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# Framework for Pink (*Chlamys rubida*) and Spiny (*C. hastata*) Scallop Fisheries in Waters off the West Coast of Canada

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## Abstract

A framework for assessment and management of the pink and spiny scallop dive and trawl fisheries is presented for these fisheries to proceed under scientific licence, and in a manner which collects key information for ongoing assessments and management. Components of the framework incorporate previously expressed concerns including distribution and abundance information, assessment of West Coast trawl gear impacts, development of the trawl fishery with a phased approach, locallized stock depletions, difficulty in species selectivity in the dive fishery. Suggestions for the resolution of these concerns are presented. Data requirements for a precautionary fishery are outlined including removal estimates, biomass estimates, and biological information. Assessment models and their data requirements are discussed. Alternative hypotheses, harvest strategies and effort controls are presented. Management options and their data requirements are presented.

Recommendations are made for the development of the pink and spiny scallop dive and trawl fisheries to follow the phased approach described in the Pacific Region Policy for New and Developing Fisheries, with suggestions on how this may be accomplished.

## Résumé

Ce document présente un cadre d'évaluation et de gestion des pêches en plongée et au chalut du pétoncle rose et du pétoncle épineux afin que ces pêches puissent s'effectuer avec des permis de pêche scientifique de façon à recueillir des données essentielles à l'évaluation et à la gestion continues des stocks en question.  Le cadre tient compte de préoccupations soulevées antérieurement, notamment au sujet de données sur la répartition et l'abondance de ces pétoncles, de l'évaluation des impacts des engins de pêche au chalut sur la côte Ouest, du développement par étapes de la pêche au chalut, d'épuisements localisés des stocks et de difficultés d'identification des espèces par les pêcheurs en plongée.  Le document suggère des moyens de résoudre ces problèmes et présente les données qu'il faudra recueillir pour effectuer une pêche prudente de ces espèces, notamment des estimations des prises et de la biomasse ainsi que des données biologiques. Il comprend une discussion sur des modèles d'évaluation et les données qu'elles nécessitent.  En outre, des hypothèses de rechange, des stratégies de récolte et des mesures de contrôle de l'effort de pêche sont présentées, de même que des options de gestion et les données nécessaires à leur réalisation.

Enfin, le document présente des recommandations pour que les pêches en plongée et au chalut du pétoncle rose et du pétoncle épineux se développent selon la démarche par étapes décrite dans la Politique des pêches nouvelles et émergentes de la région du Pacifique, de même que des suggestions pour y parvenir.

# Table of Contents

**INTRODUCTION** .......... **5**

**1 OBJECTIVES** .......... **5**

**2 PHASE 0: RESULTS AND RECOMMENDATIONS** .......... **5**

**3 RESPONSE TO SUBCOMMITTEE CONCERNS** .......... **6**

3.1 INSUFFICIENT DISTRIBUTION AND ABUNDANCE INFORMATION ON SCALLOP STOCKS IN BRITISH COLUMBIA. .......... 6
3.2 ASSESSMENT OF WEST COAST TRAWL GEAR IMPACTS. .......... 7
3.3 TRAWL FISHERY DEVELOPMENT WITH A PHASED APPROACH. .......... 7
3.4 EVIDENCE OF LOCALIZED STOCK DEPLETION IN THE DIVE FISHERY. .......... 8
3.5 DIFFICULTY IN SPECIES SELECTIVITY IN THE DIVE FISHERY. .......... 8

**4 PHASE 1 FRAMEWORK** .......... **8**

4.1 STOCK DEFINITION .......... 9
4.2 DATA .......... 10
*4.2.1 Removal Estimates* .......... *10*
*4.2.2 Abundance Estimates* .......... *10*
*4.2.3 Biological Information* .......... *13*
4.2.3.1 Growth and Age .......... 13
4.2.3.2 Reproductive Activity .......... 14
4.2.3.3 Mortality .......... 14
4.2.3.4 Recruitment .......... 16
*4.2.4 Environmental Data* .......... *16*
4.3 ASSESSMENT MODELS .......... 17
*4.3.1 Analyses of Abundance Trends* .......... *17*
*4.3.2 Surplus Production Models* .......... *17*
*4.3.3 Potential Models* .......... *18*
4.4 POLICY EVALUATION .......... 18
*4.4.1 Alternative hypotheses* .......... *18*
*4.4.2 Alternative harvest strategies and effort controls* .......... *19*

**5 MANAGEMENT OPTIONS AND THEIR DATA REQUIREMENTS** .......... **20**

5.1 SIZE LIMITS .......... 20
5.2 EFFORT REGULATION .......... 21
*5.2.1 Seasonal Closures* .......... *21*
*5.2.2 Area Closures* .......... *21*
5.3 TOTAL ALLOWABLE CATCHES (TACS) .......... 22
*5.3.1 Biomass* .......... *23*
*5.3.2 Harvest Rate* .......... *24*
5.4 TARGET AND LIMIT REFERENCE POINTS .......... 24

**6 DISCUSSION** .......... **25**

**7 RECOMMENDATIONS** .......... **26**

**8 ACKNOWLEDGEMENTS** .......... **27**

**9 REFERENCES** .......... **28**

## List of Tables

Table 1. Estimated mortalities for pink and spiny scallops…………………………...32

## List of Figures

Fig 1. Spiny scallop from PFMA 14-13 - Size distribution…………………………….33

Fig. 2. Spiny scallop from PFMA 14-13 - Age distribution……………………………33

Fig. 3. Pink and spiny scallops from PFMA 17-10 - Size distribution…………………33

Fig. 4. Pink and spiny scallops from PFMA 17-10 - Age distribution…………………34

Fig. 5. Ln frequency age distribution of spiny scallops from PFMA 14-13……………..34

Fig. 6. Ln frequency age distribution of pink scallops from PFMA 17-10……………...34

Fig. 7. Ln frequency age distribution of spiny scallops from PFMA 17-10……………..35

## List of Appendices

Appendix 1 PSARC Invertebrate Subcommittee Request for Working Paper………….36

# Introduction

As a result of the 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 the Invertebrate Subcommittee/Pacific Scientific Advice Review Committee (PSARC), the Resource Management Executive Committee (RMEC) recommended closing the commercial trawl and dive fisheries on these species. The commercial fisheries were closed by Fisheries Management on December 31, 1999. 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. The PSARC Habitat Subcommittee would consider a framework for an ecological impact assessment. This paper provides a stock assessment and management framework for consideration by the PSARC Invertebrate Subcommittee.

# 1 Objectives

This paper is produced at the request of RMEC as a follow up to the Phase 0 review of the pink and spiny scallop fisheries (Lauzier and Parker 1999) presented to the PSARC Invertebrate Subcommittee in June 1999. The main objectives of this paper are: (1) to address the questions and concerns about the data limited nature of this fishery; and (2) to provide a framework for assessment and suggest management techniques for scientifically based sustainable scallop fisheries.

The request for working paper that was submitted by resource managers included the additional questions for the dive fishery, which are listed in Appendix 1.

While a request to address these questions in the trawl fishery was not submitted, this paper will attempt to address these questions in the trawl fishery, as scientific licences were issued for both dive and trawl fisheries.

# 2 Phase 0: Results and Recommendations

The Phase 0 review (Lauzier and Parker 1999) concluded that the overall status of pink and spiny scallops in British Columbia is unknown, as there is insufficient data for assessments. The information gaps identified through this review included the distribution of pink and spiny scallop stocks, estimates of biomass, availability of suitable stocks to the fishery, recruitment rates, natural mortality and total fishing mortality. There is some limited information on growth, and very limited information on age structure and natural mortality. Additional data is required to accurately assess these two parameters in order to set precautionary harvest rates.

The Subcommittee had the following concerns with the commercial pink and spiny scallop fisheries:

- There is insufficient information about the abundance and distribution of pink and spiny scallops in British Columbia.

- Although the West Coast trawl gear is likely less intrusive than the dredge and drag gear on the East Coast of Canada and elsewhere, the habitat impacts, bycatch characteristics, size selectivity and the fate of discards has not been assessed.
- It was unlikely that the trawl fishery could meet the requirements for continuation of the fishery either biologically through the phased approach, or economically to fund the necessary assessment and management programs.
- While the dive fishery has no associated habitat destruction and is size selective, there is evidence of localized stock depletion.
- The dive fishery is not species selective as divers find it difficult to sort pink from spiny scallops due to sponge encrustation.

In addition, the Subcommittee recommended:

1. A precautionary approach should be applied in consideration of continuing the trawl fishery. The trawl fishery should only proceed under the conditions of the phased approach, guided by the policies for new and developing fisheries and in the context of policies presently being developed for selective fishing practices;
2. The phased approach be applied to the dive fishery;
3. Georeferencing be introduced as requirement for harvest logs.

# 3 Response to Subcommittee Concerns

In response to the Subcommittee concerns, the development plan for an experimental fishery will include components to address those concerns.

## 3.1 Insufficient distribution and abundance information on scallop stocks in British Columbia.

There is very little available information on the status of scallop stocks in British Columbia. There is data on reported effort and landings. However, in some cases, fluctuations in effort and landings is driven by the lack of markets rather than stock abundance. Fishing opportunities are also constrained by PSP closures. 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.

Until very recently (May 2000), there have not been any structured surveys or biomass estimates of pink and/or spiny scallops in any area in British Columbia. The first survey (May 2000) was conducted by a trawl fisher, based on preliminary protocols developed for an interim scientific permit fishery. Results of this survey will give preliminary biomass estimates and quota options, as well as test the appropriateness and feasibility of the survey design and data sheets. In addition, survey protocols need to be developed for the dive fishery. In appropriate areas, that have both a trawlable substrate and suitable dive depths, there should be an integration of trawl surveys and dive surveys to compare the results of the two sampling methodologies and to examine trawl efficiency and impacts.

While biomass estimates from historically harvested areas are useful in providing a current status of the stocks in a particular area, a single biomass estimate in a particular area does not provide a historical perspective in terms of fluctuation patterns, which are characteristically seen in scallop populations. Also, biomass estimates from a previously harvested area, is not an estimate of the virgin or initial biomass required for setting a precautionary quota. Any exploratory fisheries in any new areas should be preceded by an initial biomass estimate.

## 3.2 Assessment of West Coast trawl gear impacts.

The drags and dredges used in most scallop fisheries consist of a heavy metal frame designed to dig into the substrate, and are fitted with steel ring mesh bags. A heavy tickler chain precedes some of the larger drags and dredges. The smaller (Digby-type) drags, which have no tickler chain, are towed in gangs of 5-9, and the larger offshore drags are towed on each side of the fishing vessel. MacPhail (1954) describes the details of the original Digby drag design, and Bourne (1964) describes the details of the larger offshore drag design. There is extensive information available on the effects of scallop drags on the East Coast. These include siltation, substrate displacement, predator aggregations (Caddy 1973), sediment removal, loss of labile surface organic material, coarsening of the sediments, reduction in the number of organisms, biomass, species diversity and structural complexity (Wating and Norse 1998). In many cases cited by McLouglin *et al* (1991), the incidental fishing mortality exceeded the efficiency of the scallop drags.

The trawl used in the West Coast scallop fishery is considerably different than the drags and dredges used in other scallop fisheries. The trawl design has evolved since 1990 to produce a marketable product which is competitive with 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. The trawl consists of a steel or aluminium frame on runners or rollers fitted with a rope mesh net bag 2-m wide by 1.4 m deep. 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. Information from scallop trawl fishers and the results of the first trawl survey show very little or no bycatch retained by the trawl net. However, the question remains as to the number and fate of any organisms that go through the trawl net or the fate of any discards.

## 3.3 Trawl fishery development with a phased approach.

Experimental licences issued after the commercial trawl fishery was closed on December 31, 1999 had a number of conditions of licence to address the Subcommittee concerns that this fishery could meet the requirements of a biologically based phased approach. These conditions included:

1. Biomass estimates to be undertaken in each area identified for experimental harvest, based on an area swept trawl survey with a stratified random design.
2. Harvesting to be limited to a precautionary harvest rate based on the biomass estimates.

3. Collecting information for an age structure analysis.
4. Assessment of trawl catchability and efficiency.
5. Bycatch assessments.
6. Assessments of discard mortality.
7. An environmental impact assessment.

3.4 Evidence of localized stock depletion in the dive fishery.

Pacific Fishery Management Subarea 29-5, a historically very productive fishing area, 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 (Lauzier and Parker 1999), so the fishery was closed in Subarea 29-5 to allow the stocks to recover. As a consequence of this closure, other adjoining areas have had a great deal of fishing pressure, and fishers report apparent stock declines in those areas. There was no biomass survey conducted before the fishery was closed in Subarea 29-5, and there has not been any biomass survey since it closed.

This the third year the fishery has been closed in Subarea 29-5, and there is a great deal of pressure by the scallop dive fleet to re-open this area. While we do not have a biomass estimate depicting the conditions that lead to the closure, biomass estimates and age structure analysis should be a priority before considering re-opening, which would provide a useful reference point for assessment and future management of Subarea 29-5. In those subareas that have had a high fishing pressure due to the Subarea 29-5 closure, biomass estimates and age structured analysis should also be considered a priority.

3.5 Difficulty in species selectivity in the dive fishery.

While species selection is visibly difficult due 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 in the first two biological samples from the dive fishery show pink scallops comprised of 1.3 % and 19.2 % of the dive catch from Subareas 14-13 and 17-10 respectively. Therefore the dive fishery is targeting on spiny scallops preferentially over pink scallops.

# 4 Phase 1 Framework

The Phase 1 management system as described by Perry *et al* (1999), is designed for a fishery to proceed cautiously and in a manner which collects key information for ongoing assessments and management actions. This cautious approach is taken for the development of a sustainable fishery and does not compromise the conservation of the target species on any co-occurring species. There are other scallop fisheries in Canada and the United States, however the life history characteristics and fishing methods are considerably different than the pink and spiny scallops found in British Columbia. There is evidence that the passive management of an unlimited fishery is not sustainable for the British Columbia scallop fisheries in heavily fished areas. To date, the effort in British Columbia scallop fisheries appears to be market driven. However, as these markets develop and strengthen, a precautionary approach that protects the resource and ensures sustainability is required. Therefore a management system must be designed and adopted that actively monitors total catch, monitors stock condition, sets appropriate exploitation levels, and the system must be able to respond to changes in a timely manner.

The U.S. National Research Council publication on Improving Fish Stock Assessments (NRC 1998) gives a checklist of four basic groupings of subject areas that should be included in a stock assessment: Stock Definition, Data, Assessment Models, and Policy Evaluations. Under each subject area, important considerations are identified and the potential key data requirements are discussed.

## 4.1 Stock Definition

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 Georgia Strait or whether there are several smaller discreet stocks. Areas of concentrated fishing effort appeared to be adversely affecting stocks in particular subareas, 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 could be collected in fishery independent surveys using hydroacoustics (Questar Tangent or similar technologies).

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 anecdotal information provided by fishers.

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. Settlement in spiny scallops has been shown at 34 days in 16 ºC water, and 42 days in 12 ºC water (Cooke 1986; Hodgson and Burke

1988). However, there may be some limited dispersal with the swimming adults. Tidal currents may transport scallops passively (Belding 1910, cited in Orensanz *et al* 1991). Studies on other species have generally shown adult dispersal to range between 1.6 km (Baird and Gibson 1956, cited in Orensanz *et al* 1991) and 10 kms (Posgay 1981).

While there is likely a high degree of dispersal between populations that occur in close proximity in high current areas, some of these aggregations have been heavily harvested. Without the specific information to delineate the degree of exchange or dispersal between these aggregations, the precautionary approach would be to deal with these distinctive aggregations as separate stocks.

## 4.2 Data

The most important information in any assessment and management program is location. There is presently a requirement for depiction of well-marked and identifiable harvest sites on accompanying charts with the harvest logs. Recent digitizing of the dive harvest logs was conducted using the charts, which was fairly difficult using charts of varying quality and scale. With the availability of relatively inexpensive and accurate Global Position Systems (GPS) receivers, an accurate geo-referenced harvest location is easy to obtain. Therefore geo-referenced harvest locations should be part of the data requirements of any assessment program.

There are a number of other data requirements, issues and constraints that need to be addressed when designing an assessment framework. These issues are listed below, with suggestions for their resolution.

### 4.2.1 Removal Estimates

All removals must be included in the assessment. While there is an opportunity for appropriate size selection in the dive fishery resulting in very few discards, the trawl fishery is only minimally size selective, depending on mesh size and the size of the catch. Whether or not there is a minimum legal size limit, there will be a minimum size that will be acceptable to the market (2 inches or 51 mm at present), resulting in discards from the trawl fleet. All of these discards should be considered as mortalities, and included in the removal estimates. However, the trawl fleet is conducting discard-retention mortality studies, where discards are kept in a cage for 2 weeks, and the mortality of these discards is assessed. When a mortality rate for these retained discards is determined, it will be applied to the discard numbers and included in the removal estimates.

### 4.2.2 Abundance Estimates

Abundance and biomass are usually estimated through an enumeration process that calculates abundance and biomass as the product of density per unit habitat area times the total habitat area. Large-scale and small-scale spatial distribution must also be considered in the enumeration process. The spatial distribution of the giant scallop, as with many other species on the East Coast, is described at three different spatial scales:

(1) geographic areas known as ‘grounds’; (2) ‘beds’ which are on the scale of kilometres and (3) ‘patches” which are on the scale of 10’s to 100’s of metres (Brand 1991 cited in Stokesbury and Himmelmam 1993).

There are several ways of estimating habitat size, including:
(1) total defined area, as for intertidal clams (Gillespie *et al.* 1998; Kronlund *et al* 1998);
(2) estimated bed size, as for geoducks (Campbell *et al* 1998; Hand *et al* 1998);
(3) depth ranges, as for green sea urchins (Waddell *et al* 1997); and
(4) linear shoreline, as for sea cucumbers (Boutillier *et al* 1998).

At diveable depths where they are commercially harvested, pink and spiny scallops occur in distinctive aggregations, varying from the tops of pinnacles, to larger reefs, flats and shoals (L. Glover, *pers. comm.*). Pink and spiny scallops are not sessile such as clams or geoducks, but are epibenthic with both attached and detached or swimming phases, depending on environmental conditions. Therefore, the total defined area would not be appropriate for pink and spiny scallops.

Spiny scallops are found at depths ranging 2 to 150 m (Bernard 1983), usually on substrates of firm gravel or rock (Bourne 1991), on rocky reefs (Harbo 1997), in areas of strong current (Bourne 1991). Pink scallops are found at depths ranging 1 to 200 m (Bernard 1983), usually on softer substrates than spiny scallops (Bourne 1991), on predominantly sandy substrates and mud, but also including gravel and rocky bottoms (Quayle 1963). Because of the distinctive habitat requirements at particular depths, habitat size by depth range alone is not appropriate for scallops. Therefore, estimated bed size is likely the most appropriate estimate of habitat size.

Two methods, a dive fishery and a trawl fishery access the pink and spiny scallop resource. There are advantages to dive abundance estimates, including gathering information on: all age classes; clumping and spatial distribution; substrate; algae and co-occuring species. Dive surveys are also considered to be more accurate than trawl or dredge surveys (Stokesbury and Himmelman 1993). The disadvantages are: very limited sampling time; sampling the limited shallow (< 30 m) portion of the beds; more intensive sampling of spiny scallops than pink scallops due to their depth distribution. A portion of the resource is deeper than diveable depths, and some bed sizes may be too large to effectively survey with divers. Area swept trawl surveys also have distinct advantages and disadvantages. Both dive and trawl surveys are recommended for scallop abundance estimates.

Dive surveys usually consist of randomly selected transects across a delineated bed, or randomly selected quadrats over a delineated bed. Other dive survey methods include nearest neighbour analysis in randomly selected quadrats (Stokesbury and Himmelman 1993). Due to the depths of many of the commercially harvested areas, actual bottom time will be limited to 20-30 minutes, on each of 2 dives per day, collection for enumeration will be the only possible method. Randomly selected quadrats, using a 50 cm x 50 cm quadrat frame will be used. Those scallops with at least half their body within the quadrat frame will be included. All sampled scallops will be picked and placed in labelled mesh bags for counting and processing on the surface. The number of "escapees" or swimmers would be noted for each quadrat, and included in the enumeration on the surface. All samples will be retained for future selection for further analysis of more detailed biological information (age and size composition and size at age).

The first area swept trawl surveys in the scientific trawl fishery were intended to have a stratified random design, in order to determine species distribution and abundance by depth. The historically harvested area was separated into 3 depth strata: Stratum 1, 80-100 feet; Stratum 2, 100-120 feet; and Stratum 3, 120-140 feet (sounder depth). This first survey was an exploratory survey and helped define a survey protocol. There were 5 tows per stratum. Tows were along the depth contours against the tidal current for 15 minutes, with an average speed over the ground of 1.2 knots. Start and end times, fishing time, minimum depth, maximum depth, average depth, average speed, start and end positions were recorded. Two additional tows were made to define the bed area. The average area swept by the trawl was 1029 $m^2$. The total bed area was estimated to be 667,228 $m^2$.

As the trawl was brought aboard, the entire catch was weighed with 2 gallon buckets on a top loading spring balance, accurate to +/- 50 g. A sample was taken from each tow with a 2-gallon bucket, with a target sample of 5-10% of the total catch. The total sample was weighed and then divided by species and weighed. The sample was then further subdivided by shell height size categories: 0-53 mm, 53-58 mm, and > 58 mm. Each size class was weighed and counted. The scallops were then cleaned using a plastic tumble bucket and hose, and any remaining encrusting organisms (barnacle, calcareous worms and sand tubeworms) were removed during a final examination on the sorting table. The cleaned scallops were reweighed.

Biomass was estimated following the procedure outlined below.

The area covered by the trawl ($m^2$):

$$A = SOG * T * W \qquad (1)$$

where *SOG* is the speed over ground recorded in knots and converted to meters per hour, *T* is the time in hour and *W* is the trawl width (2 m).

Density ($kg/m^2$) per tow is estimated by

$$D = \frac{C}{A} \qquad (2)$$

where *C* is the entire catch (clean weight) in kg and *A* the trawl area. The clean weight was estimated by weighing encrusted scallop and re-weighing them once cleaned. Conversion factors were derived from these measurements and used to convert raw to clean.

The start and end of each tow location were linked to form a straight line. The bed location was estimated by drawing a polygon around the tow vectors that had a catch greater than 0 kg and estimating the polygon surface area using the LORAX tool in ArcView.

The mid-tow locations, estimated by averaging start and end positions, were then plotted in ArcView. The bed polygon was converted to a grid. The catch per tow was assigned to the mid-tow location and was used to interpolate the biomass over the bed area.

Tow success was dependent upon the amount and direction of the tide. Since the tow followed depth contours, it was not going in a straight line and locating the mid-tow position used to interpolate the biomass estimate was not precise. Biomass estimates calculated using this method may be overestimates or underestimates since the trawl efficiency has yet to be measured. This will be assessed in the future using a diver and/or a camera.

Since the other identified scallop trawl beds are not precisely delineated, future surveys will be conducted using a systematic design and similar tow duration of 15 minutes. A grid will be overlaid over the survey area and tows will be assigned systematically over the grid.

### 4.2.3 Biological Information

The requirement to collect biological samples was a condition of the scientific licence. The dive fleet have been endeavouring to collect 1500 scallops from each of the Pacific Fishery Management (PFM) Subareas that are harvested, and it is an ongoing process until the end of July, when the scientific licences expire. These samples were randomly collected by divers, and processed at the Pacific Biological Station for species, shell height, age and sex. Divers were requested to include all ages and sizes. While the sample collection does not have a statistically rigid design, as would be expected from samples of the biomass surveys, there was an immediate need for some biological samples, as scallops were last sampled in 1986. Subsamples from the trawl fleet biomass surveys were also collected for biological information.

#### 4.2.3.1 Growth and Age

The most common assessment of growth in scallops is the measurement of shell height, the maximum distance between the hinge (dorsal) edge and the margin (Thompson and Macdonald 1991). Other assessments of growth and production are outlined by Macdonald *et al* (1991), including turnover ratios, shell production, somatic production and reproductive effort. Age is determined by counting annual growth rings on the exterior of the shell.

Size (using shell height) frequency distributions and age frequency distributions derived from biological samples collected in PFM Subareas 14-13 and 17-10 are shown in Figs. 1-4. There has been no detailed analysis of the biological data, as several more samples are expected from the other Subareas that are harvested under scientific permit. The shell height mode of spiny scallops is 65 mm in Subarea 14-13 (Fig 1), compared with 60 mm in Subarea 17-10 (Fig 3) and the modal age of spiny scallops is 5 in Subarea 14-13 (Fig 2), compared with a modal age of 4 in Subarea 17-10 (Fig 4). It has not been determined whether there is a significant difference between these 2 subareas, or whether the differences are due to environmental characteristics or fishing pressure.

Until recently, the maximum age for both species was thought to be 6 years (Macdonald *et al* 1991). However, a small number of individuals (< 1%) in the biological samples were aged at 7 and 8 years, which were collected from harvested populations. Fishing pressure on the older age classes is differentially higher than the younger age classes due to the size differences. Therefore, it is particularly important that biologically samples are collected from unharvested populations in order to obtain a natural size and age structure of pink and spiny scallop populations.

Macdonald *et al* (1991) used the von Bertalanffy growth model to show the relationship between shell height with age. However, the $H_\infty$ parameter derived from the model was considerably higher than the graphical presentation of the data. The growth model did not fit the spiny scallop data as well as the other 2 species examined, which was attributed to the comparatively lower sample size (Macdonald *et al* 1991). In short lived species, such as pink and spiny scallops, growth continues until they die. Therefore, asymptotic growth is not an appropriate growth model. When all the biological samples are collected in the current scientific fisheries, there will be a re-examination of an appropriate growth model as the data is analysed.

#### 4.2.3.2 Reproductive Activity

Both pink and spiny scallops display asynchronous seasonal reproductive activity, and their gonads may not completely empty during spawning, increasing the difficulty of estimating reproductive output. Both species mature at 2 years (Bourne and Harbo 1987) and 25-35 mm shell height. Pink scallops spawn twice a year, first in March and again in September or October. Spiny scallops spawn once a year in July or August (Macdonald *et al* 1991).

Not only do pink and spiny scallops differ by spawning times, but also they differ in reproductive strategy. In pink scallops, reproductive effort slowly increases with age to an asymptotic maximum that does not exceed its somatic production. In spiny scallops, reproductive effort increases sharply after three years and exceeds somatic production in its fifth year. This pattern of increasing reproductive effort is characteristic of most iteroparous pectinids (Macdonald *et al* 1991). The large investment of reproductive effort in the final year(s) should be reflected in a management plan that provides some degree of protection of the reproductive potential of the species.

#### 4.2.3.3 Mortality

Instantaneous total mortality may be calculated using three methods: (i) catch curve analysis (Ricker 1975); (ii) estimation from maximum age with Hoenig's (1983) predictive model; and (iii) estimation from von Bertalanffy growth model parameters (Hilborn and Walters 1992).

Biological samples from the scientific dive fishery have provided age frequency distributions from PFMA 17-10 and 14-13. Mortality rates and survival for these 2 subareas 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

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

Instantaneous natural mortality estimates can also be made using Hoenig's (1983) generalized model using the predictive equation:

**$\ln(z)=a+b \ln (t_{max})$** where for molluscs: **$a=1.23; b=-0.832$**

A review of previous information (Lauzier and Parker 1999) indicated a maximum age of 6 for both species, resulting in an estimated instantaneous natural mortality is 0.77. However, biological samples recently analysed indicate a maximum age of 8 in pink scallops and spiny scallops, resulting in estimated instantaneous natural mortality of 0.61 estimated from Hoenig's (1983) model.

The mortality estimates derived from Figs 5-7 are shown in Table 1. There was considerable doubt, as to what actually constituted the descending limb due to the similar frequencies of the age 4 and 5 scallops in Subarea 17-10 (Fig 5,6). Therefore a number of different scenarios is presented in Table 1. At first glance there appears to be a large discrepancy between the annual mortality rates derived from Hoenig's (1983) model, and the annual mortality estimates derived from the Ricker (1975) catch curves. However, the mortality rates derived from Hoenig's (1983) apply to the entire life span of the animal, whereas the mortality rates derived from the differing portions descending limb of the catch curve, apply only to those particular ages.

The scallops were sampled from areas that are commercially harvested, so the mortality estimates derived from the catch curves, are actually a combination of fishing mortality and natural mortality. There is also a great deal of difficulty in sampling the younger age classes by either dive or trawl, and the younger age classes are not represented in this analysis.

While these mortality estimates are preliminary and reflect uncertainty, additional samples are being collected from other Subareas, and there will be samples taken from a Subarea that has been closed for 3 years. Additional mortality estimates will also be derived from the parameters of the appropriate growth model, when the growth analysis is complete.

Mortality estimates in other scallop fisheries on the East Coast include the enumeration of paired empty shells (clappers). This has not been explored in the West Coast fishery, as there do not appear to be frequent, eventhough the West Coast species are shorter-lived species that East Coast species

#### 4.2.3.4 Recruitment

Caddy and Gulland (1983) classified scallop stocks into four distinctive fluctuation patterns: (1) steady stocks; (2) cyclical stocks; (3) irregular stocks; and (4) spasmodic stocks. It is very important to determine the natural fluctuation pattern and the timing and magnitude of the natural fluctuations, in order to put any biomass estimates into perspective, when setting a risk averse exploitation rate.

Scallop recruitment to a population combines settlement with early mortality. Recruitment in broadcast spawning bivalves such as scallops, is typically erratic and unpredictable, due to the dispersion of gametes, the vulnerability of gametes and planktonic larvae to predation, the particular settlement requirements of veliger larvae and the high mortality usually encountered by newly settled juveniles. Installing and monitoring spat collectors can assess juvenile recruitment to a population.

Recruitment to a fishery, includes the survival of animals to the age and size at which they are harvested. As population age and size structures are derived from the biological samples taken in regular periodic surveys, we should have the ability to describe recruitment patterns that could be used to direct effort in the fisheries.

### 4.2.4 Environmental Data

The preferred habitat of each species differs slightly, but there is some overlap in their distribution. Spiny scallops are most often found on firm gravel or rock substrates (Bourne 1991) and rocky reefs (Harbo 1997) in areas of strong current (Bourne 1991) at depths ranging from 2 to 150 m and temperatures from 0 ºC to 23 ºC (Bernard 1983). Pink scallops are usually found on softer substrates the spiny scallops (Bourne 1991), including soft sediments (Ellis 1967) and predominantly on sandy substrates and mud (Quayle 1963) at depths ranging from 1 to 200 m and temperatures ranging from 1 ºC to 17 ºC (Bernard 1983). Pink scallops may also be found on gravel and rocky bottoms.

Given the lack of information on the population size, overall distribution and the natural fluctuation characteristics of pink and spiny scallops, there is insufficient information to assess the effects of past environmental change on the stocks or to predict the effect future fisheries may have on the stocks. Therefore, control (unharvested) populations should be monitored along with harvested populations in order to attribute population changes to environmental factors or fishing pressure.

Environmental data should also include the presence and fate of co-occurring species in the trawled beds. While the first trawl survey showed no bycatch in the trawl, the fate of any co-occurring species that have been passed over by the chaffing gear is not known. This can be examined by the concurrent use of divers to assess the impact of the trawl and the use of underwater video cameras before and after the trawl.

The collection and analysis of habitat data such as substrate, depth and current may be particularly useful in identifying new areas for exploratory fisheries.

## 4.3 Assessment Models

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 very limited. As data is collected from fishery-independent surveys and the fisheries, more sophisticated modelling techniques will be used.

### 4.3.1 Analyses of Abundance Trends

Abundance trends can be monitored over time from fishery-dependent data or from fishery independent surveys. This will initially 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 protocols are being developed for fishery-independent biomass estimates. In the trawl fishery, the first fishery-independent survey has recently been completed and biomass estimates are being determined in order to set quotas for an experimental fishery.

### 4.3.2 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.

### 4.3.3 Potential Models

As data is collected from surveys and experimental fisheries, increasingly complex models may 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.

On the East Coast, size-based methods are used for assessments (Hanson 1998), and abundance is reported in terms of meat weight over a given survey area. These estimates appear to be quite accurate and are not as data or assumption dependent as the traditional analytical assessments.

## 4.4 Policy Evaluation

The pink and spiny scallop fisheries were passively managed by a minimum size limit, which has been shown to be ineffective at insuring sustainable fisheries for species with highly variable recruitment. Spiny scallops in particular have evolved a reproductive strategy where the reproductive effort is highest in its final year(s), exceeding all other energetic demands. Harvesting the largest individuals of this species when somatic tissue growth is declining and reproductive effort is increasing, results in decreased yields and increasingly adversely affects the reproductive potential.

### 4.4.1 Alternative hypotheses

Scallop populations in British Columbia occur in sparsely distributed areas of commercially exploitable densities or aggregations. One of the first questions that need to be resolved is the spatial scale for assessment and management of the scallop fisheries. Fishery-dependent information indicates that these aggregations occur in fairly discrete aggregations. Many of these aggregations are in close proximity to each other within a particular Subarea, such as 29-5, or they may be in close proximity in adjoining subareas, such as 17-10 and 29-5. They may also be widely separated from each other, as seen in widely separated aggregations in some areas of Subarea 29-5. We don’t know if any of these aggregations or groups in close proximity to each other constitutes genetically unique populations. We also don't know if any genetically unique populations are vulnerable to the fishery. There is greater risk of overfishing by managing the fishery as a large single stock, when in fact it is comprised of several small isolated stocks, in comparison to managing the fishery as a number of small stocks, when it is actually only one large stock. Our abundance and biomass surveys will be based on relatively small locally delineated scallop aggregations in the dive fishery. Decisions will need to be made on whether survey designs should concentrate effort on individual aggregations, or whether survey designs should spread effort on adjacent similar aggregations. Individual aggregation assessment and management will be expensive and may be unnecessarily intensive. However, the present Pacific Fishery Management Subarea system is not applicable to scallop fisheries management, and any regionally based survey design networks should not be based on the Pacific Fishery Management Subarea system. On the East Coast, a separate Scallop Fishing Area assessment and management system was implemented to reflect historic harvesting activities and the spatial distribution of the stocks. Whether or not an assessment and management area system based on spatial distribution is feasible for the West Coast scallop fishery remains to be seen. There appears to be undocumented information available from harvesters on unexploited scallop aggregations, which will be very useful along with distributional surveys, in determining the overall distribution. Spatial data derived from the harvest logs of the West Coast fishery show the locations of individual patches, and the groups of patches in close proximity could be considered as beds. As an interim measure, consideration should be given to an assessment and management system that groups historically exploited aggregations or patches that are in close proximity into beds, and these beds would be the basic assessment and management unit.

### 4.4.2 Alternative harvest strategies and effort controls

There are two alternative harvest strategies that could be considered for the scallop fisheries: an annual adaptive management system of sliding scale exploitation rates and rotational harvests. In relatively short-lived species with unknown recruitment patterns, such as pink and spiny scallops, relatively frequent biomass estimates will be required initially to monitor the status of the stocks. If these biomass estimates were conducted annually, a sliding scale of exploitation rates could be considered for implementation on an annual basis. In areas of relatively high densities or during pulses of recruitment, increased exploitation rates could be applied and the response of the stocks assessed. In areas of relatively low densities (above a limit threshold), where there is evidence of stock depletion (above a limit threshold), or during apparent recruitment troughs, decreased exploitation rates would be applied and the response of the stocks assessed. Of course, any harvesting activities would cease if a limit reference point were reached.

There is anecdotal evidence from dive fishers and trends in the dive CPUE data (Lauzier and Parker 1999) to indicate that scallop populations in some areas were severely depleted, resulting in a closure. As a result of the continued closure, fishers now advise that adjacent areas appear to be as severely depleted. A system of rotational harvests between management units should be considered to avoid a serial depletion scenario.

Rotational harvests should also be considered in the trawl fishery, where market size selection results in discards. In the first biomass survey, an average 40% of the product was considered undersize and discarded. Mortality studies on the discards are being conducted to assess their fate. Sub-lethal effects are expected in discard survivors, including temporarily reduced growth and increased predation vulnerability. Pending the results of the environmental impact study on the trawl fishery, a rotational fishery would ensure some degree of recovery between harvesting activities, likely resulting in an increase in higher quality product.

# 5 Management Options and Their Data Requirements

Perry *et al* (1999) show a decision tree with major regulatory strategic choices for fisheries management: size limits, effort controls, and total allowable catches (TACs). The management options with their key assessment information needs, and applicability to the scallop fisheries is outlined below.

## 5.1 Size limits

The use of size limits as a management option is usually a minimum size limit to protect stocks for at least one spawning cycle before recruitment to the fishery. Information requirements include age or size at first spawning and yield-per-recruit.

There are currently minimum size limit regulations (55mm) in effect for both pink and spiny scallops. The size of first spawning in both species is 25-35 mm. There is little biological evidence that the 55-mm minimum size currently in effect provides sufficient protection. While protecting sexually mature spawning animals for 1 to 2 years before allowing commercial harvest, the current size limit may not be able to protect enough animals to provide adequate recruitment to maintain a viable, healthy population. There is evidence that size limits based on age at first maturity have been ineffective in intertidal clam fisheries without other management actions (G. Gillespie, *pers. comm*.). It has been shown that reproductive effort in pink and spiny scallops increases with age, with varying degree in each species (Macdonald *et al* 1991).

There should be a re-assessment of size limit based on reproductive potential of each species, and not on size at first maturity. Size limits should be determined based on an acceptable level of reduced egg production. A maximum size limit for spiny scallops could be considered to protect scallops in their fifth year, when the reproductive effort is highest, and exceeds somatic production. The specific maximum size limit would be determined from the size at age derived from the biological samples. The current minimum size acceptable to the markets is 51-53 mm, which still offers protection for spawners before recruitment to the fishery. However, market conditions may change, which could affect the minimum acceptable market size.

## 5.2 Effort Regulation

The decision tree illustrated by Perry *et al* (1999) show three alternatives for direct effort regulation. Effort limits require CPUE information, and run the risk of overfishing due to increases in catchability at low stock sizes. CPUE information is not an appropriate primary assessment tool for scallops (Naidu 1991). Therefore effort limits are not considered to be an appropriate management option. Inseason effort assessments require tagging and recovery, and run the risk of underestimating the exploitation rate due to tag loss. Due to the small size of the scallops and the characteristic sponge encrustations, an extensive mark-recovery program with sufficient numbers is not considered a viable option, and therefore inseason effort assessments are not an option. Other effort controls are time and area closures, and their applicability to the pink and spiny scallop fisheries are outlined below.

### 5.2.1 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. Seasonal closures are often used to protect stocks during periods of reproductive activity or during critical life stages, such as pre- and post-larval settlement. Seasonal closures may also be used to limit fishing effort, maximize product quality or for safety considerations. The scallop fisheries typically are closed in early July for a few months due to paralytic shellfish poisoning (PSP) levels. This coincides with spiny scallop spawning time and initial settlement, and the second spawning time seen in pink scallops. While there is little potential damage expected from dive harvest activities on newly settled scallops, due to the selective characteristics of the fishery, some adverse effects are expected in the trawl fishery, by the action of the trawl runners on the substrate. The significance of these effects needs to be assessed as part of an environmental impact assessment. Regular monitoring of spat collectors both during the opening of any fisheries and during PSP closures would provide some answers as to the degree of protection provided to the critical post-settlement period by PSP closures.

### 5.2.2 Area Closures

Permanent area closures are designed to provide refugia for exploited species, and/or protect critical habitat required by exploited species, and to monitor regime shifts. Area closures must include areas of high abundance of the species being protected, as well as sufficiently large areas with good habitat quality characteristics. Area closures are also used for abundance and biomass surveys of control (unharvested) areas to compare unharvested areas with harvested areas. Area closures may be very large areas over a portion of the coast, or they may be a patchwork of small areas that provide recruitment to adjacent fished areas. 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 a need to assess unexploited scallop populations for age, growth and natural mortality, as the only information available to date is from exploited populations.

While we don't have specific information on the broad distribution of pink and spiny scallops, either coast-wide or within the inside waters, large portions of the stocks are protected by their inaccessibility. In the dive fishery, the maximum feasible dive depth for harvesting is 30 m (100 ft), whereas both species range down to 150 m (spiny scallops) to 200 m (pink scallops). The trawl fleet can harvest at deeper depths, but they are restricted by the bottom topography, avoiding steep slopes, sharp reefs and pinnacles. The trawl fleet is also restricted to depths greater than 20 m.

In order to assess the adequacy of inaccessible scallop stocks as protective closed areas, we need to know the proportion of the stock that is inaccessible. Since these areas are inaccessible by conventional harvest techniques, dive and/or trawl, alternative survey techniques need to be developed in each fishery. In the case where stocks are beyond diveable depths, but there is trawlable habitat, an adjacent and concurrent trawl survey can be conducted for a biomass estimate of the inaccessible stocks. In areas that stocks extend into shallower areas that are permitted for trawl harvest or in areas that are within diveable depths but are not trawlable habitat, a concurrent dive survey can be conducted for a biomass estimate of inaccessible stocks. In areas that are neither trawlable or beyond the reach of divers, alternative methods will be needed. Hydroacoustic technology is used to map out geoduck beds, and could be applied to scallop beds. Alternative methods that could be considered are the use of remote operated vehicles (ROVs) or underwater video.

Rotational harvests are a modification of area closures. Aggregations are harvested for a season, then closed for a specified period to allow for recovery, when effort is redirected to other aggregations. Rotational harvests are applicable for sedentary species or species with a limited range that occur in discrete aggregations with a limited exchange rate between aggregations or aggregate groups. Adult scallops typically have a limited range, with a limited exchange between aggregate groupings. Rotational harvests may be particularly appropriate for the trawl fishery, where trawl areas are relatively widely separated. Information required to design a rotational fishery includes recruitment information, immigration rates, natural mortality and growth rates (Caddy and Seijo 1998)

## 5.3 Total Allowable Catches (TACs)

The scallop fisheries can be managed on a bed level similar to the geoduck fishery (Hand *et al* 1998) and the depuration clam fishery. In the dive fishery, small discrete patches often occur in groups in a small geographic area, as outlined in Section 5.4.1. These groups could be assessed and managed as a larger unit (as beds). In the trawl fishery, identified aggregations are more isolated and considerably larger than most aggregations in the dive fishery and could also be considered as beds. The individual trawl fishery beds are likely the most appropriate assessment and management unit.

Individual TACs for each assessment unit can be set by applying a harvest rate to the unexploited biomass.

The information required for management by TACs include spatial patterns of aggregations, unit stock, habitat delineation, abundance (biomass), exploitation rates, and information on growth, mortality and recruitment. The regulatory choice of TACs can proceed in one of three implementation choices with the Perry *et al* (1999) decision tree. Biomass information from surveys has the advantage of relatively low cost to industry, and the main disadvantage of missed fishing opportunities. Biomass information from production modelling has extensive data requirements that are not currently available in the scallop fisheries. Biomass information from removal experiments has the advantage of low costs to industry, but the risk of overfishing due to variance in estimates. Biomass removal experiments could be implemented under a structured rotational fishery, which may be particularly appropriate for the trawl fishery, due to the spatial scale.

### 5.3.1 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 may be particularly important in the most recently heavily exploited beds, to determine whether any particular management action is warranted.

The dive harvest log information has recently been digitized, to provide a spatial representation on the history of the dive fishery. Areas that have not been harvested for 2 or 3 years could be selected for biomass estimates. There is also the opportunity to survey aggregations in Subarea 29-5, which has been closed to the commercial dive fishery for the past 3 years. Considering the lifespan and productivity of these scallops, biomass estimates from Subarea 29-5 will likely approximate the unexploited biomass ($B_0$). Therefore, the first biomass surveys should be located in Subarea 29-5 to set a TAC in this historically productive area.

The trawl harvest locations have been outlined on charts by the harvesters. The first trawl biomass surveys were conducted in early May 2000, and the biomass estimates are being determined from the surveys results. Some modifications have been suggested from the first trawl surveys, and will be incorporated in subsequent area swept trawl surveys.

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. Both fisheries fleets are strongly encouraged to collaborate in providing indices of total abundance by supplementing each other's surveys.

### 5.3.2 Harvest Rate

As described previously in the Assessment Models section, harvest rate calculations may be taken from the natural mortality estimates. As seen in Table 1, there is considerable uncertainty in natural mortality estimates, ranging from 0.46 annual mortality derived from Hoenig's (1983) model, to 0.14-0.20 for spiny scallops and 0.16-0.22 for pink scallops, depending on which portion of the Ricker (1975) catch curve was utilized to estimate mortality. Additional data is being collected to refine these mortality estimates. Using 0.2 as a scaling factor in Gulland's model (Gulland 1971), the initial target harvest rate would range from 3 – 9 % of the original unexploited biomass. The effectiveness of the preliminary harvest rate can be tested in experimental fisheries by applying harvest rates above and below the initial harvest rate and monitoring the effects. A more precautionary harvest rate should be applied to the existing biomass in the case of exploited populations.

### 5.4 Target and Limit Reference Points

Reference points are used to describe a particular aspect of stock status, such as spawner indices, biomass levels, or fishing mortality rates. They can be used as targets for optimal fishing, or as thresholds for remedial action. In the FAO (1995) report on precautionary approach to fisheries, Article 69 states: "Biological reference points for overfishing should be included as a part of the precautionary approach". The merits of one biological reference point over another depends on a number of factors, including life history characteristics, and what is known about the life history characteristics, and the risk of fishing down stocks below a minimum threshold versus the risk of missed fishing opportunities (Mace 1993).

Target biological reference points are always more conservative than threshold biological reference points, and there should be some separation between the two to avoid triggering management responses for minor overages of the target reference point (Gillespie 1999). For the scallop fisheries, the harvest rate calculated from Gulland's production model could be considered as an appropriate target reference point. However, natural mortality estimates need to be refined before they are applied to a harvest rate based on the Gulland model.

A commonly used critical threshold reference point is based on initial biomass, where fisheries are closed if the biomass drops below a specified portion of the initial biomass. For productive animals, such as herring and pollock, 25% of the initial biomass is used as a critical threshold (Quinn *et al.*1990; Zheng *et al.*1993), and for longer lived animals such as geoducks, 50% of the initial biomass is used as a critical threshold (Harbo *et al.*1995). Even though pink and spiny scallops are much more productive than geoducks, but given the unknown variability in pink and spiny scallop recruitment, and insufficient information on a number of other parameters, including initial biomass, a conservative critical threshold limit should be applied to any developing scallop fisheries.

A limit reference point of 50% of the original virgin biomass may be precautionary in unexploited populations. However, in exploited populations, a higher limit reference point such as 75% of the existing biomass is required for a precautionary approach.

# 6 Discussion

Scallop populations, like many broadcast spawning marine invertebrates, are typically metapopulations. Given the distance between the documented aggregations and the planktonic larval period, there is likely a high degree of exchange between these populations at the larval stage. However, once scallops have settled, exchange between the adults is likely very much reduced and limited to the immediate area, based on the movement/migration data available for other scallop species.

The first problem in designing an assessment and management plan for the scallop fisheries is defining the basic assessment and management units. We don't have genetic information on what constitutes a unique stock, and a genetic survey can be very expensive work. We do have information 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 subareas occur in close proximity and in similar habitat. Therefore, in order to design a realistic achievable assessment and management plan, these aggregations should be grouped to form the basic assessment and management unit.

A scallop resource survey should be the highest priority of any assessment plan. First and foremost, abundance indices or biomass estimates are required. Initial biomass estimates are required to set a precautionary TACs or quotas, as well as for an initial reference point to assess management strategies, and subsequent biomass estimates are required for analyses of abundance trends. Fisheries independent biomass estimates are the most reliable method to assess, monitor and manage scallop fisheries, and this is the method used on the East and West Coast. In addition, reliable estimates of growth and age are required from the fishery independent surveys in order to provide reliable estimates of natural mortality, which in turn are used to set precautionary harvest rates.

Experimental fisheries are being implemented with the trawl fleet to determine the mortality of trawl discards, to assess bycatch with the trawls, and to collect biological samples for age and growth analysis. Future experiments are being planned to assess trawl catchability and efficiency using divers and video. With the dive fishery, experimental fisheries can be designed to test the initial precautionary harvest rate. A portion of the surveyed stocks can be assigned harvest rates above and below the initial harvest rate, and the response of the stocks closely monitored in case any remedial management actions are required.

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, an initial target harvest rate would range from 3 – 9 % of the original unexploited biomass.  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 number of other parameters, a more conservative limit reference point should be applied to pink and spiny scallops. A 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.

Management by time and area closures alone is not appropriate for the scallop fisheries. There are imposed seasonal closures for PSP that likely provide protection to a portion of the critical post-settlement period.  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 for habitat quantification and delineation as well as the use of ROV's, photography or video are likely the only ways these inaccessible resources can be surveyed. Rotational harvests could be considered for the trawl fishery, pending the results of the discard mortality studies, trawl efficiency experiments and environmental impact assessment. Quotas have been identified as one of the primary management options. However, the determination of conservative harvest rates needs to be refined. The use of quotas alone in previously closed areas may lead to a stampede fishery, therefore other management options to pace effort in the fishery when re-opening previously closed areas needs to be considered.

Adaptive management options, such as those being proposed in the depuration clam fishery, could be designed for the scallop fisheries to take advantage of any recruitment pulses. A sliding scale of exploitation rates could be considered on an annual basis as outlined in Section 5.3.2.

# 7 Recommendations

1. The identification and delineation of scallop assessment and management (SAM) units is the first step in designing an assessment and management plan. The spatial structure should be designed in collaboration with experienced harvesters and based on historical fishery-dependent information as well as anecdotal information on unexploited or inaccessible stocks. This should occur as soon as harvesters, stock assessment staff and resource managers are available.

2. A systematic plan of biomass surveys should be implemented during the summer of 2000, based on newly defined SAM units, historical harvesting information and development plans expressed by the respective fleets. The first dive biomass surveys should be conducted in the presently closed Subarea 29-5 during the summer of 2000.  The spatial structure and number of these surveys would depend on the size and number of new SAM units. The next dive biomass surveys should be assigned (in consultation with the experienced dive harvesters) in areas that have had the least effort in the last few years. The priority for trawl

biomass surveys should be collaborations between the trawl harvesters, stock assessment and resource management staff. Biomass surveys should also be undertaken in control areas to monitor the state of unexploited stocks, and to determine the natural fluctuation patterns of pink and spiny scallop stocks.

3. Biological samples should be collected from the biomass surveys, experimental fisheries and market samples. Initially, all exploited areas under scientific licence should have biological samples collected this year (2000), in order to assess age, growth and natural mortality.

4. Establish precautionary, preliminary biological limit reference points. In new previously unexploited areas, a limit reference point of 50% of the virgin biomass should be considered. In previously harvested areas, a limit reference point of 75% of the existing available biomass would be more appropriate, due to the uncertainty of natural mortality estimates, unknown recruitment patterns and initial biomass.

5. Alternative assessment methods in scallop beds, such as hydroacoustic technology, underwater video, or ROVS should be considered and deployed to assess the proportion of total biomass that is exploitable biomass.

6. A system of closed areas should be implemented to provide refugia and allow for the assessment of unexploited stocks. The extent and configuration of the closed areas would depend on the proportion of total biomass to exploitable biomass and the known distribution of the stocks.

7. Rotational harvest should be considered in the trawl fishery until the fate of discards has been assessed.

8. When re-opening previously closed areas to harvests, there should be effort limitation to pace the fishery to avoid a rapid fishing down to the limit reference point.

# 8 Acknowledgements

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**Table 1. Estimated Mortalities for Pink and Spiny Scallops**

| | **Pink Scallops** | **Spiny Scallops** | |
|---|---|---|---|
| Subarea Sampled | **17-10** | **17-10** | **14-13** |
| Z (Instantaneous Natural Mortality) from Hoenig | 0.61 | 0.61 | 0.61 |
| S (Survivability) | 0.54 | 0.54 | 0.54 |
| A (Annual Mortality) | **0.46** | **0.46** | **0.46** |
| Z from Ricker (4-8 yrs) | 0.25 | 0.22 | |
| S (Survivability) | 0.78 | 0.80 | |
| A (Annual Mortality) | **0.22** | **0.20** | |
| Z from Ricker (5-6 yrs) | 0.18 | 0.18 | |
| S (Survivability) | 0.84 | 0.84 | |
| A (Annual Mortality) | **0.16** | **0.16** | |
| Z from Ricker (5-8 yrs) | | 0.15 | 0.19 |
| S (Survivability) | | 0.86 | 0.83 |
| A (Annual Mortality) | | **0.14** | **0.17** |
| Z from Ricker (5-7 yrs) | | 0.22 | |
| S (Survivability) | | 0.81 | |
| A (Annual Mortality) | | **0.19** | |
| Z from Ricker (4-6 yrs) | 0.25 | | |
| S (Survivability) | 0.78 | | |
| A (Annual Mortality) | **0.22** | | |
| | | | |

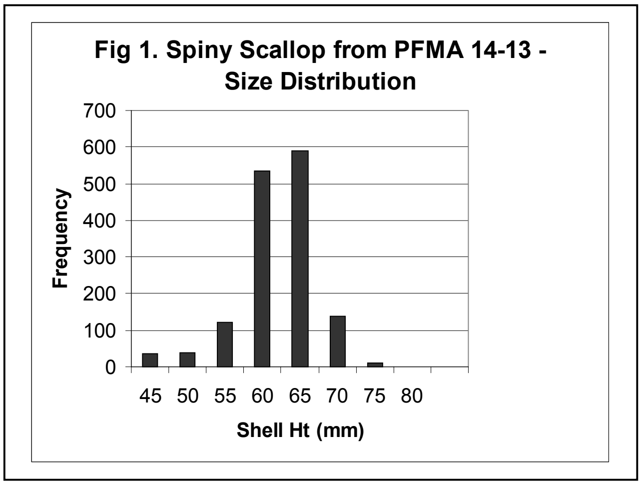
Fig 1. Spiny Scallop from PFMA 14-13 - Size Distribution
700
600
500
400
300
200
100
0
Frequency
45 50 55 60 65 70 75 80
Shell Ht (mm)

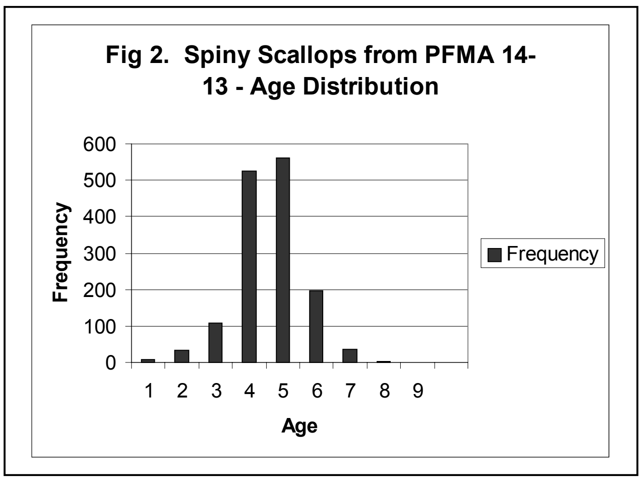
Fig 2. Spiny Scallops from PFMA 14-13 - Age Distribution
600
500
400
300
200
100
0
Frequency
1 2 3 4 5 6 7 8 9
Age
Frequency

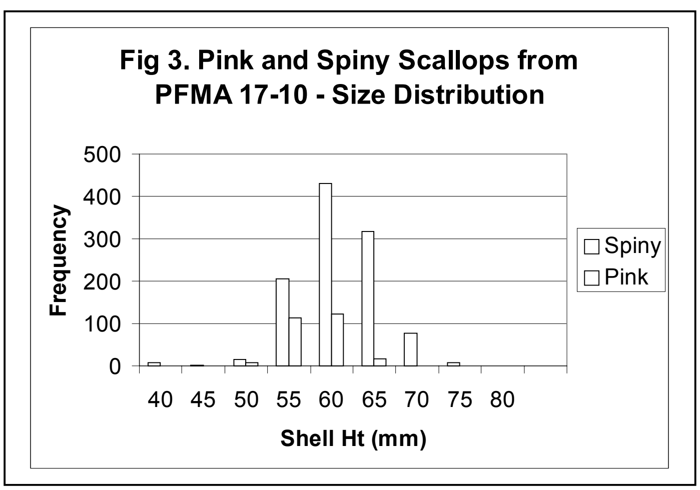
Fig 3. Pink and Spiny Scallops from PFMA 17-10 - Size Distribution
500
400
300
200
100
0
Frequency
40 45 50 55 60 65 70 75 80
Shell Ht (mm)
Spiny
Pink

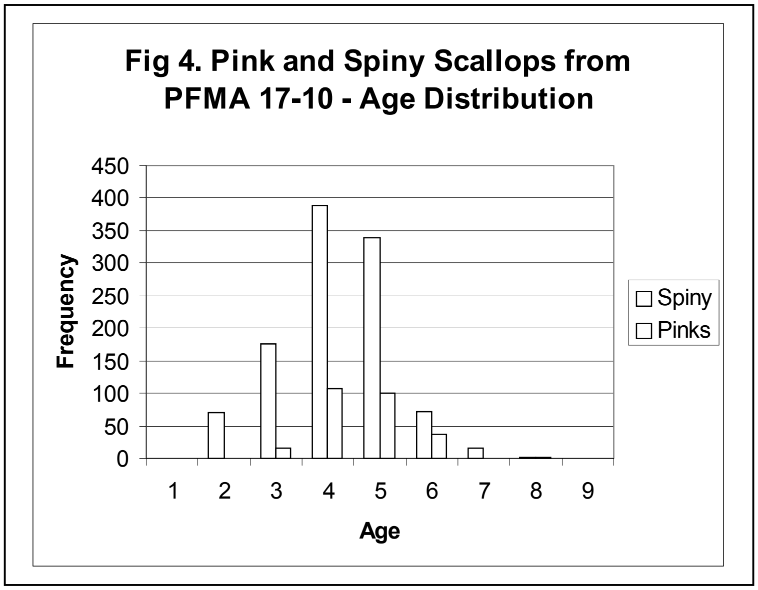
Fig 4. Pink and Spiny Scallops from
PFMA 17-10 - Age Distribution
Frequency
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
Age
Spiny
Pinks

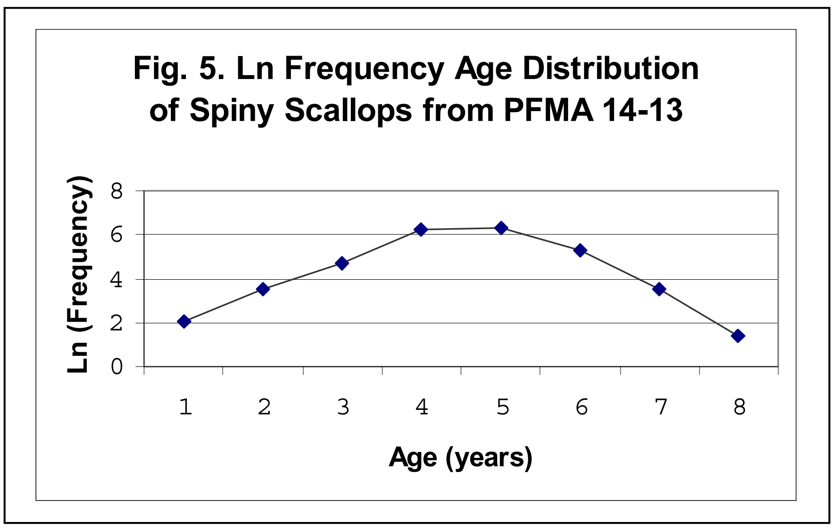
Fig. 5. Ln Frequency Age Distribution
of Spiny Scallops from PFMA 14-13
Ln (Frequency)
8
6
4
2
0
1
2
3
4
5
6
7
8
Age (years)

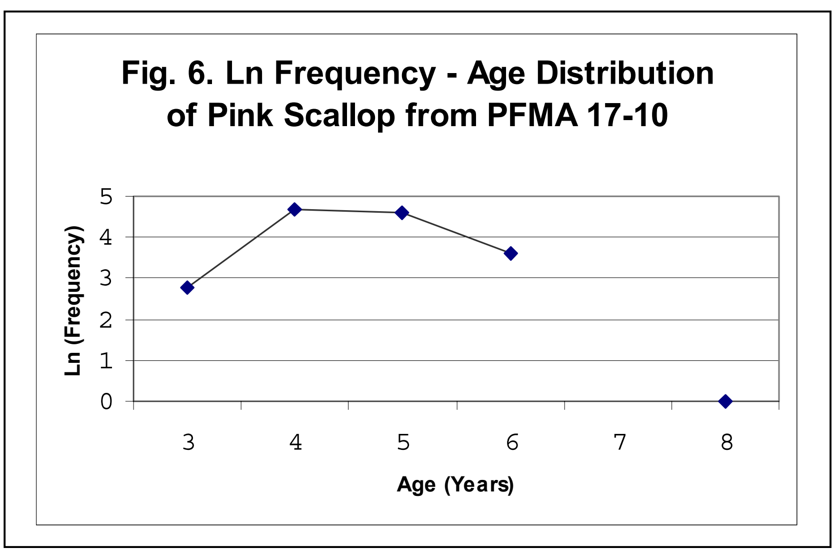
Fig. 6. Ln Frequency - Age Distribution
of Pink Scallop from PFMA 17-10
Ln (Frequency)
5
4
3
2
1
0
3
4
5
6
7
8
Age (Years)

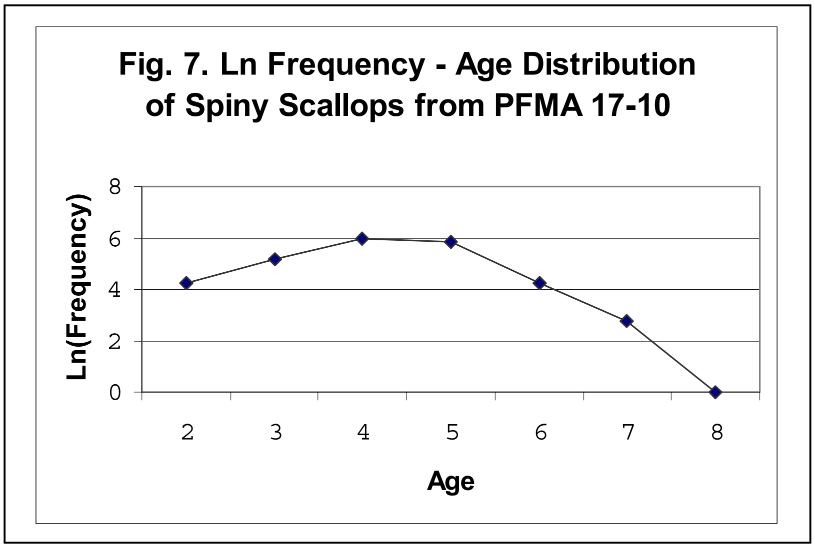
Fig. 7. Ln Frequency - Age Distribution
of Spiny Scallops from PFMA 17-10
Ln(Frequency)
8
6
4
2
0
2
3
4
5
6
7
8
Age

# Appendix 1

## PSARC INVERTEBRATE SUBCOMMITTEE

### Request for Working Paper

**Date Submitted:** Mar. 3,2000

**Individual or group requesting advice:** Erin Wylie, J. Morrison, R. Harbo – Resource Management

**Proposed PSARC Presentation Date:** June, 2000

**Subject of Paper (title if developed):** Assessment Frameworks for the Scallop by Dive Experimental Fishery.

**Lead Author(s):** Ray Lauzier

**Fisheries Management Author/Reviewer:** Erin Wylie

**Rational for request:** The commercial scallop dive fishery was closed on Dec. 31, 1999. The fishery is being presently managed on an interim basis as an experimental fishery. There is a need to develop protocols for stock assessments and to test the effects of harvesting at different rates.

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

What are appropriate biological parameters required to assess the status of pink and spiny scallops?

What type of experimental fisheries can be implemented to collect the biological information necessary to design a sustainable fishery?

What fishery independent data are required to develop an assessment framework (eg. collection of samples, biomass surveys)?

Are there appropriate biological reference points that can be used for assessment and management of this fishery? Is management by time and area closures, rotational fisheries or quotas (an experimental 20% exploitation rate has been suggested) appropriate?

Can we identify a 3 to 5 year program to develop biological and management reference points and frameworks?

Are there adaptive management options (similar to sea cucumber) that could be outlined?

**Objective of Working Paper:**

To design an assessment program and suggest management techniques for a scientifically based sustainable fishery.