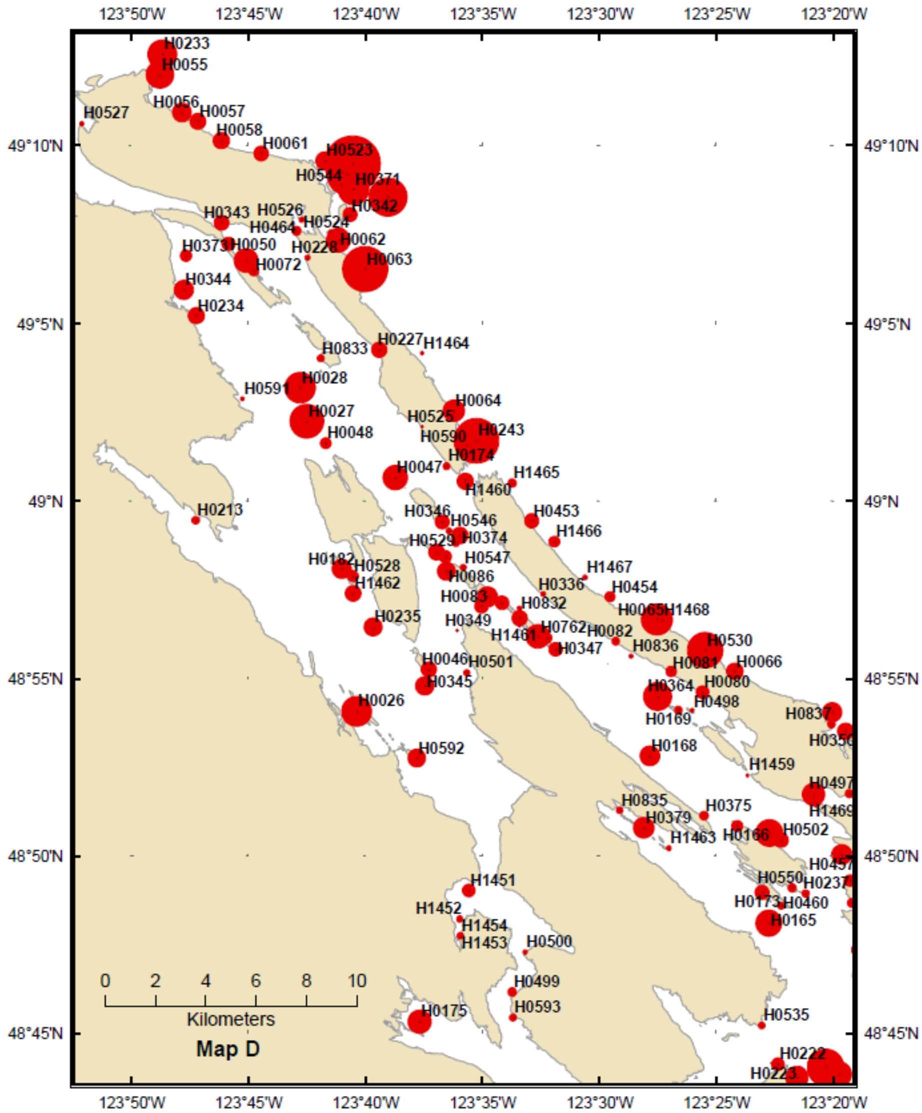
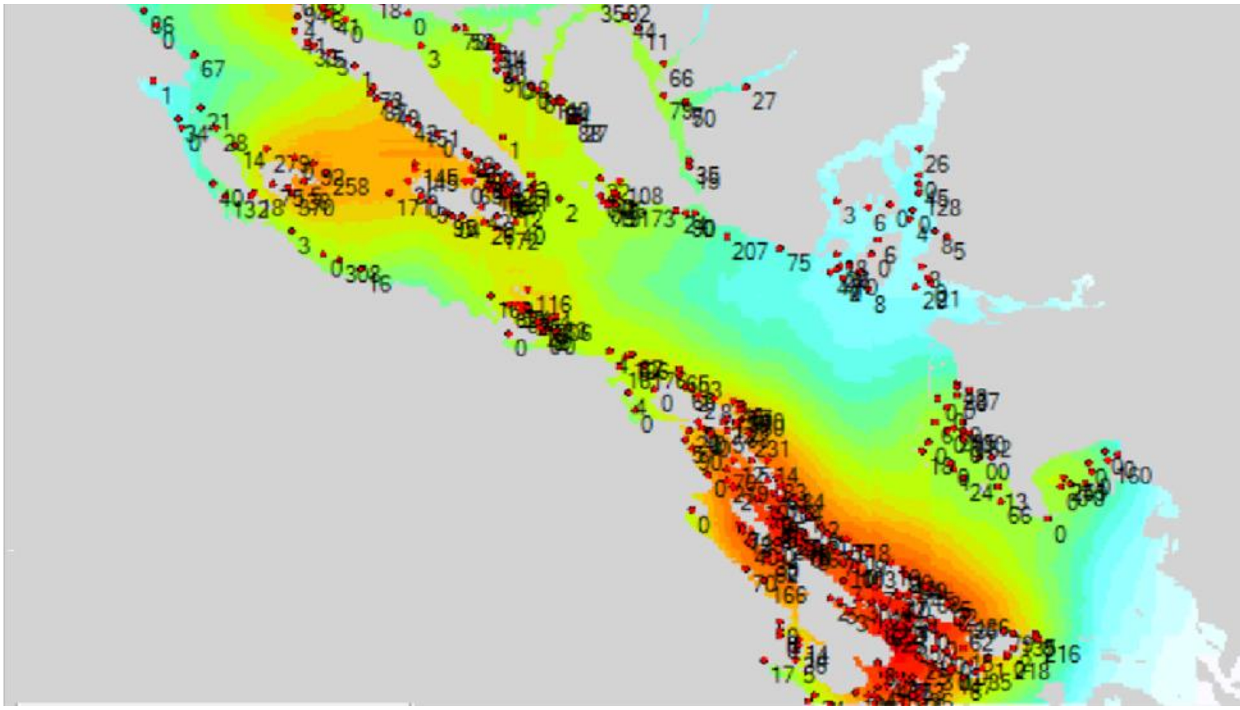


Figure 5. Distribution of harbour seal counts in the 2014 DFO survey, with color shading indicating probable spatial distribution of relative predation risk for juvenile chinook and coho salmon based on likely foraging pattern around each haulout from seal tracking studies. For areas shown in red, juvenile chinook and coho salmon likely face daily probabilities of 0.01 or higher of being at least seen by a harbour seal.



Electronic data entry of the logbook information would initially be done at the University of British Columbia (Institute for the Oceans and Fisheries) on a volunteer basis. Researchers there would also do an initial analysis of spatial exploitation rate patterns by comparing the reported harvests by haulout site to recent and updated aerial survey estimates of pinniped abundance at each site. The results of these analyses (total harvests by locale and species) would then be reported to DFO each year to be made publicly available, and would also be provided upon request for queries directed to the UBC researchers.

In view of possible public concerns about wasteful (e.g. sinking seals) and inhumane harvesting practices, it may be important to have compliance monitoring by independent observers from environmental organizations. Such observers would be allowed to accompany harvesters upon request and conditional on safety concerns and space available on fishing boats.

Harvesting would be done mainly in the fall, winter, and early spring. Product quality should be highest at these times, with richer oils and higher pelt values. Though it is probably not necessary in view of the relatively low exploitation rates (proportions of stock size) to be used, it would be possible to require catch reports on a monthly basis (by location as for the logbooks) in order to provide in-season information on cumulative exploitation rates in local areas. Further, DFO will presumably be monitoring catch as it accumulates each year to assure compliance with allowable catch limits, through analysis of sales slip information from processors.

Simplified monitoring and regulation for Phase II management

It is proposed that the catch monitoring and regulatory system be simplified to a “derby” approach during phase II, when up to 50,000 seals would be taken over just a few years and when it will be important to avoid high management costs. For all phases, DFO will be assuring compliance with catch limits by closely monitoring the catch through sales slip delivery to processors, which will provide timely information on total kill at statistical area spatial resolution. There is a need to attract substantial numbers of harvesters during Phase II, and there is not a critical need that these harvesters be either limited by permit quotas or be required to provide detailed logbook information on each kill. Therefore, it is proposed that the Phase II management system use the following approach:

1. Permits without catch quota limits would be issued annually to any applicants that hold a current personal commercial fishing license as issued by DFO, on a first come-first serve basis, up to a maximum number of permits set so as to avoid having so many harvesters as to make the fishery uneconomical for most of them.
2. As the fishery each year proceeds, DFO would monitor accumulating catch from processor sales slips, and close the fishery by statistical areas/species as allowable total catch limits are approached (just as many Canadian commercial fisheries are now managed).
3. Logbooks with spatially referenced records for each animal killed would be maintained on a voluntary basis, by fishermen who recognize the need to collaborate with scientists to obtain accurate information on localized distribution of harvesting effort and harvest rates.
4. Timing and location of harvesting over each permit year would be negotiated between fishermen and processors, so as to take the harvest at times when the animals are most valuable and with daily total deliveries timed so as to avoid limitations on processing and cold storage capacity. Absent such negotiations, there is a risk of swamping the processing system so as to cause wastage of valuable product.

This management approach will not make the fishery any less precautionary during Phase II than will occur during the other Phases (when much more severe catch limits will apply), since safe total catch limits will still be used and approach to those limits will still be monitored closely by DFO.

Harvesting methods

Harvesting would be carried out in as humane a fashion as possible. This would mean using harvesting methods that kill animals quickly with low risk of loss (sinking) and without taking females that have small pups. The following harvesting methods would be allowed:

-clubbing on all haulout sites (the traditional First Nations method)
-shooting (rifles, shotguns with slugs) in remote areas
-harpoons with retrieval line, shot from cross-bows.

Other very efficient harvesting methods have been tested, such as baited long lines set in locations where animals aggregate for feeding, but it is not clear that such methods would meet reasonable standards for humane killing. Shooting and clubbing techniques would follow DFO's existing regulations for East Coast seal harvesting (http://laws-lois.justice.gc.ca/eng/regulations/SOR-93-56/page-4.html#h-16).

Fishermen are typically very inventive about finding harvesting methods that meet various restrictions, e.g. to minimize bycatch. Proposals for using inventive method outside the list above would be reviewed by DFO science and management staff and added to the permitted list as appropriate.

Marketing and processing

Experience with commercial seal harvesting in Atlantic Canada indicates that fishermen can expect only modest prices from processors and hence only modest net incomes from the fishery (Table 4).

Table 4. Expected incomes and costs for seal fishermen. Estimates based on minimum values needed to attract people to take out permits, and likely fishing costs as a fraction of income. (budget for seal harvesting program.xls)

FISHERMAN INCOME AND COSTS		
Per animal harvested	**Seal**	**Sea lion**
Income (from processors)	$100	$240
Fishing cost	$60	$120
Net income	$40	$120
Fisherman Annual Total harvests and Net Income		
Harvest Phase II (number of animals)	10,000	2,222
Harvest Phase III (number of aimals)	3,800	2,222
Net Income Phase II	$400,000	$266,640
Net Income Phase III	$152,000	$266,640

Several PBPS board members (Chief Roy Jones, Haida; Gary Biggar, Metis; Roger Paquette, Hub City Fisheries; Calvin Kania, Fur Canada) have personal experience with marketing seal products in B.C. Their assessment based on that experience and processing experience in Atlantic Canada is that at least three products (hides, oil, and meat) should have roughly the commercial values per seal indicated below in Table 5, with the possibility of commercial value from other products as indicated. But as indicated in Table 5, high processing costs and limited market opportunities will likely lead to relatively modest net incomes for processors.

Table 5. Expected income and cost components for seal processors. Estimates based on both local marketing experience and information from Atlantic Canada. (budget for seal harvesting program.xls)

PROCESSOR INCOME AND COSTS		
	Seal	**Sea lion**
INCOME COMPONENTS PER ANIMAL		
Hides	$200	$400
Oil	$150	$450
Meat	$200	$900
Skull	$100	$100
Other body parts (e.g. whiskers)	$100	$100
COST COMPONENTS PER ANIMAL		
Harvest (paid to fishermen)	$100	$240
Plant processing	$200	$500
Hide tanning	$200	$200
Marketing	$100	$150
Misc.	$100	$150
Net Income per animal	$50	$760
Processor Annual Total harvests and Net Income		

Harvest Phase II (number of animals)	10,000	2,222
Harvest Phase III (number of animals)	3,800	2,222
Net Income Phase II	$500,000	$1,577,620
Net Income Phase III	$190,000	$1,577,620

Several seine boat operators have indicated willingness to use their chilled storage equipment to transport harvested animals from remote areas if necessary. The costs of this transportation are unclear, since those operators may also be pinniped license holders and would like to promote the harvest because of their interest in possible increases in allowable salmon harvests.

Two processing plants that need no updates or further certification are available at this time along the B. C. Coast and have indicated willingness to handle seal products:

1. Hub City in Nanaimo
2. French Creek Seafoods

Two other plants have indicated willingness to handle seal products, update/certification status unknown:

3. Stolo Nation plant in Chilliwack
4. Lax Kw'alaams plant in Port Simpson

It has not yet been decided whether these processors will simply charge fishermen for each animal processed, or will instead offer fishermen lower product prices in order to cover their costs and then take over the marketing of products.

CFIA inspection

For products used for human consumption (oil, meat), processing companies will be expected to obtain CFIA inspections and approvals. One CFIA approval has been obtained for sale of seal oil (by Roy Jones Jr. to Canagen Pharmaceuticals in Richmond, CFIA Health Certificate and Certificate of Quality available on request; Certificate of Analysis showing safe levels of contaminants is shown below as Figure 6). CFIA will already have regulations in place from the east coast of Canada and the Northern seal harvesters.

Figure 6. Certificate of Analysis showing B.C. seal oil that was approved for sale by CFIA.

FORTUNA oils

Fortuna Oils AS

CERTIFICATE OF ANALYSIS

Batch no:	**FO18/12**
Product:	**Seal Oil**
Spec.no:	**Fully refined and deodorised.**
Date of production:	**20.03.2012**
Date of analysis:	**22.03.2012**
Comment:	Sell by date is 2 years from date of production. Shelf life is guaranteed if the product is stored in unopened original closed containers, protected from heat and light.

Analysis:

Description	Unit	Specification Min	Specification Max	Results	Methods
C20:5 n3 (EPA)	Area%	6,0		**7,3**	GCRO001
	mg/g TG			**70**	GCRO001
C22:6 n3 (DHA)	Area%	8,0		**8,9**	GCRO001
	mg/g TG			**80**	GCRO001
C22:5n3 (DPA)	Area%	3,0		**4,1**	GCRO001
Total omega-3	Area%	20		**23,3**	GCRO001
	mg/g TG			**210**	GCRO001
Total omega-6	Area%			**2,2**	GCRO001
Saturated fatty acids:	Area%			**12,0**	GCRO001
Monounsaturated fatty acids:	Area%			**56,7**	GCRO001
Poly-unsaturated fatty acids:	Area%			**25,8**	GCRO001
Acid Value	mg KOH/g		1,0	**0,1**	GCRO003
Peroxide Value	mEq/kg		3	**0,1**	GCRO006
Anisidine value			10	**2**	GCRO007
Totox				**2**	Calculation
Colour	Gardner		5	**2**	GCRO004
Cold test	3h/0°C			**Passed**	GCRO005
D-alpha.tocopherol (Vit. E)	ppm	1000	2000	**1110**	Addition
Environmental analysis					
Dioxin and furanes	ng/kg WHOTEQ		2,0	**<2,0**	GCRO017
dl-PCB	ng/kg WHOTEQ		3,0	**<3,0**	GCRO017
Marker-PCBs(7 congeners)	mg/kg		0,09	**<0,09**	GCRO017
Cadmium(Cd)	mg/kg		0,1	**<0,1**	GCRO016
Arsenic(As)	mg/kg		0,1	**<0,1**	GCRO016
Lead (Pb)	mg/kg		0,1	**<0,1**	GCRO016
Mercury (Hg)	mg/kg		0,1	**<0,1**	GCRO016

Quality evaluation: This batch is approved according to specification.

APPROVED BY:

Fortuna Oils as

FORTUNA OILS AS

Public Consultation

PBPS has held meetings in Haida Gwaii, Kitimat, and Port Simpson with First Nations people. Those meetings have revealed strong support for the harvest from most communities particularly in northern B.C.

Two public meetings have been held. The first was in Nanaimo in February 2018, resulting in formation of PBPS, and was attended by about 40 people and with reporting by CHEK TV. The second was held at the Tsawassen FN Board Room in July, with 8 board members and 12 guests attending and with reporting by Global TV.

Additionally, CBC's Greg Rasmussen did an "on water" interview that was aired in August. That reporting was well balanced and included opposing opinion from an environmental group representative.

It is unclear whether there is anything to be gained from public consultation in urban areas like Vancouver and Victoria. Based on recent reaction to press stories about pinniped culling, there would certainly be vocal public opposition to commercial harvesting particularly from environmental groups. DFO is sure to hear that opposition whether or not it is further voiced in meetings organized by PBPS. It is proposed that public meetings be held in Steveston and Prince Rupert, where opposition may at least better informed about historical changes in seal and salmon populations.

Management costs, sources of funding, and potential public economic benefits

Management of the fishery would involve a variety of costs, ranging from license administration to logbook data collection to conduct of seal and sea lion surveys and compliance monitoring. During the most expensive management period, the Phase II stock reduction when all of these costs would be largest, would likely be around $85,000 per year, with component costs as shown in Table 6. The costs itemized in Table 6 were estimated as resource unit needs (days, hours, etc.) times likely costs per resource unit. Note that by far the largest cost component would be for aerial seal and sea lion abundance surveys and related analysis costs by DFO staff. Costs during development phases I-II would be modestly lower than shown in Table 5 if DFO adopts the simplified monitoring and regulation approach outlined above, but that approach would still require expensive aerial surveys.

For cost recovery, only minor amounts are likely to come from permit fees and grants from sources like the Pacific Salmon Foundation. But a very promising cost recovery approach would be to include an option for on-line tidal sport license purchasers to volunteer a small fee ($2.00) for "reduction of seal and sea lion populations"; this would be similar to the salmon conservation stamp that not all license holders purchase, and would recognize that the largest benefits from seal abundance reduction would be to sports fishing interests (see below). From the strong support heard from sports fishermen about the need for seal reduction, it is expected that at least 15% of sports tidal license purchasers would be happy to make this contribution. That voluntary contribution option would more than cover all anticipated management costs, as shown in Table 6. An alternative to voluntary contributions would be to make a modest ($1.00) increase in the price of the salmon conservation stamp, but this is would invite objections from sports fishers who are opposed to pinniped harvesting for ethical reasons or are opposed to commercial harvesting by First Nations people.

Table 6. Estimated annual management cost components, proposed PBPS cost sharing, and cost recovery options for the most expensive fishery development period (Phase II) when annual harvests would be largest (budget for seal harvesting program.xlsx).

Annual budget item	**Units needed**	**cost/unit (S)**	**total cost ($)**	**PBPS share**	**notes**
Permit administration (DFO staff time, hours)	285	$40.00	$11,400	0%	permit preparation and distribution to applicants, one hour per permit
seal permit/logbooks (50 seals/permit)	200	$7.36	$1,472.00	100%	includes 3 page logbook and 17 pages of maps
sea lion permit/logbooks (20 sea lions/permit)	85	$7.36	$625.60	100%	includes 3 page logbook and 17 pages of maps
Electronic data entry and analysis (hours)	195	$40.00	$7,800	100%	assumes 1 minute/seal, $30/hr for entry person
Seal survey floatplane charter cost (hours)	20	$500.00	$10,000	50%	assumes visit 10 major haulout sites per flight hour for seals
Steller sea lion floatplane charter cost (hours)	40	$500.00	$20,000	50%	assumes visit to each each major Steller rookery once per year, 4 hr. flight time per rookery
Survey scientist (DFO staff time, hours)	140	$100.00	$14,000	0%	Flight hours plus 10 days preparation, analysis
Survey photo interpretation (DFO staff time, hours)	130	$100.00	$13,000	50%	assumes two hours per photo for counting (120 seal sites, 10 Steller rookeries)
DFO compliance monitoring (deliveries, licenses)	20	$300.00	$6,000	0%	assumes 20 days of fishery officer time, at $300/day including expenses (travel, etc.)
TOTAL annual management cost			**$84,297.60**		survey cost component: $57,000
PBPS cost assuming cost shares above			**$31,397.60**		see proposed share percentages above
Cost recovery options					
Permit fees	285	$10.00	$2,850.00		Would only cover permit printing costs
Operating grants to PBPS	1	$20,000	$20,000.00		Applications pending to PSF

Voluntary $2.00 contribution, tidal sport license	50000	$2.00	$100,000		assumes about 15% of 330,000 tidal license buyers would volunteer to pay $2.00 each, using online license purchase system
Possible total cost recovery			**-$122,850**		

Costs of managing the fishery would be trivial compared to benefits to just two of the major South Coast salmon fisheries: the Georgia Strait sport and WCVI troll. For the Georgia Strait sport fishery, the annual number of angler days has dropped to about 100,000, and the Georgia Strait sport model (Fig. 4) predicts an annual increase of 200,000 days following seal reduction. According to Statistics Canada (https://www150.statcan.gc.ca/n1/pub/16-002-x/2008002/t/5212689-eng.htm), as of the mid-2000s there were 170,000 tidal anglers in B.C. who fished an average of 10 days each, and these anglers spent an average of $1,100 each (mainly for package deals, food and lodging, and transportation) or $110 per angler day. At this daily rate, regional businesses serving sports fishermen would gain around $22 million per year from the effort increase. Since 2000, the WCVI troll catch of chinooks has averaged around 75,000 (and only around 50,000 since 2010; PSC, 2018). This fishery could probably be restored to an annual catch of at least 150,000 chinooks if restrictions associated with protection of interior Fraser coho were relaxed due to the improvement in coho marine survival rate predicted from the mortality relationship in Fig. 3. This restoration would represent an increase in catch of around 100,000 chinook per year, with an average landed value per fish of at least $15, for an annual benefit to the WCVI troll fleet of $11 million; this increase is particularly important because a high proportion of it would come from harvest of US (mainly Columbia River) chinooks.

A 50% reduction in seal abundance in the Georgia Strait would most likely result in at least doubling the abundance of large chinooks available to southern resident killer whales even after allowing for substantial increase in sport fishing effort (Fig. 4). This is a larger increase than could likely be achieved by costly measures that have been considered, like complete closure of the sport fishery or massively increases in hatchery chinook production.

Acknowledgements

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Chief Roy Jones Jr. Chair

Ken Pearce co-founder and board member

Gary Bigger (Yogi) co-founder and board member. Minister of Natural Resources for the Metis People of B.C.

Tom Sewid FN Alert Bay

Wayne R. Paige FN Cowichan

Tim Kulchyski FN Cowichan

Matt Stabler Retired Biologist

Calvin Kanai   Fur Canada, Nanaimo
Roger Paquette Hub City Fisheries

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APPENDIX A: proposed format for logbook reporting

The following three pages show a logbook layout that should be reasonably easy for permit holders to use. The format shown could be applied whether or not each permit is associated with a limited quota for the license holder.

PINNIPED HARVESTING PERMIT

Permit Number____________

This permit allows harvesting of ________________animals in calendar year _____________

Of Species___________________ (Harbour seal, Steller sea lion, California sea lion)

In harvest region______________________________(e.g. Georgia Strait, North Coast)

Permit holder name____

Address of permit holder____

Contact phone number for monthly hail counts of catch____________________________

Date of issue__________________

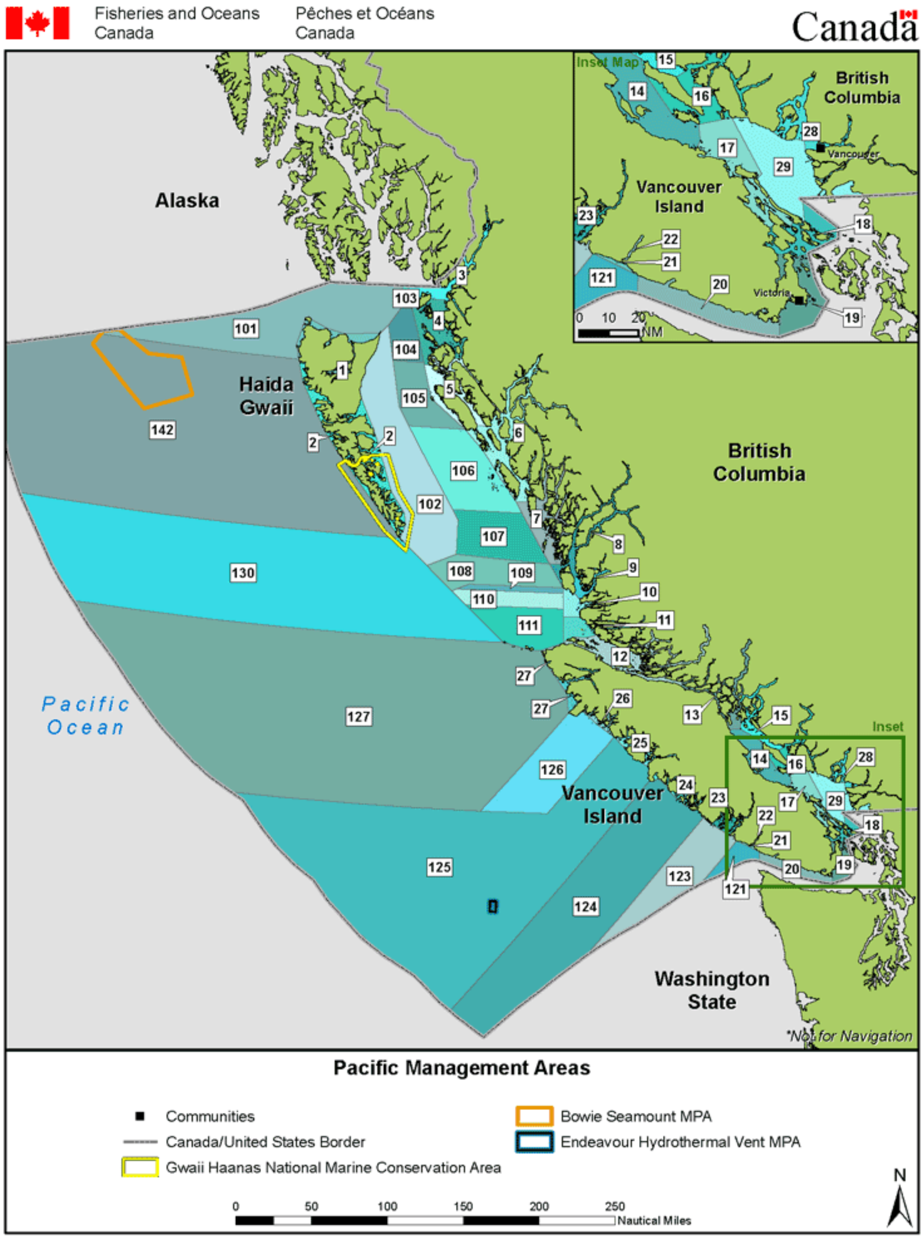
Permit issued by (signature)___________________________

Each animal harvested is to be recorded on the attached logbook. Date and DFO Statistical Area must be recorded for each animal. Additional information on kill location (DFO haulout code e.g. H0069 from attached maps and/or GPS bearings (decimal degrees of the kill, for example from Google maps or hand-held GPS) would be helpful for assuring that the kill is concentrated in areas of greatest pinniped impact on salmon and other fish species.

LOGBOOKS MUST BE COMPLETED ON EACH DAY OF HARVEST, AND SUBMITTED BY DECEMBER 31 OF THE LICENSE YEAR ABOVE. SUBMISSIONS CAN BE BY MAIL TO [address needed] OR BY PHOTOGRAPHING THE LOGBOOK PAGES AND EMAILING THESE PHOTOS TO [email address needed]

THE PERMIT NUMBER ABOVE MUST BE RECORDED ON ALL SALES SLIPS TO PROCESSORS

Maps of DFO haulout codes are provided with this permit, to assist in finding good hunting locations. DFO fisheries statistical area map is shown on the following page.



(detailed maps are available at http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/salmon-saumon/index-eng.html)

LOGBOOK RECORD

Kill	Date	DFO Stat. area eg: 28	DFO haulout code, eg: (H069)	Latitude (dec. deg) eg: 49.35886	Longitude (dec. deg) eg: 123.47295	Comments
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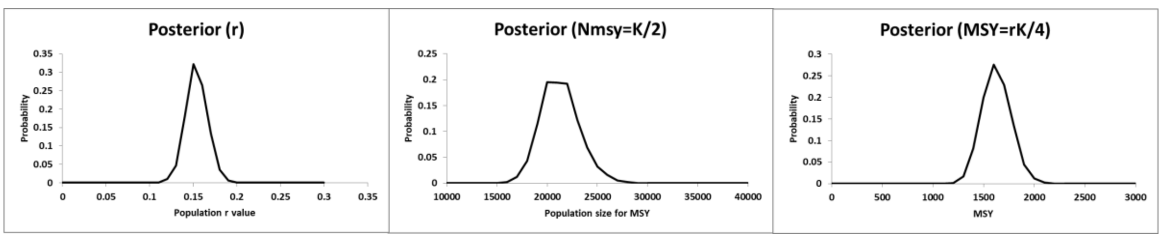
APPENDIX B: Posterior probability distributions for harbour seal reference points

Posterior probability distributions for Harbour seal management reference points estimated by Murdoch McAllister (UBC Institute for the Oceans and Fisheries) using a Bayesian state space implementation of the logistic model. For both Georgia Strait and outside stocks the assumed process variance for random variation over time in r (process error) was set to σ^2_r=0.02. The assumed coefficient of variation for q (expansion factor for counts) for the Georgia Stock was set to CVq=0.05, and for the outside stock to a larger value CVq=0.1 since the expansion factor for outside abundance estimates is much larger and more uncertain due to incomplete aerial coverage in outside surveys.

Posterior distributions for the Georgia Strait stock are quite narrow as shown in Fig. B1.

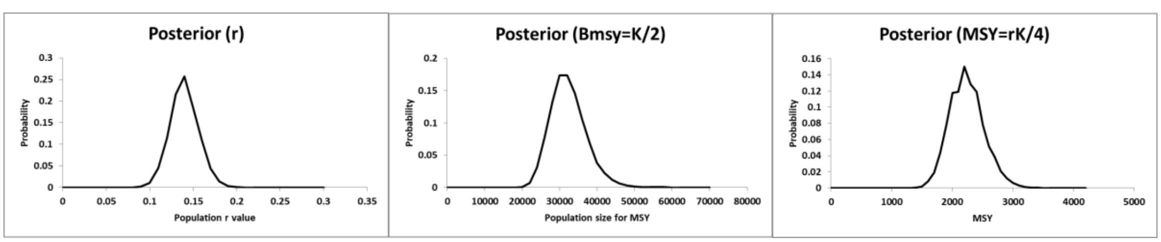
Figure B1. Posterior distributions for management reference points for the Georgia Strait harbour seal population from Bayesian state space model.



(data from Olesiuk outside seal numbers estimates.xlsx)

For the outside stock, the distributions are wider, due mainly to uncertainty about the expansion factors (proportion of seals hauled out at survey times, proportion of coastline surveyed) used to estimate total population sizes (Fig. B2).

Figure B2. Posterior distributions for management reference points for the harbour seal population outside the Georgia Strait, from Bayesian state space model.



(data from Olesiuk outside seal numbers estimates.xlsx)

It should be noted that the uncertainties indicated by Figs. B1-B2 are not large enough to justify any substantial initial “precautionary” adjustments in harvest control rules based on the reference point estimates (see Walters, 1998). Adjustments in those reference point estimates and precautionary control rules will surely be needed if/when improved estimates of productivity are obtained from monitoring population responses after the initial stock reduction period in the management plan.

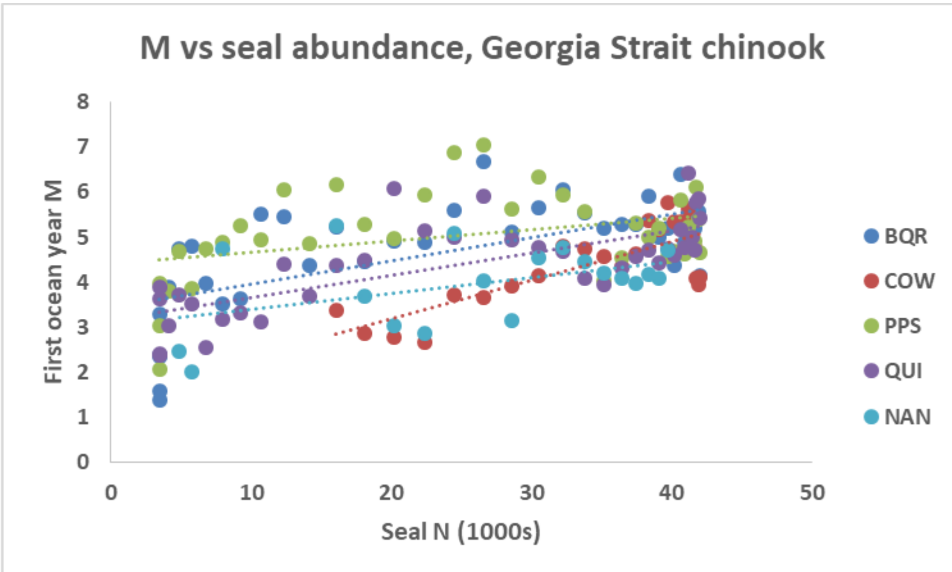
APPENDIX C: Estimation of first year marine mortality rates for chinook and coho indicator stocks

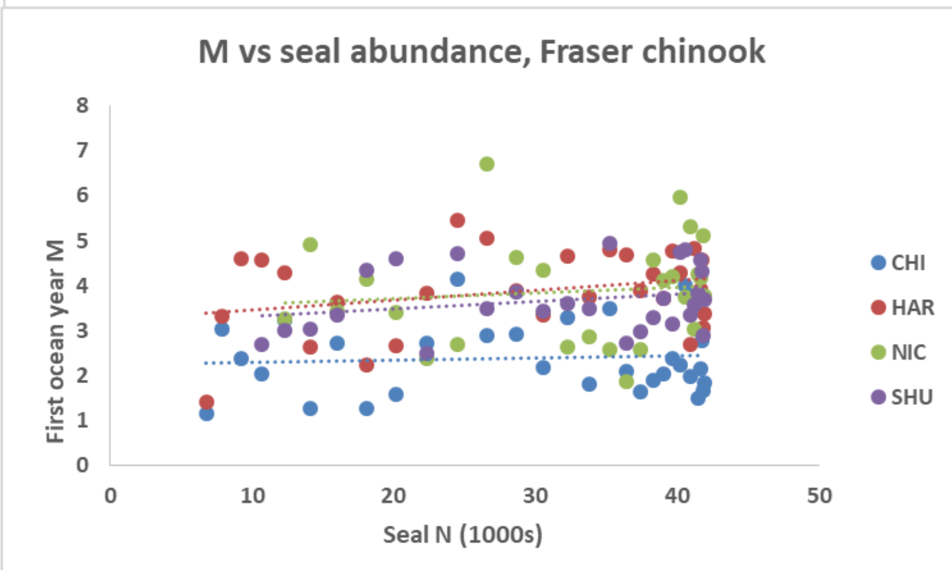
From coded wire tagging (CWT) data, we have time series estimates since the late 1970s of first ocean year survival rates (MSR) for several Georgia Strait chinook and coho stocks. These survival rates can be expressed as $MSR=e^{-M}$, and converted to instantaneous mortality rates M by the simple equation $M=-\ln(MSR)$. Averages of these M estimates over CWT indicator stocks were used for the M vs seal abundance regressions in Fig. 3. Chinook MSR estimates used in the analysis were from a database provided to the Salish Sea Marine Survival Project as an update by Marianna Alexandersdottir and Kris Ryding of estimates from the coastwide chinook CWT database by Ruff et al. (2017). Coho MSR estimates were from DFO staff updates of a database developed by Arlene Tompkins, DFO.

Instantaneous rates are convenient to use rather than survival rates for at least five reasons. First, survival rates should not be used in correlative statistical studies since these rates are compressed into a narrow range such that key mortality risks, especially later in juvenile life, are almost “invisible” in overall survival rate data. Second, instantaneous mortality rates can be partitioned into additive time components (stanzas), as recommended by Bradford (1995). Third, when several mortality agents simultaneously kill juveniles, these agents can be expressed in terms of additive mortality rate components. Fourth, predation mortality rates in particular are expected to be simply proportional to predator abundance for predators that take juveniles “incidentally” while foraging; that is, any predator that has abundance P and attack rate per predator aN, where N is juvenile density at any moment, will generate a total kill per time equal to aNP, which implies the predation rate component $Mp=aNP/N=aP$. Finally, M’s can be compared directly to estimates of changes in productivity from stock-recruitment analyses where productivity is measured by ln(recruits/spawners) and this productivity measure is regressed on spawner abundance and other factors like seal abundance (e.g. Nelson et al. 2018).

When regressions of M vs seal abundance are examined for individual chinook indicator stocks (Fig. C1), considerable stock-specific variation is evident around the average relationship in Fig. 3. Regression relationships are generally much weaker for the Fraser River stocks; this is particularly puzzling for the Harrison chinook indicators (CHI, HAR) because stock-recruit regressions have shown stronger effects (Nelson et al. 2018) and because abundance of Harrison chinook in the Georgia Strait must have declined substantially since the early 1970s. During the 1970s, Argue et al. (1983) estimated that roughly half the Georgia Strait chinook catch was Harrison fish, and this proportion has remained stable over time (Riddell et al. 2013), so the overall sport catch would not have declined as much as shown in Fig. 4 if this stock had not suffered declines in marine survival rate. Ocean Ms for the Chilliwack hatchery fish (CHI) are particularly suspect, since they are much lower than for any other chinook indicator stock on the Pacific coast. Note that the interior Fraser stocks (NIC,SHU) were not used in calculation of average mortality rates for the Georgia Strait, since they typically have low residence proportions in the Georgia Strait, i.e. their smolts migrate rapidly out of the Strait. Further, Shuswap smolts are not found in large numbers in Georgia Strait juvenile salmon surveys until September (C. Neville, DFO, pers. comm.).

Fig. C1. Regressions of M on seal abundance for Georgia Strait and Fraser River chinook hatchery indicator stocks, for smolt years 1974-2011. Stock codes are: BQR-Big Qualicum, COW-Cowichan, PPS-Puntledge, QUI-Quinsam, NAN-Nanaimo, CHI-Chilliwack, HAR-Harrison (Chehalis), NIC-Nicola, SHU-Shuswap.



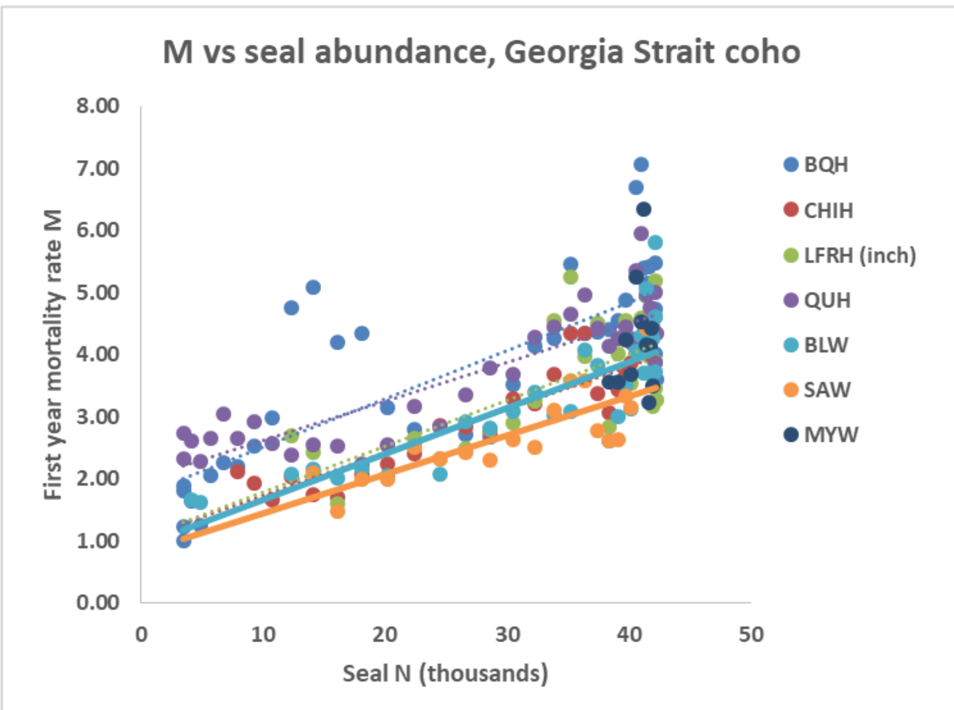


(chinook marine survival rates from CWT data.xlsx)

There is a simple hypothesis for why the Harrison chinook, and most Puget Sound chinook stocks, have shown only weak trends in marine mortality rates despite evidence of severe decline in abundance of chinooks available to the Georgia Strait fishery. This hypothesis is that a high proportion of the smolts from these stocks may have high early dispersal/migration rates out of the Salish Sea, via the Juan de Fuca Strait to southwest Vancouver Island (where Olesiuk 2010 observed much lower seal densities than in the Georgia Strait), so that only the "resident" juveniles (that later support the Georgia Strait sport fishery) have been subject to the increasing mortality rates seen for other Georgia Strait stocks. The increase in first-ocean year mortality rate for the Harrison stock (based on Chehalis hatchery data) due to seals is close to 1.0 (over seal numbers ranging from 0 to the current abundance), about half of the 2.0 estimated for Georgia Strait stocks. Coded wire tagging catches for the Harrison stock suggest that about half the stock rears outside of the Strait, i.e. is not subject to the higher "resident" mortality rate.

First ocean year Ms for coho indicator stocks (Fig C2) also show considerable among stock variation, but much of that variation is due to lower mortality rates for the two wild indicator stocks (Black Creek, Salmon River). All stocks for which there are long time series show similar regression slopes (apparent mortality rate increase per seal).

Figure C2. Regressions of first year ocean mortality rates on seal abundance for Georgia Strait coho indicator stocks, smolt years 1974-2015. Stock codes are: BQH-Big Qualicum hatchery, CHIH-Chilliwack hatchery, LFRH-Inch Creek hatchery, QUH-Quinsam hatchery, BLW-Black Creek wild, SAW-Salmon River wild (lower Fraser), and MYW-Myrtle Creek wild. Solid regression lines are for the BLW and SAW wild stocks.



(South Coast coho ER and MS to 2013 brood year.xlsx)

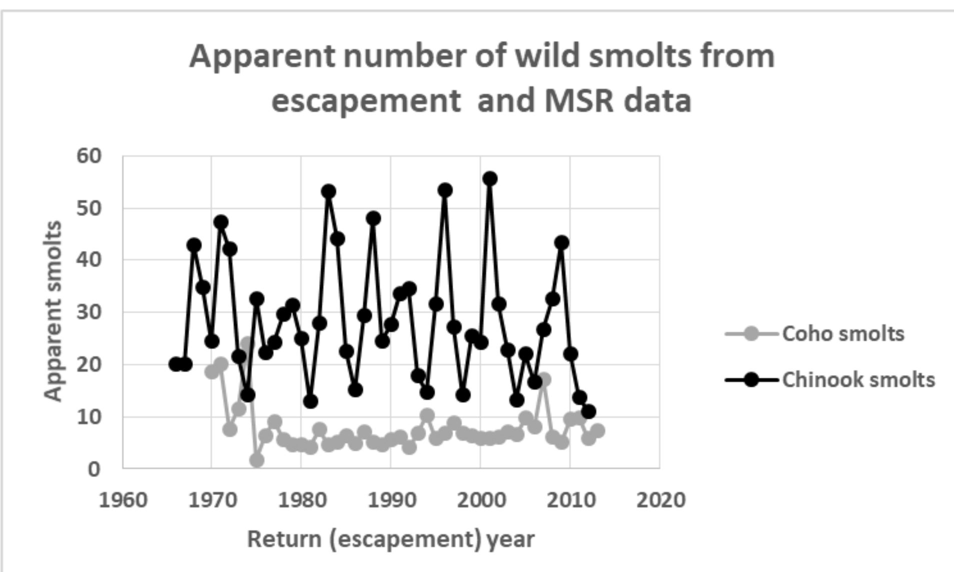
It is perhaps not surprising that the chinook data show much greater variability among stocks than than the coho data, considering that (1) chinook life histories are much more variable in terms of ocean entry size and subsequent dispersal/migration (e.g. early outmigration as noted above for Harrison chinooks), and (2) with smaller smolt body sizes, chinooks from Georgia Strait streams disperse more slowly away from natal streams than do coho and hence are subject to more localized predation risk patterns for the first few months after ocean entry (Fig. 5).

ADDENDUM A: Why not just cull problem seals?

Sport fishing groups have suggested that juvenile chinook and coho abundances would be increased simply by culling "problem" seals near river mouths, where some seals concentrate to prey on both outmigrant smolts and returning adult fish (www.srkw.org). Besides being just as controversial to the public as commercial seal harvesting, such a culling program would very likely fail to increase salmon abundances, for two main reasons: (1) seal kills of spawning adult salmon have not been large enough to limit wild smolt production, at least for the Georgia Strait, and (2) most of the juvenile salmon mortality occurs not at the stream mouths but rather later over the months of June-August after juveniles have spread widely over the Georgia Strait and risk encounters with the whole seal population.

Smolt numbers entering the Georgia Strait can be back-calculated from historical escapement (NUSEDS) data along with estimates of escapement/smolt from coded-wire tagging data (Figure 4, repeated in Figure A1). Smolt numbers have not declined over the years, indicating that declines in numbers of spawners have not been great enough to impair smolt production (i.e. freshwater factors rather than spawning numbers have been limiting for wild smolt production). This observation implies that increases in spawning due to reduction of adult salmon kills at stream mouths would not result in increased smolt abundance.

Figure A1. Historical numbers of chinook and coho wild smolts entering the Georgia Strait. Estimate for each year is the NUSEDS total escapement (for Georgia Strait and lower Fraser streams) divided by the mean coded-wire tagging estimate of escapement per smolt for that return year. Note that Nelson et al. (2018) estimated a smoother pattern for the key Harrison chinook stock using more detailed CWT data by brood year, but with an abrupt and persistent drop in apparent smolt production as of the 1992 spawning year.

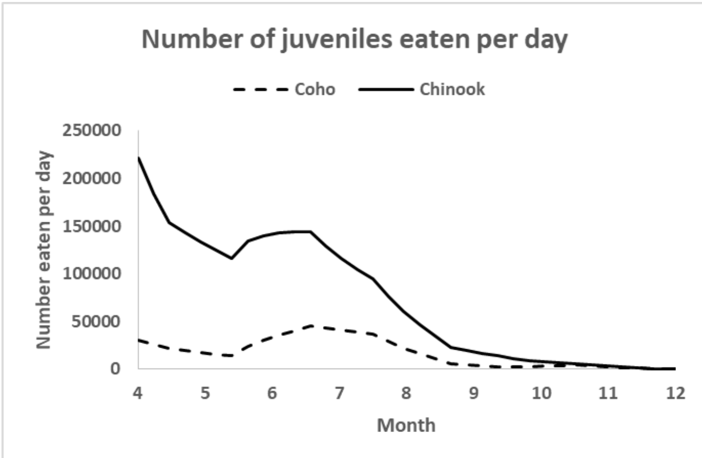


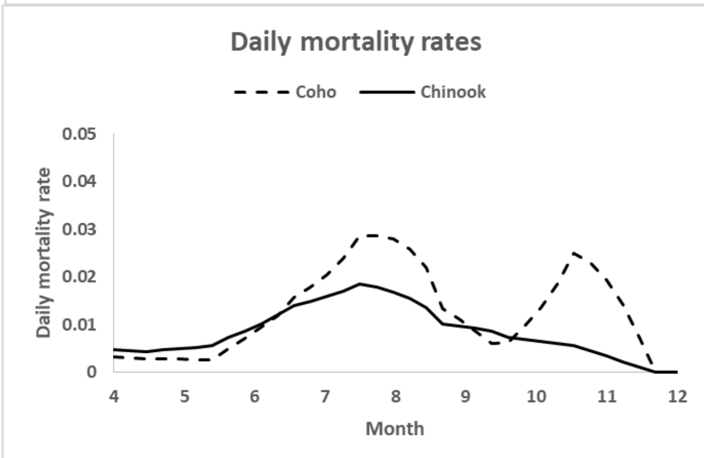
(Georgia strait sport model.xlsx)

Much more important, juvenile mortality rates would not be substantially improved by reducing the juvenile mortality that occurs over the short period when juveniles are migrating downstream and through estuarine areas. Substantial numbers of smolts are eaten during that short period, but these numbers represent only a relatively low percentage of the large number of smolts still alive ("mortality rate" is defined as (number killed)/(number at risk), and that rate is small for the migration period).

Using estimates of monthly seal diet composition for 2012-3 from Thomas et al. (2016) and seal food consumption rates from Olesiuk (1993), and recent seal abundance of around 40,000, Nelson and Walters (ms in prep.) have calculated the number of juvenile chinook and coho killed per day over the first few months of ocean life in the Georgia Strait (Figure A2). These kill numbers show an early peak at the time of smolt outmigration, then a second peak later in the summer. Nelson and Walters also estimated size-dependent daily natural mortality rates due to factors other than seal predation, from marine survival rate estimates for years prior to the seal population increase. When the seal kill and other mortality estimates are combined to estimate numbers of smolts over time at risk to predation, the resulting estimates of daily seal predation rates (as proportions of the numbers of juveniles still alive each day) show a peak later in the year, from June through August (Figure A2). By the time of that peak mortality, juvenile chinook and coho are widely distributed over the Georgia Strait (Figure A3). So it appears that most of the total mortality rate caused by seals is due to "incidental" encounters of juvenile salmon with the overall Georgia Strait seal population, over the first summer of ocean residence.

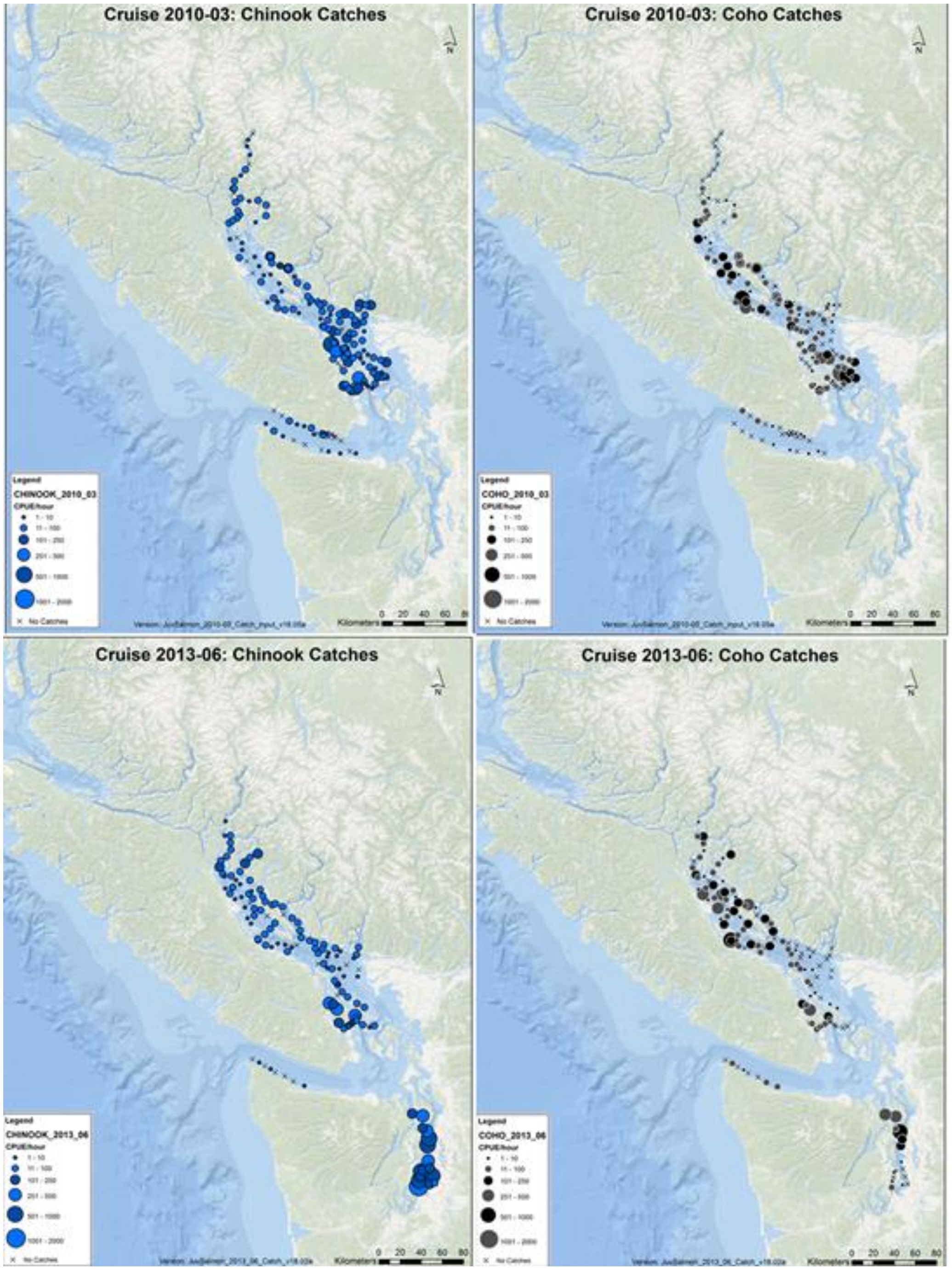
Figure A2. Estimates by Nelson and Walters (ms in prep.) of the daily number of chinook and coho juveniles killed per day by seals in 2012-13, and daily mortality rates implied by these kills when juvenile numbers at risk each day are predicted from both seal kills and mortality rates due to factors other than seal predation.





(prediction of first year total M from Thomas seal diet data.xlsx)

Figure A3. Distributions of juvenile chinook and coho over the Georgia Strait in June, estimated from catch rates in DFO trawl surveys; similar patterns are apparent for years other than those shown (maps courtesy of Chrys Neville, DFO). By September, Chinook surveys show high abundances near the Fraser mouth due to outmigration of South Thompson chinook, while coho densities become concentrated in the northwest portion of the Strait.



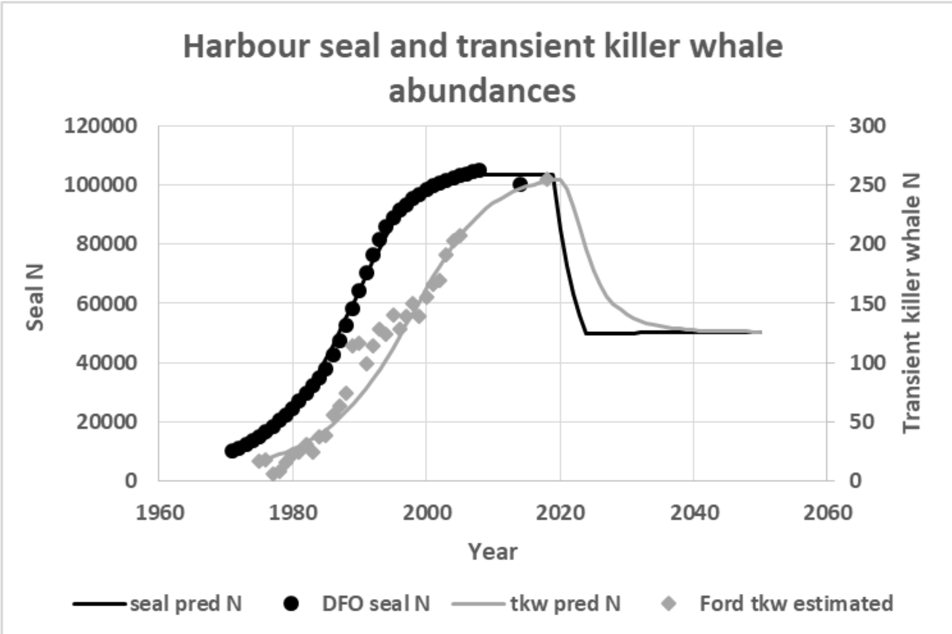
Addendum B: An assessment of possible impacts of seal population reduction on transient killer whale abundance in B.C.

Concern has been expressed that harvesting of pinnipeds could have negative impacts on transient or Bigg's killer whales (*Orcinus orca*) that prey mainly on marine mammals. The analysis below indicates that this concern is reasonable, but that large impacts are unlikely due to the wide range of prey available to the transients.

Transient killer whales are specialist predators on marine mammals, and range widely along the Pacific coast. They are listed as threatened by COSEWIC: "due to small population size (521 individuals were identified between 1990 and 2011), very low reproductive rate (one calf approximately every five years), and high levels of chemical contaminants that are persistent, bioaccumulative and toxic." (http://www.dfo-mpo.gc.ca/species-especes/profiles-profils/killerWhale-PAC-NE-epaulard-eng.html). Estimates of "study area" abundance of these animals regularly using B.C. coastal waters have been obtained with mark-recapture models based on sightings of known individuals, and these estimates show that the study area (B.C.) population has grown rapidly since the mid-1970s (Fig. B1) in parallel with increases in harbour seal abundance (Ford, et al. 2008, DFO 2013), and use of the Georgia Strait in particular increased dramatically around 2005 (Houghton et al. 2015; Shields et al. 2018). Based on prey kill composition data reviewed in Ford et al. 2008, harbour seals have been about 55% of the transient prey consumption by numbers, and Steller sea lions about 12%; in terms of weight of prey eaten, seals make up about 27% of prey mass consumption while sea lions make up a higher percentage 49% (because of their much higher body mass per individual, averaging 500kg vs 60 kg for seals).

Based on the population estimates in Ford et al. (2008), the coastwide transient population has been growing at a rate of about 3.3% per year since 1990, well within the range of maximum population growth rates (2%-4%) expected for killer whales in general given their life history characteristics (longevity, age at maturity, birth frequency; see Brault and Caswell 1993). Before 1990, the more rapid growth rate estimated by Ford et al. is likely due either to increasing use of the B.C. coast by the overall population, or to downward bias in early abundance estimates due to spatial concentration in observation effort.

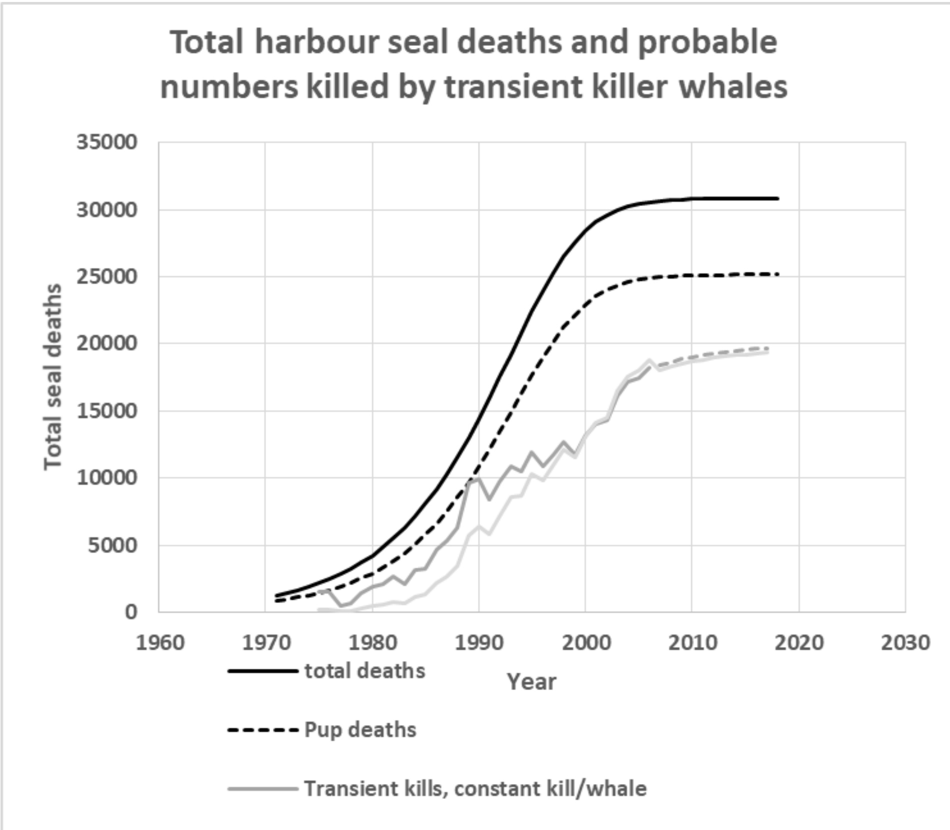
Figure B1. Growth in the B.C. harbout seal and transient killer whale populations. Harbour seal abundances from Olesiuk (2010), transient abundances from Ford et al. (2008). Predicted impact on the transient population after simulated seal reduction of 50% beginning in 2019 is based on a worst-case assumption that the carrying capacity for the transient population has been simply proportional to seal abundance, i.e. that transient abundance will stop growing when the number of seals available per transient drops to about 400. From "harbour seal balance model fitted to data with transient killer whale mortality est.xlsx"



(harbour seal balance model fitted to data with transient killer whale mortality est.xlsx)

Using an age-structured population model fitted to the seal data in Fig. B1, it is easy to calculate the likely total number of seal deaths that have occurred each year since the early 1970s, and most of those deaths have been of pups (Fig. B2). It is also easy to calculate how many of those deaths have been due to transient killer whale predation (Fig. B2), using the Ford et al. (2008) abundance and diet composition data along with a daily food requirement estimate for the whales (roughly 60kg/day based on food consumption rates of captive killer whales and observed kill rates in Hood Canal by London 2006; see also Williams et al. 2004). Importantly, it appears that transient killer whales now account for a very high proportion of the total annual deaths of harbour seals in B.C.

Figure B2. Estimates of annual numbers of seal deaths since 1970, and estimates of numbers of seals eaten by transient killer whales. Seal death estimates based on an age-structured model fit to historical data, killer whale deaths based on population estimates and diet data in Ford et al. 2008), under two extreme assumptions about how seal kill per whale has varied with seal abundance: constant number killed per whale or number killed per whale proportional to seal abundance.



(harbour seal balance model fitted to data with transient killer whale mortality est.xlsx)

If transient killer whales are in fact dependent on harbour seals for successful reproduction and survival, the total death patterns in Fig. X2 imply that the transient population (or at least transient use of the B.C. coast) would have to decline by up to 50% if the seal population is reduced by harvesting (Fig. B1), i.e. if the transient population declines until the ratio of seal numbers to transient numbers stabilizes at around 400 (the recent observed ratio leading to the mortality estimates in Fig. B2).

However, the extreme scenario for transient abundance decline under seal harvesting shown in Fig. B1 is not really credible, for several reasons. First, dependence of transients on harbour seals is not that great when estimated in terms of the proportion of the transient diet by weight that is seals (27% as mentioned above). Second, transients may simply switch to spend more time using foraging tactics that are best for other prey (e.g. spending more time away from shorelines to increase encounter rates with whales, dolphins, porpoises, sea lions) that are at healthy and possibly growing abundances, or simply spend a bit more time searching so as to maintain nearly the same food intake rates. Third, transients may simply shift their overall distributions along the coast, to spend more time for example in southern California and south-east Alaska, as they likely did historically when B.C. seals were much less abundant.

One reasonable concern that cannot be evaluated without actually reducing seal abundance is that transient killer whales will exert a depensatory impact on seal mortality rates, i.e. that they will exhibit a type II functional response to seal declines so as to maintain relatively high per capita consumption rates of seals (which will mean higher ratios of numbers killed to numbers at risk, i.e. depensatory mortality rate increase). This will only happen if the transients do not exhibit the compensatory behavioral changes mentioned in the previous paragraph (switching to foraging tactics best for other prey, shifts in spatial distribution away from areas with low seal abundance). Also, depensation is only expected if declines in seals result in substantial increases in the proportion of time that the whales spend searching for prey in general; such increases are not expected given the relatively low proportion of total handling time that type II functional response models attribute to seal handling given the relatively small body size of seals compared to other prey that the whales have been taking.

Effects of changes in seal abundance on total food intake and time spent foraging can be predicted with the multispecies generalization of Holling's "disc equation". This equation was derived by C.S. Holling by examining how animals partition their total available time Tt for foraging between time spent searching for prey, Ts, and time spent handling (or resting or otherwise being nonreactive to prey) Th:

$$Tt=Ts+Th \qquad (1).$$

If there are multiple prey types with individual handling times hi and densities Ni, Holling argued that the number of each prey type captured (NAi) will vary as

$$NAi=aiNiTs \qquad (2)$$

In the multispecies version of his model, total handling time Th is predicted as

$$Th=\sum_i NAihi \qquad (3).$$

Combining these equations and solving for NAi results in the multispecies disc equation predicted number of each prey type killed:

$$NAi=aiNiTt/(1+\sum_i aiNihi) \qquad (4).$$

Given an estimate of the total number of prey eaten per year NAtotal and the numerical proportion pi of each prey type, it is possible to calculate observed NAi as just piNAtotal, and then if one assumes some value for the total search time Ts (e.g. roughly 50% of total time, Baird and Dill, 1995) one can calculate aiNi for each prey type from eq. (2) and this assumed Ts, as

$$aiNi=NAi/Ts = piNtotal/Ts. \qquad (5).$$

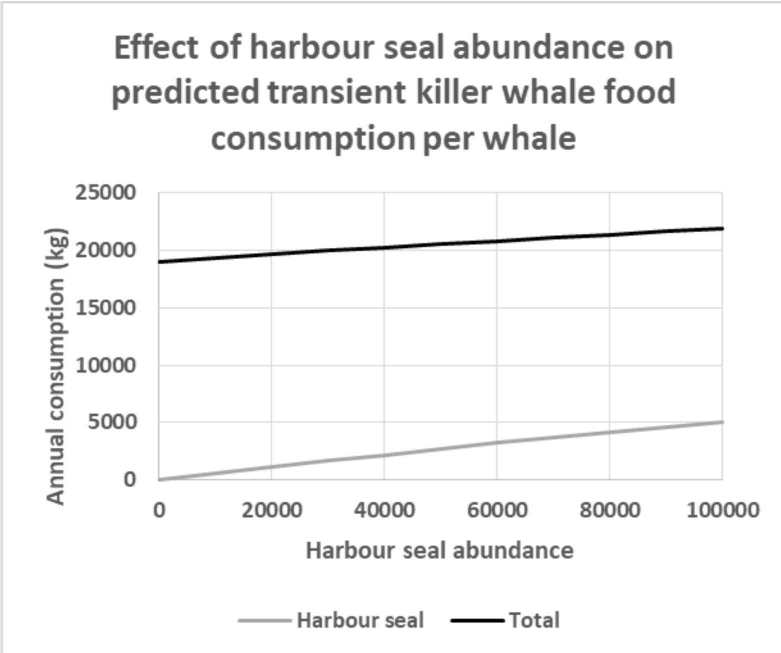
For prey types not assumed to vary over time, these values of the product aiNi can be used in conjunction with handling times hi (assumed proportional to mean prey weights Wi) to solve the disc equation for the total number and biomass of prey eaten as the number of just seals Nseal is varied. The rate of effective search aseal for just seals can be calculated from the estimated number of seals captured NAseal at some base seal abundance Nseal. For such calculations, a simple estimate of NAtotal is obtained by first estimating Wtotal, the total mass of food eaten per whale per year, and dividing this by the mean weight of all prey, given by $Wbar=\sum_i Wipi$. Assuming that total is around 60 kg/day, this along with average body size data by prey type gives NAtotal=155 prey per year (0.42 prey/day, somewhat lower than estimated by Dahlheim et al. (2010) at 0.62 prey/day for direct observations of killer whales feeding on a similarly diverse prey field in southeast Alaska). The total would be nearer 365 if seals were the only prey taken.

Reasonable values for the type II functional response parameters (Table B1) result in a prediction that total food consumption per transient killer whale should not in fact decline greatly with reductions in harbour seal abundance, and that kills of harbour seals should be almost proportional to seal abundance such that there should be only very weak depensatory predation effects (Fig. B3). These predictions are highly insensitive to alternative assumptions about handling times (e.g. if hi per prey is not much greater for large vs small prey) and current proportion of time spent foraging (Ts). Similar predictions about availability of alternative prey on feeding rates were obtained with a very detailed, agent-based model that represented searching, bioenergetics, and population dynamics of transient killer whales (Testa, et al. 2012), but this model did predict strong population responses to transient reductions in prey abundance and carrying capacity apparently due mainly to bioenergetics effects on reproductive success.

Table B1. Estimation of type II functional response parameters for transient killer whales, using the average diet composition reported by Ford et al. (2008). See text for explanation of component calculations. (harbour seal balance model fitted to data with transient killer whale mortality est.xlsx)

Prey	Prey weight (kg)	hi (days)	diet proportion (pi)	kills/year (NAi)	aiNi
Minke whale	1000	8.3	0.02	3.1	0.017
white dolphin	100	0.8	0.06	9.2	0.051
dall porpoise	110	0.9	0.10	15.4	0.084
harbour porpoise	53	0.4	0.16	24.6	0.135
Cal. sea lion	200	1.7	0.02	3.1	0.017
steller sea lion	500	4.2	0.12	18.4	0.101
harbour seal	60	0.5	0.54	84.5	0.463

Figure B3. Predicted variation in total weight of food consumed per transient killer whale using the multispecies disc equation model, for a range of harbour seal total population sizes along the B.C. coast, while assuming abundances of alternative prey (Table X1) remain stable.



(harbour seal balance model fitted to data with transient killer whale mortality est.xlsx)

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Addendum C: possible impacts of commercial seal harvesting on marine ecotourism

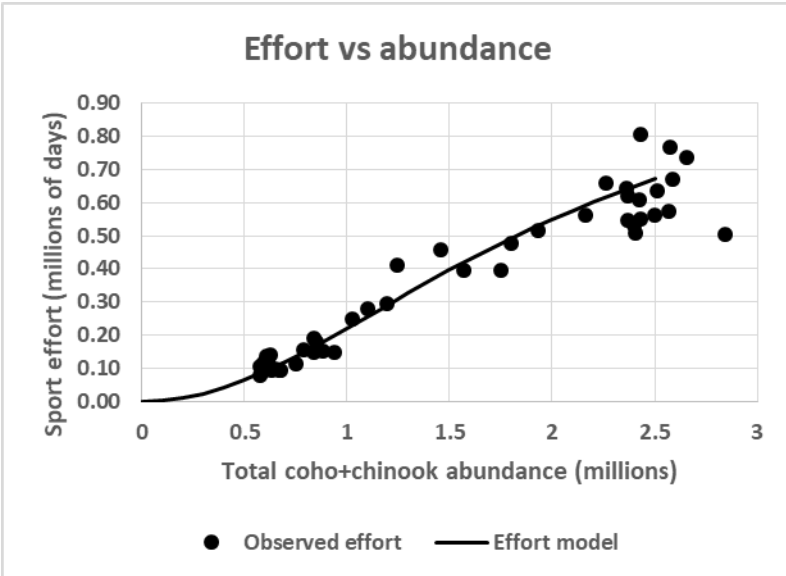
Marine ecotourism (e.g. whale watching, kayaking) is a growing industry in British Columbia, generating important income and employment for coastal communities. Over a million people engage in "Nature based" tourism in B.C., involving over 2,000 businesses (Tourism British Columbia, 2005) with at least one third of these businesses specifically related to marine ecotourism. As of 1998, whale watching in particular likely generated a total revenue of $108 million as compared to $487 million from tidal sport fishing (Fisheries and Oceans Canada, 2003), and sea kayaking may now attract even more tourists than whale watching. Interviews with sea kayaking operators have indicated that opportunity to see seals and sea lions is important to their marketing and clients (MacDuffee et al. 2016).

Any management policy that negatively impacted the marine ecotourism industry would certainly not be acceptable from an economic impact perspective. But there are several reasons to not expect such a negative impact and to in fact expect positive economic benefits to the tourism industry in general from carefully managed commercial seal harvesting.

First, predicted increases in chinook and coho abundance in the Georgia Strait region due to a 50% reduction in seal abundance would likely be beneficial to resident killer whales, particularly the southern resident whales that are important to whale watching. The B.C. whale watching industry is concentrated around Victoria.

Second, sport fishing effort in the Georgia Strait has declined from over 800,000 angler days in the early 1970s to under 100,000 angler days in recent years (Fig. C1, from Nelson et al. 2019 ms in prep), as chinook and coho abundance has declined. Given the predicted increase in salmon abundance, effort would likely increase by at least 200,000 angler days given the increase in sport effort predicted by the data in Fig. C1, with attendant increases in economic benefits to local communities.

Figure C1. Historical relationship between sport fishing effort (angler days) in the Georgia Strait and abundance of chinook and coho estimated from catch and escapement data. Source: georgia strait sport model.xlsx)



(Georgia strait sport model.xlsx)

It is difficult to see how ecotourists who prize the opportunity to see pinnipeds would even be able to detect, let alone respond negatively, to a 50% reduction in the numbers of seals and sea lions that they would be able to see in the water and at haul-out sites. There will still be large numbers for them to see, particularly at major rookeries, though the animals may become more wary (after some are shot by seal harvesters) and not allow tourists to approach so closely as is now possible.

There would doubtless be ecotourists who would simply refuse to visit B.C. as a way of protesting the killing of marine mammals in general. This could become a minor problem if any environmental organizations promote such protests, and/or provide misleading information about the severity of the harvest impact ("they are going to kill all the seals"). It may be worthwhile for DFO staff to contact people in Newfoundland to find out whether they saw, and how they handled impacts of protests about seal killing in that region.

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