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Framework for Goose Barnacle (*Pollicipes polymerus* Sowerby, 1833) Fishery in Waters off the West Coast of Canada

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Abstract

A framework for assessment and management of this fishery is presented for the fishery to proceed in a precautionary manner under scientific licence, and in a manner which collects key information for ongoing assessments and management actions. Components of the framework incorporate previously expressed concerns including non-selective harvest techniques; impacts on breeding success; discards; catch reporting and sustainability of the fishery in traditionally harvested areas. Suggestions for the resolution of these concerns are presented. Data requirements for a precautionary fishery are outlined including removal estimates; abundance estimates and biological information. Assessment models and their data requirements are discussed. Alternative harvest practices are presented. Management options and their data requirements are presented.

Recommendations are made for the development of the goose barnacle fishery 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

On présente un cadre d'évaluation et de gestion de cette pêcherie procédant de manière prudente conformément à un permis délivré à des fins scientifiques servant à recueillir des renseignements clés qui serviront aux travaux permanents d'évaluation et de gestion. Le cadre porte, entre autres, sur des questions qui ont déjà fait l'objet de préoccupations, notamment les techniques de pêche non sélectives, les répercussions sur le succès de la reproduction, les rejets, les rapports sur les prises et la durabilité de la pêche dans des zones d'exploitation traditionnelles. On y propose des solutions à ces problèmes. On y dresse une liste des données nécessaires pour que la pêche soit pratiquée avec prudence, incluant des estimations du prélèvement, des estimations de l'abondance et des renseignements de nature biologique. Il y est question des modèles d'évaluation et des données requises. On y traite aussi d'autres pratiques de pêche alternatives. On y parle des options de gestion et des données nécessaires à cette fin.

On formule des recommandations pour que la pêche du pouce-pied soit mise au point conformément aux étapes décrites dans la politique des pêches nouvelles et en développement de la région du Pacifique, ainsi que des suggestions pour y arriver.

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1 Introduction

As a result of the Phase 0 review of the biology and fisheries of the goose barnacle (*Pollicipes polymerus* Sowerby, 1833) and the concerns expressed by the Invertebrate Subcommittee/Pacific Scientific Advice Review Committee (PSARC), the Resource Management Executive Committee (RMEC) recommended closing the fishery. The fishery was closed by Fisheries Management on May 30, 1999. Any re-opening or development of the goose barnacle fishery would depend on the results of an ecological impact assessment and meeting the criteria for a new and developing fishery. The framework for an ecological impact assessment is in preparation for consideration by the PSARC Habitat Subcommittee. This paper provides a stock assessment and management framework for consideration by the PSARC Invertebrate Subcommittee. Both papers are to be used to provide an overall assessment framework for the potential re-opening and development of the goose barnacle fishery.

2 Objectives

This paper is produced at the request of RMEC as a follow up to the Phase 0 review of the goose barnacle fishery (Lauzier 1999) presented to the PSARC Invertebrate Subcommittee in January 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 management of a new fishery, which addresses the data needs for a sustainable fishery.

3 Phase 0: Results and Recommendations

The Phase 0 review concluded that the overall status of goose barnacles in British Columbia is unknown, as there is insufficient data for assessments. The information gaps identified through this review included the distribution of goose barnacle stocks, estimates of biomass, total fishing mortality, and an updated estimate of proportion of the stocks available to the fishery. While there is some limited information on recruitment, recruitment mechanisms are unknown, as well as the dynamics of recovery following harvesting or disturbance. There is also 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 goose barnacle fishery:

- Non-selective harvesting techniques.
- Ecological impacts.
- Impacts on breeding success.
- Discarding of product due to poor harvest techniques and product suitability.
- Poor catch reporting.

- The sustainability of this fishery is unknown.

In addition, the Subcommittee recommended:

1. Given there are not sufficient data to recommend biologically based management for goose barnacles, more precautionary measures, including new management controls and assessment programs, be considered.
2. That continuation of the goose barnacle fishery must follow the phased approach described in the Pacific Region Policy for New and Developing Fisheries.

4 Response to Subcommittee Concerns

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

4.1 Non-Selective Harvest Techniques

Product quality is a very important factor in this fishery. Goose barnacles vary considerably in body shape and size due to local growing conditions, competition and wave exposure. Stalk configuration determines the consumer product quality: thicker stalks are considered to be better quality product. Harvesting goose barnacle adults attached to mussels and acorn barnacles has resulted in higher quality goose barnacle product (Austin 1987). In a research fishery conducted on the West Coast of Vancouver Island, Austin (1987) showed what is considered to be premium quality, acceptable product and unacceptable product by comparing stalk length, width and volume. In the research fishery, the proportion of the harvest considered to be acceptable ranged from 25% to 73% by weight (mean 50% for 28 samples) and 21% to 64% by number (mean 49% for 11 samples)(Austin 1987).

Experienced harvesters have expressed concerns with local stock damage caused by inexperienced harvesters. This fishery was an unlimited entry fishery, and some inexperienced harvesters were likely attracted by the high value of the fishery, and were only interested in short-term high yield gain.

When the fishery was open, the season was year-round. The only restrictions were that fishing gear was restricted to hand tools and handpicking; no power or mechanical devices were permitted; and harvest by diving was not permitted. There were no restrictions as to the size of a cluster that could be removed at one time. Bernard (1988) found that removal of a segment of a goose barnacle cluster often results in the detachment and loss of the entire structure, either from predation or wave surge. Also, the size of the harvest patch in or near a mixed community may affect the stability of the remaining community.

Therefore harvest techniques should be developed that result in the highest proportion of premium quality and suitable product, and minimizes damage to the surrounding community. In order to test harvesting techniques, experimental protocols can be developed with experienced harvesters. The experimental protocols may be site specific due to the widely varying local conditions found on the exposed coast and the micro-topography that determines the orientation of goose barnacle clusters. The optimum size of cluster removal that results in highest product quality with minimal damage to the remaining community should be determined.

Many harvested species have a seasonal variation in consumer product quality, due to the physiological demands of spawning, or a seasonal low level in metabolic activity and/or nutritional value as a result of seasonal food supply. It is not known whether there is a seasonal factor in the product quality of goose barnacles. Reproductive activity has been shown to occur year round on the West Coast of Vancouver Island, but occurs most frequently from May to November (Bernard 1988). In the San Juan Islands, there was no reproductive activity found between November and March (Lewis and Chia 1981). There is likely a seasonal variation in quality and quantity of food supply for adult goose barnacles, which mainly consists of crustacean remains, as large as 500-1000 μm long, with small copepods, cirripede nauplii, cyprids, diatoms and fine particulate debris (Barnes 1959). An examination of the harvest logs and sales slip database show a substantial increase in landings from May to September. This coincides with the best tides for harvesting, which occur in the morning during the summer months and after dark from September to March (Austin 1987). The research fishery and examination of proportion of suitable product by Austin (1987) was carried out in the summer, during the best daylight tides, but also during peak reproductive activity.

4.2 Ecological Impacts

As was discussed in the Phase 0 review, the effects of goose barnacle harvesting activities on co-occurring species needs to be evaluated, especially when goose barnacles attached to acorn barnacles and mussels are considered to be premium quality product. Changing the harvest log to include a field for substrate can capture information on the mortality of the "host" species. The larger issue of an ecological impact assessment of goose barnacle harvesting on the rocky intertidal community is being addressed in a concurrent paper (Jamieson *et al*, in prep).

4.3 Impacts on Breeding Success

Goose barnacles are unique in comparison to most other crustaceans, in that they are sessile organisms with only proximal mobility and fertilization is internal. Lewis and Chia (1981) demonstrated there are particular proximity requirements for successful fertilization. Techniques and guidelines need to be developed for the selective harvest of adults that allow for the retention of viable adults on the rocks within a feasible breeding distance. A comparison of selective harvesting versus cluster removals on the recovery of harvested areas as well as an examination of the effect of cluster removal size on harvested area recovery is required to evaluate the impacts of various harvest techniques on breeding success and subsequent recruitment.

Brooding activity is common in crustaceans, and goose barnacles brood their developing larvae internally for 50 to 60 days on the West Coast of Vancouver Island, with 2 to 5 broods produced per year. While reproductive activity has been shown to occur year round on the West Coast of Vancouver Island, it occurs most frequently from May to November (Bernard 1988). Therefore the issue of seasonal harvesting needs careful consideration as was discussed in Section 4.1, as seasonality may affect product quality as well as breeding success.

4.4 Discards

The development of harvest techniques and guidelines that substantially reduce damaged and unsuitable product could alleviate concerns about the substantial discard rate. Results from a test fishery (Austin 1987) showed that on average, 50% of the harvest was not acceptable product. There is anecdotal information on large amounts of product being harvested, which is not commercially acceptable, resulting in high discards (W.C. Austin, *pers. comm.*). Unlike, many other commercially harvested species, all discards in the goose barnacle fishery are mortalities. Therefore an accurate assessment of proportion of the harvest that is discarded is required to obtain an accurate estimate of total fishing mortality. Adding fields to the harvest log for weight and numbers of unsuitable product would capture the information required for an estimate of total mortality. Discard rate should be closely monitored and evaluated when testing various harvest techniques discussed in Section 4.1.

4.5 Catch Reporting

Catch reporting is one of the most serious issues confronting stock assessment biologists and fisheries managers in this fishery. Experienced harvesters estimate less than 50% compliance with harvest log submission in recent years (T. Hamilton, *pers. comm.*). Judging from the response of the closure in May 1999, compliance may have been overestimated. There are several unresolved inconsistencies between the fish slip database, harvest log database, and the export records. Re-opening this fishery under scientific permit would allow a closely monitored fishery with stringent and enforceable catch reporting requirements. In a commercial fishery, observer coverage or validated landings should be considered to ensure complete and accurate data is available for assessments.

4.6 Sustainability

This fishery has shown the classical pattern of a “gold rush” fishery, with a high initial peak in licences and reported landings, followed by rapid decline to relative stability at apparently low levels. However, there is no accurate estimate of actual fishing mortalities due to lack of reporting compliance in the harvest logs, and no reporting of discards. There are anecdotal reports from experienced harvesters on the decline of suitable product in traditionally fished accessible areas. In the inaccessible or unfished areas are stock trends are unknown. It is also unknown whether stocks in the inaccessible areas provide recruits to stocks in the fished areas. However, there is traditional knowledge from First Nations harvesters that only specific locations have been traditionally harvested, and that repeated harvesting was thought to improve subsequent harvests. This traditional knowledge may be quantified by determining the local distribution, site specific appropriate harvest level, and appropriate recovery times.

It has been estimated that less than 10% of the stock is available to the fishery due to inaccessible harvest areas, and/or unsuitable size and quality of the product for the market (DFO 1998). The estimate of stock availability should be refined or confirmed with distributional and biological surveys, as this will significantly affect the estimate of a sustainable total allowable catch (TAC) or exploitation rate. The issue of sustainability will be addressed in the plan for a phased approach in the goose barnacle fishery.

5 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 goose barnacle fisheries in Europe, South America and South Africa, but information on their management systems, fisheries performance and stock status is not available for comparison with our previously unlimited goose barnacle fishery. From the limited information available on the historic goose barnacle fishery, and the repeated effort of the fishery in particular areas due to accessibility, it has become apparent that the passive management of the past is not appropriate for British Columbia goose barnacles. Therefore a management system must be designed and implemented, 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 (National Research Council 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.

5.1 Stock Definition

At the present time the spatial scale of the stocks under consideration can only be defined by their potential habitat: the rocky intertidal of the open exposed coast. An overall estimate of the species distribution is required, not just the prime accessible areas where the species occurs, in order to confirm what proportion of the stock is vulnerable to potential fisheries, as was discussed in Section 4.6. For example, the proportion of the total stock is on the West Coast of Vancouver Island (Pacific Fishery Management Areas 23, 24, 26) is unknown, but these areas have historically had 92% of the reported effort.

Due to the characteristically isolated areas of the rocky open exposed coast, it could be extremely difficult to conduct a broad range of on-site distributional surveys. However, with the availability of cost-effective and recently refined remote sensing imagery, in combination with detailed surveys at selected ground-truthed sites, a broad-brush distributional survey could feasibly be accomplished over a very wide area, that would also cover inaccessible areas.

Goose barnacles often occur in distinctive rosette-shaped aggregations in the upper intertidal (Hoffman 1989), and these aggregations are typically tightly formed humped clusters 20-40 cm in diameter. Goose barnacles also occur in the mid to lower intertidal, interspersed in dense aggregates with mussels to form the distinctive *Pollicipes-Mytilus* community (Barnes and Reese 1960, Hoffman 1989). Areas of goose barnacle settlement are called habitat patches, and the individuals in each habitat patch make up a population.

Goose barnacles populations, like California mussels, typically are a metapopulation. A metapopulation is a system of local populations that interact by dispersing individuals between populations. In sessile organisms such as goose barnacles, the dispersal is from the planktonic larval stages. Dispersal of goose barnacle larvae can theoretically range from 185 to 930 kilometres, based on the planktonic period of the naupliar larvae (42 days at 12°C) and an average current speed varying between 0.1 and 0.5 knots (Lewis 1975). However, current velocities measured off the West Coast of Vancouver Island are considerably lower (Thompson *et al* 1989), and larval dispersal would likely be restricted locally to areas on the West Coast of Vancouver Island. Substantial impairment of reproductive potential may result in locallized recruitment failure. Recovery would be affected by limited larval dispersal from other areas due to low current velocities.

5.2 Data

There are a number of 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:

5.2.1 Removal Estimates

All removals must be included in the assessment. As was previously stated, lack of compliance in catch reporting is one of the most serious issues confronting stock assessment biologists and fisheries managers in this fishery. Evidence from a previous research fishery, as well as anecdotal information, indicates a very high proportion of the catch is discarded, and this is not being reported in the harvest logs. Harvest logbooks must document all product removed, including product considered unacceptable and discarded. While attempts can be made to reduce the discard rate in future fisheries by a variety of measures, an accurate estimate of total fishing mortality is absolutely essential in the assessment. Adding fields to the harvest log on weight and numbers of unsuitable product would capture the information required for an estimate of total mortality. In the absence of an accurate estimate of total fishing mortality rate, a conservative discard rate should be assumed and applied to estimate total fishing mortality. In order to resolve a potential compliance issue, random observer coverage or validated landings should be considered.

5.2.2 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.

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).

Since goose barnacles are highly visible, clearly defined and distinctive aggregations, the delineation and measurement of individual goose barnacle patches or beds will be relatively easy. Therefore, the first method, the total defined area, will be used for goose barnacles. The abundance and biomass surveys will be conducted in previously harvested areas, in areas where experimental or test harvesting will take place, and in control (non-harvest) areas.

Individual beds can be located from broad-brush surveys or area reconnaissance, and their centres should be geo-referenced with a differential global positioning unit. Bed area may determined with a 100 m tape or surveyors chain by measuring the length of the bed parallel to the water, and taking width measurements at specified intervals perpendicular to the length. Bed area may be calculated by hand or by using geographic information system (GIS) software.

Because goose barnacles occur in highly aggregated clusters, as well as widely interspersed with mussels, a stratified two-stage random design is recommended. Stratified sampling is used to partition the population into that the sampling units within a stratum are as similar as possible (Gillespie and Kronlund 1999). For example, prior knowledge suggests that an area of high barnacle density, the highly aggregated clusters of the upper intertidal, should be partitioned into a stratum and separated from the mid to lower intertidal, where goose barnacles occur in lower densities interspersed with the mussels. Other habitat information could also be used to partition the area into strata, such as settlement substrate. Stratification may not be necessary or appropriate for all sites. However, it will likely to be used at most sites, as there are potential benefits of reduced variances and narrower confidence intervals associated with the resulting estimates (Kronlund *et al* 1998). The delineation of strata will be site-specific after an initial reconnaissance of the sampling area.

Two potential methods for abundance estimates are: (1) individual barnacle enumeration; and (2) cluster enumeration, which would be limited to the upper intertidal where goose barnacles typically occur in tightly humped clusters. Individual goose barnacle enumeration and resulting density estimates can use the same methodology outlined for mussels by Gillespie (1999). As recommended by Paine (1989) for California mussels, sampling quadrats should likely be limited to 100 cm^2 (10 cm x 10 cm), to allow quick recovery. Given the natural densities encountered by Austin (1987) of 2000-5000 barnacles m^{-2}, 20-50 animals could be expected in each 100 cm^2 quadrat. However, an appropriate quadrat size could be determined with field-testing, and sampling intensity (the number of quadrats over a given area) will also need to be determined.

Sample quadrats are selected using a two-stage design. In the first stage, distances are selected at random along the length axis of the stratum. Assuming the quadrat size is 10 x 10 cm, and the stratum length is 20 m, then there are 200 possible quadrats along the length axis. A quadrat position is selected at random between 0 and 199, 89 for example. The quadrat position is then converted to actual distance along the axis by dividing by the quadrat size (0.1 m), and the first selected distance is 8.9 m along a 20 m axis. At each selected distance along the length axis, the width is measured perpendicular to the length axis. At the second stage of selection, three quadrats are systematically placed along the width measurement line from a random starting point. Assuming a 10 x 10 cm quadrat is used along a 5 m width line, then there are 50 possible quadrats for selection. The next largest sample frame that can be divisible by three (number of quadrats to be selected) is 51, representing three 17-quadrat strings arranged from end to end. A random starting point is selected between 0 and 16, 13 for this example. The remaining quadrat positions are determined systematically (by adding 17 to the initial starting point, 13) to give the quadrat positions 30 and 47. These positions are then converted to the actual distances along the width line at 1.3 m, 3.0 m, and 4.7 m. The randomization process is then repeated independently for each width line at the first stage distance along the length axis. The systematic placement of quadrats along the width lines ensures an even sampling effort across potentially strong gradients over tidal heights.

A quadrat frame (recommended 10 x 10 cm) is used to select the animals for sampling. Those that have at least half their body within the quadrat are included. All sampled goose barnacles are carefully pried loose, picked, bagged, labelled and retained for detailed processing. Data required for biomass and abundance estimates are total count and total weight per quadrat. All samples are retained for future selection for further analysis of more detailed biological information.

Mean densities (biomass or abundance) and associated variance can then be estimated using either the two-stage or stratified two-stage estimators provided by Kronlund *et al.* (1998). Mean estimates are then expanded by the bed area to give estimates of total biomass or total abundance. The variances are expanded by the square of the bed area, and then used to calculate standard 95% confidence intervals (Gillespie 1999).

An alternative to enumeration of individual barnacles is the enumeration of barnacle clusters, which could then be expanded by the average density of individual barnacles within clusters. However, this type of estimate would only be suitable in the upper intertidal where the highly aggregated goose barnacle clusters typically occur. The sampling design would be similar to that outlined for enumeration of individual goose barnacles, however the quadrat frame should be considerably larger (eg. 100cm x 100cm), considering that the clusters are typically 20-40 cm. in diameter. Due to the quadrat frame size, the clusters should only being counted and left intact, due to concerns previously expressed about maximum disturbance size (Paine 1989).

Due to the largely inaccessible areas of goose barnacle habitat, the proportion of the stock being exploited needs to be determined, as well as what proportion of the stock is actually being estimated. As a result, only relative indices of abundance and biomass can be expected for goose barnacles on a regional basis. However, in exploited areas, these estimates may then be combined with removal estimates, growth, recruitment and natural mortality as the information becomes available, and then modelled using a variety of techniques to yield estimates of absolute abundance and biomass for a particular area. In most fisheries, catch per unit effort (CPUE), as an index of abundance, has a number of problems including hyperstability, unstandardized fishing effort and changes in catchability (Hilborn and Walters 1992). This is particularly the case in goose barnacles, with individual hand harvesting. The experience, stamina and motivation of the harvester will be a major factor in CPUE, as well as environmental conditions, such as ambient light, visibility, tide cycle, etc.

5.2.3 Biological Information

The biological characteristics of a local population can be assessed by a more detailed examination of individuals collected for enumeration from the abundance and biomass surveys. Quadrat samples should be randomly selected from the survey quadrats and all the goose barnacles in each selected quadrat should be sampled and measured in detail to ensure unbiased estimates of the local population. Individual goose barnacles should be measured for rostral-carinal (RC) length, peduncle length, peduncle volume, weight, and reproductive activity (brooding). The systematic arrangement of quadrats along the width of the sample area of the abundance/biomass survey results in a stratified approach to selecting samples from different tidal heights. Additional biological information could be collected from the commercial catch.

5.2.3.1 Growth and Age

Estimates of growth and evaluation of the size structure of a population will not be a straightforward process with goose barnacles. Growth in goose barnacles is usually determined by measuring the distance between the rostrum and the carina, called the capitulum, or rostral-carinal (RC) length. This may be the most stable relationship, and the biometric variable that best represents linear growth (Cruz 1993), compared to total length, width or weight measured under a range of conditions (W.C. Austin, *pers. comm.*). However, Austin (1987) found significant variations in the capitulum/peduncle size relationship. Bernard (1988) found that the height of the capitulum versus the length of the peduncle vary significantly, depending on the site, intertidal height and exposure to wave surge. There are also examples of variations in the capitulum allometry, related to habitat (Chaffee and Lindberg 1980). While the RC length may often be the best indicator of linear growth, this is not always necessarily the case, depending on local conditions. Therefore, the biological sampling should include individual weight, RC length, as well as peduncle length and volume. Since local conditions appear to have a significant effect on the configuration and growth of the animals, growth and configuration should be assessed from a variety of sites.

Information on age and size structure is required if we are to understand the impact of the fishery on the exploited portion of the population. Ageing will be particularly difficult, as there are no simple proven techniques to age goose barnacles. There is only one study in the scientific literature that attempted to age goose barnacles (Bernard 1988). This consisted of a growth study on 250 tagged individuals, and ageing on 25 individuals using annual check marks on the carinal plate, using the process developed for fish otoliths (Chilton and Beamish 1982). However, this technique for ageing goose barnacles is somewhat tenuous, as the outer layers of the carinal plate have been shown to slough off periodically (Wootton 1993, W.C. Austin *pers. comm*.). It appears that tagging individual in the field and monitoring their growth may be the only reliable method of ageing goose barnacles. This will be a very time consuming and long process. There are also potential problems with tag loss, harvesting, and differential natural mortality.

5.2.3.2 Reproductive Activity

Goose barnacles are cross-fertilizing hermaphrodites. As was discussed previously, fertilization is internal, there are definitive periods of brooding activity, and there are proximity requirements for successful fertilization. Brooding activity and the presence of newly recruited juveniles on adult peduncles should be evaluated during the detailed biological sampling. Comparing brooding activity and an index of proximity from the biological samples would provide valuable information in developing a code of responsible harvesting practices. The number of animals in the sampling quadrat (density) will give a good indication of their proximity. An analysis examining the relationship of brooding activity with consumer product quality may provide information on optimal harvest time for maximum proportion of premium quality product with minimal disruption to reproductive effort.

5.2.3.3 Mortality

Due to a lack of data, the only way to date to estimate natural mortality of goose barnacles is with Hoenig's (1983) generalized mortality model, using the predictive equation:

$$\mathbf{\ln (z) = 1.44 - 0.982 \ln (t_{max})}$$

It should be noted that Hoenig's model is from combined data for all taxonomic groups: molluscs, fish and cetaceans. From Bernard's (1988) data, the maximum age is likely 12 years, and solving the equation results in a natural mortality estimate of 0.37.

Other methods for estimating natural mortality are through catch curve analysis (Ricker 1975), tagging in controlled and uncontrolled areas, and cohort analysis. The use of catch curves for goose barnacles requires information on age, or on growth rates to assign age classes to length-frequency data, both of which will be difficult to obtain as discussed in the Age and Size section above. Mark-recapture tagging in uncontrolled areas has some difficulties in tag-induced mortality, tag loss, or misreporting of recaptures. Tagging studies in controlled areas with a size-structured and habitat-structured program is likely initially the most appropriate method for goose barnacles. However, this will involve continuing studies for several years, and it will be labour intensive.

5.2.3.4 Recruitment

Connell (1985) defines settlement as the point when an individual first takes up permanent residence on the substratum and recruitment as the measure of survival of individuals for a period of time after settlement. Pineda (1994) found that settlement rate of goose barnacles required detailed knowledge of several processes. Recruitment combines settlement with early mortality. Anecdotal information from harvesters on the west coast of Vancouver Island indicates successful recruitment in some areas a year after harvesting, while adjacent areas may show no recruitment for over 6 or 7 years (Leonard Pavio, pers. comm.). Austin (1987) found varying recruitment in Barkley Sound and Clayquot Sound 11 months after harvesting, but four years after harvesting, Austin (1992) found that most of the previously harvested areas could not be distinguished from unharvested areas.

The success or degree of annual recruitment can be evaluated by monitoring previously harvested sites or survey plots. Recruitment and recovery experiments can be conducted by a systematic comparison of settlement substrates, harvest patch size, and habitat characteristics, such as tidal height, exposure, slope, and co-occurring species. These types of studies will be addressed in more detail in Jamieson *et al*, 1999.

5.2.4 Environmental Data

The preferred habitat of the goose barnacle, the rocky open exposed coast, is a dynamic high-energy environment. This is not considered to be a stable environment in terms of extrinsic forces. Given the lack of information on the population size, distribution and recruitment of goose barnacles, there is insufficient information to assess the effects of past environmental change on populations or to predict the effect future fisheries may have on populations. Therefore, it is particularly important that control populations are monitored along with fished populations in order attribute population changes to environmental factors or fishing pressure.

Goose barnacles are closely associated with or attached to California mussels (*Mytilus californianus*), which have been identified as keystone species (Gillespie 1999), and acorn barnacles (Austin 1987). Goose barnacles harvested off acorn barnacles or mussels have less damage due to peduncle rupture than those animals harvested off bare rocks. As was previously discussed in the Ecological Impacts section, harvest substrate information should be collected on the harvest log, to include the mortality of the host species, if there is a host species. An analysis of consumer product quality with harvest substrate would provide additional information in developing a code of responsible harvesting practices.

Additional environmental data should be collected on co-occurring species, as there are numerous examples in the scientific literature on the effects of human activity, such as trampling on organisms of the rocky intertidal. Monitoring ecosystem characteristics, such as species diversity indices, in fished and unfished areas should be considered. A detailed ecological assessment framework will be provided by Jamieson *et al*, in prep.

5.3 Assessment Models

Because of information gaps identified in the Phase 0 review of the goose barnacle fishery, the choice of assessment models for goose barnacles is very limited in the initial attempts of assessment, due to the lack of data. As data is collected from surveys and experimental fisheries, more sophisticated modelling techniques could be used in future assessments.

5.3.1 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. Data will be collected from experimental harvests and fishery-independent surveys.

5.3.2 Surplus Production Models

Specific data requirements for surplus production models are not available for goose barnacles. However, when sufficient data is collected in experimental fisheries and surveys for analysis, 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).

5.3.3 Potential Models

Patterson (1992) suggests that F_{opt} may be 2/3 M when a population is at optimal production levels. However, given our tenuous estimate of M for goose barnacles and our lack of information on the status of the goose barnacle stocks, this approach is not considered precautionary with the data available.

Biomass dynamic models require abundance time series that are not available and fishery-dependent data, which is considered to be inadequate and unreliable in this fishery. Other models require age or size structure, recruitment or biomass indices and/or fishery-dependent data, and cannot be used at this time due to a lack of data. However, these options will be available, when there is sufficient information for analysis.

5.4 Policy Evaluation

5.4.1 Alternative hypotheses

We need to evaluate a spatial scale for assessment and management. We have assumed that goose barnacle populations are a metapopulation. However, we don't know if there are isolated populations that are genetically unique. We also don't know if any 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 are based on local delineated sites of goose barnacle habitat (analogous to mussel beds). We need to determine the applicability of site specific information to expanded areas. We need to determine the most appropriate management unit (individual sites, rock groupings, geographic area (ex Clayquot Sound), or Pacific Fishery Management Subarea) for this fishery.

5.4.2 Alternate harvest strategies and effort controls

There are two important alternate harvest strategies that should be considered for this fishery, rotational harvests, and developing a code of responsible harvest practices. Effort controls could also be considered as alternate harvest practices, but they will be identified as potential management options.

5.4.2.1 Rotational Harvests

In fisheries where exploitation rates may be high, where there are bycatch issues, and where there is expected habitat disturbance, time should be given to allow the area to recover. The goose barnacle fishery will affect other species in the rocky intertidal. We don't know the degree or significance of the impact, which is the subject of a concurrent study (Jamieson *et al.*, in prep.). In an experimental fishery, Austin (1992) found that most of the previously harvested sites could not be distinguished from unharvested areas after 4 years. Other information shows there may be little or no recovery after 6 or 7 years. While we don't understand recruitment mechanisms, we can design fisheries to maximize recruitment by implementing rotational harvests.

5.4.2.2 Responsible Harvesting Practices

Experienced harvesters have been concerned for the past several years with local stock damage caused by inexperienced harvesters who were attracted to the high value of the fishery, and were interested only in short-term high yield gain (T. Hamilton, *pers. comm.*; L. Pavio, *pers. comm.*). The PSARC Invertebrate Subcommittee identified the issues of non-selective harvest techniques and high discard rates as requiring some resolution if this fishery were to proceed in a precautionary manner.

We need to work with experienced harvesters in developing a code of responsible harvesting practices and techniques. We should investigate the feasibility of developing new harvest techniques that result in a high proportion of acceptable quality product. Training should be provided to all harvesters once a code of responsible harvesting practices and techniques has been developed, with subsequent monitoring to ensure the code is being followed.

6 Management Options and their Data Requirements

6.1 Seasonal Closures

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. It appears from the harvest log data, that a large portion of the catch is landed during the summer months, when there are the most favourable tides, but there is some harvest year-round. The time of highest reported landings is also the time of peak brooding activity, followed by period cyprid larvae settlements, which settle preferentially on adult peduncles. We need to determine whether harvesting activities affects the settlement success and survival of juveniles. The effects of winter harvesting activities, combined with the increased and sustained wave surge or debris collisions of winter storms, should be evaluated. These questions can be addressed by designing a year-round experimental fishery that monitors larval settlement and natural disturbance events in harvested areas and control areas.

6.2 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 should 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 (unfished) 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.

While we don't have specific information on the broad coast-wide distribution of goose barnacles, large portions of the stocks are protected by their inaccessibility, and are not vulnerable to the fishery. An updated estimate of what portions of the stocks are inaccessible could be addressed by a broad-brush survey.

We know that historically 92% of the reported effort was from the West Coast of Vancouver Island (Pacific Fishery Management Areas 23, 24, and 26). These areas are interspersed with a patchwork of numerous protected areas from Pacific Rim National Park reserve and other forms of protection. The adequacy of these local refugia in areas of concentrated fishing effort should be evaluated. Protected area delineation will be fairly simple with the recent publication of an atlas on protected areas (Jamieson and Lessard 1999).

6.3 Rotational Harvests

A rotational harvest plan may be particularly appropriate for an experimental goose barnacle fishery, where there is an expected habitat disturbance, but the significance or degree of disturbance is unknown. In order to quantify stock responses to harvests, an initial biomass estimate is required before any harvesting activity. An onsite survey is the preferred method, as it would provide a site-specific estimate with relatively tight confidence intervals. There is also the option of applying a mean density estimate derived from similar sites and expanding the density estimate by the harvest site area to yield a biomass estimate. Biomass surveys or estimates should be repeated at intervals to monitor the response of the stock after a recovery period. In order to quantify community impacts, an initial species inventory would be required before harvesting activity, in order to derive an initial species diversity index. Evidence from a test fishery indicates there would be at least a 3 to 5 year recovery period (Austin 1992).

6.4 Total Allowable Catches (TACs)

The goose barnacle fishery can be managed at a local site or bed level similar to the geoduck fishery (Hand *et al* 1998) and the depuration clam fishery. Individual TACs can be set for each site by applying a harvest rate to the unexploited biomass. While there are few nearshore crustacean fisheries managed with TACs, managing sessile populations by TACs may be particularly appropriate for protection against recruitment overfishing. The regulatory choice of TACs can proceed in one of three implementation choices with the decision tree of Perry *et al* (1999). Biomass information from surveys has the advantage of relatively low costs for industry, and the main disadvantage is the risk of missed fishing opportunities. Another choice could be biomass information from removal experiments, with the advantage of low costs to industry, but with the risk of overfishing due to a variance in estimates. Biomass removal experiments could be implemented under a structured rotational fishery plan, and the biomass data collected could be used to set TACs for commercial fisheries in the future.

6.4.1 Biomass

To set a TAC for an area, an estimate of the available unexploited biomass (B_0) is required. Unfortunately there are likely not many accessible places left on the West Coast of Vancouver Island that have not had some form of exploitation in the last few years. Because the harvest logs have not been geo-referenced, it is impossible to trace the harvest sites through the harvest logs. Anecdotal information from the harvesters may be useful, but we don’t know the extent or sites of unreported catch.

Estimates of biomass at each site can be conducted with the survey design outlined in the Abundance Estimates section prior to harvest. Ideally, all sites would be surveyed at least once, and as the fishery develops, average densities for sites within geographic areas could be developed. Representative sites, randomly selected from known sites in the area, are surveyed to yield average densities. The average density could then be expanded over measured sites to give preliminary biomass estimates for each site. These preliminary densities could be ground-truthed by on-site observers during the fishery. Monitoring of the effects of the fishery at each site could be accomplished by rotating biomass surveys to coincide with a rotational fishery, if this policy is adopted.

6.4.2 Harvest Rate

As described previously in the Assessment Models section, harvest rate calculations may be taken from natural mortality estimates. However, we need good estimates of natural mortality (*M*), and currently we only have a preliminary estimate (0.37) based on Hoenig's (1983) general model and a 12 year maximum age. Using 0.2 as a scaling factor in Gulland's model (Gulland 1971), the initial target harvest rate could be 7.5 % of the unexploited biomass. We can test the effectiveness of the preliminary harvest rate by monitoring the effects of experimental fisheries that have applied harvest rates above and below the initial recommended harvest rate.

6.5 Target or Threshold 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 goose barnacle fishery, the harvest rate calculated from Gulland's production model could be considered as an appropriate target reference point. However, we need to refine our estimate of natural mortality before we apply a harvest rate based on this 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 goose barnacles are considerably more productive than geoducks, but given the potentially high variability shown in goose barnacle recruitment, and insufficient information on a number of other parameters, including initial biomass, a conservative critical threshold limit should be applied to any developing goose barnacle fishery.

Target and threshold reference points would be very useful in an adaptive management system. However, to ensure the reference points are precautionary and appropriate, there must be accurate estimates of initial virgin biomass and natural mortality.

7 Discussion

The goose barnacle fishery is not a new fishery as First Nations people have historically used goose barnacles on the west coast, and there has been an unlimited commercial goose barnacle fishery since its inception in 1978 until the recent closure in May 1999. While the fishery has been unlimited in terms of regulatory controls, it has been limited by accessibility and by market forces. It has been estimated that less than 10% of the stock is available to the fishery, indicating that the coast-wide stocks themselves are not at risk. However, the sustainability of the fisheries in small and limited areas may be at risk, with no regulatory controls and fishing effort concentrated on these small and limited areas. The goose barnacle fishery has the traits of an over-utilized fishery in some of the historical fishing areas.

There is considerable evidence for under-reporting of catch, from non-compliance of harvest logs requirements, and from the apparently high discard rate. Therefore, it is extremely difficult to obtain an estimate of unexploited or virgin biomass. This is an extremely important parameter for basic assessment models and critical threshold levels. There are other assessment models and threshold levels that could be used as the fishery develops, but they have considerable data requirements that cannot be met at this time.

The goose barnacle fishery is being considered as a developing fishery for management purposes, as we are only now starting to develop a management plan. Some of the precautionary measures suggested by FAO (1995) for developing fisheries, or existing fisheries that are not yet managed include:

(1) Immediately put a cap on both fishing capacity and total fishing mortality. This can be achieved by strictly limiting effort and by developing a conservative TAC. Limiting entry will be by scientific permit, since the goose barnacle fishery is now closed. Site-specific TACs would be developed using the survey protocols and precautionary harvest rates described previously.
(2) Establish area closures to limit risk to the resource and the environment. There are presently area closures in areas of previously concentrated harvesting activity, and the efficacy of these closures will be evaluated. In addition, large areas of the coast are inaccessible to the fishery.
(3) Establish precautionary, preliminary biological reference thresholds. A threshold of 50% of the existing available biomass could be considered, as it may be very difficult to obtain an estimate of the initial biomass in many areas.
(4) Encourage responsible fishing practices to ensure the long-term persistence of a productive stock or other parts of the ecosystem. A rotational fishery is being recommended for the goose barnacle fishery as well as the evaluation of

harvesting techniques and the development of a code of responsible fishing practices.

(5) Encourage the development of fisheries that are economically viable without long-term subsidies. The goose barnacle fishery was a relatively high value (~$9.00/kg) at its closing. However, the total assessment and management costs in relation to the total landed value should be determined.

(6) Establish a data collection and reporting system for new fisheries early in their development, including both fishery-dependent (logbooks, verified landings) and fishery-independent (assessment surveys, experimental harvests) sources of information. Compulsory observer coverage and verified landings are recommended for the goose barnacle fishery to overcome the reporting non-compliance problem and assess and document the discard rate. In addition, abundance and biomass surveys are recommended before any harvesting proceeds.

(7) Immediately start a research program on the stock and fisheries. This Phase 1 framework for a goose barnacle fishery has provided an outline to collect the required information that addresses the needs for a sustainable fishery. Experiments are recommended to assess age and growth.

(8) Take advantage of any opportunities for setting up experimental fisheries to generate information on the resources. Experimental fisheries in limited areas that test the appropriateness of the preliminary harvest rate have been recommended.

In addition, FAO (1995) recommendations for over-utilized fisheries, that may be applicable to the goose barnacle fishery in some historical fishing areas, include special precautionary measures:

(1) Establish a recovery plan that will rebuild the stocks over a specific time period with reasonable certainty.

(2) Reduce fishing mortality rates long enough to allow rebuilding of the stocks. A rotational fishery is recommended for the goose barnacle fishery to allow for recruitment in the harvested and recovery of the surrounding community.

(3) Reduce fishing capacity to avoid recurrence of over-utilization. The goose barnacle fishery was closed in May 1999 due to conservation concerns.

The purpose of this paper is to address the concerns arising from the Phase 0 review on the biology and fisheries of goose barnacles and to provide a stock assessment and fisheries management framework for a sustainable goose barnacle fishery. In addition, to address concerns on the ecological impact of goose barnacle harvesting, a framework on the ecological impact of harvesting activities on the rocky intertidal is also being prepared concurrently. Both papers are to be used in developing an overall assessment framework for the potential re-opening and development of the goose barnacle fishery.

8 Recommendations

In order for the development of the goose barnacle fishery to follow the phased approach described in the Pacific Region Policy for New and Developing Fisheries, the following recommendations are presented:

(1) A broad-brush survey/inventory of goose barnacle populations in wide geographic areas (e.g. West Coast of Vancouver Island) is necessary to identify the large scale distribution, identify index and study areas, and to estimate the proportion of the stock accessible to potential harvesting. This the first activity that should take place, in the early to mid spring of 2000.

(2) Selected goose barnacle sites within smaller geographic areas (e.g. Clayquot Sound) should be identified, measured and geo-referenced in order to provide baseline information for the selection and establishment of control sites and experimental harvest sites within the smaller geographic areas. Experimental fishing areas should be established to test alternative harvesting practices. This should occur in mid spring 2000.

(3) Following site selection, biomass surveys or biomass estimates using defined protocols would be conducted prior to any harvesting activity at a particular site. These are necessary to provide baseline information on initial biomass, a vital component in the establishment of biological reference points, the derivation of TACs and necessary to assess the recovery of harvested sites. Biomass surveys of harvest sites, which are scheduled to be harvested in the immediate future, should be conducted first, in order to expedite the harvesting opportunities. This could be followed by biomass surveys of regionally representative sites, in order to develop mean density estimates for specific areas. This in turn would be followed by biomass surveys of the control sites. These surveys could occur from late spring, throughout the summer until the fall.

(4) Biological information collected by measuring specific parameters from a subsample of the samples collected from the biomass surveys is necessary to derive estimates of growth and natural mortality, a vital component in the establishment of precautionary harvest rates. These data would be analyzed concurrently with the biomass surveys. Experiments will also be conducted over the long term to monitor and assess age, growth, recruitment, and natural mortality to supplement the biological information collected from the abundance and biomass samples.

(5) Recommended changes to the harvest log include geo-referencing landings in order to track effort, reporting of discards in order to estimate total fishing mortality, and documentation of substrate in order to assess collateral damage. This should be implemented before there is any further harvesting activity.

(6) Harvest techniques, including the development of new approaches, if considered necessary, that are more selective and result in a higher proportion of high quality product should be evaluated.

(7) A code of responsible harvesting practices should be developed and training should be provided to all harvesters once a code has been developed and approved.

(8) A rotational harvest plan may be particularly appropriate for an experimental goose barnacle fishery, considering the recruitment and habitat disruption issues that have been identified. A specific rotational harvest plan should be established in close consultation with stakeholder groups, as this fishery was prosecuted from small isolated coastal communities, and provided a major source of income to these communities. The harvest plan should take into consideration the economic stability requirements of these communities.

(9) The participation of committed stakeholders in planning the implementation of these recommendations as well as in the surveys and experiments is highly recommended to integrate their experience and traditional knowledge with a scientifically based assessment and management plan.

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