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Potential implications of differential size limits in the Dungeness crab fisheries of British Columbia

Conséquences possibles de l'application de limites de taille différentielles dans les pêches au crabe dormeur de la Colombie-Britannique

Antan Phillips and Zane Zhang

Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, B.C. V9T 6N7

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Abstract

Dungeness crabs are harvested by commercial, recreational and First Nations fishermen coast-wide. In recent years, intensifying commercial crab fisheries have made it difficult for recreational and First Nations harvesters to catch crabs in many areas. In the past, demands for increased crab fishing opportunities by these two sectors has been dealt with by closing specific areas to commercial harvest. Further closures will begin to impact the viability of some of the coastal crab fisheries.

Differential minimum harvest size limits are proposed as an alternative to isolated total closures to commercial harvest. The limits chosen are 165 mm, measured across the widest part of the shell, for recreational and First Nations harvest with minimum commercial size increasing to 170 mm. The biological ramifications of differential limits are investigated in this paper.

Examination of the current proportion of the crab population falling between the old limit of 165 mm and the proposed new commercial limit of 170 mm indicate that an initial loss to commercial harvest of 20-30% by number or 10-20% by weight in the first year of implementation of this proposed new harvesting scheme. Boundary Bay is an exceptional case where there would be an initial reduction in harvest of greater than 50% by numbers and 30% by weight. If crabs between the old size limit and the proposed new size limit are allowed to moult, a maximum of 20% will do so over a period of 3 years, and the modal size of those crabs will be approximately 198 mm. The commercial fishery will probably stabilize at the level of initial loss due to harvest of *allocation crabs* by aboriginal and recreational harvesters except for Boundary Bay, in which it may stabilize at 60%-70% of the current landing level.

Résumé

Le crabe dormeur fait l'objet de pêches commerciales, récréatives et autochtones sur l'ensemble de la côte. Au cours des dernières années, l'intensification des pêches commerciales a rendu la capture de crabes difficile pour les pêcheurs récréatifs et autochtones de nombreux secteurs. Par le passé, les demandes de hausse des possibilités de pêche du crabe formulées par ces pêcheurs ont mené à l'interdiction de la pêche commerciale dans certaines zones. Des fermetures supplémentaires commenceront à avoir des répercussions sur la viabilité de certaines des pêches de crabe menées sur les côtes.

Des limites de taille minimale différentielles sont proposées à titre de solution de rechange à la fermeture complète de la pêche commerciale dans certaines zones. Les limites établies sont de 165 mm, largeur entre les points les plus éloignés de la carapace, pour les pêches récréatives et autochtones et une augmentation de la taille minimum à 170 mm pour les pêches commerciales. Les effets biologiques de l'application de limites différentielles sont examinés dans ce document.

L'examen de la proportion actuelle de la population de crabes dont la taille se situe entre la limite commerciale de 165 mm et la limite proposée de 170 mm révèle que la perte initiale pour le secteur commercial serait de 20 à 30 % en termes de nombre total de crabes ou de 10 à 20 % en termes de poids total des captures au cours de la première année du plan de pêche proposé. La baie Boundary constitue un cas exceptionnel puisque la perte initiale y serait supérieure à 50 % sur le plan du nombre et à 30 % sur le plan du poids des captures. Si on permet aux crabes d'une taille entre 165 et 170 mm de muer, un maximum de 20 % de ceux-ci le feront au cours d'une période de trois ans, et la taille

modale de ces crabes sera d’environ 198 mm. Les débarquements de la pêche commerciale se stabiliseront probablement au niveau suivant la perte initiale en raison de la capture de *crabes alloués* par les pêcheurs récréatifs et autochtones, sauf dans la baie Boundary, où les débarquements pourraient se stabiliser à un niveau correspondant à environ 60 à 70 % du niveau actuel.

1.0 Introduction

The Dungeness crab fishery is the second largest invertebrate fishery coast wide with annual landings in excess of 37 million dollars. Crabs are also harvested by First Nations and recreational fishermen coast wide. In recent years, there have been increasing demands by First Nations for Dungeness crab as a food, social and ceremonial resource and as a part of the negotiated settlement of land claims. With the loss of harvest opportunity for finfish and with an increasing urban population, recreational harvesters are also turning to crabs to augment or replace other sports fish catches. Due to a high market demand, commercial harvest has intensified during this same interval. As a result there have become problems with meaningful access to the resource by First Nations and recreational fishermen. The most common complaint is a lack of harvestable crabs due to an aggressive commercial fishery which in most areas continues throughout the year and reduces the number of legal sized crabs to very low levels.

In the past, many of the allocation problems have been dealt with by closing portions of the coast to commercial harvest. In some cases this is successful but in others it is impossible to provide access by this means without eliminating the commercial fishery over a large area. The commercial sector is already facing continual loss of harvest area for other reasons such as parks, marine protected areas, navigational closures, contamination closures and sea otters. This paper was prepared in response to a request to investigate differential size limits as one possible alternative to arbitrary area closures in the commercial crab fisheries (Appendix I).

The minimum size of retention, 165mm across the widest part of the shell, is currently the same across all harvest sectors. The proposed new limits would be 165 mm for First Nations and recreational harvesters and 170 mm for commercial harvesters. The intention of this regulation would be to provide year-round access to crabs by First Nations/recreational fishers while allowing a commercial harvest to continue simultaneously. It should be made clear that a differential size limit would not supersede closures for conservation concerns such as softshell periods.

1.1 Dungeness crab biology

Crabs mate in late spring/early summer. The female crab can only be bred in the softshell condition immediately after moulting. She stores the sperm which she then uses to fertilize eggs produced the following fall. The eggs are fertilized using the stored sperm as they are extruded and adhere to the female's abdomen where she incubates them throughout the winter. Hatching occurs in the spring and larvae are released into the water where they spend up to 5 months in the plankton before settling as juvenile crabs.

Crabs grow by moulting, the process by which they shed their old shell which allows the new shell underneath to swell with water and harden at a new, larger size. The instantaneous size increase by this process is in the order of 15 -25 % for crabs near legal width. The new shell is soft and requires up to three months to become fully hard, during which time the crab is most vulnerable to predation by a variety of fish and invertebrates and is also most susceptible to injury through trapping and handling.

Female Dungeness become sexually mature at about 100mm carapace width; males mature at about 130mm but due to competitive interaction with larger crabs, cannot effectively breed much below 150mm carapace width. Only male crabs that are completely hardened are able to mate, which requires a minimum period in excess of 90 days after moulting. With intensive fishing, most legal size crabs are removed before they have hardened sufficiently to breed. Furthermore, in many populations, there is insufficient time between the male moult and the female moult to allow the recently moulted males to breed that year. For these reasons, reproduction in the present intensively fished environment is to a large extent sustained by male crabs that are below the current legal width.

1.2 Crab management

For the last century, Dungeness fisheries have been managed primarily by size limit. This minimum size of retention was established to be 6 ½ inches more by market preference than by any biological consideration. This measurement was later changed to the metric equivalent of 165 mm across the widest part of the shell. The minimum harvest size limit ensures that the reproductive potential of the crab stock is conserved overall by allowing a proportion of the crab stock (the undersize crabs) to breed. It does *not* ensure that a male crab has the opportunity to breed at least once as an adult before capture as is commonly believed. It is therefore important to conserve undersize and female crabs by avoiding softshell periods and by otherwise reducing capture and handling of undersize and female crabs. Management by this means, commonly known as 3S management (Size, Sex and Season) have successfully maintained the Dungeness crab populations throughout their range for over a century. In recent years with fishing pressure on crab stocks greatly intensified, most management has focussed on limiting effort to avoid impacting the sub-legal and female component of the stocks.

2.0 Materials and Methods

2.1 Data sources

The data used to determine the notch to notch width (NW) and point to point width (PW) regression equation, the NW to weight equation, moult frequency, modal widths, catch per unit effort and population characteristics of crabs in the seven crab license areas (Fig. 1) were obtained primarily from the Shellfish Crab Database. This database contains records of both research and commercial crab trap samples from approximately 1985 onward with isolated records before that time. The only other published NW/PW regression (Weymouth and MacKay 1936) is presented for comparison in Table 1. Our own carapace width / weight regression was used to calculate the average contribution to the fishery of crabs in the 165 to 169 mm if they were to moult to larger size.

2.2 Carapace width analysis

All recent (>1980) crab carapace measurements in the Crab Database are in the NW format, i.e. the width across the carapace (exclusive of shell curvature) between the notches just anterior to the 10^{th} antero-lateral spine (Fig. 2). This measurement is made using 30cm slide machine callipers in all cases and the original measurement is recorded in mm.

Regulation of minimum legal retention size for both commercial and recreational harvest is defined as the maximum distance across the carapace (exclusive of shell curvature) *inclusive* of the 10^{th} antero-lateral spines. This width is known as point-to-point width (PW) (Fig. 2). It was therefore necessary to generate a PW/NW regression equation to calculate the bin width in notch measurement that would correspond to the proposed range from 165 – 169 mm inclusive PW that would provide recreational and First Nations exclusive harvest.

The relationship between PW and NW was formulated using data collected from Masset Inlet, McIntyre Bay, Hecate Strait, Fraser Delta (including Boundary Bay) and Vancouver Harbour. Linear regressions for these five areas are very similar, although analysis of covariance indicates that slopes of the five equations are not identical (Table 1). Because the differences are biologically insignificant over the size range under consideration, for simplicity, we combined the five data sets to formulate a simple linear model (Fig. 3):

$$PW = 1.093 \times NW - 3.228 + \varepsilon \qquad \varepsilon \sim N(0,\ 1.078^2) \qquad (1)$$

The NWs corresponding to 165 and 170 mm PWs were found to be 153.9 mm and 158.4 mm respectively. Because the carapace width measurements used in analysis were recorded in whole millimetre units rounded to the nearest millimetre, the 5 mm width bin in NW format that represents crabs that would be lost to commercial harvest through differential size limits was accepted to be 154-158 mm inclusive. This will hereafter be referred to as the *allocation bin* and will (unless otherwise stated) be in the NW format. Crabs within the *allocation bin* (between 154-158 mm inclusive) are defined to *allocation crabs*, which will be available solely to recreational and First Nations harvest under the proposed differential size limit scheme.

2.3 Moulting probability and modal size calculations

In the absence of fishing mortality, the initial contribution of crabs in the *allocation bin* to the population of crabs above 158 mm (commercial allocation) through moulting is the product of the moult expectation and the natural mortality associated with that moult over the intervening time to harden (30-60 days). Further contribution(s) involves an intermoult mortality rate, handling mortality rate and a similar probability of moulting with the associated survival expectation immediately post moult. Impact of handling mortality rate (*h*) was examined using rates of 0.0 or 0.1.

Post-moult size is correlated with pre-moult size of crabs (Butler 1961; Collier 1983; Warner 1987). We used the model presented by Smith and Jamieson (1989) in the current study:

$$NW_2 = 1.069 \times NW_1 + 18.07 + \varepsilon \qquad \varepsilon \sim N(0,\ 3.29^2) \qquad (2)$$

where NW_1 and NW_2 are pre-moult and post-moult notch-to-notch widths respectively.

Other biological parameters used in the analyses were presented by Zhang et. al. (2002, 2004). The size-specific moulting probability is:

$$\begin{cases} p = -0.0014 \times NW + 1.14 + \varepsilon & \varepsilon \sim N(0,\ 0.081^2) \quad (if\ \ 130 < NW < 150) \\ p = -0.014 \times NW + 2.71 + \varepsilon & \varepsilon \sim N(0,\ 0.39^2) \quad (if\ \ NW > 150) \end{cases} \qquad (3)$$

Analyses were done for two areas for which mortality estimates were available, Area E (WCVI, Tofino) and Areas I and J (Fraser Delta).

For Fraser Delta population, we used an instantaneous natural mortality rate (M) of 0.97 with a standard error (SE) of 0.39 (Zhang et al. 2002, 2004). We assumed that a crab must either moult again or die within three years of its last moult, therefore we estimated moulting likelihood for three consecutive years. On the Fraser Delta, with no fishery, the survival rate (*S*) for the moulted crabs in one month following the moult is 70.1%.

The proportion of moulting for crabs in Fraser Delta after *ith* (*i*: 1, 2 or 3) year is estimated as:

$$\begin{cases} Nmoult_i = N_{i-1} \times \exp\left(-\frac{3}{12} \times Z\right) \times \exp\left(-\frac{8}{12} \times M\right) \times p \times S \\ N_i = N_{i-1} \times \exp\left(-\frac{3}{12} \times Z\right) \times \exp\left(-\frac{9}{12} \times M\right) \times (1-p) \end{cases} \quad (4)$$

where *Z*, *M* , *p*, and *S* are instantaneous total mortality rate, instantaneous natural mortality rate, moulting probability, and survival rate for the moulted crabs in the month following the moulting respectively. We assume that the fishery lasts for 3 months, and the instantaneous fishing mortality rate (*F*) is 11 so that about 95% of legal-sized crabs would be removed by the end of the fishery. The total mortality rate, Z , is calculated to be $Z = M + F \times h$, where *h* is the handling mortality rate.

For analysis of WCVI crab population, we used an instantaneous natural mortality rate (*M*) of 2.5 with a SE of 0.13 (Smith and Jamieson 1991). However, because this is a year-round fishery, for convenience of calculation we assumed an instantaneous natural mortality rate (*Mm*) of 4.3 for moulted crabs for one month after the moult, which approximates the Fraser survival rate of 70.1%. The proportion of crabs moulting on the WCVI after *ith* (*i*: 1, 2 or 3) year is estimated as:

$$\begin{cases} Nmoult_i = N_{i-1} \times \exp\left(-\frac{11}{12} \times Z\right) \times p \times \exp\left(-\frac{1}{12} \times Z_m\right) \\ N_i = N_{i-1} \times \exp(-Z) \times (1-p) \end{cases} \quad (5)$$

where Z_m is the instantaneous total mortality rate for moulted crabs in the month following the moulting: $Z_m = 4.3 + F \times h$.

In equations 4 and 5, N is the number of crabs remaining in the *allocation bin*. With N_0 set to be one, the calculated values for $Nmoult_i$ are equivalent to the likelihood of moulting for this size group of crabs for each of the three following years.

Simulations were conducted to assess levels of uncertainty about the estimation. One thousand simulations were conducted with crab size, *M*, and *p* randomly generated for each simulation. Crab width was randomly generated between 153.9 and 158.4 mm. *M* was generated from a normal distribution with mean of 0.97 (SE = 0.39) for Fraser Delta or 2.5 (SE = 0.13) for WCVI. The moulting probability, p, was generated using Equation 3.

Post-modal size in NW was calculated using Equation 2, and was then converted to the size in PW using Equation 1 with addition of a random error. One thousand simulations were conducted, and for each simulation, pre-moult crab size and *M* were randomly generated as described above.

2.4 Loss to commercial harvest due to new size limit

Loss to commercial fishery landings as a result of increasing minimum retention size was estimated in 2 ways. Initial loss in the first year was assessed by subtracting *allocation crabs* from present width frequencies of legal sized crabs by area; and average loss over the long term was assessed by comparing yield per recruit at the present size limit with that at the new size limit over 3 years.

2.4.1 Subtraction of *allocation crabs* from commercial landings

To determine the proportion of the crab population in the *allocation bin* that would be lost to commercial harvest during the initial year after implementation of differential size limits, a width frequency histogram with cumulative percentage of male crabs above the current legal width (154 mm NW) was constructed using available data for each crab licence area. The proportion of all harvestable crabs in the *allocation bin* was read directly from the cumulative frequency curve at 158 mm (the upper limit of the *allocation bin*). In order to reflect current fishery status, analysis was limited to the most recent 5 years of data where possible. Where a seasonal commercial closure is in effect, pre-commercial fishery proportions vs. post commercial-fishery proportions were estimated. Where there is no commercial closure, immediate post-moult proportions vs. proportions after 4 months of fishing were calculated. When the moult period is unknown, it is assumed that the population is in a post-fishery state. Proportions are given for Spring and Fall in Vancouver Harbour, which though technically part of area I, is not fished by any sector and is therefore presented separately as reflective of an un-fished population.

2.4.2 Yield per recruit analysis

The impact on the commercial fishery over the long term was examined by calculating and comparing yield-per-recruit with the existing size limit (154mm NW) and for the new size limit (159mm NW). We used the procedure described by Zhang et. al. (2002, 2004) with slight modifications. Crabs were grouped into 130 width classes from 80 to 210 mm NW in 1 mm interval. A recruit is represented by one crab spreading among the first 20 width classes (80-100 mm NW). Analyses were conducted for Fraser Delta and WCVI with the same values of M and F described in Section 2.3. One thousand simulations were conducted to assess levels of uncertainty about the estimation. For each simulation, M and p (probability of moulting) were randomly generated as described. Besides, average weight (W) for each size (NW) of crabs was calculated with addition of a random error:

$$\ln(W) = 3.096 \times \ln(NW) - 9.189 + \varepsilon \qquad \varepsilon \sim N(0,\ 0.0422^2) \qquad (6)$$

In addition to examination of the impact of handling mortality rate, the impact of *allocation* crab harvest by the recreational and First Nation fisheries with 0.0 and 0.5 levels was also considered.

2.5 CPUE calculations

CPUE for this analysis is defined as number of crabs per standard trap day (24 hrs) fished. Data for these calculations were taken from our Crab Research Database which is a record of catches from standardized traps using standardized bait with 24hr soak times. Where standardized research gear was not used (Hecate Strait and Nass River) approximations were made based on our knowledge of relative gear efficiency and effect of soak time on catch rates.

2.6 Increase in availability of crabs to recreational/aboriginal sector

Expected CPUE is used to estimate increase in availability due to differential size limits. In commercial fisheries where there is a softshell closure in effect, specifically Areas A, I and J, it is possible to estimate expected CPUE increase directly from width frequency histograms by adding the entire *allocation bin* to the present CPUE of crabs above 158 mm NW (170 mm PW) both pre-fishery and post-fishery. In the other areas, because crabs in the *allocation bin* are harvested commercially year-round, the 5 mm width bin from 149 to 153 mm NW inclusive immediately below was used as a proxy for the *allocation bin*. This bin (149-153 mm NW) was substituted for the *allocation bin* (154-158 mm NW) and added to the overall CPUE of crabs above 158 mm NW to yield expected CPUE pre-fishery and post fishery under the new differential limit.
Expected CPUE of recreational and aboriginal harvesters due to size allocation is the same as pre-season CPUE for the commercial sector in areas with a closure. The predicted CPUE will drop with commencement of a commercial fishery and may increase again once that fishery closes for reasons to be discussed below.

In areas with a year-long fishery, expected CPUE for the recreational/aboriginal sector (generated by substituting the 149-153 mm NW bin for the *allocation bin*) is the sum of the number of crabs above 158 mm NW and the expected number of crabs in the *allocation bin* divided by the number of traps used in the original calculation of CPUE. Losses to this allocation from fishing mortality and competition are discussed.

3.0 Results

3.1 NW/PW regression

All carapace width measurements in the field are rounded to the nearest millimetre regardless of which measurement is recorded. The 5 mm PW bin width corresponds to a similar 5 mm NW bin. The PW/NW relationship is presented in Fig. 3. From this equation, the NW bin was determined to be from 153.9 mm (which represents current minimum width of retention) to 158.4 mm (corresponding to the new commercial minimum width of 170 mm PW under consideration). For analysis purposes the 5mm bin containing the *allocation crabs* was arbitrarily set to be 154 to 158 mm NW inclusive.

3.2 Contribution of *allocation crabs* to the commercial fishery

Contribution of crabs in the *allocation bin* to the commercial harvest through moulting, after accounting for natural mortality, is presented in Table 2. The proportion of crabs moulting over a 3 year period is about 19% overall for the Fraser dropping to approximately 12% if a handling mortality of 10% is imposed. For WCVI, using higher natural mortality rates, the overall contribution is about 4% dropping to 3% with 10% handling mortality. The contribution in other areas could not be directly estimated because we lack specific mortality rates. There is indirect evidence through the presence of large crabs in catches from some areas that the contribution is probably closer to levels observed on the Fraser rather than those for Tofino. Maximum time for the commercial fishery to stabilize would be 3 years after the moult period following the implementation of the new size limit. Most of the stabilization would be complete after 2 years.

3.3 Modal size

In all Crab License Areas, the larger size mode resulting from crabs in the *allocation bin* moulting will be the same given there are no significant regional differences in the NW/PW equation. Crabs in the *allocation bin* (154 – 158 mm NW) would be expected to produce crabs in the range of 182.7-186.9 mm NW post moult. Expected modal size resulting from the midpoint width of the *allocation bin* is 184.8 mm NW. Distribution around these points has been shown to be normal (Smith and Jamieson 1989).

Because of variation in moult increments and in the NW/PW conversion, the simulated modal size distributions are wider than the NW and PW distributions measured on survey (Fig.4). It can be seen that the relatively few large legal-sized crabs encountered on the Fraser (Fig. 5) and other recruitment fisheries can be explained by the low probability of crabs surviving the commercial fishery long enough to moult up from the *allocation bin*. Larger crabs found in the North Coast (and in Vancouver Harbour) are the result of larger crabs moulting rather than a greater moult increment. This suggests that a higher proportion of larger legal crabs on the North Coast survive at least one year of the commercial fishery in order to do so. This may reflect a lower harvest rate or be the result of some portion of the crab population being unavailable to the fishery during the fishing season.

3.4 Initial loss to commercial landings by crab license area

3.4.1 Allocation as a percentage of total numbers of crabs caught

The percentage of numbers of crabs that would be lost to harvest by Area in the first year if a new minimum size limit of 159 mm NW (170 mm PW) were introduced to British Columbia commercial fisheries ranges from 13% in Area A to 60% in Boundary Bay, depending upon the season and the range of the data used (Table 3). Annual variation noted in all areas could be the result of several factors (to be discussed below). Percentage of crabs in the *allocation bin* increases as the fishery progresses, from a low immediately following the annual moult (pre-fishery), to a high immediately prior to the following moult (post fishery). In areas where a predominant annual moult cannot be identified, the proportion of crabs in the *allocation bin* tends to be consistently high throughout the fishery. In the absence of fishing pressure (Vancouver Harbour) the proportions are consistent throughout the year. The latter two observations indicate that there is marked trap selectivity for capture of large crabs which are removed at a greater rate than those near legal width.

3.4.2 Allocation as a percentage of weight of crabs caught

Crab fishermen are paid by weight. Losses by weight as a percentage of the total weight of crabs available for harvest at the present size limit are also presented in Table 3. Crabs moulting from the *allocation bin* would produce a range of weights from 0.9 – 1.1 kg by applying Equation 6. Using the average weight of a crab from the midpoint of the *allocation bin* of 156mm (629g) moulting produces a crab with an average size of 184mm (1050g), resulting in an overall weight increase of 61%. The average size of crab produced will be the same over the entire coast, however the amount of the contribution is proportional to the average weight (by Area) of crabs landed. If the average weight of landed crabs is small, contribution of crabs moulting up from the *allocation bin* will be greater than if the average landed weight is large. The results of these calculations are shown in Table 4 where average weight of crabs is calculated from our research data. Good regional data from the commercial fishery is lacking. It may be seen that over the range of moulting probabilities given in Table 2, that depending on the Area average weight of crabs landed and on the mortality rates used, crabs moulting from the *allocation bin* may contribute from 1% to 13% to the total weight of all crabs landed to replace some of the losses due to allocation. Harvest of crabs from the *allocation bin* will affect the number of crabs available to moult in direct proportion to the degree of harvest. If all of the crabs in the *allocation bin* are harvested, there will be no benefit from those crabs moulting to larger size and the losses to the commercial harvest will be the same as the initial loss.

3.4.3 Yield per recruit analysis

Yield per recruit analyses with handling mortality of 0% and 10% and Recreational /First Nations harvest of *allocation crabs* at 0% and 50% levels were used to estimate losses to the commercial fishing in the long term (Table 5). Populations with a mortality rate similar to the Fraser can expect, in the absence of any other losses, an approximate reduction in total harvest of about 12% once the fishery has stabilized. With 10% loss to handling and a 50% exploitation of the *allocation crabs,* the reduction amounts to about 16%. Using mortality rates from WCVI, losses are higher due to the fact that *allocation crabs* are more likely to die before they can contribute to future harvest through moulting. Reduction of 34% is possible with 10% handling loss and 50% exploitation of *allocation crabs*.

3.5 CPUE

In areas A, I and E, where there is a known synchronized annual moult period, CPUE is highest just after the moult as the crabs become available to the fishery (Table 6). In other areas, where there is no synchronized annual moult period, or in areas with no fishing (Vancouver Harbour) there is little seasonal change in CPUE. An estimate can be highly variable within an area and can change rapidly with the advent of a moult or an influx of crabs from an adjacent area. Expected CPUE for recreational and aboriginal harvesters will be reduced due to competition and to fishing mortality associated with an intensive commercial harvest (Table 7). In Table 7, no allowance is made for reduction in CPUE due to allocation harvest throughout the season. Natural mortality throughout the harvest period is assumed to be offset by crabs moulting into the *allocation bin* throughout the season, which occurs to some degree in all areas even in areas with a synchronized annual moult period.

4.0 Discussion.

4.1 Carapace width analysis

Our own data were used to generate the NW/PW relationship with which to convert current and proposed regulation widths (PW) to the NW format of our research data. This data set contains some 2860 measurements from South and North Coast areas

(Fig. 1) and was deemed most appropriate for this analysis. The width bin corresponding to crabs between 165 and 170 mm PW from our data was found to be 153.9-158.4 mm NW. Previous conversions given in the Dungeness crab IFMP are 154.3–158.8 mm and are taken from Weymouth and MacKay (1936) who used the equation :

$$PW = 0.0715\ NW – 0.029.$$

That study included only 259 crabs from Boundary Bay and is therefore considered to be less representative of crabs along the whole B.C. coast. Although the slopes of the equations from our different samples varied, this was not considered to be biologically significant over the narrow range of carapace widths under consideration. These equations are presented in Table 1.

PW measurement used in regulation is most convenient to fishermen who use a simple fixed calliper to determine if a crab is legal size (undersize crabs pass through the calliper). This least accurately represents the size of the crab because the spines on the shell tend to wear down or break as the shell ages so that a crab that is barely legal size just after the moult will become undersize as wear progresses. On the other hand, NW measurement remains the same regardless of shell wear and is conveniently measured using machine callipers with bevelled jaws that fit into the notch. Measurements are in all cases rounded to the nearest millimetre. Errors in rounding tend to cancel out.

4.2 Loss to commercial harvest due to allocation

4.2.1 Immediate losses estimated by removal of *allocation crabs*

When there is a well defined synchronized annual moult period, the majority of crabs that will be available to harvest that year are recruited within a short time of the moult. In this case, the number of crabs that would be forgone due to the new size limit can simply be determined as a percentage of the legal sized crabs under the current size limit. Loss of these crabs to natural mortality is probably more than offset by crabs moulting to legal size outside the synchronized annual moulting period resulting in the relative proportions remaining the same.

This is the case on the Fraser Delta (exclusive of Boundary Bay), Area A (North Coast) and Area E (WCVI). In these areas, the percentage of the total catch of *allocation crabs* increases as the fishery progresses reaching a maximum just prior to the next synchronized annual moult period.

Breen (1985) observed that un-baited traps continued to fish with entrance and egress of crabs throughout the year of the experiment. These escaped through the escape ports or the entrance tunnels either around or between the triggers. As a fishery progresses and soak times increase due to lowered CPUE, crabs have a longer time in which to escape. Large crabs are less likely to be able to escape in this fashion. Trap experiments (Zhang et al 2002) have shown a progression of crabs entering traps, beginning with the smallest, which are replaced by larger crabs with increasing soak times. The presence of large crabs in a trap also discourages the entrance of smaller crabs. As a result, the only crabs available for capture near the end of a fishing season are newly moulted crabs that have just attained legal width and those within a few millimetres of legal width (*allocation crabs*) which have probably spent a good part of the season entering and leaving traps.

Analysis of shell age bears this out. Over most areas of the coast, oldshell crabs (shells older than 9 months since the last moult) contribute 5-10% to total landings (by number) whereas in Boundary Bay they amount to 40%. It should be kept in mind that although a high proportion of crabs may be in the *allocation bin* during the latter part of a fishery, their numbers as measured by CPUE are also very low. The result of increasing the commercial size limit will be to shift the size range of barely-legal crabs up 5 mm, however because there would now be fewer crabs to harvest overall, the low catch rates will probably be arrived at earlier in the season than at present. Continuing to commercially fish at low CPUE will reduce numbers of *allocation crabs* due to incidental handling mortality and confinement in traps.

In calculating the loss to commercial harvest, it is important to determine at what stage of the fishery the sample was collected. A sample obtained immediately post-moult, where a well defined synchronized annual moult period is known to exist, using research gear with no escape ports probably most accurately represents the true proportions of *allocation crabs* available to harvest for the rest of the season (until the next synchronized moult period). Proportion estimates from samples taken later in the fishery will be biased by declines in large crab abundance and increasing catchability of small crabs due to decreased competition in the traps.

The losses by area in terms of percentage of total numbers of crabs and also as a percentage of total weight and are given in Table 4 and are discussed by Crab Licence Area. All but Hecate Strait and the Nass Estuary are from samples using standard research gear with soak times approximating 24 hours.

It may be seen from this table that losses by weight are always less than losses by number. This is because the loss from the present level of harvest in the commercial fishery is from the lighter end of the weight distribution. Since fishermen are paid by weight and not by numbers of crabs and because weight increases exponentially with crab width, the loss of small crabs has a less serious impact to total landed value of crabs harvested.

Area A MacIntyre Bay The data for this area come from a research sample of 70 traps fished immediately prior to the opening of the commercial fishery. The proportion of 22. % *allocation crabs* is thought to reflect the true status. MacIntyre Bay is fished by both aboriginal and recreational harvesters.

Hecate Strait Data for this area come from Area A soft-shell crab surveys prior to the fishery using commercial gears. *Allocation crabs* are proportionately less due to the presence of predominantly larger crabs in this area. This is probably the result of larger modal size for newly recruited crabs as well as higher percentage of legal sized crabs that have survived the previous year's commercial fishery to moult to an even larger size. Competitive interaction with those larger crabs may tend to further under represent *allocation crabs*. This area is the least likely to be impacted by differential size limits because fishermen already select larger crabs through larger escape ring size in some cases and through discarding smaller (legal) crabs upon capture. The economics of the area favour large hard crabs that can survive transport to markets. This area is least likely to be fished by aboriginal and recreational harvesters due to its remoteness and exposure.

Area B *Nass River* Data for this area were collected in a pre-fishery survey conducted in 2000-2001. Moulting apparently takes place in late Spring, however there is no commercial fishery until late November. *Allocation crabs* occupied 27% of the legal sized crabs.

Area E *Tofino* Data used for this area were collected in 1989 and 2002. In 1989 the Tofino fishery was closed due to the Nestuca oil spill. A sample was obtained just prior to the spring moult, and another just after showing the proportions presented. Even though the data is 15 years old, the fishery there was already intensive and the proportions of *allocation crabs* presented probably reflect the true condition. This area has a year-long fishery, however a major spring moult is known to occur. Individual samples show allocation crab in catches to be as high as 37% in late fall, however a sample taken in late April 2002, just after the spring moult, shows proportions down to 24%.

AreaG *Nimpkish* This area is closed to commercial harvest and shows a post moult proportion of 20.1%

PFMA 12 This area is represented by a few isolated samples from the mouth of Knight Inlet. The moult time is unknown and abundance appears to be sporadic. The proportion of 38% seems reasonable in light of other areas with a continuous fishery.

Area H *PFMA Area 17 (Nanaimo Area)* The fishery is open year round except for a partial closure near Kuper Island that had just gone into effect at the time of the samples. Post-moult and pre moult samples show a range of 16% - 32% consistent with other areas

Area I *Fraser Delta* (exclusive of Boundary Bay) Pre fishery and post-fishery samples were taken consistently throughout the last 13 years. The average over the last 5 years of samples 27-28% in the *allocation bin* just prior to the commercial opening. This proportion increases to a high in late fall for Indian Arm of 52%. These levels are consistent between years.

Vancouver Harbour There is no (legal) fishery in Vancouver harbour. A smaller portion of *allocation crabs* here than for the rest of the delta is the result of all the crabs in the *allocation bin* being given the opportunity to moult. Composition of *allocation crabs* is about 22% spring and fall. A sample taken in 1976 when a commercial fishery was in effect in the harbour shows an even lower proportion (17%) of *allocation crabs*. This may in part be due to competitive interaction with larger crabs and may also be due to the commercial traps having escape rings. Both Hecate Strait and Vancouver Harbour have greater numbers of large crabs than other areas of the coast.

Area J Boundary Bay Pre-fishery and post fishery samples have been consistently collected for this area since 1991. The proportions in the *allocation bin* are the highest on the coast at 52-61% by numbers or 41% by weight. A late spring moult is known to occur in this area approximately one month later than the rest of the Fraser Delta. In most years shell age analysis shows the majority of the moult to have taken place at the time of the survey. This analysis also shows a much higher proportion of legal size oldshell crabs throughout the year than in any other area. Subsequent moulting is known to occur throughout the fishing season from July to December. This fishery exploits a trans-boundary stock which is aggressively fished in U.S.A. waters where harvest size is currently 169mm (NW). Although it is closed from January to July in Canadian waters, it is thought that a large part of the stock enters deeper USA waters throughout winter and late spring where it continues to be fished there by commercial, First Nations and recreational harvesters. Removal of large crabs immediately as they are produced throughout the year places this stock in a perpetually post-harvest state. Many of the crabs fished by Canadian harvesters have already been subject to what amounts to differential size harvest strategy employed in American waters, which accounts for the high proportion of crabs in the allocation size range.

Here, as in all areas of the coast, we are hampered by lack of in-season samples which would detect the widths of the crabs removed through the commercial fishery. The Boundary Bay crab stock appears to be no different from the rest of the Fraser Delta, having recruited from a common larval pool in the Strait of Georgia. The stock structure is in fact identical to that for the Fraser River if only newshell crabs are considered. This area is probably the most intensively fished area on the coast.

From our analysis, overall proportions of crab that would be lost to the commercial harvest coast-wide during the first season through increasing the harvest size is probably in the vicinity of 20% - 30% by numbers or between 10%- 20% by weight. Losses in boundary Bay would be 52% by numbers and 41% by weight.

4.2.2 Gains as a result of *allocation crabs* moulting

Gains from crabs moulting from the *allocation bin*, after accounting for fishing mortality will be in the neighbourhood of 5-15% by weight depending on the area (Table 4). After stabilization, without taking into account any directed harvest of *allocation crabs*, the reduction to the present commercial harvest will probably be in the range of 10% to 20% (by weight), exclusive of Boundary Bay where losses will be between 28% and 38%.

It should be iterated that the degree of harvest of *allocation crabs* by recreational, First Nations and others will affect the benefits accruing to those crabs moulting to larger size in direct proportion to crabs harvested. If a high proportion of the allocation is removed, downstream benefits in terms of larger crabs and increased reproductive capacity will be minimal. In most areas of the coast recreational /aboriginal harvest is currently low in proportion to the commercial harvest and will probably remain so in the foreseeable future. On the South coast, specifically Crab Licence Areas H, I and J, this may not be the case. With a large body of crabs available to recreational /aboriginal harvest due to the allocation, fishing success will improve significantly from current levels which will in turn drive increasing effort directed at *allocation crabs*. Whereas effort limits are in place in the commercial and recreational sectors through regulations and fishing licence conditions, no such limits are in place for First Nations harvesters nor in most cases have harvest limits for Food, Social and Ceremonial purposes been defined. It is conceivable that a large proportion of the allocation could be harvested by one or the other of the allocation stakeholder groups leaving the other in an identical situation to the present where they no longer have reasonable access to the resource. It should also be bourn in mind that a large body of crabs immune to the depredations of the commercial fishery will also be attractive to poachers who have ready markets for crabs caught, thus eroding the allocation.

4.2.3 Yield per recruit analysis

Table 5 shows the results of the yield per recruit analysis for the two areas of the coast for which mortality rates are available. This analysis has the advantage of incorporating gains due to *allocation crabs* moulting. The results are in general agreement with those obtained by removing the *allocation bin* from present catches. It has been argued (Butler and Hankin 1992) that the natural mortality rates proposed for WCVI (Smith and Jamieson 1989) are too high, a view supported by the authors of this paper. These rates lead to a reduction of 33% in weight if handling mortality of 10% and a fishing mortality of 50% on the allocation stock are imposed. This reduction, which would be overestimated if *M* is overestimated, seems excessive if one compares it to the reduction found by subtracting the allocation (Table 4). Yield per recruit results for the Fraser show a smaller loss than those obtained by subtraction of the *allocation bin*. With lower mortality rates, the commercial reduction in catch is less sensitive to losses through handling and removal of *allocation crabs*.

4.3 CPUE

4.3.1 CPUE calculations

Observed CPUE is taken directly from our research trap data and is presented in Table 6. The areas chosen for this table represent areas and depths where recreational/First Nations harvest is likely to occur. CPUE is variable due not only to levels of harvest but also due to depth, biological activities of the crabs and seasonal movement and behaviour. In most areas a pre-fishery (immediate post-moult) estimate is given. In areas where there is a closure of some type, and the moult period is known, the pre-fishery CPUE is the same for all harvesters under the present size limit. With differential limits, the CPUE is reduced in the commercial sector and increased in the allocation sector.

If the moult is less well defined, if there are multiple moults or if the moult time cannot be determined, it is difficult to estimate the number of crabs that would be available either to commercial harvest or to allocation due to their constant removal throughout the year-long fishery. For this reason, the 5 mm bin from 153 to 149 mm just below the *allocation bin* (below current legal size) was substituted for the *allocation bin* in calculations. The assumption was made that the number of crabs in both bins is approximately equal. This is not strictly true and varies both within and between areas and with season. The mode of crabs near minimum harvest size fluctuates between years since it may be composed of 2 different year classes of crabs whose growth rates since settlement as megalopae may be different. Because our research traps, from which this data is taken, have no escape ports, retention of undersize crabs is much greater than that of commercial gear, nevertheless there is a size related vulnerability to capture. For License areas I, J E and H, use of the lower bin as a proxy seems appropriate; in areas where undersize crabs are not well represented (North Coast), the technique is less useful and in the extreme will give values less than those observed. Calculated CPUE for the allocation sector is presented in Table 7 along with projected reductions to the commercial CPUE by removal of the *allocation crabs*. In most cases this results in a lower allocation post-fishery because the pre-fishery rates include all crabs available to harvest including the large ones. By the end of a fishing season, most of the large crabs have been removed by the commercial fishery and also a proportion of the *allocation crabs* have been lost due to natural and fishing related mortality. Reduction in activity levels of crabs during the winter and relocation to deeper water will also reduce the number of crabs available to First Nations/recreational harvesters post-season.

The allocation CPUE is lowest post-fishery where the proportion of *allocation crabs* is lowest pre-fishery. It approaches pre-fishery rates when proportions in the *allocation bin* are high. Low CPUE in some areas may also reflect crab habitat and may not be the result of fishing.

4.3.2 Losses to *allocation crabs*

Reduction in availability crabs in the *allocation bin* will be primarily due to the commercial fishery if one assumes harvest rates by the recreational/aboriginal sector (for which we have no accurate data at present) to be comparatively modest. An intensive commercial fishery will simply out-compete other harvesters due to the large number of traps in the water, their greater efficiency and because they fish continuously throughout the season. The attraction of those traps, whether the crabs are able to escape or not, will effectively render unavailable a portion of the allocation during the course of the fishery. The size range of crabs most vulnerable to retention will be the *allocation bin* and will be subjected to handling most frequently. This in turn will lead to losses through fishing related mortality which will impact all sectors but especially First Nations/recreational harvesters. Estimates of losses are in the neighbourhood of 10% – 25%. These losses will lower the CPUE for allocation traps and will ultimately lower returns to all harvesters in subsequent years.

An examination of the post-fishery width histogram for the Fraser Delta (Fig 5) shows removal of a portion of the crab population at least 2 mm below legal width. Some of this can be accounted for by variation in spine width by which the harvest size is regulated. The rest is probably the result of incidental handling mortality and accidental or intentional removal of undersize crabs just below the legal width. With an increased commercial harvest size, these effects will be transferred upwards 5 mm to the upper end of the *allocation bin*. It can be argued that this loss will be returned on the lower end of the bin however the losses due to incidental fishing mortality and undersize retention are associated with intensive commercial harvest and will probably not apply to the same extent at the lower end of the bin unless there is very high exploitation by allocation harvesters. Losses due to intensive commercial harvest may detract significantly from the *allocation crabs* available in some areas.

Some commercial crab fisheries are already near the limit of viability. A further reduction of crabs available to the commercial sector with the introduction of differential limits may manifest itself in increased effort levels beyond the already excessive levels at present or an increase in illegal activity or both. With intensive competition for crabs, gear conflicts will arise both within the commercial sector and between the commercial and allocation sectors. Loss of gear through entanglement, theft of gear, theft of crabs and vandalism may make it difficult for some harvesters to gain access to the resource in some areas. This was the situation in Area A before the introduction of electronic monitoring and these types of problems have already reached chronic proportions in Area H.

Intensive fishing also results in injuries to crabs which detract from the acceptability of the crab from an allocation harvester’s standpoint and from marketability of commercially- caught crabs. Limb loss rates are commonly 15% and may be as high as 20% in some areas. In un-fished populations, the rate is about 7%. The size range available to allocation harvesters will overall be smaller than the commercial sector. This may or may not be acceptable to allocation harvesters. No account is made of losses due to poaching which is significant in some areas and which will likely to increase if poachers are no longer in direct competition for the same crabs as the commercial harvesters. There are well established markets for soft and undersize crabs at present.

4.3.3 Means of reducing allocation loss due to fishing related mortality

There are a number of means by which losses due to accidental death and injury of undersize crabs can be reduced. It should be pointed out that whereas losses due to fishing related mortality will be greatest to the allocation sector with differential limits similar losses presently occur though at a smaller size range (<153mm NW) to the detriment of all harvest sectors. Since there are no means at present to increase crab abundance and with continual loss of habitat from human activities, the only way of increasing the number of crabs available to harvest is to reduce losses by modifying fishing behaviour.

4.3.3.1 Escape rings

One means of reducing the handling of undersize crabs is by use of a fixed escape ring in traps. This device allows undersize crabs (which includes most female crabs) to leave the trap through an open ring of a specified diameter while ideally retaining all of the legal sized crabs. This, in practice, is a difficult balance. Dungeness crabs are wider than they are long and so exit via an escape port sideways. The diameter currently specified (100mm) was established in 1990. It was soon realized that many undersize crabs were being retained which lead to a PSARC review of escape ring size (Jamieson 1990, 1991, 1992) which recommended a 110mm ring. Implementation was to occur in 1992. Those fishermen that voluntarily changed their rings to 110 mm not surprisingly found that their catches of legal crabs were much less than those with 100mm rings owing to the fact that many fisheries, especially near the end of a season, are sustained largely on crabs within a few millimetres of legal width for reasons discussed above. The proposed regulation was dropped in 1994 after discussions with the commercial sector and agreements to impose soft shell closures in some areas as an alternative to an increased ring diameter although the two issues are not related. The 100mm ring size was retained throughout most of the coast. Area B elected 110mm rings in 1998 as an alternative to softshell closures (again unrelated) and remains the only area of the coast to do so although many fishermen in Area A have installed larger rings to avoid the nuisance of measuring crabs within a few millimetres of legal size.

If a larger commercial size limit were imposed, a larger escape ring would also be necessary in order to reduce the retention of undersize (allocation) crabs. An appropriate diameter would need to be established by means of crab morphometrics and field trials rather than simply increasing the current ring size by 5 mm. Nevertheless undersize crabs will still be attracted to and be retained in the commercial gear, escape ring or not, thus reducing their availability to First Nations/recreational harvesters. That effect will be constrained by the total amount of gear in the area (which is limited by specific trap limits and the number of commercial licenses by area) and may not be a significant reduction to the allocation crab population if the overall crab population in the area is high in relation to the number of traps.

4.3.3.2 Discard ratios

Another means of reducing undersize and female handling, related to escape rings, is to cease fishing when the ratio of crabs kept to crabs discarded falls below a certain (as yet to be determined) ratio. At present, commercial fishing continues at very low CPUE in some areas (< 1 crab in ten traps fished). This would be acceptable if all the crabs retained in traps were legal sized males. This is not the case. Even with long soak times (in excess of 7 days), undersize and female crabs continue to be caught even though they are physically able to escape via escape rings. Once the population of large crabs has been reduced to very low levels, it will remain so until the next moult. In the mean time, the same undersize crabs may be captured and discarded numerous times in an attempt to catch an occasional legal male resulting in loss of undersize and female crabs through handling induced mortality. Losses are compounded when fishing continues through a softshell period. In order to regulate fishing by discard ratios levels, these will need to be established and a commercial sampling program will be necessary. Management by discard ratio has the advantage of encouraging harvesters to voluntarily reduce capture of undersize crabs by a variety of means of their own device including larger escape rings and longer soak times and avoidance of areas with soft crabs.

4.3.3.3 CPUE closures

Where there is a well defined annual moult, fishing can be terminated at a pre-defined CPUE regardless of the discards. Once closed, legal crabs would continue to accumulate until they reached an acceptable level for harvest. This method is not as yet part of current management strategy but is approximated by arbitrary seasonal closures in Areas I and J. These two fisheries close approximately 5 months before the annual moult at CPUE levels of 0.1 or less and remain closed throughout the ensuing soft-shell period.

The closing dates were originally established as fishermen brought in their gear when fishing ceased to be profitable, i.e. low CPUE. Timing of the opening, although arbitrary has been monitored by the Department over the past two decades as part of ongoing stock assessment activities. Management by CPUE requires fairly extensive commercial monitoring to determine closures and fishery-independent sampling to determine levels for re-opening, unless an arbitrary season is set which is sufficiently long in duration as to prevent fishing when stocks are exhausted and to minimise the chances of opening before crabs have completed their moult.

4.3.3.4 Soft-shell closures

Crabs remain soft for one or more months following a moult. During this time they are extremely vulnerable to injury and death as a result of being confined in traps with other (hard) crabs or by being handled and discarded. Once a crab survives the soft-shell period, resistance to handling is much greater. At present, soft-shell closures are only in place in Areas A, I and J. Other areas or sub-areas would probably benefit from closures but lack of current harvest information has prevented this. If there is a marked annual moult, this can be accomplished by arbitrary closures mentioned above. If not, a monitoring program is necessary to effectively avoid soft-shell periods without prolonged arbitrary closures. Fishermen in Area A have already taken this approach to the management of crabs in their area and have a fishery monitoring program in place to determine closing and opening dates for the fishery.

Soft-shell closures are conservation closures as they effect crabs of all sizes and may directly impact the reproductive potential of stocks. It is a matter of interest that soft-shell seasons have traditionally been defined by the numbers of large, soft male crabs.

The female soft-shell period usually does not coincide with that of the males but handling of undersize soft females is no less destructive to reproductive potential and should be considered when implementing closures. We currently lack sufficient data to identify female soft-shell periods although our research data indicates they tend to moult more or less synchronously over the entire coast of B.C. in late spring. Avoiding harvest of soft-shell crabs is probably the most effective means of reducing losses to allocation (and commercial) harvest.

4.3.3 Gains as a result of differential limits

It is assumed that because the crab fishery in British Columbia has been sustained for well over a century with the current minimum size limit, there can be no detrimental biological effects of increasing that limit. Conversely there should be some benefit associated with an overall more “normal” population of crabs.

Commercial crab fisheries will continue to be recruitment fisheries to a large extent even if differential limits are adopted. Nearly all the breeding in many areas is done by sub-legal sized crabs because there is insufficient time for the males that have moulted to legal size to harden sufficiently to breed that year. Our data indicates a minimum time from moulting to breeding of about 100 days. On the Fraser estuary, the fishery opens 40-50 days after the main male moult. Crabs are rapidly removed from the population shortly after the season opens or are removed as soon as they are legally hard enough to keep if they moult during the commercial fishery. There is insufficient time between moulting and removal by the fishery for most of these crabs to harden fully and breed. Allowing a greater proportion of larger crabs (crabs in the *allocation bin*) to breed may translate into higher breeding success overall and increased larval production. This ultimately could result in a greater post larval settlement and increased recruitment to the fished population. The benefit may be difficult to detect against the background variability between year classes and would not occur for a minimum of 3 years after implementation of differential limits because that is the minimum time for a crab to grow to legal size. Presently about 20% of the female population on the Fraser Delta shows no evidence of having been bred. The reasons for this are unclear but it may be due to a lack of mature males at the time of the female moult which coincides with the opening of the fishery.

The increase in numbers of larger crabs through moulting out of the *allocation bin* has already been discussed but it should be emphasized that all crabs above the current legal width will also be available to allocation harvesters with differential rates and all sectors will realize benefits in terms of large crabs. Harvest rates of the *allocation crabs* in most areas of the coast will probably never approach those of the commercial sector except in limited areas on the South coast. It is unlikely that 50% of the available *allocation crabs* could be harvested in areas like the Fraser Delta or Tofino without a directed commercial-scale harvest, although some smaller portions of those areas may be depleted, especially around piers and docks.

4.4 Availability of *allocation crabs*

We used CPUE to provide an estimate of the availability of crabs. A range of values is presented in Tables 6 and 7 from our data which reflects crab availability to our research gear. This does not necessarily reflect the availability to recreational and First

Nations or to commercial harvesters due to differences in soak time, trap design, bait loads, selected areas fished etc. however it does provide an index of abundance that can be used to define availability. It is the experience of the authors that a CPUE above 3 (as defined by research traps soaking for 24 hours) is good fishing whereas anything below 1 is poor fishing. Although fishing expectation is difficult to define, current sports regulations allow the use of 2 traps per licence. For the purpose of this paper we define the expectation that 2 traps will provide at least 1 crab total on each occasion they are fished and that individual trap soak time will be 5 hrs.

There are little data on recreational soak times, however many fishers set their gear on the way to some other destination and recover it within about 6-8 hrs. Trap theft is a problem in some areas which tends to shorten soak times. Other fishers fish the trap continually over the space of several hours. Some continually fish the trap throughout the year leaving it in the water the entire time.

Analysis of soak times vs. catch from Vancouver harbour shows that over one half the crabs are caught within the first 5 hours the trap fishes. This of course is influenced by a number of factors including tide and position of trap in relation to current, time of day, the amount of other gear in the area etc. To achieve the goal of one crab with a total of 10 soak hours between 2 traps, the CPUE as measured in our research traps would have to be above 2. This assumes a recreational efficiency somewhat less than that of our research gear.

By looking at Table 6, it may be seen that in most areas, present pre-fishery abundance (for all sectors) is well above 2, however in most areas post-fishery abundance is well below 2. The calculated CPUE for *allocation crabs* (Table 7) if differential rates were imposed is in all but one case above 2. By this criterion, the differential limits would provide reasonable access in most areas. By the same token, any harvest of that allocation by recreational/First Nations or competitive interaction with commercial harvesters as described above, will alter that level of abundance.

5.0 Summary

In answer to the questions posed in the RFWP:

- If the commercial size limit is increased to 170 mm PW, an initial loss to commercial harvest of between 20% and 30% by numbers of crabs and between 10% and 20% by weight can be expected in the first year of implementation. Boundary Bay is an exceptional case where there would be an initial reduction in harvest of greater than 50% by numbers and 30% by weight.
- If Crabs in the 154 - 159 mm (NW) are allowed to moult, a maximum of 20% will do so over a period of 3 years. The modal size of those crabs will be approximately 184 mm (NW) since moult increment appears to be similar in all areas.
- The commercial fishery will probably stabilize at 80% - 90 % of current landings levels (by weight) except for Boundary Bay which may stabilize at 60%-70%.
- Differential size limits would appear to be effective in providing recreational/First Nations access. An intensive commercial fishery may significantly detract from that access in some areas during the fishing season.

5.1 Cautionary remarks

- Anticipated reduction in landings (by weight) of from 10% - 30 % with the introduction of differential limits may threaten the viability of some commercial fisheries, particularly Boundary Bay which exists largely on small crabs. This may result in a counter-productive (in terms of the resource) increase in effort and may also manifest itself as an increase in illegal activities.

- In light of present low CPUE levels presently observed in some commercial crab fisheries and with a further reduction in availability of commercial crabs through differential size limits, the commercial sector in some areas will likely respond by increasing fishing effort. It should be emphasised that access to the crab resource by Recreational and First Nations harvesters as a result of differential harvest size will be eroded if measures are not undertaken to minimise capture and handling of undersize and soft crabs, many of which will be in the allocation size range. Measures may include but not be limited to:
    - identifying softshell periods coast-wide and discouraging or prohibiting harvest during those times.
    - closing and re-opening commercial fisheries on a discard ratio for legal vs. sub-legal and female crabs;
    - managing commercial fisheries to a minimum catch per trap level of abundance for legal male crabs

- developing an appropriate escape ring diameter (for both Recreational/First Nations and Commercial size limits) to reduce retention of undersize crabs in traps.
- Adopting minimum soak times

6.0 Acknowledgement

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Table 1. Regressions of Point Width on Notch Width for 6 Areas of B.C.

Fraser Delta	y = 1.0657x + 1.6385 R^2 = 0.9891	N = 530
McIntyre Bay	y = 1.09x - 2.3459 R^2 = 0.9734	N = 1338
Hecate Strait	y = 1.0831x - 1.7752 R^2 = 0.9995	N = 377
Vancouver Harbour	y = 1.0889x - 2.1845 R^2 = 0.9995	N = 356
Masset Inlet	y = 1.07x - 0.5704 R^2 = 0.975	N = 259
Weymouth & MacKay 1936 Boundary Bay (not used in our calculations)	y = 0.0715 x - .029	N = 203

Table. 2. Predicted proportion of Dungeness crabs recruiting to the fishery from the *allocation bin* (165-169 mm PW) over three consecutive years following implementation of a new 170mm PW commercial size limit.

Area	Handling Mortality Rate		1st year	2nd year	3rd year	Total %
Fraser Delta	0%	Mean	0.160	0.031	0.006	19.7
		Standard Deviation	0.111	0.036	0.010	
	10%	Mean	0.122	0.018	0.003	14.3
		Standard Deviation	0.084	0.021	0.004	
WCVI	0%	Mean	0.037	0.001	0.000	3.8
		Standard Deviation	0.021	0.001	0.000	
	10%	Mean	0.028	0.001	0.000	2.9
		Standard Deviation	0.016	0.001	0.000	

Table 3. Initial losses to commercial landings of Dungeness crab as a percentage of current landings by numbers and by weight with an increase in minimum commercial width to 170 mm (PW).

Crab License Area	Location	Crab Status	Period	% loss by numbers of crab	% loss by weight
A	MacIntyre Bay	pre-fishery	1998	22.22	17.76
	Hecate Strait	pre-fishery	1999 - 2003	13.28	10.18
B	Nass Estuary	pre-fishery	2000- 2001	27.77	23.2
E	Tofino	pre-fishery	1989	16.06	13.07
		pre-fishery	2002	24.58	20.23
		post-fishery	1989	37.35	31.93
		post-fishery	1999 - 2003	41.6	36.83
G	PFMA Area 12	pre-fishery	2001	20.11	16.16
H	PFMA 17	pre-fishery	2003	18.61	14.68
		post-fishery	2003	31.58	29.88
I	Fraser Delta	pre-fishery	1999 - 2004	26.59	22.48
		post-fishery	1999 - 2004	43.83	38.84
	Indian Arm	pre-fishery	1999 - 2004	28.34	24.22
		post-fishery	1999 - 2004	51.69	48.02
	Vancouver Harbour	pre-moult	1999 - 2004	21.85	17.58
		post - moult	1999 - 2004	21.5	17.66
J	Boundary Bay	pre-fishery	1999 - 2004	51.78	41.11
		post-fishery	1999 - 2004	60.63	55.62

Table 4. Reduction of commercial harvest of Dungeness crab by weight after stabilization at different probability levels of crabs moulting up (recruiting) from the *allocation bin*.

Crab License Area	% Initial loss to landings by weight	ave.wt.of crab (kg.) by License area	proportional weight increase as result of moulting	probability of recruitment after accounting for mortality	%contribution by weight due to allocation crabs moulting	% overall reduction in harvest by weight	% original harvest by weight after stabilization
A	10.1	0.822	1.28	0.05	0.65	9.5	90.5
				0.1	1.29	8.8	91.2
				0.2	2.58	7.5	92.5
B	23	0.730	1.44	0.05	1.65	21.3	78.7
				0.1	3.31	19.7	80.3
				0.2	6.62	16.4	83.6
E	20	0.800	1.31	0.05	1.31	18.7	81.3
				0.1	2.63	17.4	82.6
				0.2	5.25	14.8	85.3
G	16	0.780	1.35	0.05	1.08	14.9	85.1
				0.1	2.15	13.8	86.2
				0.2	4.31	11.7	88.3
H	15	0.780	1.35	0.05	1.01	14.0	86.0
				0.1	2.02	13.0	87.0
				0.2	4.04	11.0	89.0
I	22	0.740	1.42	0.05	1.56	20.4	79.6
				0.1	3.12	18.9	81.1
				0.2	6.24	15.8	84.2
J	41	0.670	1.57	0.05	3.21	37.8	62.2
				0.1	6.43	34.6	65.4
				0.2	12.85	28.1	71.9

Table 5. Yield per recruit analysis. Percentage reduction in commercial landings of Dungeness crab by number and by weight after population stabilizes with implementation of differential limits.

Area	Handling Mortality Rate	Exploitation Rate for First Nation/Recreational fisheries	% of Reduction in Landings(numbers)	Standard Deviation	% of Reduction in landings (weight)	Standard Deviation
Fraser Delta	0%	0%	17.0	4.1	12.0	4.3
		50%	18.7	3.3	14.4	3.2
	10%	0%	18.8	3.9	14.0	4.0
		50%	20.1	3.3	15.8	3.2
Tofino	0%	0%	37.6	3.1	31.5	3.4
		50%	38.3	2.8	32.6	3.0
	10%	0%	39.5	3.0	33.5	3.2
		50%	40.0	2.7	34.4	2.9

Table 6. Catch per unit effort of Dungeness crab in research traps with a 24 hour soak.

License			pre-fishery		post-fishery	
Area	*Location*	*Period*	observed	*N traps*	observed	*N traps*
A*	Hecate Strait*	1999-2002	11.43	72	2.4	40
	Macintyre Bay*	1997	7.6	70	N/A	N/A
B*	Nass River*	2000-2001	4.87	91	3	28
E	Tofino (inside)	2000-2002	2.9	76	0.31	68
G	Nimpkish*	2000-2002	6.3	126	4.9	29
	PFMA 12	2000-2002	N/A	N/A	0.92	135
H	Kuper Island*	2003	1	120	0.3	40
I*	Coalport	1999-2004	5.27	90	0.48	63
J*	Boundary Bay*	1999-2004	4.1	135	0.39	66

*seasonal closures in effect

Table 7. Present Catch Per Unit Effort (CPUE) and predicted CPUE with differential limits

		pre-fishery			post-fishery			
Crab Licence Area	***Location***	Present CPUE pre-fishery for all sectors	Commercial CPUE with Allocation removed		present Commercial CPUE Post-fishery	Commercial CPUE with Allocation removed	Calculated CPUE for Allocation sector	
A*	Hecate Strait*	11.43	9.91		2.4	2	2.8	
B*	Nass River*	4.87	3.55		3	2.46	3	
Eqw	Tofino (inside)	2.9	2.22		0.31	0.19	3.05	**
G	PFMA 12	1.2	1		0.92	0.61	1	**
H*	Kuper Island	1	0.86		0.3	0.2	1	
I*	Coalport	5.27	3.9		0.48	0.2	3	
J*	Boundary Bay*	4.1	2.54		0.39	0.15	2.42	

* seasonal closures in effect
** CPUE calculated using present sublegal CPUE as proxy

(CPUE from standardized research gear with 24 hr soak)

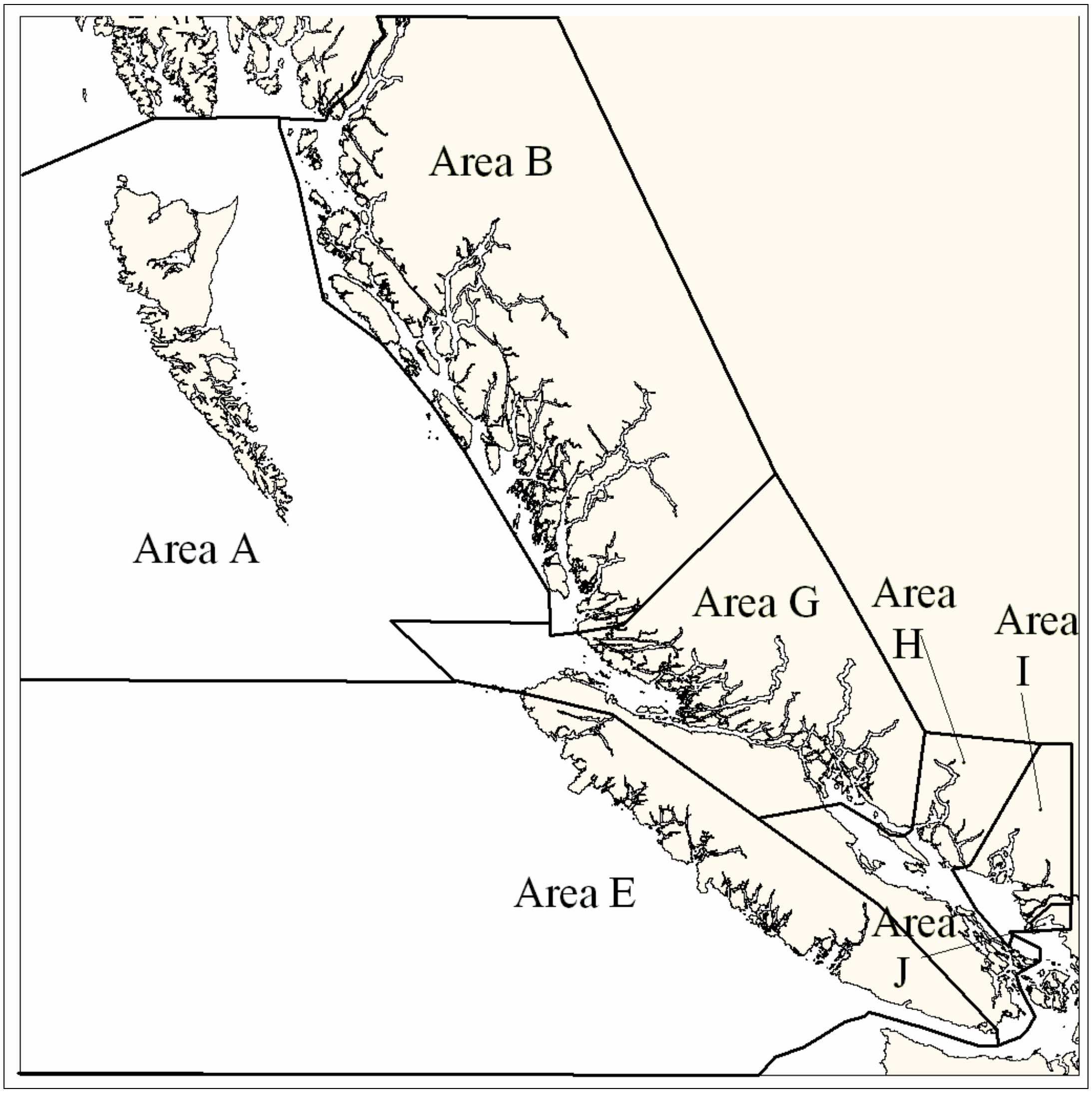

Fig. 1. Commercial crab license areas in British Columbia.

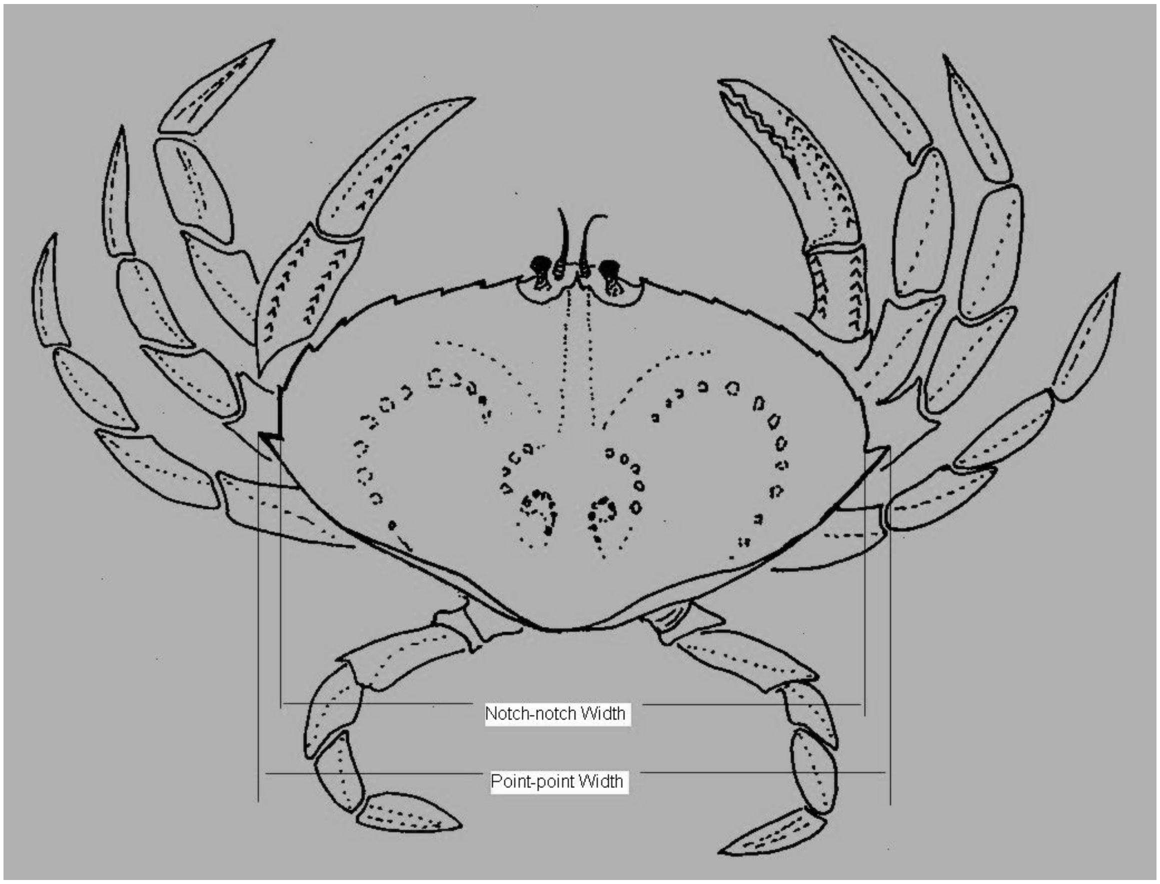

Fig. 2. Drawing of a Dungeness crab showing notch-to-notch (NW) and point-to-point (PW) measurement.

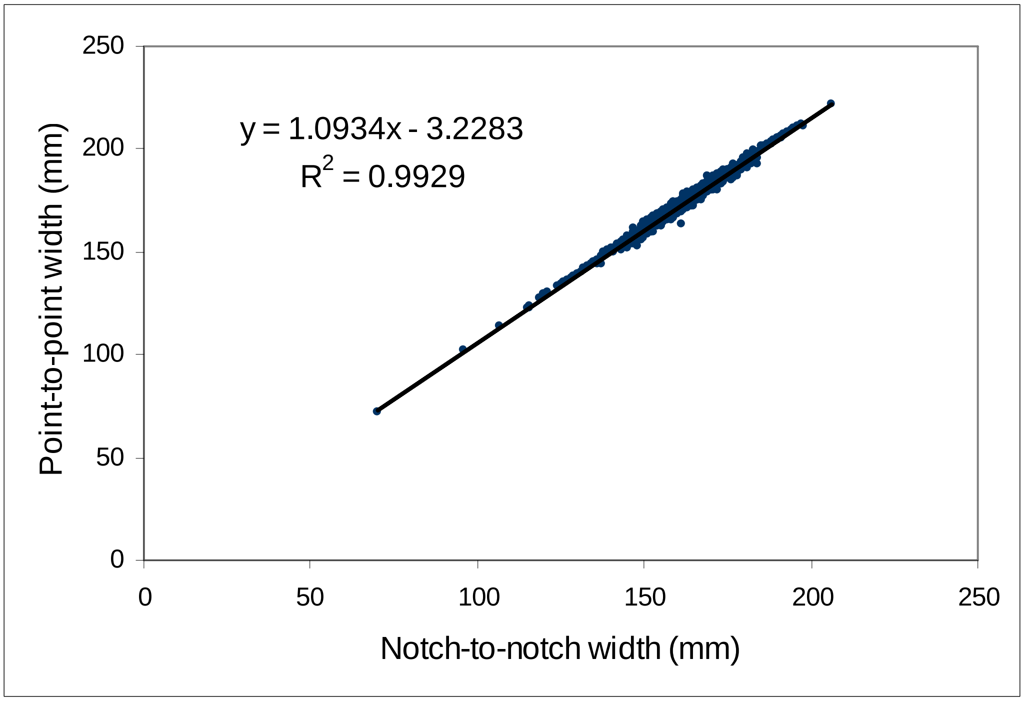

Fig. 3. Relationship between notch-to-notch width and point-to-point width.

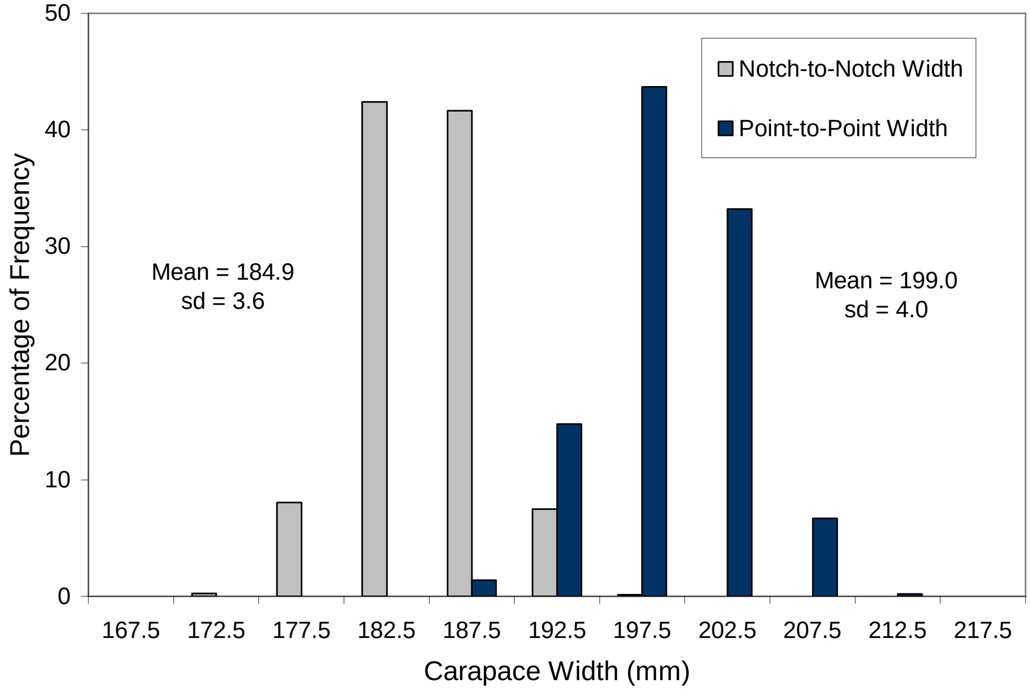

Fig. 4. Estimated frequency distribution post-moult for Dungeness crabs in the allocation range (154-158mm NW).

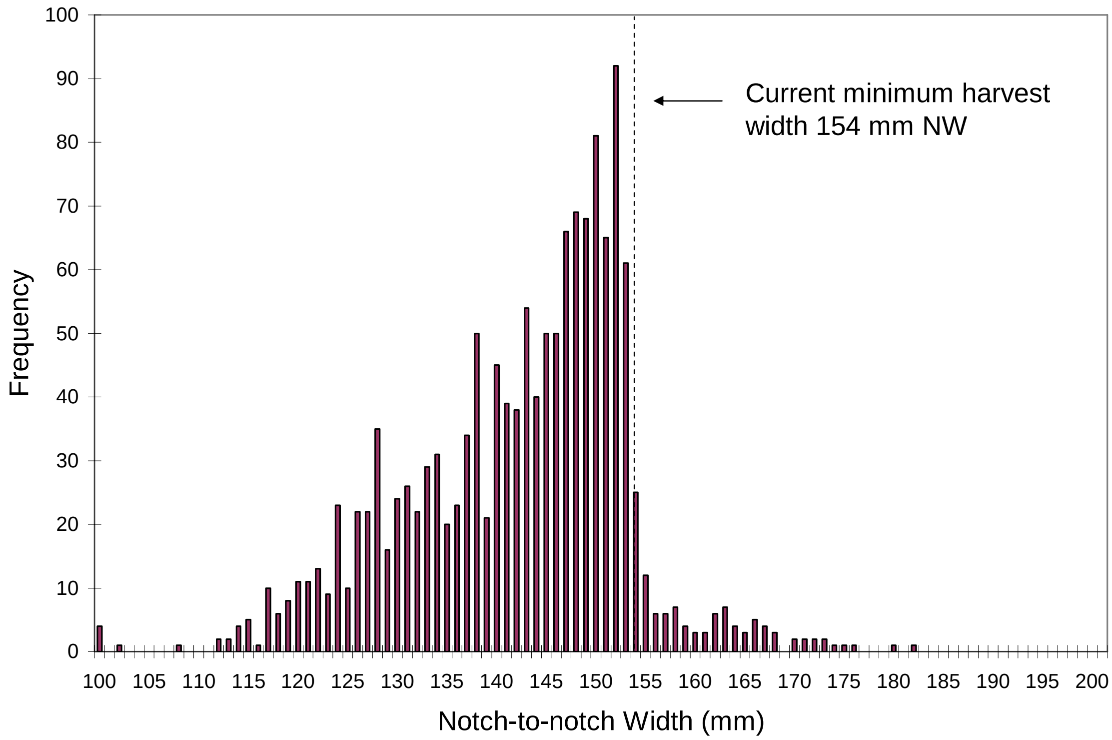

Fig. 5. Notch width frequency of male Dungeness crab on the Fraser Delta post-fishery 2004.

Appendix I.

PACIFIC SCIENTIFIC ADVICE REVIEW COMMITTEE (PSARC)
INVERTEBRATE SUBCOMMITTEE

Request for Working Paper

Date Submitted: September 2004

Individual or group requesting advice:

- Beth Pechter and Jim Morrison - Fisheries Management

Proposed PSARC Presentation Date: November 2004

Subject of Paper (title if developed): Potential implications of differential size limits in the Dungeness crab fisheries.

Science Lead Author: Antan Phillips

Resource Management Lead Author: Beth Pechter and Jim Morrison

Rationale for request:

- This paper will provide the scientific advice for management when considering the potential implications of a higher size limit for the commercial crab fishery than the recreational/aboriginal crab fisheries.
- When considering differential size limits an understanding of the potential outcome in terms of population size structure, the time required for increased growth into the new size limit range, and the effect of natural mortality is essential.

Objectives of Working Paper:

- To determine the likely impacts on the commercial, recreational, and First Nation fisheries if the commercial size limit for Dungeness crab is increased to 170 mm point to point.

Question(s) to be addressed in the Working Paper:

- If the commercial size limit is increased to 170 mm, what is the potential reduction in commercial crab harvest in the first year of implementation?
- What is the likelihood, after accounting for natural mortality, and over what time interval will crabs in the 165 – 169 mm size range become commercially harvestable. What will be the modal size?
- How will a differential size limit affect commercial fishery production after the population and fishery stabilizes at the new size limit? How does this vary from

crab management area to area (i.e. southern small crab vs. northern Area A large crab).

- How effective will this measure be in providing a First Nations/Recreational allocation (by area)? Are there area characteristics (e.g., an intensive fishery) that could influence the effectiveness?

Stakeholders Affected:

- All commercial crab fishers, crab processors and buyers, recreational crab fishers, and coastal First Nations

How Advice May Impact the Development of a Fishing Plan:

- A differential size limit may reduce the conflict between harvest sectors and meet the requests by recreational fishers and First Nations for improved fishing opportunity.
- Fewer area and time closures may be needed to address FSC and recreational requirements. It should be noted that closures may still be necessary to manage trap competition effects and to reduce gear conflicts.
- A change in the commercial size limit could be dealt with through consultation and a variation order.

Timing issues related to when Advice is necessary:

- Recreational fishing advisory groups are strongly in support of early attention to this question.
- A PSARC paper in November 2004 will provide managers time to consult with stakeholders, consider potential impacts and to implement changes (if so decided) for 2006.
- A PSARC paper delayed until June 2005 would not provide for sufficient time to consult, decide and implement change by 2006.

Approval:

Regional Director ________________________ Date:_______________________
Fisheries Management

Regional Director ________________________ Date:_______________________
Science