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Progressing to a scientifically-based assessment and management system for renewed commercial pink and spiny scallop fisheries off the British Columbia coast

Vers un système d'évaluation et de gestion fondé sur la recherche scientifique pour le renouvellement de la pêche commerciale au pétoncle rose et au pétoncle épineux au large de la Colombie-Britannique

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Abstract

This document reviews the experimental pink and spiny dive and trawl scallop fisheries for 2 years in British Columbia waters. Biological data collected during the surveys and experimental fisheries show each species has different growth characteristics, and there are reduced growth rates in northern in comparison to southern waters. Survey methods were developed for each fishery, and the results of surveys are presented. The results of the experimental fisheries are presented and compared to the recommended harvest options. Natural mortality rates have been revised, resulting in a revision of recommended harvest rates. Issues of concern raised during the initial review on abundance and distribution of scallop stocks, sustainability and viability of the trawl fishery, assessment of fishing characteristics of the scallop trawl, localized depletions have been addressed. Assessment and management options have been made on progressing to limited commercial fisheries. Recommendations are made on assessment programs and management measures for limited commercial fisheries.

Résumé

Une revue des pêches expérimentales (en plongée et au chalut) aux pétoncles rose et épineux menées pendant deux ans dans les eaux de la Colombie-Britannique, est présenté. Les données biologiques recueillies au cours des relevés et des pêches expérimentales montrent que les deux espèces présentent des caractéristiques de croissance différentes et que les taux de croissance sont plus faibles dans les eaux du nord que dans les eaux du sud. Des méthodes ont été mises au point pour effectuer les relevés dans chaque type de pêche. Les résultats des relevés sont présentés, tandis que les résultats des pêches expérimentales sont exposés et comparés aux options d’exploitation recommandées. Les taux de mortalité naturelle ont été revus, ce qui a donné lieu à des modifications des taux de prélèvement recommandés. Certaines questions préoccupantes soulevées lors de l’examen initial de l’abondance et de la répartition des stocks de pétoncles, la durabilité et la viabilité de la pêche au chalut, l’évaluation des caractéristiques du chalut à pétoncles et l’appauvrissement localisé des stocks sont au nombre des points étudiés. Une évaluation a été effectuée et des options de gestion ont été élaborées en vue d’une pêche commerciale limitée. Des recommandations sont formulées sur des programmes d’évaluation et la mise en place de mesures de gestion concernant une pêche commerciale limitée.

1) Introduction

Within the Stock Assessment Division of the Department of Fisheries and Oceans, Pacific Region, a framework was developed for the provision of scientific advice for the management of new and developing invertebrate fisheries. This included established fisheries whose expansion is limited due to a lack of information of the species distribution or abundance (Perry *et al.* 1999). This framework included three phases for the precautionary development of a fishery:

Phase 0: Collection of all available information on the target species, and from similar species elsewhere, to provide a baseline with which to advise on the alternative management options and to identify areas where information is lacking (Lauzier and Parker 1999);

Phase 1: Involves surveys and experimental fishing where the objective is the collection of data required to fill in the information gaps identified in the first phase and to explore the fishery potential (Lauzier *et al* 2000);

Phase 2: Fishing for Commerce. A fishery is developed at the commercial level, while stocks are monitored and management strategies are evaluated, which is the main objective of this document.

As a result of the initial Phase 0 (Lauzier and Parker 1999) review of the biology and fisheries of the pink and spiny scallop (*Chlamys rubida* and *C. hastata*) and the concerns expressed by PSARC, senior managers closed the commercial trawl and dive fisheries on these species at the end of 1999.

Those concerns expressed included:

- Insufficient information about the abundance and distribution of pink and spiny scallops in British Columbia.
- Sustainability and viability of the trawl fishery
- An assessment of habitat impacts, bycatch characteristics, size selectivity and the fate of discards of the West Coast trawl gear, even though the West Coast trawl gear is likely less intrusive than the dredge and drag gear on the East Coast of Canada and elsewhere
- Evidence of localized stock depletion in the dive fishery even though it is size selective and there is no associated habitat destruction with this fishery.
- The dive fishery is not species selective as divers find it difficult to sort pink from spiny scallops due to sponge encrustation.

Any re-opening or development of the trawl and dive commercial scallop fisheries would depend on meeting the criteria for new and developing fisheries and the results of an ecological impact assessment for the trawl fishery. As a first step, the information gaps identified in the initial review needed to be addressed by a Phase 1 framework for experimental fisheries, surveys, and assessments.

The main objective of this paper is to report on the results of the Phase 1 experimental fisheries, surveys, and assessments and to present options on actively assessing and managing renewed commercial fisheries on pink and spiny scallops.

2) Surveys and Biological Information

a) Biological sampling

The first priority with the experimental fisheries was to collect biological samples. The most recent biological samples collected were from the mid-1980's, and updated information on age, growth, natural mortality, etc was required to set some parameters for experimental fisheries. A minimum of 1500 scallops from each assessment area was originally measured for species, shell height, weight, age and sex at the initiation of each experimental fishery. In addition, a minimum of 200 scallops is taken during each biomass survey. After several thousand samples, investigators detected a basic difference in shell size configuration between the 2 species, with pink scallops exhibiting an apparently thicker body shape in comparison to spiny scallops. Therefore, maximum body thickness (through both valves, with the valves closed) was added as an additional measurement to compare the growth characteristics of the two species.

i) Results

The results of the biological sampling are shown in Tables 1-4. There are considerable differences in growth in each species between areas. Elk Pt., McMullan Pt., Moriarty Pt., Okisollo Inlet, and Octopus Islands are areas around the northern end of Quadra Island. Wilby Shoal, Sentry Shoal, Hornby Is./Cape Lazo are in the northern Gulf of Georgia, yet south of Quadra Island. Gabriola/Valdes, Valdes/Porlier and Mayne Island are in the southern Gulf Islands. In Tables 1-4 there were obvious differences in growth between the northern areas and southern areas. Both pink and spiny scallops have approximately 10 mm less shell height at age in northern areas in comparison to scallops from southern areas.

There are also marked differences between species. Pink scallops have less shell height at age than spiny scallops, but have a greater body thickness at a given shell height, in comparison to spiny scallops. A preliminary analysis of the relationship between shell height and body thickness, with the limited number of samples where body thickness was measured shows:

Spiny scallops $y = 0.2708x + 1.3251$ $r^2=0.9682$
Pink scallops $y = 0.4193x - 5.7093$ $r^2=0.9861$
Where x = shell ht (mm)
y = body thickness (mm)

There is a need for more detailed growth analysis that has not yet be done with the available data collected from the biological samples. A preliminary analysis was started using the von Bertalanffy growth model that is often used with other bivalves, but there was a poor fit. Macdonald *et al* (1991) attributed the poor fit with spiny scallops seen in their work to low sample size. However, it was found that even with 1200-1300 samples, the fit was still rather poor (r^2 = .37 to .60). In relatively short-lived species, such as pink and spiny scallops, growth continues until they die. Therefore an asymptotic growth model is not appropriate, and an alternative model is being sought.

Age frequency distributions were derived from biological samples. Mortality rates and survival were estimated using Ricker's (1975) catch curves. The total instantaneous mortality rate (Z) was estimated from the slope of the descending limb of the plot of Ln(frequency) at age. Annual survival rate (S) and annual mortality rate (A) were calculated from the equations outlined by Gillespie *et al* (1998):

$$S = e^{-z} \tag{1}$$

where z is the instantaneous mortality rate calculated from the slope of the descending limb of the catch curve, and

$$A = 1 - S \tag{2}$$

Table 5 shows the instantaneous mortality (z), survivability (S) and annual mortality (A) of pink and spiny scallops from various areas and years calculated from Ricker catch curves, as well as the ages sampled, and whether there were experimental fisheries under way in the sampled areas. The only area that was not being harvested when the samples were taken was Valdes-Porlier in 2000 and 2001, therefore the annual mortality estimates are natural mortality estimates over the ages indicated. In the other areas, the mortality estimates are for combined natural mortality and fishing mortality. In 2002 at Valdes-Porlier, annual mortality increased substantially from previous years, likely due to a combination of factors: the expected die-off of older age classes that were close to their maximum natural lifespan, and had not been harvested for 4 years, as well as recently introduced but limited harvesting pressure.

b) Insufficient distribution and abundance information on scallop stocks in British Columbia.

Prior to May 2000, there was very little available information on the status of scallop stocks in British Columbia, and the available information was only fishery-dependent data. However, in many cases, fluctuations in effort and landings is driven by the lack of markets or constrained by PSP closures rather than stock abundance. In other cases, a historically very productive fishing area was closed due to concerns expressed by some harvesters on stock abundance, based on anecdotal information. It quickly became apparent from the initial review of existing information that the highest priority in developing a science-based assessment and management plan was scallop resource surveys. Protocols and survey methodologies were developed for both the dive and trawl fisheries and biomass surveys were implemented in active fishing areas for the past 2 years.

i) Dive Survey Methods

The typical dive survey consists of two concurrent surveys in the same location. Because of the depth of the dive surveys (50-100 ft), there is limited bottom time allowed, and there are requirements for decompression breaks. The diver portion of the survey consists of divers laying 0.25m^2 quadrats along transect lines, sampling every fourth quadrat, collecting all the scallops within the quadrats and bringing them to the surface for biological samples. Due to the bottom time restrictions, divers could collect only 30-40 quadrats per day. In order to augment the sample size, a submerged video camera mounted on a quadrat frame is used to collect several hundred quadrat images per day. The biological data collected from the dive surveys is used to calibrate the video surveys, where there are a sufficient number of data points for a reliable biomass estimate.

A model was derived in S-Plus using the biological data collected from the dive surveys, and using the visual counts of the video surveys to estimate the legal-size density.

$$B = \exp(x_0 + x_1 * \ln P + \varepsilon)$$
$$\varepsilon \sim N(0, \sigma^2)$$

- B is the legal biomass per quadrat
- P is the population-density (all sizes) per quadrat
- x_0, x_1, σ are positive constants

The linear term, x1, is statistically significant (p<.0001). Quadratic and cubic terms were not significant (p>0.45)

When the units of weight and area are grams and one-quadrat=0.25 metre-squared, the estimated values of the constants are $x_0 = 4.3620071$, $x_1 = 0.4272712$ and $\sigma = 0.6341626$.

The fitted values for individual quadrats are shown in Figure 2. Note that where there were no legal-sized scallops, the legal-biomass was arbitrarily set to 50 grams for the purposes of taking logs and estimating parameter values.

It is more useful to measure the density in kilograms per metre-squared.

$$B_{kg/m^2} = \frac{1}{1000 * Q_{size}} \exp(x_0 + x_1 * \ln P + \varepsilon)$$

- Q_{size} is the size of the quadrat in metre-squared.

For a given population density, the legal-biomass has a lognormal distribution. Therefore a large-sample approximation to mean biomass density is

$$\overline{B}_{kg/m^2} = \frac{1}{1000 * Q_{size}} \exp(x_0 + \frac{1}{2} * \sigma^2) * \frac{1}{n} * \sum_{i=1}^{n} \exp(x_1 * \ln P_i)$$

- i is an index for the surveyed quadrats
- n is the number of surveyed quadrats

Non parametric bootstrapping was used to estimate confidence bounds. The resampling was done in two steps. First the biodata was resampled with replacement and the corresponding values of x_0, $x1$ and σ were re-estimated. Then the population values from the video-quadrats were resampled with replacement. The b^{th} bootstrap mean is:

$$B_b = \frac{1}{1000 * Q_{size}} * \frac{1}{n} * \sum_{k} \exp(x_{0,b} + x_{1,b} * \ln P_k + \sigma^2{}_b)$$

- k is a set of n resampled (with replacement) indices with possible values from one to n.
- $x_{0,b}$, $x_{1,b}$ and σ_b are the parameter values estimated from the b^{th} resampling of the biodata.

One thousand bootstrapped means were estimated.
The estimated bias for the bootstrapping is:

$$bias = average(B_b) - \overline{B}_{kg/m^2}$$

The percentile or naïve method (Davison and Hinkley, 1997) was used to determine the 95% confidence bounds on mean density:
$Q(B_b,.025)$ - bias and $Q(B_b,.975)$ - bias

$Q(B_b,.025)$ and $Q(B_b,.975)$ are the bootstrap-means ranked 25 and 975 out of 1000

Bed area was estimated by two methods: area of digitized historical fishing events, where there has been previous harvesting activity; and area of depth contours of 15-30 m, in the survey area. As a precautionary measure, the least of the two area estimates was used to estimate the total overall biomass by multiplying with the lower 95% confidence limit of the estimated mean biomass per square metre.

ii) Dive Survey Results

The results of the dive/video biomass surveys (means and 95% CL) are shown in Table 6. The highest legal-sized densities were found off the Valdes Island/Porlier Pass area, which had not been harvested for 4 years, due to concerns expressed on over-harvesting. After 4 years, a portion of this area was opened to limited harvesting in a restricted area with a closely monitored recommended catch ceiling, which was not reached mainly due to market conditions. The legal-sized density dropped considerably over 1 year, not only due to fishing pressure, but may also be due to a portion of the accumulated biomass reaching it's natural maximum lifespan. When the commercial fishery closed for this area in 1997, scallops that were just below legal size would be approximately 4 years old, and this age class would have been 8 years old when the fishery reopened on a limited basis in 2001, which is well beyond the most frequently observed maximum age for spiny scallops. There is no visible evidence of a substantial die off, such as empty shell (clappers), but this is rarely seen in the small, relatively thin shell of swimming scallops.

The lowest legal-sized density was seen in the Okisollo survey in March 2002. The survey was restricted to within diveable depths, and occurred at several peaks and along sloping shorelines. The estimated legal-sized densities estimated from the dive/video surveys were considerably higher than density estimates from the trawl surveys, but it is difficult to compare these densities. The dive surveys concentrate in accessible areas and are restricted to depths less than 100 feet, with the density and biomass estimates applicable to very small areas. The trawl surveys encompass much larger areas at greater depths.

iii) Trawl Survey Methods

In the trawl fishery, historically productive beds were considered the highest priority for surveys. Any new areas had a pre-survey qualitative video assessment to determine the substrate type, extent and density. Area-swept trawl tracks were randomly selected along each 20-foot depth contour. A stratified random design was used in large areas, and a random design was used in the smaller areas. For the large stratified areas, the sum of the strata density variance was used to calculate the standard deviation and the 95% confidence intervals of the mean density estimate. The lower 95% confidence interval of the mean density estimate was used to estimate biomass. Area was estimated with Arcview. The trawl efficiency was assessed from video observations. The efficiency varied considerably from 3% to 30% under varying conditions. The tow speed, speed and direction of the current, the contents of the net bag, and the substrate, all affected the efficiency of the trawl. However, for the purpose of calculating an interim catch ceiling or Total Allowable Catch (TAC), the biomass estimation used an average trawl efficiency of 20%, based on several hours of video observation. While this may be considered to be relatively high, it is being used as a precautionary measure, which has a greater tendency to underestimate stocks rather than overestimating stocks.

iv) Trawl Survey results

The biomass estimates calculated from the trawl survey density estimates (95% lower confidence of the mean) and three differing area estimates are shown in Table 7. Due to the uncertainty of bed delineation with the trawl surveys, the biomass estimates are presented as range, taking into consideration an error in the area estimation. The bed areas were measured with Arc-view, and the average of 3 measurements is given as the average estimate in Table 7. It is difficult to provide a realistic estimate of error in these measurements, as they are affected by scale, which varies from area to area. This average area was decreased by 10% and 25% respectively to give the mid-range and low range in Table 7.

There is an apparent anomaly with the Hornby Island/Cape Lazo survey results from 2002. There was such a large variance encountered in this survey and there was a greater variance in the total estimate in comparison to the legal-size estimate, resulting in wider 95% confidence limits. In this case, by using the lower 95% confidence limit of the mean, it appears that there were more legal-sized scallops than the total number of scallops, eventhough the mean total estimate is higher than mean legal-sized estimate.

Two areas were surveyed twice, and had active fisheries between the two surveys: Wilby Shoals and Hole-in-the-Wall. The legal-sized biomass decreased considerably by (69%) from 2000 to 2002 in Wilby Shoals, but the total biomass increased dramatically (by 5 times), indicating a very large recruitment event. At Hole-in-the-Wall, there was 23% decrease in legal-size biomass, but the total biomass only decreased by 3%.

v) Additional Surveys

In addition, exploratory surveys were conducted using submersible video technology to identify new harvesting opportunities, which would in turn be preceded by an initial biomass survey. Ideally, there could be an integration of trawl surveys and dive surveys on a test bed to compare the results of the two sampling methodologies and to refine trawl efficiency and impact assessment, in appropriate areas that have both trawlable substrates and suitable dive depths.

3) Experimental Fisheries

When the commercial scallop fisheries closed on December 31, 1999, scientific licences were issued, not only for resource surveys and biological information, but also for experimental fisheries to test any recommended catch ceilings, and to closely monitor harvest patterns and landings.

a) Dive Fisheries

Figure 3 shows total reported dive landings (kgs.) by year since the inception of the fishery. Landings peaked in 1996 at approximately 95,000 kg. The commercial fishery started a marked decline from this peak to approximately 37,000 kg in 1999 when the commercial fishery was closed. When the experimental fishery was implemented in 2000, landings increased slightly and then stabilized for the next 3 years close to the long term average of approximately 48,000 kg/year.

Table 8 shows the major experimental dive fishery landings annually by area, the estimated biomass range and calculated harvest rate range. There were no biomass estimates in 2000, as the protocol for dive/video surveys was being developed. In 2001, the dive protocols were being tested and rented submersible video equipment was used for biomass estimates in two high priority areas. The highest annual landings were from Sentry Shoal in 2001. As landings decreased in Sentry Shoal, there were concurrent increases at Mayne Island, Gabriola-Valdes, and Valdes-Porlier. The Valdes-Porlier had been previously closed due to reported over-harvesting. When a portion of this area reopened in the fall 2001, a TAC was recommended, and a hail system was implemented to closely monitor landings.

b) Trawl Fisheries

Figure 4 shows the total reported scallop trawl landings by year since 1993. It should be noted that the experimental fishery started in 2000 after some delay and that only the first few months of 2003 are reported. The experimental scallop trawl fishery landings are shown in Table 9. It should be noted that most of the surveys were conducted in February and March, 2002, when the trawl fishery normally takes place. The timing of the surveys and soft markets did not give sufficient harvesting opportunities so only small portions of the recommended catch ceilings were realized.

c) Assessment of West Coast trawl gear impacts.

The drags and dredges used in many scallop fisheries consist of a heavy metal frame designed to dig into the substrate, and are fitted with steel ring mesh bags. A heavy horizontal tickler chain precedes some of the larger drags and dredges. There is extensive information available on the physical and biological effects of scallop drags in European waters, Australia, and the U.S. Mid-Atlantic. In many cases cited by McLouglin *et al* (1991), the incidental fishing mortality exceeded the efficiency of the scallop drags. It was partially based on the existing information of old trawl designs used early in the West Coast scallop fishery, as well as the available information on the effects of other scallop trawls, that it was originally recommended closing the trawl fishery.

Taking into consideration the two characteristic features of the fishery, it soon became apparent that the available trawl designs were not appropriate for this fishery. Two or three harvesters came to the common understanding that in order to avoid bycatch, which slowed down processing time, and to avoid substrate inclusion, a trawl that worked at a level above the substrate was a solution for the harvest of swimming scallops. A few designs evolved, including an aluminium tube frame on runners, a steel frame made with split rims from truck wheels, and steel frame on runners.

However, it was quickly demonstrated to Fisheries and Oceans staff that some of the trawls used in the West Coast scallop fishery is considerably different than the drags and dredges used in other scallop fisheries. The majority of the harvesters in the British Columbia scallop trawl fishery use the butterfly scallop trawl.

This trawl design has evolved since 1990 to produce a marketable product which is competitive with the dive harvested product, and to reduce bycatch. This trawl is designed to capture scallops as they are swimming, as the crossbar and the bottom of the trawl net is usually 20 cm off the bottom. On the bottom crossbar, a heavy rubber mat (½ in thick) made of belting material from a pulp mill is attached. This serves as chaffing gear to prevent the net bag from snagging on any bottom substrate, and allows any sessile organisms to slip under the trawl relatively easily as the trawl moves forward. The net bag consists of heavy rope mesh (3 inch mesh). At the tail end of the mesh bag is a haul line to allow easy tipping of the net bag into a sorting trough, when the trawl is brought to the surface. When the trawl is deployed, this haul line is attached to the head of the frame to prevent entanglement.

For best results the trawl is typically towed against a moderate current for 20-30 minutes, with a resulting ground speed of 0.5-0.7 knots. The trawl is also towed at a very steep angle of 1.2 – 1.3 aspect, and as a result, only a small portion of the weight of the trawl is on the bottom substrate.

Unlike the scallop drags used on the East Coast that are towed in arrays, only 1 trawl with a maximum 2 m width is permitted in the West Coast fishery. Video monitoring of the trawl showed minimal habitat impacts and very little damage to co-occurring species. Estimates of trawl efficiency were also made from video monitoring. Information from scallop trawl surveys and close monitoring of the experimental fisheries show very little or no bycatch retained by the trawl net. Additional monitoring of discarded undersized scallops in prawn traps for 1-2 weeks, show very low mortality attributed to capture and handling.

d) Sustainability and viability of the trawl fishery.

Based on the initial review of the available information, it was recommended to close the trawl fishery. However, it quickly became apparent there was some misinformation on trawl designs, and practices for a small sustainable fishery. It was agreed to reconsider the original recommendation due to the sincerity and commitment of the harvesters to work with the Fisheries and Oceans staff on a sustainable viable fishery, and also taking into consideration their investment of time and money to progress as far as they had. Experimental licences were issued after the commercial trawl fishery was closed on December 31, 1999, that had a number of conditions of licence to address the concerns that this fishery could meet the requirements of a biologically based phased approach. These conditions included:

1. Biomass estimates were undertaken in each area identified for experimental harvest, based on an area swept trawl survey.
2. Harvesting was limited to a precautionary harvest rate (6-9% of the legal size) based on the biomass estimates.
3. Biological information (species, shell height, shell thickness, weight, and sex) was collected for an age structure analysis.
4. Assessment of trawl impacts and fishing characteristics (outlined above).

As seen from previous sections of this paper, these conditions have all been met. Biomass estimates have been undertaken in seven areas, and in three areas biomass estimates were undertaken twice. The trawl industry has taken steps to ensure as much data was collected as possible with the limited funding that was available to support the biomass surveys. A hail system has been implemented to ensure effort and catch is tracked so the recommended catch ceilings are not exceeded. Biological information was collected throughout the biomass surveys and experimental fisheries. An examination of trawl impacts and fishing characteristics shows that if the butterfly scallop trawl is used following a developed code of best practices, the habitat impacts and bycatch is negligible. If the sublegal catch is handled properly on deck, the handling mortality of released sublegal scallops is less than 3%.

e) Evidence of localized stock depletion in the dive fishery.

A historically very productive fishing area, Valdes-Porlier, in the southern Gulf Islands of B.C., was closed due to concerns expressed by some harvesters on stock abundance, based on anecdotal information. An examination of harvest logs showed a decline in CPUE with a substantial increase in effort in 1997, so the fishery was closed in the area to allow the stocks to recover. As a consequence of this closure, other adjoining areas have had a great deal of fishing pressure and harvesters reported apparent stock declines in those areas. There was no biomass survey conducted before the commercial fishery was closed in Valdes-Porlier.

Three years after harvesting was closed, a biomass estimate and an examination of the age structure showed that a limited opening in a portion of the closed area would be appropriate with close monitoring. In those adjacent areas that have had a high fishing pressure due to the closure, biomass estimates landings and harvest rates were examined.

Four years after harvesting was closed, experimental harvests were allowed in a portion of the previously closed area, starting in November 2001. A range of options was given for an experimental dive harvest, taking into consideration bed area estimates and precautionary harvest rates. The lowest recommended catch ceiling of 53,094 kg with a 6% harvest rate applied to the lowest estimated bed area was chosen by resource management. Table 4 shows that in 2001, 2,014 kg were landed, with a calculated harvest rate of approximately 0.2% of the estimated biomass. In 2002, 10,671 kg were landed, with a calculated harvest rate of 1.4 – 2.0%. At the same time, the estimated mean legal sized density decreased from 0.45 kg/m2 to 0.26 kg/m2 (Table 6). This decrease in density is not only due to harvesting pressure but may also be due to the die-off of an accumulated ageing population. From the start of the experimental fishery, to the 2002 survey, approximately 3,200 kg were landed. Another confounding factor is during the 2002 surveys, a very heavy Chaetoceros bloom severely impaired visibility. While in its present form, the model only estimates legal density, an examination of the biological information collected from this area shows some recruitment.

During discussions with harvesters on reopening this area, their advice was to pace the harvest rate, so as not to deplete the accumulated stock. This is particularly important when there is a high natural mortality on an ageing population.

f) Difficulty in species selectivity in the dive fishery.

While species selection in the dive fishery is visibly difficult due to sponge encrustation, there are underlying selective processes that preferentially select for spiny scallops. Divers select for larger scallops when they are picking due to the higher economic return. Pink scallops are also typically deeper than the spiny scallops, with a greater portion of the pink scallops beyond the diveable depths. An examination of the species composition of all biological samples (totalling over 6000 scallops) from the dive fishery show spiny scallops comprised of 89 % of the dive catch, indicating the dive fishery is targeting on spiny scallops preferentially over pink scallops. Similarly, in species composition in the trawl fishery show that pink scallops comprised of 55 % of the trawl catch.

4) Assessment Options

a) Assessment Areas

The pink and spiny scallop fisheries were managed as one species and one stock, which is not appropriate for a precautionary approach. It is not known whether there is one large stock within British Columbia inside waters or whether there are a number of smaller discreet stocks. Areas of concentrated fishing effort appeared to be adversely affecting stocks in a particular area, which resulted in a closure.

In order for the pink and spiny scallop fishery to reopen under commercial licence or proceed with a precautionary development plan, an understanding of the stock distribution is required. Dive harvest location information from the harvest logs has incorporated in Arcview Geographic Information System (GIS), providing a spatial depiction of historically harvested beds. In addition trawl harvesters have outlined their fishing areas in their proposals for scientific licence. However, this distributional information has only been compiled from fishery dependent data. Additional distributional information has been collected in fishery independent surveys using submersible video by the trawl industry.

The complete set of charts produced by the GIS from the dive harvest logs cannot be shown in this report, as information on the site specific locations do not meet the confidentiality requirements for disclosure. However, the general trend is that apparently discrete scallop aggregations accessed by divers occur on reefs, pinnacles, and in some cases, flats and shoals. Many of these commercially exploited aggregations occur in fairly close proximity (within 10 kms) to each other, while some aggregations occur in relative isolation. Scallops also occur sparsely in widely scattered areas between these aggregations, based on trawl surveys in some areas and anecdotal information provided by harvesters.

Scallop populations, like many marine invertebrates, are typically metapopulations. A metapopulation is a system of populations that interact by dispersing individuals between populations. In the case of pink and spiny scallops, the major dispersal is likely from the prolonged planktonic larval stages.

With this information in mind, the following Scallop Assessment and Management (SAM) Areas are proposed:

Area A-1: Discovery Passage, Okisollo Channel, Octopus Islands, Hoskyn Channel, including Pacific Fishery Management Areas (PFMA) 13-3 to 13-12. This includes the following sample areas: Granite Pt; Moriarty Pt; Elk Bay; Elk Pt; McMullan Pt; Okisollo Channel; Octopus Islands. There are major tidal currents throughout the area, and scallops have been found at depths of over 300 feet between the more commonly harvested aggregations in shallower water. Growth appears to be considerably reduced in comparison to southern areas.

Area A-2 : Hole in the Wall. Portions of PFMA 13-18 within the channel known as Hole in the Wall. While this relatively small area could be considered a subarea of the preceding identified Area A-1, the narrow and shallow opening at each end may not allow much larval recruitment or export. It is considerably more productive than any other northern passage waters. Growth appears to be reduced in comparison to southern areas.

Area B-1: Northern Gulf of Georgia, from Quadra Island to Parksville, including: PFMA 13-1; 13-2; 13-13 to 13-16; all PFMA 14; 15-1; 15-2; 16-1;16-2; 16-18 to 16-22. This includes sample areas Wilby Shoal, Shelter Pt, Willow Pt, Oyster Bay, Exeter Shoal, Cape Lazo, Hornby Island, Lambert Channel, Baynes Sound, Texada Is, Lasqueti Is. Growth appears to be enhanced in comparison to SAM Areas A-1, and A-2.

Area C-1: Southern Gulf of Georgia and southern Gulf Islands, including all PFMA 17, all PFMA 18, 19-5, 29-3 to 29-5. This includes sample areas Gabriola-Valdes, Valdes Porlier, and Mayne Island. This area contains highly productive aggregations with enhanced growth characteristics in comparison to other areas.

Area D-1: Victoria-Juan de Fuca. Includes PFMA 19-3, 19-4, 20-1 to 20-5. This includes waters from Cadbaro Pt to Carmanah Pt.

b) Assessment Methods

Due to the information gaps identified in the initial review of these fisheries (Lauzier and Parker 1999), the choice of assessment models for pink and spiny scallops is limited initially. As data are collected from fishery-independent surveys and the fisheries, more sophisticated modelling techniques will be used.

i) Analyses of Abundance Trends

Abundance trends can be monitored over time from fishery-dependent data or from fishery independent surveys initially. This will be the primary assessment tool in both fisheries. In the dive fishery, fishery-dependent data is being collected and monitored from the experimental fishery, and biomass surveys were conducted for fishery-independent biomass estimates. In the trawl fishery, two sets of biomass surveys were completed in some areas, and one set in new areas. The resulting biomass estimates were used with precautionary harvest rates to set quotas for experimental fisheries.

On the East Coast, there are a variety of methods used for analysis of abundance trends. In Québec waters, assessments range from a combination of fishery-independent surveys and fishery data, to only fishery-dependent data in some areas (DFO, 2002)

In Northumberland Straits size-based methods were used for assessments, and abundance is reported in terms of meat weight over a given survey area (Hanson 1998). Kriging is then used to determine distribution and abundance. These estimates appear to be quite accurate and are not as data intensive or assumption dependent as the traditional analytical assessments. In Newfoundland, fishery-independent surveys and commercial fishing activity is correlated with RoxAnn acoustic seabed classification surveys to better understand and predict the distribution and abundance of scallop stocks (Naidu et.al., 2001).

ii) Surplus Production Models

Surplus production models are often used in data-limited fisheries, as these models have the fewest data requirements. The specific data requirements for surplus production models are not yet available for either (dive or trawl) scallop fishery. However, as data is collected from the experimental fisheries and biomass surveys, there is the option of using surplus production models. These types of models require estimates of natural mortality (M), vulnerability, fishing mortality (F), and B_0, the unexploited or virgin biomass. These models are used to develop biological reference points for fisheries management. The Gulland model (Gulland 1971) estimates maximum sustainable yield (MSY) as:

$MSY = XM\,B_0$ where X is a scaling factor (common scaling factors often used: 0.2 (Garcia *et al.*1989); 0.4 (Caddy 1986); and 0.5 (Gulland 1971)

The original scaling factors were considered to be too high for data limited fisheries (Garcia *et al.* 1989) and have been reduced for other developing fisheries, such as the sea cucumber fishery (Boutillier *et al.*1998).

While surplus production models may have few data requirements, one has to consider the applicability of these models to scallop fisheries. The assumptions outlined by Perry *et al* (1999) include: all losses are due to catch or natural mortality (no immigration or emigration); catchability is constant (in time, space across ages); all animals are available to the fishery throughout the life cycle and equally vulnerable to gear; and gear or vessel efficiency remain unchanged. The main disadvantages are: stocks are assumed to be at equilibrium to calculate MSY; variations in growth, natural mortality and recruitment are ignored; and the assumption that entire stocks are being exploited rather than just a harvestable portion.

iii) Potential Models

As data are collected from surveys and experimental fisheries, increasingly complex models will be considered as their data requirements are met. Biomass dynamic models require abundance time series and fishery-dependent data. Yield-per-recruit models include growth, natural mortality, fishing mortality and assume no stock-recruit relationship. These models do not allow for variation in growth or natural mortality over time. Virtual population analyses (VPA) have extensive data requirements, but provide estimates of absolute population abundance and recruitment. However, these models assume constant natural mortality, which is not the case in scallops.

More recent scallop population assessments on the East Coast use a variety of increasingly sophisticated models. On Georges Bank assessments, two models were used: sequential population analysis; and the Collie-Sissenwine production model. (Robert et al 2000). In the Bay of Fundy, the modified DeLury or Catch-Survey Analysis (CSA) model and a delay-difference model was used for scallop population analysis and forecasting. The population dynamics were modelled with a state-space form of the delay-difference model and model parameters were estimated using Bayesian Gibbs sampling methods (Smith and Lundy, 2002).

5) Management Options

Perry *et al* (1999) shows a decision tree with major regulatory strategic choices for fisheries management: size limits, effort controls, and total allowable catches (TACs). We considered these management options starting from the simplest and their applicability to the scallop fisheries along the British Columbia coast.

a) Minimum Size Limit

A minimum size limit has been in place since the initiation of these fisheries. At the close of the commercial fisheries, the minimum size limits were 55 mm for both species. The size of first spawning for both species is 25-35 mm. The 55 mm minimum size limit was initially implemented to protect sexually mature spawning animals for 1 – 2 years before recruitment to the fishery, but it may not be appropriate to provide adequate recruitment for a healthy viable population. Biological sampling shows that the growth characteristics vary between the two species, with spiny scallops having a higher shell height than pink scallops at a given age. Also, the reproductive effort in pink and spiny scallops increases with age, with varying degrees in each species (Macdonald *et al* 1991). In spiny scallops, reproductive effort appears to be highest in its final year, exceeding somatic production, whereas in pink scallops, reproductive effort reaches an asymptotic maximum that never exceeds somatic production. The previous minimum size limit may have actually directed harvesting effort at maximum reproductive effort.

b) Effort Controls

There are a number of alternatives for effort regulation. Effort limits require CPUE information, where there is the risk of overfishing. CPUE information is not considered to be an appropriate primary assessment tool for scallops (Naidu 1991). In working with both dive and trawl harvesters over the past few years has shown that CPUE is not a reliable index of stock status. With trawl harvesters, harvester experience, substrate, bottom topography, tides and weather greatly influence catchability. With dive harvesters, harvester experience, visibility, currents, and sea lion presence greatly influence catchability. Due to the relatively small number of harvesters, CPUE will be highly variable, and CPUE will not be used as a management option in these fisheries. Inseason assessments require tagging and recovery, and run the risk of underestimating the exploitation rate due to tag loss. Due to the small size of pink and spiny scallops, their characteristic sponge incrustations, and their relatively broad dispersion and a small fishing fleet, an extensive mark-recovery program with sufficient numbers was not considered to be a viable option. Therefore inseason effort assessments are not an option in these fisheries.

The only effort control that we have implemented to date is limited entry into the experimental fisheries. In the first year of the scientific dive fishery, opportunities to harvest were open to any fishermen interested and willing to take part in the surveys and the collection of biological data. Following the first year the scallop dive association recommended that the experimental licences be limited. Eligibility criteria were established for the issuance of dive scientific licences, with input from stakeholders. In order to qualify for an experimental dive licence fishermen must have a landing history of 10,000 lbs. between 1995 and 1999 or 6,000 in any one of those years.

The dive fishery was limited to 7 licences approved to harvest in the historic areas. There were fishermen who had contributed to the experimental fishery in the first year but did not qualify under the recommended criteria. The association recommended that these 3 were issued licences for limited areas.

Similarly, the trawl fishery was unlimited initially but interested harvesters had to use approved gear and conduct a biomass survey in order to be provided with a harvest opportunity. As the trawl fishery became more established several fishermen were showing interest in trawl fishing. To ensure conservation objectives could be met within the historical harvest areas, eligibility criteria were established for the issuance of scientific licences. This measure has been taken to control fishing capacity during the experimental phase of this fishery. Scientific licences were issued to scallop harvesters with past recorded landings in the period 1995 to 1999, or to those persons who have participated with their vessels in recent scientific surveys with the Department during the period of 2000 to 2002, in order to conduct scallop biomass surveys along the coast.

c) Seasonal Closures

In the absence of other effort controls, seasonal closures provide little real protection to a harvested population. The timing of harvest effort around the spawning season and settlement periods may provide increased benefits to spawning stocks and improve recruitment success. The scallop fisheries typically shuts down in early June or July for several months due to paralytic shellfish poisoning (PSP) levels. Due to reduced shelf life with product harvested from warm waters, activity in the scallop fisheries is considerably reduced in late spring, summer and early fall. This coincides with spiny scallop spawning time and initial settlement, and the second spawning time seen in pink scallops.

d) Area Closures

Permanent area closures are being considered to provide refugia for pink and spiny scallops, to provide control (unharvested) areas in order to assess unexploited scallop populations for age, growth and natural mortality, as the only information available to date is from exploited populations. In the case of scallops, a patchwork of small areas would be the most effective protection, due to their apparently limited dispersal, and the area of concentrated fishing effort in the inside waters. There is also a need to test various exploitation rates, which would take place in delineated experimental areas that would be special management zones. There are several areas closed as marine reserves to all the fisheries including the scallop fisheries. As well areas around popular recreational dive sites are closed to scallop dive fishing. Only a portion of Valdes-Porlier was reopened for experimental harvests after a 4 year closure, and the remaining area was retained as closed refugia

Areas of the pink and spiny scallop resource are not accessible to one of the two fisheries or to either fishery. The extent of these areas is unknown, and the portion of the stocks in these inaccessible areas is unknown. A comprehensive resource survey using hydroacoustics (such as Questar Tangent) for habitat quantification and delineation as well as the use of submersible video is one of the ways these inaccessible resources can be surveyed. Another method is using complementary survey techniques, for example, dive surveys adjacent to trawl grounds, and trawl surveys adjacent to dive areas.

Rotational harvests are a modification of area closures. This is practiced by both dive and trawl fleets by agreement amongst the harvesters. There are a number of examples where harvesting effort moves out of areas before recommended harvest levels were reached. As new areas of harvestable populations have identified with the exploratory and experimental fisheries of the past 2 years, there are more options for rotational harvests. In the trawl fishery, consideration is also being given as to whether a limit reference point of the sublegal catch as a percentage of the total catch should be used to implement a rotational fishery.

e) Total Allowable Catches

Eventhough the scallop fisheries along the British Columbia coast are small and in relatively limited areas, there was an obvious need for more active and refined assessments and management actions than the minimum size limits and de facto seasonal and area closures in place. The total allowable catch is the most precautionary of the management options considered but requires the most information.

As more refined assessment and management plans were being considered for the scallop fisheries, it quickly became apparent that there was a need to define the basic assessment and management units. Genetic information on what constitutes a unique stock is not available, and a genetic survey can be very expensive work. Information indicates that the repeatedly commercially harvested aggregations of scallops are spatially discrete. The most conservative approach would be to separately assess and manage each of these apparently discrete aggregations. However, many of these aggregations in historically productive areas occur in close proximity and in similar habitat. Therefore, in order to design a realistic achievable assessment and management plan, these aggregations were grouped to form a basic assessment and management unit.

f) Biomass

An estimate of the unexploited biomass (B_0) is required as an original reference point to evaluate alternative management strategies as well as a first step to setting TACs or quotas. Estimates of biomass in each assessment unit will be conducted with the survey designs outlined for the dive and trawl fisheries in the Abundance Estimates section prior to harvest in any new areas. Unfortunately there are likely not many known scallop aggregations left in the inside waters of Vancouver Island that have not had some form of exploitation in the last few years. Biomass estimates were particularly important in some of the most recently heavily exploited beds, to determine whether any particular or urgent management action was warranted.

The dive harvest log information was digitized to provide a spatial representation on the history of the dive fishery, and areas that have not been harvested for 2 or 3 years were selected for the first biomass estimates. There was also the opportunity to survey aggregations in the Valdes-Porlier area (PFMA 29-5), which had been closed to the commercial dive fishery for 4 years. Considering the lifespan and productivity of these scallops, biomass estimates from this area depict a population recovering from heavy exploitation towards an equilibrium state.

The use of area swept trawl surveys exclusively on the trawl grounds and the use of dive surveys exclusively on the traditionally dive harvested aggregations will only give a relative abundance index of exploitable biomass.

g) Harvest Rates

As described previously in the Assessment Models section, harvest rate calculations were taken from the natural mortality estimates. The most recent annual natural mortality estimates range from 0.55-0.80 for spiny scallops, and 0.38-0.61 for pink scallops. Additional data is being collected to refine these mortality estimates. Using 0.2 as a scaling factor in Gulland's model (Gulland 1971), the lowest harvest rate is 8 % of the original unexploited biomass for pink scallops and 11 % for spiny scallops. Since the two species are harvested together, the lower harvest rate should apply to both species. However, all of the currently exploited areas have been previously exploited. Therefore reduction to half the harvest rate of unexploited biomass, results in harvest rates of 4 % in previously exploited areas. The proposed harvest rates should be applied to the legal-sized biomass, not the total biomass.

Applying the revised harvest rates to the previous biomass estimates reduces the previously recommended harvest levels in the trawl fishery, especially in previously harvested areas, and only slightly in newly exploited areas as seen in Table 9. Actual landings exceeded the revised recommended harvest levels a few times. Harvesting activity ceased at Wilby Shoal in April 2002, by choice of the harvester. Harvesting activity at Hole in the Wall was greatly reduced from 2001 to 2002, when the landings exceeded the newly revised recommended harvest level by 50%. The most recent biomass survey in this area shows only a slight decrease in total biomass.

h) Reference Points

As a start, the most appropriate target reference point for the scallop fisheries is a harvest rate derived from Gulland's model. Based on our current ranges of estimates of annual natural mortality, a recommended target harvest rate would be 8 % of the original unexploited biomass, and 4 % of the unexploited biomass. There should be an ongoing re-evaluation, as additional information becomes available.

The most commonly used critical or limit threshold point is based on initial biomass. For productive animals, 25% of the initial biomass is used as a limit reference point. However, due to the unknown variability in pink and spiny scallop recruitment, and the uncertainty of a number of other parameters, a more conservative limit reference point was applied to pink and spiny scallops. The suggested limit reference point is 50% of the virgin biomass estimates in unexploited populations, and a higher limit reference point of 75% of the existing biomass in exploited populations. In two experimental fisheries areas, the suggested limit reference points were exceeded likely due to the combination of die-off of an ageing population and some harvesting pressure. Repeated biomass surveys should be conducted in these areas as a high priority.

i) Catch Reporting

In addition to the catch reporting requirements of the regular commercial fisheries of harvest logs, with monthly submissions to the shellfish data unit, there are also additional reporting requirements with the trawl fishery of bycatch, and discards of sublegal sized product. A hail out/hail in line has also been implemented with the trawl fishery, where harvesting is being monitored in relation to the TAC, and in limited areas with the dive fishery where a previously closed area was reopened.

j) Code of Best Practices

In addition to the classical management options, the trawl industry has developed a code of best practices. At the inception of the dive and trawl fisheries, the trawl fishery was considered the least desirable of the two, due to habitat impacts, bycatch issues, fate of discards and a lower quality product. However, they have made tremendous progress in trawl design, as well as to harvest responsibly. Their code of best practices was developed in collaboration with experienced harvesters, and Fisheries and Oceans management and assessment staff. It sets guidelines to ensure the sustainability and viability of the trawl fishery, and provides a training document to any new or less experienced harvesters.

6) Discussion

A number of questions arose from the review of the original draft of this document on some of the analytical techniques, and methodologies improve with peer review. The authors recognize that assumptions underlying the estimate of mortality may not hold for the data. However, there was insufficient data at the time of the analysis to calculate the Paloheimo *Z* method for total mortality. Both the paucity of CPUE data and the suspect nature of some of the CPUE data from particular areas led us to believe that this type of analysis would be seriously flawed. There are different methods utilized for determining confidence intervals of bootstrapped means. While the percentile or naïve method was used in this analysis, the Bias Corrected and Adjusted (BCa) method would be used in subsequent analyses.

The authors recognize that the limitations and assumptions of the surplus production model initially being used in the assessment and management of the scallop fisheries. While this may not be an ideal fit, we consider it is the best fit with the limited data that has been collected thus far. We have used low scaling factors, and applied low harvest rates to only a limited portion of the total population. Should the scallop fisheries expand in scope and area, we realize the need to apply the collected data to more sophisticated and appropriate models and processes. At present these are comparatively small fisheries in limited areas, and the proposed assessment and management framework is considered to be appropriate for the present scale of these fisheries, yet precautionary to ensure sustainability and viability of the harvested portion of the stock.

The request for working paper (RWP) in Appendix 1 has specific questions that are to be addressed by this document and these questions will now be addressed to the best of our ability with the information available.

Proposed Scallop Assessment and Management (SAM) areas are identified and delineated in the Assessment Options section. These relatively broad areas are based on available information consisting of harvest patterns, growth and productivity, surveys, physiographic features and geographic distance. There is no conclusive evidence that there are separate stocks bounded by the proposed SAM areas, but preliminary information indicates there is potential for stock delineation in these proposed areas. A detailed examination of oceanographic data would be very useful, but time constraints have been too short to pursue this. The alphanumeric system is intended to be flexible so that as new information becomes available on potentially refined stock delineation or new areas are identified, new areas can be readily identified and designated. Any system of SAM areas should apply to all scallop harvest types, as the information was gathered from both fisheries. Eventhough each fishery may be managed differently, it is the conservation of any discrete populations that is the ultimate goal of a SAM system, and the system must take into account the activities of both harvest types.

While relatively broad SAM areas have been proposed for assessment and management purposes, bed by bed assessment and management should be continued in the trawl fishery and expanded to include the entire dive fishery.

The Valdes-Porlier area, also known as PFMA 29-5, was closed to harvesting for 4 years due to anecdotal evidence of over-harvesting. A biomass survey showed a large accumulation of legal-sized biomass that could support a controlled experimental fishery. The lowest harvest level option of 53,094 kg adopted by resource management for the experimental fishery is slightly higher than the historic high harvest level of 50,627 kg landed by 6 vessels in 1995. Between the time the experimental fishery was implemented and the second biomass survey, approximately 3,200 kg was landed. Yet the estimated legal-sized density and biomass decreased by almost one-half. This most likely the result of the die-off of the ageing year classes that had built up since the commercial fishery had closed 4 years earlier. The survey conditions were very poor when the last survey was undertaken with visibility less than 1 foot due to an extensive *Chaetoceros* bloom.

In previously exploited trawl fishery areas, the revised recommended harvest options exceed the historic landings of the last 10 years substantially in one area, only slightly in 2 areas, and do not exceed historic landings in one area. In previously exploited dive fishery areas with no preset harvest level, the landings from the experimental fishery were very close to the revised harvest rate in two areas, and considerably lower in three areas.

To address the question on compensatory response, a good example of compensatory response in populations with a die-off of the older age classes either from natural mortality and/or harvesting pressure can be seen at Wilby Shoal. From Table 7, it can be seen that while the legal-sized biomass estimate decreased to 31% of the original level over 2 years, total biomass estimate (sublegal and legal size) increased by 567 % over the same time period. The actual experimental landings were 55% of the original recommended harvest level and 122% of the revised harvest level. There had been no harvest since the 2002 biomass survey.

Biological samples taken during the biomass surveys indicate that in the northern SAM areas A-1, and A-2 there is reduced growth in both pink and spiny scallops compared to the more southern SAM areas B-1 and C-1. Water temperatures are colder, and currents faster in A-1 and A-2. There is a recognized need to pursue the application of a suitable growth model to adequately assess these differences. The total sample number of 200 annually from each harvest bed is not sufficient to assess growth. There is often species selectivity, where in the dive fishery most of the samples are spiny scallops. As can be seen from Table 5, most of the mortality estimates derived from the biological sampling is in the last 2 years. A greater number of samples from each species will provide a much better perspective. It is recommended that 500 of each species from each harvest bed be submitted annually.

The current interim size limits for each gear type was partially based on the different growth characteristics from the different areas in which each gear type operates. The trawl fishery mostly occurs in northern areas, where the growth rate is considerably slower than in the south, where the dive fishery mostly occurs. As outlined in the Management Options section of this document, and demonstrated by Macdonald *et al*

(1991), there are considerable differences in growth characteristics between the two species. As seen from the Biological Information section, pink scallops seem to increase more in body thickness and less in shell height in comparison to spiny scallops. The minimum size limit for pink scallops could be reduced to 50 mm without an apparent biological risk to the species. There appears to be preliminary evidence in spiny scallops, reproductive effort appears to be highest in its final year, exceeding somatic production (Macdonald *et al* 1991). The reproduction cycle of pink and spiny scallops could be investigated using a simple gonadal-somatic technique or more detailed histological examination of the reproductive cycle at the tissue level would confirm if this was the case. If so, targeting the largest and oldest spiny scallops has a greater impact on reproductive potential than harvesting over a broader size range and age classes. The growth rates of spiny scallops in northern waters are less than southern waters, so there may be potentially more of an impact on reproductive potential. If these fisheries will be managed by a combination of measures, such catch ceilings, as well as minimum size limits, then there is less risk then by managing by size limits alone.

It is not possible to compare biomass estimates from diver quadrat studies and towed video transects, as both methods are used for the overall biomass estimates in the dive fishery. There are comparable densities between the diver quadrat surveys, and the submersible video surveys, which are also quadrat surveys. Divers retain all of their quadrat survey catch in separate mesh bags, which are brought to the surface and measured. This information is used to calibrate the video quadrat numbers with an S-Plus model developed specifically for these surveys. The diver quadrat surveys provides the biological information that is applied to the video quadrat surveys, which was the only method available to provide a sufficient number of samples for biomass estimates. Several dive and video transects, and trawl tows (3-5) are conducted at each location, and appear to be repeatable. As outlined in an earlier section, the dive surveys and trawl surveys are not comparable as they each sample different environments and their respective scales are very different. Each method was designed for their respective fishery biomass assessments, are not applicable to the other. Differences with depth, habitat or current were not evaluated, but the information is available for future use.

Future techniques that are being considered for the trawl survey protocol are video transects similar to the dive surveys, and possible changes to the dive surveys with the acquisition of more sophisticated video equipment.

The frequency of surveys in each area will depend on a number of factors. The degree of harvesting pressure should be a factor. For example, if landings are a small portion of the recommended harvest level due to extrinsic factors such as markets, PSP closures, etc., then biomass estimates could be every 2 years. If harvesting pressure approaches or exceeds recommended harvest levels, then biomass estimates should occur annually. If a strong recruitment of sublegal size scallops is detected during a survey, then the next biomass estimate could probably be delayed for a year. If a survey shows an ageing declining population with little evidence of recruitment, then a survey should follow within a year. Survey priorities should be set in consultation with harvesters, as harvesters often see trends before they may be detectable in surveys.

Most of the scallop trawl studies focussed on the butterfly scallop trawl developed by Tim Richards, as this design is most commonly used in the trawl fishery. There is another design currently in use consisting of a metal frame made of split rims from truck wheels, with cross bars that samples 20-25 cm off the bottom and has similar fishing characteristics to the butterfly scallop trawl. Video assessments were also conducted on this design, but the efficiency studies could be refined. Two other designs were used previously in the commercial trawl fishery, but they have not been evaluated for efficiency, bycatch and habitat impacts. As outlined in the Trawl Methods section, trawl efficiency ranges from 3-30 % depending on several factors. A relatively high trawl efficiency of 20% is used for the biomass estimates resulting in relatively low, but precautionary estimates of biomass. There was very little bycatch seen in the trawl surveys, and continuous monitoring of the experimental fisheries show very little bycatch. From submersible video observations, it appears that bycatch occurs when the trawl “climbs” over large rocks, and animals at the top edge of the rock face tumbles into the trawl. Red urchins that have been found in the trawl have all their spines intact, and sea cucumbers are not marked or damaged, indicating there is very little damage to those more fragile animals that may be caught in the trawl. As outlined in the Assessment of West Coast trawl gear impacts section, submersible video from differing angles in and behind the trawl shows minimal collateral species damage. Some species are impacted if they are in the direct path of the runners, but this is a very small area in comparison to the total area covered by the trawl. Sessile organisms slip under the bottom cross-bar, and re-emerge from the back of the chaffing gear, as the trawl moves forward. Mobile organisms escape the trawl altogether by either moving away from the path of the trawl, or moving under the bottom cross-bar. Discard mortality studies showed a very survival of sublegal sized scallops retained in prawn traps for 2 weeks. In most test runs there was no mortality, and when mortality did occur in two of the runs, it was 2-3%. These were single run tests, with sublegal sized scallops only being used once (of which we are aware). Mortality test runs were not conducted repeatedly with the same animals.

Apart from the area that remains closed to the dive fishery north of Detwiler Point in the Valdes-Porlier area, no other refuge areas have been identified or surveyed. During the surveys, the available resources were directed towards areas that were identified for harvest. In most cases, each fishery is well separated by geographic distance. Only in SAM Area A-1, and potentially in B-1, do they occur in close proximity. As a result, they are defacto closed areas, as divers have very limited bottom time below 100 feet, and the trawlers cannot harvest shallower than 100 feet by regulation. There a few alternatives that can be considered in providing refugia. Survey and close areas adjacent to areas with high fishing pressure; when exploring new areas, set aside a portion of the productive areas as refugia; and keep the two fisheries well separated so that areas immediately adjacent to harvesting activities remain closed due to the limitations in each fishery.

The current management strategy may provide adequate fishery monitoring to assess the trawl fishery in a precautionary way by providing a hail system to monitor the status of the catch in relation to the recommended harvest level. This only occurs in a limited area in the dive fishery. There has been at least one instance in the dive fishery, where the incoming harvest logs are suspect. This is particularly disturbing, as it is occurring under scientific licence during an experimental fishery design to collect accurate data to formulate policies and guidelines on any potential reopening of a commercial fishery. There needs to be a mechanism in place to address suspect harvest logs. If after an investigation of suspect harvest logs and catch reporting requirements, there are still concerns over the accuracy of catch reporting of a particular licence holder, then mandatory observer coverage would be required of that particular licence holder at their own expense.

7) Recommendations

1. An Integrated Fishery Management Plan (IFMP) should be initiated for limited commercial pink and spiny scallop dive and trawl fisheries in British Columbia waters.

2. Initially licences in each fishery should be limited to the current level in each fishery.

3. Plan and structure future assessment and management programs using the proposed SAM areas, and refine or further delineate the SAM areas as supporting information becomes available.

4. Collect at least 500 samples of each species for shell height, body thickness, weight and sex annually from each major harvest location. For example, Wilby Shoal and Sentry Shoal are in the same SAM area, but 500 of each species should be collected from each location.

5. Apply the newly revised harvest rates of 8% of unexploited biomass and 4% of previously exploited biomass to any new biomass estimates to determine recommended harvest levels. Apply the same rates to previous biomass estimates to monitor the progress of the fisheries.

6. A schedule for biomass surveys should be developed in collaboration with industry, taking into consideration: landings as a portion of revised recommended harvest levels; available information on the age structure of local stocks; when the last biomass surveys were conducted; and how surveys would be integrated with a rotational harvest plan.

7. Conduct detailed growth, gonadal-somatic and/or histological reproductive studies to investigate the appropriate minimum size limit for each scallop species, taking into consideration their individual growth characteristics as well as the productivity of the growing waters.

8. The catch reporting requirements of the experimental fisheries should continue with any commercial fisheries. A mechanism to enforce accurate catch reporting is required.

8) Summary: How far have we progressed?

In 1999 there were 2 declining commercial scallop fisheries, with unlimited entry in each fishery, and approximately 20% of issued licences reporting landings. It was unknown whether this was due to a lack of effort, but there were concerns that there was a large potential capacity for fishing pressure that was not being exercised. The resource was being passively managed as one species, one stock, with few management controls. There were also reports of localized over-harvesting, and damage by trawl gear. The only information on distribution and abundance of stocks was limited fishery-dependent data.

In 2002, there were 2 actively managed experimental scallop fisheries based on scientific information with ongoing assessment programs with active participation from industry. In each fishery, landings and participation had increased in the first 2 years of the experimental fishery phase in comparison to the last 2 years of the "wide open" commercial fisheries. Soft market conditions still have an effect on effort and landings.

The experimental fisheries, resource surveys and trawl assessment have addressed the concerns raised in the original review of the pink and spiny scallop fisheries in British Columbia waters.

9) The Future: Where are we going?

In the near future, the current scientific licences expire July 31, 2006. We believe there is sufficient information to initiate an Integrated Fishery Management Plan for small limited commercial pink and spiny scallop dive and trawl fisheries. The efforts to collect scientific information for the assessment and management of these fisheries should not diminish. If harvesters receive the assurances of progressing towards small limited commercial fisheries with paced development, then opportunities will increase for collecting scientific information. Monitoring the progress of any renewed commercial fisheries should receive the same attention and effort as monitoring the experimental fisheries.

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Table 1. Summary of spiny scallop biological characteristics sampled from dive surveys

Area	Year	# sampled	Mean Age (rd)	Mean Shell Ht (mm)±S.D.	Mean Thickness (mm) ±S.D.	Mean Weight (g) ±S.D.
A-1	2002	521	5	49.4±7.3	14.7±2.5	11.8±4.6
B-1	2000	1463	5	59.9±6.1		
B-1	2000-2002	1849	5	59.9±6.0.	14.4	29.3
C-1	2000	3075	5	60.2		
Valdes/ Porlier	2001	642	5	55.1		21.3
Valdes/ Porlier	2002	335	6	58.4	17.2	21.4

Table 2. Summary of pink scallop biological characteristics sampled from dive surveys

Area	Year	# sampled	Mean Age (rd)	Mean Shell Ht (mm)	Mean Thickness (mm)	Mean Weight (g)
Okisollo	2002	36	5	41.8	12.0	7.3
Sentry Shoal	2000	9	5	52.6		
Gabriola/Valdes	2000	66	5	51.1		
Gabriola/Valdes	2002	68	6	47.7	14.2	11.8
Mayne Island	2000	136	5	54.5		
Valdes/Porlier	2000	281	5	54.1		
Valdes/Porlier	2001	196	4	45.5		13.5
Valdes/Porlier	2002	15	5	47.3	13.8	12.3

Table 3. Summary of spiny scallop biological characteristics sampled from trawl surveys

Area	Year	# sampled	Mean Age (rd)	Mean Shell Ht (mm)	Mean Thickness (mm)	Mean Weight (g)
Wilby Shoals	2000	197	6	61.5	18.3	25.3
Wilby Shoals	2002	194	6	57.8	17.1	18.5
Shelter Pt/Willow Pt	2002	150		54		16.3
Elk/McMullan	2002	44	5	53.2		15.8
Moriarty	2002	92	5	56.6		18.5
Octopus Is	2002	120		54.5		18.1
Hornby Is/Cape Lazo	2002	223	6	64.2		33.0

Table 4. Summary of pink scallop biological characteristics sampled from trawl surveys

Area	Year	# sampled	Mean Age (rd)	Mean Shell Ht (mm)	Mean Thickness (mm)	Mean Weight (g)
Wilby Shoals	2000	495	6	53.1	16.6	17.5
Wilby Shoals	2002	206	6	51.3	16	14.2
Shelter Pt/Willow Pt	2002	50		51		14.7
Elk/McMullan	2002	156	5	52.0		17.3
Moriarty	2002	108	5	50.6		17.3
Octopus Is	2002	80		49.1		15.7
Hornby Is/Cape Lazo	2002	160	4	46.8		12.8

Table 5. Instantaneous mortality (z), survivability (S) and annual mortality (A) of pink and spiny scallops from various areas and years calculated from Ricker catch curves

Area	Year	Exp Fishery ?	Species	Ages	Z	S	A
Valdes-Porlier	2002	D	Spiny	6-8	2.6688	0.0693	0.93
Valdes-Porlier	2001	N	Spiny	3-7	0.7907	0.4535	0.55
Valdes-Porlier	2001	N	Pink	2-4	0.4789	0.6195	0.38
Valdes-Porlier	2000	N	Spiny	4-7	1.5854	0.2044	0.80
Valdes-Porlier	2000	N	Pink	4-6	0.9402	0.3905	0.61
Hornby Island	2002	T	Spiny	6-8	2.0595	0.1275	0.87
Hornby Island	2002	T	Pink	4-6	1.3650	0.2554	0.74
Mayne Island	2000	D	Spiny	4-7	1.4313	0.2390	0.76
Mayne Island	2000	D	Pink	4-6	1.1709	0.3101	0.69
Wilby Shoal	2002	T	Spiny	6-7	4.0558	0.0173	0.98
Wilby Shoal	2002	T	Pink	6-7	4.9202	0.0073	0.99
Wilby Shoal	2000	T	Spiny	6-8	2.5530	0.0778	0.92
Wilby Shoal	2000	T	Pink	6-8	2.9513	0.0523	0.95
Sentry Shoal	2002	D	Spiny	5-8	1.6576	0.1906	0.81
Gabriola-Valdes	2002	D	Spiny	6-8	1.9459	0.1429	0.86
Gabriola-Valdes	2000	D	Spiny	5-7	1.8627	0.1553	0.84
Okisollo	2002	D	Spiny	6-7	3.8219	0.0219	0.98
Okisollo	2002	D	Pink	5-6	4.3106	0.0135	0.99

Experimental Fishery: D – Dive; T – Trawl; N- No experimental fisheries during that year

Table 6. Estimated legal-sized density and estimated biomass from dive/video surveys in 2001 and 2002

Survey Area/Year	Estimated Legal Density (Kg/m^2)		Estimated Legal Biomass (Kg)		
	Est Mean	95% LCL	Mean	Mid range	Low range
Mayne Island 2001	0.2985	0.2801	331,981	280,313	233,594
Sentry Shoal 2002	0.3473	0.3288	268,472.	228,769	190,640
Okisollo 2002	0.2077	0.1915	93,938	77,950	64,959
Gabriola-Valdes 2002	0.3598	0.3316	230,283	191,021	159,184
Valdes-Porlier 2001	0.4461	0.4077	1,179,873	1,061,886	884,905
Valdes-Porlier 2002	0.2628	0.2456	760,418	639,631	533,038

Table 7. Legal-sized estimated biomass and total estimated biomass from area-swept trawl surveys during 2000 and 2002, for 3 area estimates: measured area from Arc-View (Average); measured area from Arc-View –10% (mid range); measured area from Arc-View – 25% (low range)

		Estimated Biomass (Kg)					
Area	Year	Legal-sized Average	Total Average	Legal-sized Mid range	Total Mid range	Legal-sized Low range	Total Low range
Wilby Shoal	2000	85,505	101,854	76,954	91,669	64,129	76,391
Wilby Shoal	2002	26,380	577,995	23,742	520,196	19,785	433,496
Shelter Pt/Willow Pt	2002	90,555	154,540	81,500	139,086	67,916	115,905
SW Quadra Is	2002	81,670	156,880	73,503	141,192	61,252	117,660
Hole in the Wall	2000	56,829	195,871	51,146	176,284	42,622	146,903
Hole in the Wall	2002	43,805	190,220	39,425	171,198	32,854	142,665
Okisollo	2002	77,165	181,295	69,449	163,166	57,874	135,971
Octopus Is	2002	17,645	24,955	15,881	22,460	13,234	18,716
Elk/Moriarty/McMullan	2002	14,975	28,710	13,478	25,839	11,231	21,533
Hornby Is/Cape Lazo	2002	40,850	33,207	36,765	29,886	30,638	24,905
Lambert Channel	2002	53,162	75,738	47,846	68,164	39,837	56,804

Table 8. Experimental dive fishery landings from major harvest areas with biomass estimates and calculated harvest rates

Area	Year	Landings (Kg)	Estimated Biomass (kg)	Estimated Harvest Rate (%)
Mayne Island	2000	8,694		
Mayne Island	2001	10,975	233,594 - 331,981	3.3 - 4.3
Mayne Island	2002	18,121		
Sentry Shoal	2000	29,670		
Sentry Shoal	2001	17,375		
Sentry Shoal	2002	5,238	190,640 – 268,472	2.0 - 2.8
Okisollo	2001	433		
Okisollo	2002	924	64,959 – 93,938	1.0 – 1.4
Gabriola-Valdes	2000	3,718		
Gabriola-Valdes	2001	8,581		
Gabriola-Valdes	2002	8,716	159,184 – 230,283	3.9 – 5.5
Valdes-Porlier	2001	2,014	884,905 – 1,179,873	0.2
Valdes-Porlier	2002	10,671	533,038 – 760,418	1.4 – 2.0

Table 9. Experimental scallop trawl fishery landings and recommended catch ceilings by area and year

Area	Year	Recommended TAC (kg)		Landings (Kg)
		Previous	Revised	
Wilby Shoal	2001	5,610	2,493	1,745
Wilby Shoal	2002	2,374	1,055	1,314
Elk/McMullan/Moriarty	2002	1,348	1,198	114
Elk/McMullan/Moriarty	2003			872
Okisolo	2002	1,588	1,412	410
Okisolo	2003			1,513
Hole in the Wall	2001	5,144	2,286	3,345
Hole in the Wall	2002	3,942	1,742	759
Hole in the Wall	2003			184
Lambert Channel	2002	4,785	2,127	66
Lambert Channel	2003			432
Hornby Is/Cape Lazo	2002	3,677	3,268	582
Shelter Pt/Willow Pt	2002	8,150	7,244	

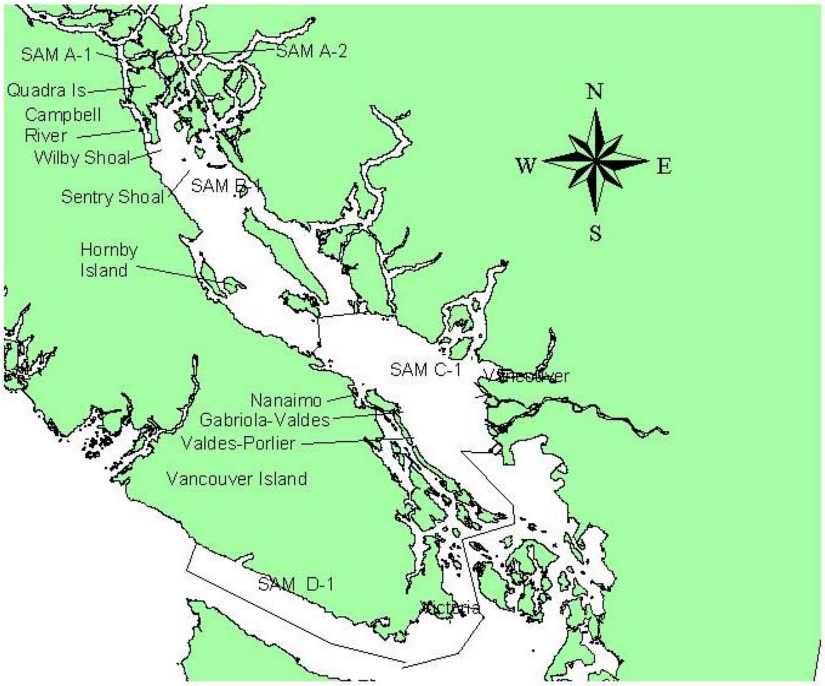

Figure 1. Location of selected sample areas and Scallop Assessment and Management (SAM) areas in the inside waters of British Columbia

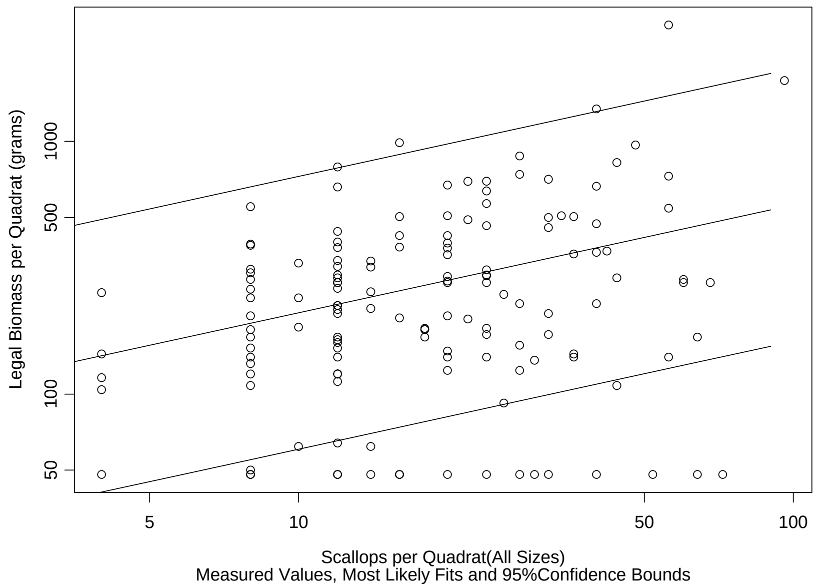

Figure 2. Measured values of scallops per quadrat and legal biomass per quadrat, most likely fits, and 95% confidence bounds

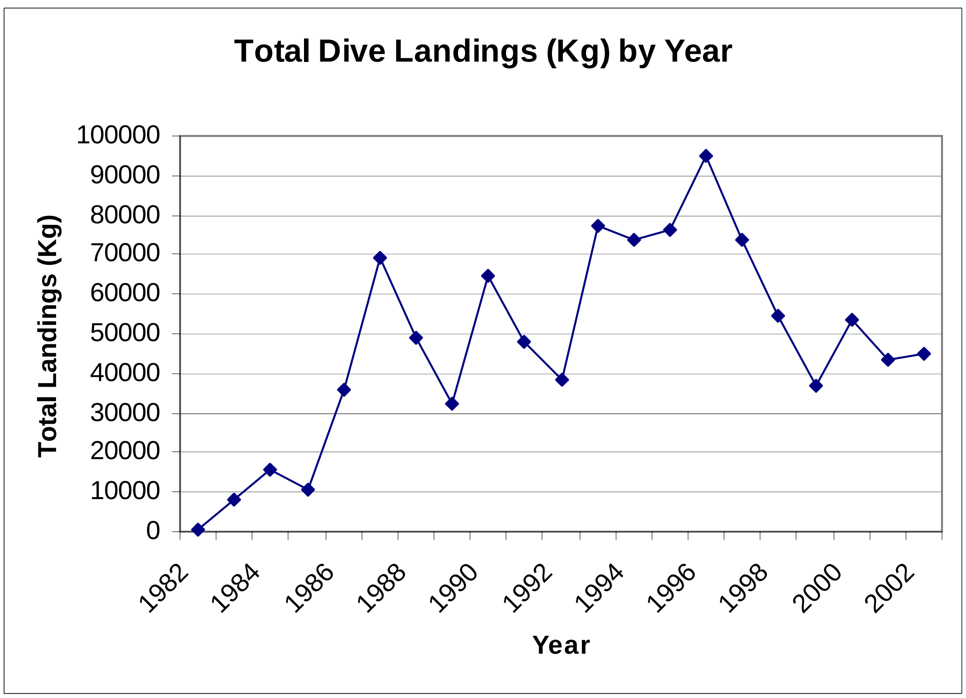

Figure 3. Total scallop dive landings (kg) by year

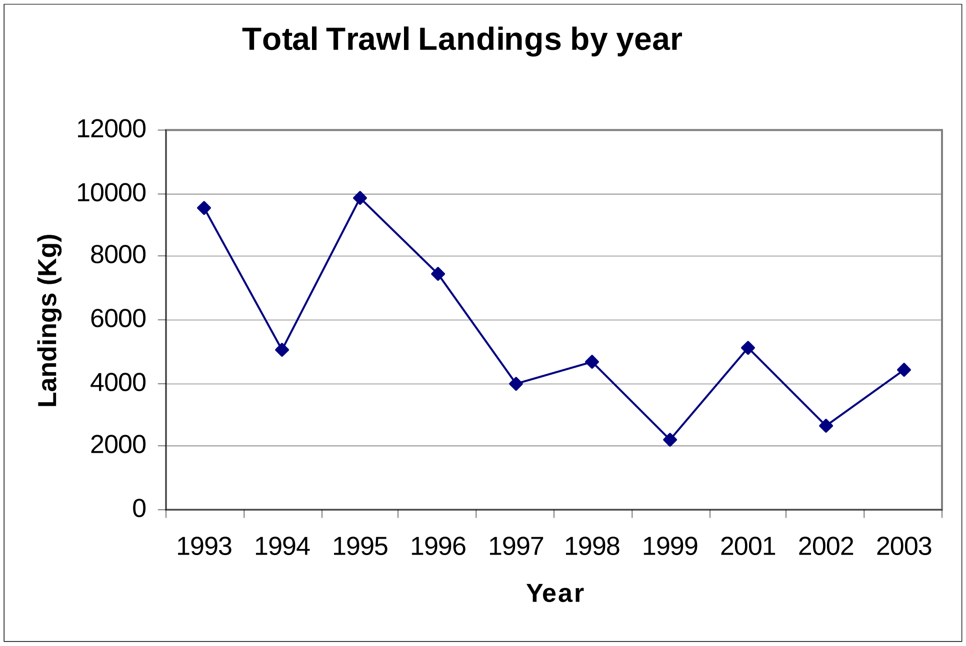

Figure 4. Total trawl fishery landings by year

Appendix 1

PSARC INVERTEBRATE SUBCOMMITTEE

Request for Working Paper – Scallop Studies

Date Submitted: June 17, 2002

Individual or group requesting advice:
(Fisheries Manager/Biologist, SWG, PSARC, Industry, Other stakeholder etc.)
Erin Wylie, R. Harbo, G. Parker – Resource Management

Proposed PSARC Presentation Date: Nov. 2002

Subject of Paper (title if developed): Stock Assessments and Management Options for Scallop Assessment and Management Areas in B. C.

Stock Assessment Lead Author: Ray Lauzier

Fisheries Management Author/Reviewer: Erin Wylie, Guy Parker

Rational for request:
(What is the issue, what will it address, importance, etc.)
The implementation of a biological basis for the assessment and management of pink and spiny scallop is necessary for a precautionary approach to managing scallop resources. The assessment of the by-catch and habitat damage from the trawl fishery is necessary to continue with this gear type.

Fishery managers will prepare an experimental harvest update paper, outlining the effort and harvest over the period of the experimental program. Guidelines have been developed for the current dive experimental fisheries and draft guidelines are in preparation for the trawl fishery. These will be included as appendices.

Objective of Working Paper:
(To be developed by FM & StAD)

1. The objective of the scallop assessment and management framework is to define limit and target reference points and to provide Scallop Assessment and Management (SAM's) area specific biomass estimates.

2. The objective of the working paper is to summarize and evaluate the data collected to date during the stock assessment and experimental fisheries and to determine what on-going assessment would be required to expand the areas of fishing, monitor the stocks and evaluate the impacts of fishing (i. e. success of the management strategies).

Question(s) to be addressed in the Working Paper:
(To be developed by initiator)

1. What are the Scallop Assessment and Management (SAM's) areas defined for British Columbia and the specific densities, age distribution, bed areas and resulting biomass identified for each SAM? Should SAM's be defined differently for the two harvest types?

2. How did the survey estimates and harvest level options compare to historical landings in an area? Surveys were conducted in Area 29-5 pre-harvest and after a limited harvesting opportunity. By comparing results are we able to determine if there are annual changes in scallop biomass? Is there evidence of compensatory response in the populations under harvesting pressure? Is the limit reference point for previously harvested areas of 50% of current biomass a precautionary level and does it permit a sustainable harvest?

3. Biological samples were taken from each Area harvesting occurred. What were the initial findings and how frequently should samples be collected to examine age assessment, growth and natural mortality?

4. Currently we have different size limits for different gear types. Based on biological data, is there one size limit that is the most appropriate for pink and spiny scallops harvested by trawl and dive?

5. How do the biomass estimates resulting from diver quadrat surveys, towed video transect and point quadrat estimates compare? What is the repeatability of these methods? Which assessment methodology provides the best index of abundance for pink and spiny scallops? Are there differences with depth, habitat, current, or other conditions? Are there other techniques that should be added to the biomass estimate protocol? How often should surveys be conducted within each SAM to ensure harvesting is sustainable?

6. Impacts were monitored for the scallop trawl; what selective fishing, habitat impact, discard mortality and trawl efficiency results were obtained?

7. What areas have been or should be identified for refugia? Were non-harvested areas surveyed for designation of refugia?

8. Is the current management strategy providing adequate fishery monitoring and catch data (fishery dependant data) to assess this fishery in a precautionary way? Are there alternative management strategies that could be evaluated in an experimental approach? Is a rotational fishery for both gear types appropriate?