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A review of the biology of the Pacific milky venus clam (Compsomyax subdiaphana) and the fisheries of related subtidal species

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Abstract

A review of the biology on the Pacific milky venus clam *Compsomyax subdiaphana* was conducted from previous surveys, scientific literature, technical reports and consultant reports. Where there was little or no existing information, a review of the biology of similar species was conducted from the scientific literature and stock status reports.

A review of previous fisheries on similar species was conducted, focusing on East coast stocks, where there is a history on the mechanical harvests of subtidal clam stocks, and where there are developmental fisheries on subtidal clam stocks. Stock assessment strategies, management strategies and measures from previous fisheries were reviewed. Recommendations for additional information requirements for stock assessment are given.

Résumé

Un examen de la biologie du clam venus du Pacifique, *Compsomyax subdiaphana* a été réalisé à partir des résultats de relevés antérieurs, de publications scientifiques, de rapports techniques et de travaux de consultants. Lorsque les renseignements s'avéraient insuffisants ou absents, l'examen a alors porté sur les caractéristiques biologiques d'espèces semblables mentionnées dans les publications scientifiques ou les rapports sur l'état des stocks.

Il a aussi été procédé à l'examen de pêches ayant déjà porté sur des espèces semblables. On s'est surtout intéressé aux stocks de la côte est où il y a eu récolte mécanique de clams de la zone infratidale et où l'on procède à des pêches de mise en valeur de ces stocks. Les stratégies d'évaluation des stocks de même que les stratégies de gestion et les modes de mesures appliqués aux pêches antérieures sont passés en revue et l'on formule des recommandations sur les besoins de renseignements supplémentaires aux fins de l'évaluation de ces stocks.

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1. Introduction

The Department of Fisheries and Oceans placed a moratorium on new invertebrate fisheries in the Pacific Region in 1990, as the department lacked the resources to adequately manage new fisheries and to collect and analyze the biological information necessary to develop a sound management strategy. Since then, several new invertebrate stocks have been identified for future potential exploitation. The neon flying squid (*Ommastrephes bartrami*), Pacific milky Venus clam (*Compsomyax subdiaphana*), and the deepwater or grooved Tanner crab (*Chionoecetes tanneri*) have been identified as having the most immediate potential. An exploratory licence was issued for the Pacific milky Venus clam in 1991 and in 1994, and exploratory fishing has focussed mainly on the Trincomali Channel area of the southern Gulf Islands.

There are ongoing discussions between Fisheries and Oceans Canada and the Ministry of Agriculture, Fisheries and Food of the Province of Briitish Columbia, in order to develop guidelines for the development of new fisheries, and to increase the diversity of seafood available for the markets

1.1 Fishery Development

1.1.1 Pacific Region Interim Guidelines for the Development of New Invertebrate Fisheries

The objective of the Pacific Region Interim Guidelines for the Development of New Fisheries is to ensure the orderly development of a sustainable, viable fishery. In order to meet this objective, five goals are proposed for managing new fisheries:

(1) Ensures sustainability and conservation through a precautionary approach to management. DFO requires a reasonable scientific basis for the management of any new fishery. Unfortunately, little information on the resource and the impact of harvesting or culture is available for most new fisheries. Until sufficient information exists for reasonable biological basis to manage the resource, development of new fisheries will be conservative and gather the necessary information for sound resource development.

(2) Encourages Aboriginal involvement. Aboriginal people have the constitutional right to fish for food, social and ceremonial purposes, and this right to the resource is second only to conservation. Any new fishery must not neglect this constitutional right.

(3) Allows an economically viable fishery to develop. Fishery participants must be given the chance to learn whether or not the new fishery is viable.

(4) Keeps new fishery development cost neutral to government. Since government resources are already subscribed to manage existing fisheries,

participants in new fisheries must pay additional costs to initiate and manage a new fishery.

(5) Provides open, fair and consistent process for participation. The roles of the federal and provincial governments, the fishing industry, and other stake holders must be clearly specified. For specific fisheries, the process decided upon for a given species or stock must be publicly released and adhered to. Further, agreements with licensees, which detail all responsibilities to be undertaken, will be required before a licence is issued.

(6) Provides a return to the public for access to a public resource.

Under the interim guidelines, new fisheries will generally involve two distinctive stages:

(1) Exploratory Stage. The objective of this stage is to determine whether harvestable quantities of a species or stock exist in a particular fishing area, if a proposed harvesting technology can work successfully, or if new methods of culture are feasible. Fisheries at this stage would be short and held to low harvest levels. Licence holders would be required to provide the basic data needed for assessment of a fishery at this stage.

(2) Development Stage. The objective of this stage is to determine whether a species or stock can sustain a commercially viable operation. At the same time, the biological data necessary to create a preliminary database on stock abundance and distribution will be collected. Participation and harvest would still be controlled at precautionary levels but large enough to ensure that sufficient information is generated for an adequate stock assessment and commercial evaluation of the new fishery.

1.1.2 Goals for the Development of a New Fishery

The goals for establishing a new fishery as outlined in the Memorandum of Understanding between the Federal Government of Canada and the Provincial Government of British Columbia signed in December 1995 are to:

(a) diversify British Columbia fisheries and seafood production to ensure the conservation of stocks and realize the optimal sustainable use of fisheries resources and fish culture;
(b) encourage a competitive business approach to fisheries and aquaculture diversification, and maximize marketing opportunities;
(c) diversify the seafood sector in British Columbia to promote employment opportunities, foster community development and secure social and economic stability; and
(d) encourage public and private sector cooperation in fisheries diversification, including new arrangements between regional communities, harvesters and growers.

1.2 Biological Objectives

The biological objective for a fishery on the Pacific milky Venus clam (*Compsomyax subdiaphana)* is to maintain a viable, healthy, and productive stock throughout it's natural range in British Columbia. Three basic biological objectives were provided for the management of Pacific Region fish and invertebrate stocks by Rice *et al.*. (1995). These provided the framework for the specific biological objectives for the Venus clam. These objectives are:

(1) Ensure the population and subpopulations of Venus clams along the B.C. coast do not become biologically threatened (as defined by COSEWIC) throughout their ecological range.
(2) Ensure sufficient production and survival of progeny, after accounting for all sources of mortality (including all fisheries and natural mortality), to ensure sustainable reproduction throughout it's ecological range.
(3) Ensure that a fishery for Venus clams does not violate the two previous objectives for other ecologically related species.

There is an underlying requirement to collect sufficient biological data in order to determine a safe (in terms of risk averse) level of harvest, as well as to be able detect changes in stock dynamics (from any cause) in time to prevent long-term decline or collapse of the stock due to over-exploitation.

1.3 Plan for the Development of a New Fishery on Venus Clams

The framework for providing scientific information for precautionary management strategies is described in detail by Perry *et al.*. (1997 in press). Basically three phases of activities are required to develop fisheries in a precautionary manner:

Phase 0: Collection of existing information. This involves a summary of all known biological, distribution, and fisheries related information on the target species, and from similar species in similar habitats. A thorough literature review and an examination of all available data sources should provide some of the information required and suggest appropriate management strategies.

Phase 1: Fishing for information. A limited fishery is conducted in order to acquire information that may be lacking in Phase 0, as well as to test or develop management strategies and to determine the feasibility of a fishery.

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

This paper is the Phase 0 review of known and derived information on the Venus clam, *Compsomyax subdiaphana.*

2. Current Knowledge of *Compsomyax subdiaphana*

2.1 *Biology and Life History*

2.1.1 Background

The Pacific milky Venus clam *Compsomyax subdiaphana* (Family Veneridae, Subfamily Clemintiinae) is also known as the deep water little neck clam and the deep water venus clam. Other species in the same family include the butter clam (*Saxidomus giganteus*), the little neck clam (*Protothaca staminea*), the Manila clam (*Tapes philippinarum*), and the hard clam (*Mercenaria mercenaria*).

The *Compsomyax subdiaphana* is described as plump with a thin shell with fine concentric lines (Harbo 1997) The white to light gray valves are characteristically very thin, and translucent (Keep and Bailey 1935) or semitransparent (Morris 1974), and somewhat brittle.

There is little information on the biology of *Compsomyax subdiaphana*.

2.1.2 Distribution

C. subdiaphana is distributed from 28°N (Baja California) to 61°N (Alaska) in the Eastern Pacific Ocean (Bernard 1983). In Washington, *C. subdiaphana* is distributed along the outer coast (Lie and Kisker 1970), and in Puget Sound (Goodwin 1973). The presence of *C. subdiaphana* was documented in British Columbia from the southern Gulf Islands, near Victoria, Burrard Inlet, the northern Strait of Georgia, Kanish Bay near Discovery Passage, the West Coast of Vancouver Island from Barkley Sound to Quatsino Sound, and the Queen Charlotte Islands in benthic surveys conducted in the early and mid-1960's (Quayle 1961, Quayle 1963, Ellis 1967a, 1967b, 1968). In most areas sampled by Quayle (1961), *C. subdiaphana* were relatively sparsely distributed, even though it was the most abundant bivalve species collected. However, in Trincomali Channel off Saltspring Island, and Skidegate Inlet in the Queen Charlotte Islands, relatively high concentrations were encountered by Quayle (1961). Relatively high concentrations were also found in Fulford Harbour, Satellite Channel, and the mouth of Cowichan Bay by Ellis (1967a) (Table 1).

2.1.3 Habitat, Ecological Relationships, and Co-occurring Species

C. subdiaphana are a dominant species in soft mud/silt bottom communities, typically 20-100 m deep (Bernard 1978, Quayle 1961). This species has been collected from concentrated pockets (21-119/m^2) using a Van Veen grab in sand/silt/clay substrates at 24-76 m depths, in Fulford Harbour and Satellite Channel by Ellis (1967a, 1968). Off the west coast of Washington and the Juan de Fuca Straits, *C. subdiaphana* were collected in lower densities (1.6-8.3/m^2) at greater depths (80-164 m) with a Van Veen grab (Lie and Kisker 1970) (Table 2). More recent surveys using rocker dredge tows in a wide variety of habitats (Krause 1994) found increased densities of *C. subdiaphana* in sediments with a higher sand and mud component (Table 3). This study also indicates that *C. subdiaphana* may be the dominant molluscan species in the samples with muddy substrates, as the bycatch was considerably reduced with increasing *C. subdiaphana* density (Table 3). Quayle's (1961, 1963) dredge surveys also showed that when *C. subdiaphana* was present, it was often the dominant species. However, this may be a sampling artifact of the dredge. A close examination of surveys using a Van Veen bottom grab indicates that while *C. subdiaphana* may be the dominant biomass in a sample, densities of *Macoma* species, sedentary polychaetes (*Sternaspis fossor, Pista cristata*), errant polychaetes (*Nephthys* spp., *Lumbrinereis* spp.) and *Brisaster* spp. are usually higher than *C. subdiaphana* densities (Ellis 1967a, 1967b, 1968).

C. subdiaphana were commonly found with other bivalves (*Yoldia amygdalea, Y. ensifera, Macoma carlottensis, M. calcarea, M. brota, M. elimata, Axinopsida serricata*), sedentary polychaetes (*Sternapsis fossor, Pista cristata, Praxillella* spp., *Prionospio* spp., *Maldane* spp.), errant polychaetes (*Lumbrinereis* spp., *Gonaida* spp., *Nereis* spp., *Nephthys* spp., *Onuphis iridescens*) and the echinoderm *Ophiura sarsi* in the southern Gulf Islands (Ellis 1967a). In a Trincomali Channel dredge survey, *C. subdiaphana* were found with bivalves (*Yoldia* sp.), polychaetes (*Aphrodite* sp., and Sabellid and Nereid polychaetes), tunicates, anemones, and seastars (*Luidia* sp.), in muddy substrates (Cousens and Lee 1991). In deeper waters, *C. subdiaphana* were also found with *Macoma carlottensis, M. elimata, Yoldia ensifera, Axinopsida serricata, Sternapsis fossor, Pista cristata, Prionospio* spp., and *Nephthys* spp. (Lie and Kisker 1970).

Bernard (1978) characterized the benthic communities of Georgia Strait by their dominant species. The dominant species found in the mud/silt substrates of Georgia Strait are shown in Table 4. *C. subdiaphana* was found to co-occur as a dominant species along with *Acila castrensis* (bivalve), *Brisaster latrifons* (heart urchin) and *Glycera capitata* (errant polchaete) at depths ranging from 20 m to 300 m. The presence of *C. subdiaphana* as a dominant species over a broad range of depths in Georgia Strait, is indicative of it's adaptation to reduced oxygen, which is characteristic of deep water habitats, but may also be found in shallow (20 m) water where debris accumulation and persistent sedimentation occur (Bernard 1978). A large portion of the sediments of Georgia Strait are muds and clays (Pharo and Barnes 1976), the habitats where *C. subdiaphana* is commonly found.

2.1.4 Food, Feeding Habits

C. subdiaphana has a relatively short siphon and may reside just at, or partly below the sediment surface (Bourne, cited in Krause 1994). *C. subdiaphana*, a venerid clam, is typically a filter feeder (Bourne, pers. comm.).

C. subdiaphana has been shown to co-occur with *Macoma* species over a range of depths and varying substrate (Ellis 1967a, Lie and Kisker 1970). *Macoma* species appear to have developed a competitive advantage over other species in the broad range of depths and substrate types in which they are found, by adapting to use one of three feeding modes: deposit feeding; suspension feeding; and/or feeding on bacterial film off sand grains. It is not known if *C. subdiaphana* has developed a similar competitive advantage with feeding adaptations, as the siphon is relatively short in comparison to *Macoma* (G. Gillespie pers comm.).

2.1.5 Reproduction

There has been no work done on reproduction of *C. subdiaphana*, with the exception of a preliminary examination of clams caught in an exploratory fishery in March 1992. Evidence of sexual maturity was seen in clams as small as 30 mm (Bourne 1992). The reproductive habits of closely related species will be discussed in Section 3.1.5 of this paper.

2.1.6 Growth and Age

The length frequency distribution of *C. subdiaphana* sampled in the southern Gulf Islands in 1994 is shown in Fig. 1. The size distribution of *C. subdiaphana* sampled from Fulford Harbour differed from those sampled from other areas, as the mode is 45 mm, and in other areas, the mode is 50. The tow at Fulford Harbour was made at the mouth of the harbour along a shelf (Krause 1994). The substrate was also a gravel/mud mixture (Table 3), which is not the preferred habitat of *C. subdiaphana*. Ellis's sampling of Fulford Harbour was much closer inshore, about midway in the narrow portion of the harbour (Ellis 1968). The biomass estimated by Ellis sampling with a van Veen grab were much higher (357.4 g/m^2)(Table 1) than the biomass estimate from the mouth of the harbour using a dredge (4.26 g/m^2)(Table 3). The population from Plumper Sound appears to have a larger portion of larger individuals in comparison to Fulford Harbour and Ganges/Swansen Channel. The densities in Plumper Sound were also considerably higher than any other areas sampled (Table 3). The most densely (19.82 g/m^2) populated area sampled by dredge was also the shallowest (15-18 m) area sampled. A comparison of the length frequencies in 1991 and 1995 in Trincomali Channel and the 1994 frequencies in the southern Gulf Islands is shown in Fig. 2. The mode for all areas was 50 mm. However, the frequency at the mode was higher (39%) in the 1994 overall southern Gulf Islands sample compared with the 1991 (28%) and 1995 (30%) Trincomali samples.

A comparison of length and weight data for *C. subdiaphana* sampled from various areas in the southern Gulf Islands is shown in Table 5. The Fulford Harbour sample had the fewest number of individuals and the narrowest range, likely due to the marginal *C. subdiaphana* habitat that was sampled in 1994. In the other areas, length and weight parameters were similar. The sample from Plumper Sound had the smallest minimum sized clam (length 25.9 mm, weight 4.0 g), and the sample from Trincomali Channel had the largest maximum sized clam (length 66.9 mm, weight 78.7 g).

The length at age data for *C. subdiaphana* sampled from Trincomali Channel in 1995 is shown in Fig 4. The ages remained to be confirmed as the age determination criteria have not been verified (Bourne, pers comm.). Although the rings have been interpreted as being deposited annually, this may not necessarily be the case. However, this is only aging data available for *C. subdiaphana*, and this was used in preliminary analyses of age, growth and mortality estimates. The fitted line in Fig 4 is the von Bertalanffy growth curve. The calculated growth parameters from the fitted curve are L_∞ (asymptotic maximum length) = 58.61 mm, k (growth constant) = 0.2447, and t_0 (age at which the length would be hypothetically zero) = -0.0290. This similar to values calculated for littleneck clams (L_∞ = 56.778, k = 0.287, t_0 = 0.193) from a beach at Savary Island (Gillespie *et al.* 1995).

The catch curve for *C. subdiaphana* sampled from Trincomali Channel in 1995 is shown in Fig 5. Natural mortality estimates can be made from the slope of the decreasing limb of this graph. The linear least squares fit of the descending limb is:

$$y = 1.9959 - 0.2042x, \quad R^2 = 0.9569 \qquad \text{Eqn 1}$$

However, $y = \ln z$, therefore substituting in Eqn 1:

$$\ln z = 1.9959 - 0.2042x. \qquad \text{Eqn 2}$$

The maximum age of *C. subdiaphana* was 15 years, solving for z when $x=15$:

$$\ln z = 1.9959 - 3.0630 = -1.0671 \text{ and } z = 0.3440.$$

The natural mortality rate estimated from the descending limb of the catch curve in Fig. 5 is 0.3440.

Natural mortality estimates were also made using Hoenig's (1983) predictive equation of:

$$\ln(z) = a + b \ln(t_{max}) \qquad \text{Eqn 3}$$

where, for mollusks $a = 1.23$, $b = -0.812$,
and this particular case of *C. subdiaphana*, $t_{max} = 15$, substituting in Eqn 3 and solving for z:

$$\begin{aligned} \ln(z) &= 1.23 - 0.812 \ln(15) \\ &= 1.23 - 2.1989 \\ &= -0.9689 \end{aligned}$$

and $z = 0.3795$.

The natural mortality rate of *C. subdiaphana* sampled from Trincomali Channel in 1995, based on preliminary aging, ranges between 0.3440 and 0.3795.

2.1.7 Population Dynamics

There has been no work done on the population dynamics of *C. subdiaphana* populations. There has not been a commercial fishery on this species. and this species is not exploited by the recreational fishery, due to it's relatively deep subtidal habitat. Dredge design and operation, as well as sampling methodology, has not been fully developed to adequately evaluate the resource, and thus collect sufficient data to study the population dynamics of *C. subdiaphana*.

2.1.8 Predators, Parasites and Diseases

There has been no work done on predators, parasites or diseases of *C. subdiaphana*. However, this topic will be addressed Section 3.1.8 on related species.

2.2 Fisheries

2.2.1 Review of the *Compsomyax subdiaphana* Experimental Fishery

There has only been a limited experimental fishery for *C. subdiaphana* conducted in 1991, 1992 and 1995 mainly in Trincomali Channel. The landings and effort are shown in Table 6. The total landings were 3052 lb from 14 fishing days between June, 1991 and June, 1992 (Bourne and Harbo 1992). The initial fishery was conducted with a home made dredge, but a Fall River rocker dredge was used from November, 1991 onward. The low landings in June 1991 may have been due to the original dredge, as the landings increased substantially with 1 day's fishing in Nov. 1991 (Table 6). The very low landings in 1995 are a reflection of the very low effort in comparison to 1991 and 1992.

3. Discussion and Literature Review of Related Species

Because there is little information on the biology of *C. subdiaphana*, the biology of venerid clams in general, or the biology of a closely related venerid clam species should be reviewed, in order to assist in the understanding of the biology of the target species. Also, because *C. subdiaphana* has not been previously commercially exploited, with the exception of a very limited experimental fishery, the fisheries of other subtidal clam species should be reviewed in order to anticipate what might be expected from this type of fishery.

The closely related species of the same family (Veneridae) which are found in British Columbia waters include the butter clam (*Saxidomus giganteus*), the littleneck clam (*Protothaca staminea*), and the Manila clam (*Tapes philippinarum*) (Bernard 1983). These species are mainly found in intertidal habitats, however *Saxidomus giganteus* and *Protothaca staminea* have been found in the shallow (up to 15m depth) subtidal zone (Quayle 1963, Goodwin 1973). The northern quahog or hard clam *Mercenaria mercenaria* of the same family (Veneridae) is native of East coast intertidal and subtidal habitats (AFSSR 96/102).

Clam species that occur exclusively in the subtidal, and have been exploited by dredge fisheries on the East coast include: the ocean quahog (*Arctica islandica*) (Murawski and Serchuk 1989); the Stimpson's surf clam (*Mactromeris polynyma*)

(Lambert and Goudreau 1995); and the Atlantic surf clam (*Spisula solidissima*) (Murawski and Serchuk 1989) The soft-shell clam (*Mya arenaria*) occurs in the intertidal and has been exploited by dredge fisheries during high tides (AFSSR 96/10). The soft-shell clam is also found in the intertidal zone on the West coast (Bernard 1983). In Alaska, the Alaska surf clam (*Mactromeris polynyma*) occurs in the subtidal at potentially exploitable levels (Hughes and Bourne 1981)

3.1 Biology and Life History

3.1.1 Background

Eventhough it is predominantly an intertidal clam, the littleneck clam (*Protothaca staminea*), probably has the most similar characteristics to *C. subdiaphana* in comparison to other venerid clam species, including subtidal clams. It is closely related phylogenically (Bernard 1983), it also occurs in the subtidal zone, it has similar size and growth characteristics, as shown Section 2.1.6, it has similar age distribution, and it is found in slightly different substrates, usually gravel/mud/sand, whereas *Compsomyax* is usually found in mud/silt/sand substrates. Therefore, in terms of biology and life history of venerid clams, discussion will focus on the littleneck clam (*P. staminea*).

3.1.2 Distribution

The littleneck clam (*P. staminea)* is one of the most widely distributed hard-shell clams along the Pacific coast of Canada and the United States, occurring in well sheltered areas (Chew and Ma 1987). It is found from California to the Aleutians from the mid-intertidal to 10 m subtidal (Quayle and Bourne 1972). In Puget Sound, they have been found at the 18 m depth (Goodwin 1973).

3.1.3 Habitat, Ecological Relationships, Co-occurring Species

Littleneck clams are subjected to temperature fluctuations from slightly less than 0°C to up to 25°C when they occur intertidally. Optimum conditions for larval littlenecks are temperatures ranging from 10 to 15°C and salinity ranging from 27 to 32 ppt (Phibbs 1971). For adult littlenecks, salinity tolerance ranges from slightly less than 20 ppt to 30 ppt (Chew and Ma 1987).

Young littleneck clams are restricted to the upper 2 cm of sediment (Paul and Feder 1973 cited in Chew and Ma 1987). Adults in the intertidal zone burrow to a maximum depth of 20 cm (Glude 1978 cited in Chew and Ma 1987).

Littleneck clams are often found with butter clams, but the usually occur in a firmer more gravely substrate and slightly higher in the intertidal zone (Quayle and Bourne 1972). In a Puget Sound shallow (1-21 m depth) subtidal survey, butter clams and littleneck clams were the two most frequently sampled species. Butter clams were found in 31 % of the samples, and littleneck clams were found in 26 % of the samples. Littleneck clams were found with butter clams 94% of the time they were sampled.

The abundance of littleneck clams was greatest in shell substrates, and least in mud and sand substrates. Littleneck clams were found as deep as 18 m (Goodwin 1973). The littleneck clam is not restricted to permanent residence at the initial settlement location (such as the butter clam), as it has the ability to use it's foot to crawl to a new location (Shaw 1985).

3.1.4 Food and Feeding

The littleneck clam is a filter feeder, by collecting a particular particle size fraction from plankton, which is small enough to ingest (Schmidt and Warme 1969). Juvenile littlenecks are restricted to particles less than 10 μ in diameter, mainly benthic diatoms, and perhaps sediment bacteria (Peterson 1982).

In general, clams feed on living organisms and detritus within a particular size range, with phytoplankton forming a major part of the diet (Quayle and Bourne 1972). Water is drawn through the inhalant siphon into the mantle cavity and over the gills, which are used for respiration as well as filter feeding.

Littleneck clams have two pairs of highly specialized gills (ctenidia), one each side of the visceral mass. Food particles are caught in the food grooves of the gills, and moved by ciliary action to the labial palps and the mouth (Chew and Ma 1987). Size selection takes place at the labial palps and the mouth, where particles of suitable size are ingested, and the remaining particles are expelled as small compacted clumps (pseudofaeces) through the inhalant siphon (Quayle and Bourne 1972) (Schink *et al.*. 1983). There is some evidence that littleneck clams move to optimize their food intake (Schmidt and Warme 1969)

Some species feed directly on surface mud, from which food is extracted. (Quayle and Bourne 1972). Some clams absorb dissolved substances, such as calcium and amino acids, from water. The subtidal Atlantic surf clam (*Spisula solidissima*) readily removes at least six amino acids from seawater (Stephens and Schinske 1961). As mentioned in Section 2.1.4, *Macoma* species have developed the ability to use one of three feeding modes.

3.1.5 Reproduction

Littleneck clams have separate sexes, and mature at 2-3 years and at 22-35 mm length (Quayle 1943). Spawning period varies throughout it's range (Chew and Ma 1987), however in British Columbia, they spawn from April to October (Quayle 1943). During spawning, eggs and sperm are discharged through the exhalant siphon, and mass fertilization takes place in open water (Quayle and Bourne 1972). The first stage of development, the trochophore larvae takes place about 12 hours after fertilization, followed by the veliger stage in the next 24 hours. After 1 week, the larvae are about 0.15 mm long, and they feed on phytoplankton in the upper water column. The planktonic larval period is approximately three weeks, after which they settle as to the bottom and search for suitable substrate. Once a suitable substrate is found, the larva undergoes metamorphosis (Chew and Ma 1987). Reproductive success is often determined by the critical larval period (Quayle and Bourne 1972). Size on settlement is 0.26-0.28 mm length (Shaw 1985). Mortality is highest during the first year after settlement (Schmidt and Warme 1969).

3.1.6 Growth and Age

Growth of the littleneck clam varies throughout it's range. A comparison of length vs age data from populations in California (Mugu Lagoon), Alaska (Porpoise Island, Galena Bay), and British Columbia (Strait of Georgia, Victoria) show the best growth in the Strait of Georgia (Chew and Ma 1987). There can be a great deal of variation in growth between sites in fairly close proximity, as seen on Savary Island in 1995 (Gillespie *et al.* 1995). This is mainly due to the vertical position on the beach, which limits the available time for the animals to feed (Gillespie pers comm.). At one site (Site 101), the growth parameters for littlenecks from the von Bertalanffy curves were similar to the growth parameters from a population of *C. subdiaphana* sampled from Trincomali Channel in 1995, as discussed Section 2.1.6.

3.1.7 Population Dynamics

Recruitment patterns in bivalves are often erratic and unpredictable (Bourne 1987). Annual recruitment of littleneck clams varies a great deal between areas (Chew and Ma 1987). In California, Peterson (1975) found variation in recruitment was highest in littleneck clams in compared with all other species in a 3 year study in Mugu Lagoon. In Prince William Sound, Alaska, recruitment has been erratic, with very low recruitment between 1967 and 1971 (Paul and Feder 1973 cited in Chew and Ma 1987).

An examination of mortality rates of littleneck clams in Mugu Lagoon, California, showed that mortality rates varies with age in a sigmoidal pattern. The risk of death was high in larvae and juveniles, but lowered considerably on reaching sexual maturity, and rising again with "old age" (Schmidt and Warme 1969).

3.1.8 Predators, Parasites and Diseases

The moon snail (*Polinices lewisi*) is a common predator of intertidal littleneck clams (Quayle and Bourne 1972). Crabs (*Cancer anthonyi*) (Peterson 1982) and octopus (*Octopus dofleini*) are also predators, with littleneck clams making up 16% of the diet of octopus (Hartwick *et al.*. 1982). Benthic fishes, such as the Pacific staghorn sculpin (*Leptococcus armatus*), diamond turbot (*Hypsopsetta guttulata*) and California halibut (*Paralichthys californicus*) are known to crop the siphons of littleneck clams (Peterson and Quammen 1982). Two carnivorous gastropods, *Forreria belcheri* and *Shakyus festivus* have been observed feeding on littlenecks in California (Schmidt and Warme 1969. In Prince William Sound, the seastars *Pycnopodia helianthoides* and *Evasterias troschellii* prey heavily on littleneck clams (Chew and Ma 1987).

In California, two species of tetraphyllidian cestodes have been found in littleneck clams. These clams often harbour large numbers of the larval tapeworms (*Echeneibothrium* spp.) (Chew and Ma 1987).

There are no known epidemic diseases in littleneck clams (Quayle and Bourne 1972).

3.2 Fisheries

3.2.1 Background

Since the proposed fishery for *C. subdiaphana* is a subtidal dredge fishery, discussion of previous fisheries on other species will focus on subtidal dredge fisheries. This discussion will focus on fisheries on the East coast, where subtidal populations of other species are harvested by various types of dredges.

3.2.2 Subtidal Clam Fisheries

3.2.2.1 Stimpson's/Arctic Surf Clam

Stimpson's surf clam (*Mactromeris polynyma*), also known as the Arctic surf clam, is a deep water clam found in the north Pacific and northwestern North Atlantic Ocean. It is slow growing species with a life span of 30 to 40 years. Data collected from 4 sites in the Gulf of St. Lawrence showed average sizes ranging from 89 mm to 104 mm, with corresponding ages of 28 to 40 years (AFSSR 96/103). In the Gulf of St. Lawrence, surf clam beds are mainly in sandy substrates at depths to 40 m (Lambert and Goudreau 1995).

The Stimpson's surf clam fishery in the southern Gulf of St. Lawrence began in 1990 with two experimental permits. In 1992, 4 zones were established where biomass was estimated and TAC's set from the estimated biomass. The original TAC in 1992 was set at 633 t or 1.7% of the total fishable biomass. In 1995, two more zones in the St. Lawrence estuary were added to the fishery, and the number of participants increased to 12. By 1995, the estimated total fishable biomass was 50,000 mt. (AFSSR 96/103). A history of TAC's and catches of the Stimpson's surf clam in the Gulf of St. Lawrence is shown in Table 8. The fishing gear used in this fishery is the New England hydraulic dredge, which has a reported efficiency of over 90%. However, the mortality of non-harvested clams due to damage from the dredge has been estimated at over 67% (Lambert and Goudreau 1995b).

The Gulf Stimpson's clam fishery has gone through several management changes since it's beginning (AFSSR 96/103). Several new beds have been found within existing fishing areas, which would be suitable for harvesting. Many of the fishing areas have a number of beds, and there is a risk of over exploiting these beds (Lambert and Goudreau 1995b). There is consideration being given to a rotational harvesting strategy, in order to have a better distribution of fishing effort. This would protect the reproductive potential of the harvested beds, as there is an estimated 90% decrease in reproduction caused dredging activity. There is also evidence that clams left exposed from dredging activity are heavily preyed upon by groundfish and crustaceans (Waiwood unpublished data cited in AFSSR 96/103).

The Arctic surf clam fishery on Banquereau Bank began with developmental surveys in 1980-1983. A survey conducted in the 1980's estimated a biomass of 561,000 t of the Arctic surf clam on Banquereau Bank. However, as the fishery developed, there are indications that the area containing commercial concentrations may be smaller than originally estimated (AFSSR 96/37). A new extensive survey is being conducted in the area, including the collection of RoxAnn data on two banks, which was used to stratify a dredge survey (Roddick 1996). A history of TAC and annual catch is shown in Table 9. The fishery on Banquereau Bank grew until 1989, when effort switched to the Grand Bank. In 1992 and 1993, all fishing took place on the Grand Bank. However, in recent years, effort has returned to Banquereau Bank, and landings in 1995 were the highest on record (Table 9) (AFSSR 96/37). The fishery is presently being conducted by 3 large freezer vessels using hydraulic dredges. These highly mobile vessels are shifting to unfished areas, and have not returned to previously fished areas (AFSSR 96/37).

Management measures being considered for the Arctic surf clam which would be used with, or in place of a TAC, include permanently closed broodstock areas, and rotational harvesting. Permanently closed broodstock areas would prevent recruitment overfishing. Rotational harvesting, which would be on a schedule tied into growth and recruitment patterns, would prevent growth overfishing (AFFSR 96/37).

In the United States, reported landings of the Arctic surf clam occurred only in 1990 and 1991, at 688 mt and 211 mt respectively, and the gear used was clam dredges (NMFS Commercial Fisheries Statistics Division).

3.2.2.2 Atlantic Surf Clam

The Atlantic surf clam (*Spisula solidissima*), also known as the surf clam and the bar clam, is distributed from the Gulf of St. Lawrence to Cape Hatteras, in sandy substrates at depths ranging from coastal beaches to 60 m (AFSSR 96/100). This species does not burrow deeply, and is usually found in 2-3 cm in the substrate (AFSSR 96/122). The Atlantic surf clam can live up to 37 years with a maximum shell length of 226 mm (Ropes and Shepherd 1988). Sexual maturity is reached in the second year, with shell length of 45-85 mm (Ropes and Shepherd 1988). Spawning occurs from late July to early October with external fertilization. The planktonic stage is 4-5 weeks (AFSSR 96/100).

In the Gulf of St. Lawrence, it is fished intertidally by hand and subtidally with hydraulic dredges (76 cm blade width) towed by lobster boats. Recruitment to the commercial fishery takes 5-6 years. The commercial fishery is supplemental to the lobster and crab fishery. Few of the 21 mechanical harvesting licences in PEI are active, and only 20% of the 716 manual licences are active. A history of commercial landings in the southern Gulf of St. Lawrence is shown in Table 10.

The commercial hydraulic, manual and recreational fisheries are managed by seasonal closures, gear type, daily bag limits (recreational only), and minimum size limits. In southeastern New Brunswick, the fishery is closed during the spawning period, from June 1 to October 1. In Prince Edward Island, the fishery is closed to diving from April 1 to December 31. The minimum size in Prince Edward Island and Nova Scotia is 76 mm, while in New Brunswick, the minimum size was recently increased to 102 mm. It has been suggested that the minimum size be increased to 102 mm in all areas of the Gulf in order to allow spawning for 2 years before recruitment to the commercial fishery (AFSSR 96/100).

Off the Atlantic coast of the United States, there has been an Atlantic surf clam fishery since 1940 (Murawski and Serchuk 1989). A history of the commercial Atlantic surf clam fishery and ocean quahog fishery is shown in Table 11. Landings during the 1950's increased steadily, with an expansion of the fleet to 100 small boats (Murawski and Serchuk 1989). However, a fleet restructuring followed with half the number of boats by 1965, but with a individual increase in size and fishing capacity and a shift from owner-operated to processing company ownership. From 1966 to 1976, there was a shift to large stern-rigged vessels, and changes to the hydraulic dredge design, including a substantial increase in dredge width. Technological changes were also occurring with processing, with automatic shucking. This was an important development, as with hand shucking, only the largest clams (>140 mm) were landed, due to the inefficiencies of shucking small clams. At the same time, intensive research, initially sponsored by industry, was undertaken to survey for new harvestable concentrations, as well as to characterize the size composition, growth and recruitment and to monitor production and productivity (CPUE) of the various fishing areas (Murawski and Serchuk 1989). Production was fairly stable, around 20,000 mt between 1965 and 1969 (Table 11). A large concentration of clams of a single year class was found off Chesapeake Bay in the early 1970's. Fleet size increased in numbers (from 54 to 98 vessels) and individual vessel size (from 26-75 GRT to > 100 GRT), and there was an increase in processing capacity to accommodate the increased landings (Murawski and Serchuk 1989). Landings peaked at 43,596 mt in 1974 (Table 11), but by 1976 the Chesapeake stocks were quickly depleted (Murawski and Serchuk 1989), and landings in 1976 declined by 49% to 22,298 mt (Table 11). Also, in 1976, a large hypoxic water mass killed a large portion of the surf clam resource off northern New Jersey. With the surf clam stocks at historic lows, and the concentration of the fleet at the limited resources of another area, management plans for the Atlantic surf clams were first implemented (Murawski and Serchuk 1989). With the decline of surf clam landings, effort was directed at ocean quahogs (*Arctica islandica*). Prior to 1976, all quahog landings were from the nearshore close to Rhode Island. However, a fishery developed offshore from New Jersey and Maryland (Murawski and Serchuk 1989). Ocean quahog landings increased substantially with the new fishing areas in the mid-1970's, and stabilized in the late 1970's (Table 11).

By late 1977, management plans for surf clam and ocean quahog fisheries were implemented. The objectives (Murawski and Serchuk 1989) of the initial fishery management plan were:

(1) Rebuild the declining Atlantic surf clam stocks to allow an eventual harvest level approaching 23,000 tonnes (the 1960-1976 avg. annual catch);
(2) Minimize short-term economic dislocations to the extent possible with the first objective, and promote economic efficiency; and
(3) Prevent the harvest of ocean quahogs from exceeding biologically sound levels, and direct the fishery towards maintaining optimum yield.

Initial management strategies included annual quotas on surf clams and ocean quahogs, with quarterly quotas on surf clams to spread the catch throughout the year. There was also a moratorium on new vessels in the surf clam fishery, as well as mandatory logbook reporting requirements for vessels and processing plants. There was also a weekly limitation on fishing time. The initial surf clam quota was 13,600 tonnes. Short-term closures were imposed when quarterly quotas were significantly exceeded. By 1985, the quota had increased to 20,400 tonnes, but each vessel was only allowed 6 hours fishing time every 2 weeks as the CPUE had risen several hundred percent. An initial minimum size was set at 140 mm to restrict the catch of small individuals. In 1983, a target discard rate of not more than 30% of the landed catch was set. In 1985 the minimum size was adjusted to 127 mm to achieve this target (Murawski and Serchuk 1989) and could be accomodated by the automated shucking.

Ocean quahogs are a very slow growing long-lived (up to 100 years) (Ropes 1988) (Ropes and Jearld 1987). Ocean quahog landings have been relatively constant (Table 11). Calculations of the MSY have been based on "area-swept" population estimates with biological reference points derived from yield per recruit studies. Recognizing the limited productivity of the ocean quahog resource, managers chose a relatively low exploitation rate of approximately 2% per year (Murawski and Serchuk 1989). Ocean quahogs are particularly vulnerable to commercial exploitation as there is little annual variability in population size or structure, due to the absence of recruitment, very slow adult growth rates, low rates of adult mortality, and long time to maturity. In the early 1990's, the ocean quahog stocks off New Jersey were heavily fished, and by the mid-1990's, these stocks were depleted (Kennish and Lutz 1995). However, fishing effort has shifted to other areas which were less exploited, and overall U.S. commercial landings have been fairly stable (Table 11).

The rapid development of the surf clam industry on the U.S. Atlantic coast and subsequent shift in fishing effort to ocean quahogs is an excellent example of the vulnerability of this type of fishery to over capitalization.

4. Discussion

Newly discovered fishery resources are often developed before the basic information required to prudently manage the stocks is available. Information such as the biological characteristics of the target species, and the size, structure, and productivity of the newly exploited stocks is gathered during the developmental phase. A typical scenario for a developing fishery is an increase in catch and effort over time, as experience is gained in the fishery, until catches decrease despite high levels of effort (Hilborn and Sibert 1988). With any new fishery, there is the risk of overfishing the resource, but there is also the risk of underexploiting the resource, such that there is a failure to test the productive potential (Smith 1993).

4.1 Biological Considerations

The typical reproductive strategy of bivalves is the release of millions of eggs and sperm into the water column, and fertilization in the water column. A single spawning period of a population may last several months. Viable larvae undergo development through the trochophore and veliger stages, followed by settlement and metamorphosis to benthic juveniles. There are three basic life history categories of potential bivalve recruits: planktonic larvae, meiobenthos (newly settled larvae), and macrobenthos (Feller *et al.*. 1992). An operational definition of recruitment for macrobenthos given by Feller *et al.* (1992) is the settlement of larvae followed by post-larval survival and growth to a size capable of retention on a 0.5 mm. sieve. Given the uncertainty of stock recruitment relationships in bivalves (Bourne 1995), and the highly variable recruitment patterns seen in bivalves (Bourne 1987, Feller *et al.*. 1992), one must assume that there are many complex relationships affecting bivalve recruitment which warrant close examination.

A close examination of the transitional stages in bivalve recruitment by Feller *et al.* (1992) showed that despite variability in timing of settlement, and recruitment of soft-bottom benthos, the timing when recruitment activity is highest is very predictable. The best correspondence between peak abundances was between larval abundance and meiobenthic abundance, and the relationship between larval abundance and macrobenthic abundance was poor, indicating a possible bottleneck between the meiobenthic and macrobenthic stages.

Knowing that there may be a possible bottleneck between the meiobenthic and macrobenthic stages of a bivalve species, and that this a critical phase in determining the chances of successful recruitment, should be taken into consideration when planning the type and timing of harvest activities. There are examples of how harvesting activities have detrimentally affected the reproductive success of remaining stocks of Arctic surf clams (AFSSR 96/103). Hydraulic harvesting has left broken remnants of the heavy shelled bivalve *Cyprina islandica* in it's tracks, resulting in feeding by flounder and cod (Medcof and Caddy 1971). In an Australian scallop fishery, there is evidence that 4-5 times more scallops were damaged by the dredge than were caught and landed by the dredge, and within 9 months of the start of the fishery, all the stock in the fishing area was lost, likely due to bacterial infection resulting from decomposing scallops left on the bottom (McLoughlin *et al.* 1991). Knowing some of the unique biological characteristics of the target bivalve species, such as the shell thickness and brittleness, predator/prey relationships, it's proximity to the sediment surface, and it's ability to reburrow, should also be taken into consideration when planning the type of harvest activity.

From a community standpoint, the effects of harvesting activity on co-occurring species should be evaluated. There is evidence that sediment resuspension from dredging has lethal effects, such as smothering benthos, and creating anaerobic conditions sufficient to kill infaunal benthos, as well as sublethal effects, such as preventing spat settlement, inhibited settlement of veliger larvae, reduced growth rates by enforced anaerobic respiration, and reduced nutrient value of suspended material available for filter feeders (Jones 1992). Caddy (1973) showed that predatory fish and crabs were attracted to scallop dredge tracks within 1 hour of fishing at densities 3-30 times higher than background densities. A shift in community structure may have profound long-term effects on the future productivity of the target species. Finally, potential changes (and their longevity) in physical habitat characteristics, such as substrate particle size distribution, dissolved oxygen gradients, and sediment compacting or flocculation should be evaluated.

4.2 Management Strategies

Guidelines for the development of new fisheries developed by FAO (1995) outline precautionary measures that should be utilized in developing fishery management plans, including: restricted access; conservatively capping fishing capacity and total fishing mortality rate; temporary licences; protective measures for the resource and the environment, such as area closures; fishing in a manner to ensure the long-term persistence of a stock; establishing a data collection and reporting system early in the fishery; and conducting research and experimental programs to generate additional information on the resource. Also, in developing a precautionary management plan, there is the need to develop responses to unexpected or unpredictable events in a timely manner (FAO 1995). An adaptive management strategy is required. The strategy outlined by Hilborn and Sibert (1988) has two elements: the first is a monitoring system which estimates the stock size and measures effort; and the second is a response system which allows an effective control of effort as biological and environmental conditions change.

Management measures for intertidal clams on the West Coast include a minimum size limit (which allows clams to spawn at least once before reaching legal size), area licencing, time and area closures, gear restrictions (no mechanical harvesting), and the present open access fishery will become a restricted access fishery in 1998. The depuration harvest is more conservatively managed with TAC's which are set as a proportion of the estimated legal stock from the most recent assessment survey (PSSR 1997a in press). Management measures for geoduck clams, which are harvested by divers subtidally, include a harvest rate of 1% per annum based on yield-per-recruit analysis, area management, and area and time closures to allow for recovery (PSSR 1997b in press).

On the East coast, management measures for Arctic surf clam, which is still in a developmental phase, include limited access, area management, TAC's set at 1.7% of the total fishable biomass, and there is consideration being given to rotational harvesting, due to the detrimental effects of the hydraulic dredge being used for harvesting (AFSSR 96/103). On Banquereau Bank, extensive surveys are being carried out using RoxAnn, followed by stratified surveys using dredges, in order to estimate biomass and set a TAC. In addition, permanently closed broodstock areas, and rotational harvesting are being considered (AFSSR 96/37).

Management strategies appropriate for *C. subdiaphana* should include: a very limited entry, due to the unknown virgin biomass; limited exploratory fishing areas, TAC's, time and area closures, and rotational harvesting, due to the destructive potential of dredging activity; and permanently closed areas in order to monitor regime shifts and protect broodstock.

4.3 What Can Be Expected for <u>Compsomyax subdiaphana</u>

There is little known of the commercial distribution of *C. subdiaphana*. While this appears to be a widely distributed species, it is not known if there are extensive aggregations sufficient to support a commercial fishery. As seen with other developing subtidal clam fisheries on the East coast, additional areas supporting significant concentrations of clams may be found with further exploratory surveys. A learning phase is anticipated as the sufficient aggregations are sought out, and the operation of the dredge is refined to enable sufficient catches with a low discard rate. Large fluctuations in CPUE are expected during the initial learning phase, as seen in previous surveys, which may not reflect relative abundance accurately. As the fishery develops, there will likely be decreases in CPUE, and size and age composition, as seen in other subtidal clam fisheries (Murawski and Serchuk 1989). Also, fluctuations in abundance and size composition over time can be expected as a natural occurrence. The catch rates in a sustainable fishery are expected to be lower than initially observed during the developmental phases.

The destructive potential of dredging activities is major concern in the proposed fishery for *C. subdiaphana*. Due to the very thin shell of *C. subdiaphana*, it should be assumed that contact with the dredge, whether it is retention or "pass-through" by the dredge, or contact with the dredge on the bottom, will result in 100% mortality of the affected *C. subdiaphana*. In addition, it is expected that additional mortality will occur in the surrounding area from increased predation pressure on the remaining stock and potential bacterial infections from damaged animals. It is expected that there will be sublethal effects from increased respiration difficulties and decreased nutrient value in suspended food particles resulting sediment resuspension.

The area proposed for the *C. subdiaphana* fishery is an ecosystem that depends on a number of physical processes for the transfer of energy from the highly productive near-surface waters and sediment input sources to the benthos. *C. subdiaphana* is found in the relatively undisturbed soft sediment areas, implying a relatively slow currents. Transport of food to benthic communities is heavily influenced by currents (Levings *et al.* 1983), and slow currents imply a slow rate of energy transfer. Population dynamics are affected by this energy flow, and it is expected that production would be lower than in intertidal, or shallow water species found in higher current areas. It is expected that recovery of the soft sediment benthic community following dredging activity would be slower than anticipated for communities in higher current areas.

5. Conclusions

5.1 Conclusions on Available Information

From the available information in previous benthic surveys, we know that *C. subdiaphana* is relatively wide-spread in soft silt/muddy substrates throughout the West coast of British Columbia. We know the type of habitat preferred by *C. subdiaphana*, the type of species co-occurring with this species, and *C. subdiaphana* is often the dominant species in particular types of habitats. We also know, that some relatively concentrated aggregations of this species occurs in some areas. Data from previous surveys, and a comparison of other similar species in the scientific literature shows a number of similarities between *C. subdiaphana* and the littleneck clam (*P. staminea*) in terms of age, growth and reproduction, as well as their close phylogenic relationship.

What we don't know specifically about *C. subdiaphana* is their biomass in different areas and the productivity of various types of habitat. We also don't know their specific food preferences and feeding habits, and whether or not they have the ability to change feeding strategies as seen in some co-occurring species. We don't specifically know their vertical distribution in the sediments, their reburrowing ability, or their mobility. We don't know their predators and their potential for predation following harvesting activities. We don't know their spawning time, duration or fecundity. We don't know specifics about their larval stage, such as length of time, settlement timing, metamorphosis to meiobenthos and development to macrobenthos. We have no specific information on the population dynamics and productivity of this species.

From the literature, we know the results of a rapidly expanding fishery on subtidal clams, and the management strategies and measures required to maintain a sustainable fishery. From stock status reports, fisheries management plans, and the scientific literature we know the harvest rates set for developing fisheries. From the literature, we also know of some of the effects of particular types of mechanical harvesting activity on differing species of subtidal clams on the East coast.

5.2 Basic Information Requirements

In order to effectively manage a developing fishery for *C. subdiaphana* we need certain basic information to make prudent decisions affecting the future of this resource. Primarily we need to know the virgin biomass and confirm the natural mortality. There are no other fisheries which may have affected this resource, and the opportunity must be taken to collect such vital information at the start of the fishery. From the East coast experience, TAC's for developing subtidal clam fisheries are set as a proportion of the total fishable biomass. Initial TAC's should be set as a proportion of the known accessible biomass. The available data do not reflect substantial stocks, and considerable work is required to realistically assess the available biomass. TAC's may be adjusted in the future to reflect any changes in biomass estimates, as was seen in the East Coast fishery in the Gulf of St. Lawrence.

As with the Banquereau Bank stocks of Arctic surf clam, extensive bottom typing surveys using RoxAnn, Questar Tangent, or similar types of sophisticated echo sounding are required to delineate the potential habitat for *C. subdiaphana* within the proposed fishing area, followed by a statistically rigorous sampling design for stock assessment, including biomass estimates, and an assessment of age and growth. Sampling stocks with a dredge will cover fairly large areas in a reasonable amount of time, and give some realistic expectations for catches. Using a stratified random design would give reasonably accurate estimates with a relatively small number of samples, as was seen with Russell's (1972) estimates of *Mercenaria mercenaria* stocks in New England.

A great deal of information, including stock size, age structure, estimates of production, growth, mortality and stock yield, can be derived from initial dredge surveys, as was seen in the stock assessment of newly discovered Alaska surf clam (*Mactromeris polynyma*) stocks (Hughes and Bourne 1981). A biological sampling program, concurrent with the dredging activity, is required for an assessment of age, growth, productivity, and sexual maturity. Biological sampling should include: length; weight; age; length at annulus; and sexual maturity. Dredge survey information should include: vessel name; date sampled; haul number; gear used (description and dimensions, warp length); time, depth and position at start; time, depth and position at end; predominant substrate types; wind direction and speed; sea state; capture information (species and number, collateral damage).

In addition to dredge surveys, concurrent benthic grab surveys should be conducted to assess any possible dredge bias in sampling and to provide another means of assessing co-occurring species. Dredge efficiency studies should be conducted to evaluate the actual dredge catch and "pass-through". Evidence from previous dredge fisheries shows a very high mortality of "pass-through" and discarded animals and the extent of this expected mortality must be assessed.

All sampling programs and fishing activity should be geo-referenced as there is a reasonable expectation that a rotational fishery may be required to allow the remaining stocks to recover from dredging activity, and directing and controlling effort has been successfully used in other subtidal clam fisheries. Recent advances in position location hardware make geo-referenced data easy to acquire at a reasonable cost, and is invaluable both from a stock assessment and fisheries management point of view.

The proposed new fishery is significantly different from other developing fisheries in that the method of harvest may have more potentially adverse effects on the remaining stocks, than the actual removal of harvested product. There is conflicting evidence from dredge fisheries on the East coast as to the extent and duration of damage. However, there is convincing evidence that hydraulic dredging has severe detrimental effects on Arctic surf clam. There is also evidence that other types of clam and scallop dredges have detrimental lethal and sublethal effects on the target species and co-occurring species. Due to the unique characteristics of the target species, such as a thin and brittle shell, and suspected shallow position in the substrates, the effect of harvesting activity on the remaining stock warrants close examination. This should include in situ studies of the remaining stocks of the target species, as well as the co-occurring species. Any shifts in community structure, such as species abundance and diversity, and the magnitude and duration of these potential shifts should be evaluated. Monitoring species abundance and diversity of permanently closed areas as a control to assess potential regime shifts should also be conducted.

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Table 1: Density, Biomass, and Habitat Characteristics of *Compsomyax subdiaphana* in Satellite Channel south of Saltspring Island, B.C. (from Ellis 1967, 1968)

Station	Date	Density #/m²	Biomass g/m²	Depth (m)	Mean Substrate Composition		
					% Sand	% Silt	% Clay
Fulford	02/10/65	119	357.4	24			
Satellite Ch. Ctr	01/10/66	21	522.7	76	62.2	23.8	14.0
Satellite Ch. W	01/11/66	77	933.8	62	18.7	45.9	35.5
Cowichan Bay	01/11/66	9	201.9	61			
Satellite Ch. E	01/12/66	23	134.2	50	76.1	15.2	9.1

Table 2: Density and Habitat Characteristics of *Compsomyax subdiaphana* sampled off the west coast of Washington and the Straits of Juan de Fuca by Lie and Kisker (1970)

Station	No./0.6m²	Mean Substrate Composition			Depth (m)
		% Gravel	% Sand	% Mud	
43	1	0	38.3	61.6	125
8	1	0	32.5	67.3	117
1	1	0	30.7	69.3	126
16	3	0	38.1	61.9	140
42	2	49.0	12.3	38.7	80
20	1	0	56.3	43.7	164
33	5	0	77.9	22.1	96
27	1	0	60.4	39.6	123
46	26	0	50.9	49.1	70

Table 3: Bottom type, depth, *Compsomyax subdiaphana* biomass, and bycatch from rocker dredge tows conducted in southern Gulf Islands, Juan de Fuca Strait and Victoria by Krause (1994).

Tow # & Area	Depth (m)	Bottom Type	*Compsomyax subdiaphana* Ttl Biomass (Kg)	*Compsomyax subdiaphana* Biomass/m^2 (g)	Bycatch Ttl No + Vol + Wt	Bycatch Ttl Species
1 Cowichan	30	Mud	1.3	1.05	23	7
2 Cowichan	30	Mud	1.3	1.14	5	2
4 Ganges	25	Mud	6.3	2.47		
5 Fulford	25	Gravel/Mud	6.6	4.26		
6 Satellite	27-32	Gravel/Rock	1.25	1.86	43	6
7 Fulford	27	Gravel/Sand	7.0	5.63	24 + 1L	8
8 Moresby	26	Mud/Rock	3.0	2.76	30 + 1.5L + 1 Kg	9
9 Plumper	15-18	Sand/Mud	26.75	19.82	7	3
10 Plumper	26	Sand/Mud	10.0	8.04	12 + 0.1 Kg	4
11 Haro Str	25-28	Rock/Sand	0.75	0.96	59 + 3L	12
12 J de Fuca	10-14	Rock/Mud	0.3	0.52	53 + 30L	11
15 J de Fuca	25-30	Gravel	0	0	9 + 1L	7
16 J de Fuca	25-30	Gravel/Sand	0	0	34 + 3L	11
17 J de Fuca	15-21	Gravel/Sand	0	0	13 + 1.5L	7
18 Victoria	25-28	Sand/Mud	0.25	0.12	32 + 3L	9
19 Victoria	26	Mud	1.5	2.06	8 + 1L	6
20 Victoria	26	Mud/Sand	0.5	0.69	39 + 30L	9
21 Victoria	32-34	Rock/Sand	0	0	37 + 20L	8

Table 4: Summary of dominant species in mud/silt substrates by depth in Georgia Strait from Bernard (1978)

20-100 m Depth	100-200m Depth	200-300 m Depth	300-400 m Depth
Acila castrensis *Aphrodite japonica* *Brisaster latrifons* ***Compsomyax subdiaphana*** *Glycera capitata* *Luidia foliata* *Maldane glebifex* *Pachycerianthus fimbriatus* *Pandora filosa* *Sternaspis fossor* *Tachyrhynchus lacteolus*	*Acila castrensis* *Aphrodite japonica* *Arhynchite pugettensis* *Brisaster latrifons* *Cidarina cidaris* ***Compsomyax subdiaphana*** *Glycinde armigera* *Glycera capitata* *Lucina tenuisculpta* *Pandora filosa* *Sternaspis fossor* *Thyasira gouldii* *Travisia pupa*	*Acila castrensis* *Arhynchite pugettensis* *Brisaster latrifons* ***Compsomyax subdiaphana*** *Cidarina cidaris* *Crangon communis* *Glycera capitata* *Lucinoma annulata* *Macoma brota* *Onuphis iridescens* *Paracaudina chilensis* *Solemya* spp. *Thyasira disjuncta* *Thyasira gouldii* *Travisia pupa*	Aphrodita minuta *Arhynchite pugettensis* *Brada villosa* *Brisaster latrifons* *Echiura* spp. *Lucinoma annulata* *Pachycerianthus fimbriatus* *Paracaudina chilensis* *Pasiphaea pacifica* *Sipuncula* spp. *Solemya* spp. *Thyasira disjuncta* *Travisia pupa*

Table 5. Length and Weight Data of *Compsomyax subdiaphana* sampled at various southern Gulf Islands locations in 1994 (Ganges, Fulford, Plumper) and 1995 (Trincomali).

	Ganges		Fulford		Plumper		Trincomali	
	Length	Weight	Length	Weight	Length	Weight	Length	Weight
Average	45.72	27.39	47.10	28.59	48.75	36.04	47.14	28.19
Std. Dev.	6.87	13.39	1.56	3.58	7.06	15.66	6.09	11.92
Min.	33.58	7.5	42.13	19.50	25.91	4.0	34.40	7.2
Max.	62.07	73.50	49.64	36.50	61.06	68.50	66.90	78.70
Count	144	144	48	48	117	117	203	203

Table 6. Landings and effort for *Compsomyax subdiaphana* from experimental fishery in 1991, 1992 (from Bourne and Harbo 1992), and 1995.

Dates	Statistical Area	Location	Fishing Days	Landings (lb)
June 9/91	17	Trincomali Channel	1	67
Nov 26/91	17	Trincomali Channel	1	320
Nov 28/91	17	Nanoose Bay	1	0
Dec 2,3,4,6/91	17	Trincomali Channel	4	895
1991 Total Landings				**1282 (0.6 tonnes)**
	17	Trincomali Channel	4	1130
	17	Trincomali Channel	3	590
	18	Sidney	1	0
	17	Trincomali Channel	1	50
1992 Total Landings				**1770 (0.7 tonnes)**
Nov 27/95	17	Trincomali Channel	1	13
1995 Total Landings				**13**

Table 7. Parameters of the von Bertalanffy growth curve for littleneck clams by site, obtained from length-at-annulus at Savary Island, 1995. (from Gillespie *et al.* 1995)

Site	n	L_∞	95% C.I.	k	95% C.I.	t_0	95% C.I.
101	303	56.778	0.116	0.287	0.001	0.193	0.003
102	1406	49.688	0.021	0.363	0.001	0.173	0.001
103	39	28.218	1.841	0.639	0.095	0.123	0.042

Table 8: Stimpson's surf clam (*Mactromeris polynyma*) TAC and landings (mt) by fishing zone in the Gulf of St. Lawrence (from AFSSR 96/103).

Zone		New Brunswick			Quebec		
		1993	1994	1995	1993	1994	1995
Haute Cote Nord	TAC						113
	Catch						3
Pte-des-Monts	TAC						23
	Catch						0
Sheldrake	TAC	30	30	30	68	91	91
	Catch	0	32	0	NA	NA	85
Natashquan	TAC	136	182	182	170	284	284
	Catch	0	168	0	NA	NA	102
Magdalen	TAC	68	68	68	136	136	227
	Catch	0	55	4	NA	NA	55
Miscou	TAC	15	15	15	0	0	0
	Catch	0	13	1	NA	NA	0
Total	**TAC**	**249**	**295**	**295**	**374**	**511**	**602**
	Catch	**0**	**268**	**5**	**NA**	**NA**	**242**

Table 9. Arctic Surf clam (*Mactromeris polynyma*) TAC and landings (thousands of tons) in Banquereau Bank (from AFSSR 96/37).

	1986-90 Avg.	1991	1992	1993	1994	1995
TAC	30	30	30	30	30	30
Ttl Landings	5.6	0.7	0.0	0.0	5.4	11.6

Table 10. Atlantic Surf/Bar clam (*Spisula solidissima*) commercial landings (mt) for the southern Gulf of St. Lawrence areas of New Brunswick, Prince Edward Island, and Nova Scotia (AFSSR 96/100).

Area	1985-89 Avg.	1990	1991	1992	1993	1994	1995
NB	161	787	152	226	233	187	217*
PEI	423	385	539	805	677	719	277*
NS	36	37	55	96	22	15	25*
Total	**620**	**1209**	**746**	**1127**	**932**	**921**	**519***

*Preliminary Data

Table 11. Commercial landings (mt) for Atlantic Surf Clam (*Spisula solidissima*) and Ocean Quahog (*Arctica islandica*) from the Atlantic coast of The United States. (Data from the National Fisheries Marine Service, Commercial Fisheries Statistics Division).

Year	Atlantic Surf Clam Landings (mt)	Ocean Quahog Landings (mt)
1950	3,511.7	100.1
1951	4,757.0	93.1
1952	5,737.0	219.6
1953	4,637.3	125.4
1954	5,276.0	172.4
1955	5,452.8	201.0
1956	7,247.0	175.3
1957	8,143.7	176.5
1958	6,560.6	119.4
1959	10,539.3	43.3
1960	11,371.4	84.6
1961	12,475.0	56.4
1962	13,995.1	30.4
1963	17,502.9	47.3
1964	17,301.9	51.1
1965	19,997.9	42.2
1966	20,463.0	41.3
1967	20,436.9	20.5
1968	18,394.3	101.9
1969	22,487.1	290.0
1970	30,535.6	792.5
1971	23,829.7	921.8
1972	28,790.3	635.2
1973	37,362.9	660.7
1974	43,596.0	380.3
1975	39,442.1	588.2
1976	22,298.1	2,540.6
1977	23,324.5	8,486.6
1978	17,825.2	10,348.8
1979	16,001.4	15,696.6
1980	17,272.7	15,475.7
1981	21,132.0	14,937.8
1982	23,232.2	16,300.4
1983	24,831.7	15,942.2
1984	32,301.7	16,132.2
1985	31,832.4	19,257.7
1986	34,969.0	16,435.1
1987	26,905.0	17,204.1
1988	28,174.5	13,803.5
1989	29,522.2	20,242.4
1990	32,145.0	14,959.1
1991	30,568.6	16,488.4
1992	33,107.5	19,062.2
1993	32,341.9	21,870.5
1994	32,284.4	19,342.7
1995	27,189.2	20,300.4
1996	25,586.3	16,638.5
Total	1,002,690.2	337,636.0

Fig 1. Size Frequency of Compsomyax subdiaphana collected from southern Gulf Islands in 1994 (from Krause 1994).

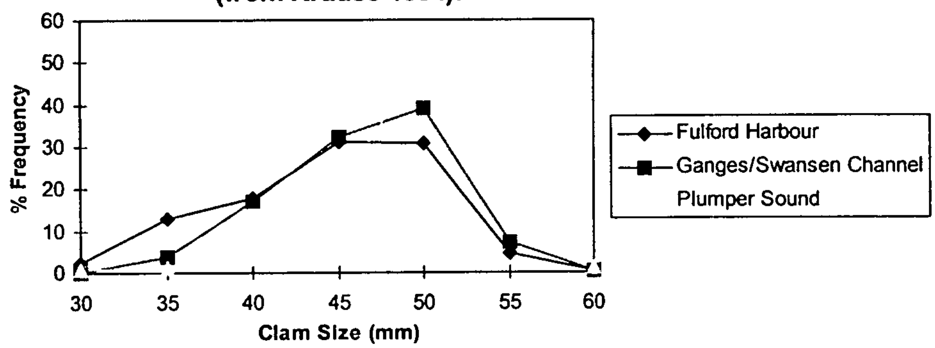

Fig 2. Size Frequency of *Compsomyax subdiaphana* collected in the southern Gulf Islands in 1991, 1994 and 1995.

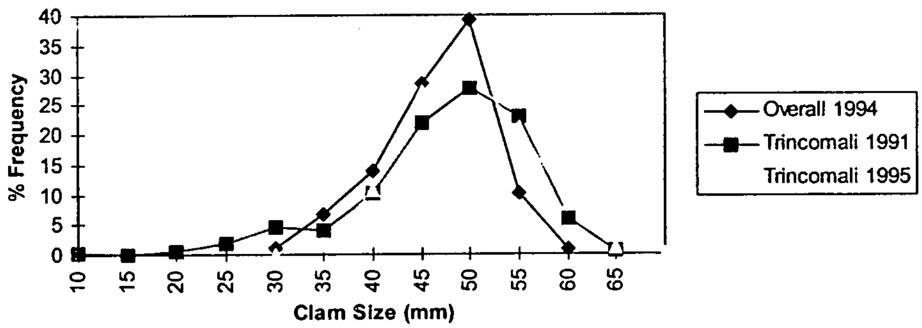

Fig 3. Length vs Weight in *Compsomyax subdiaphana* From Trincomali Channel, 1995

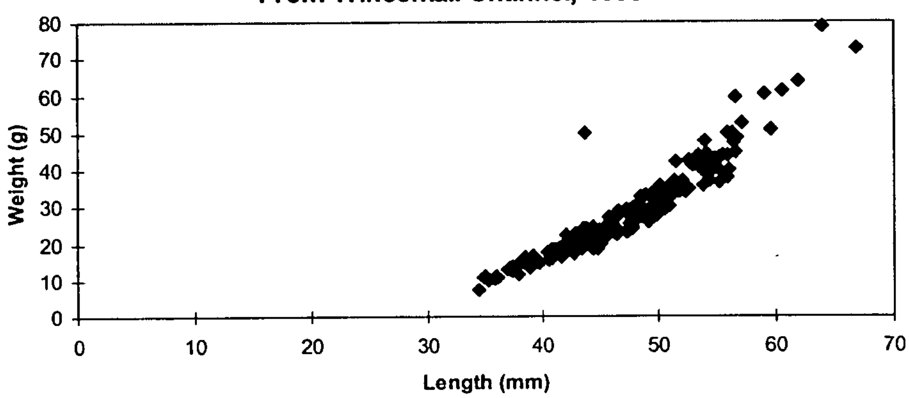

Fig. 4 Shell length (mm) on age of *Compsomyax subdiaphana* collected in Trincomali Channel 1995. Fitted line is
von Bertalanffy growth curve (L_{∞} =58.61 mm, k = 0.2447, t_0 = -0.0290)

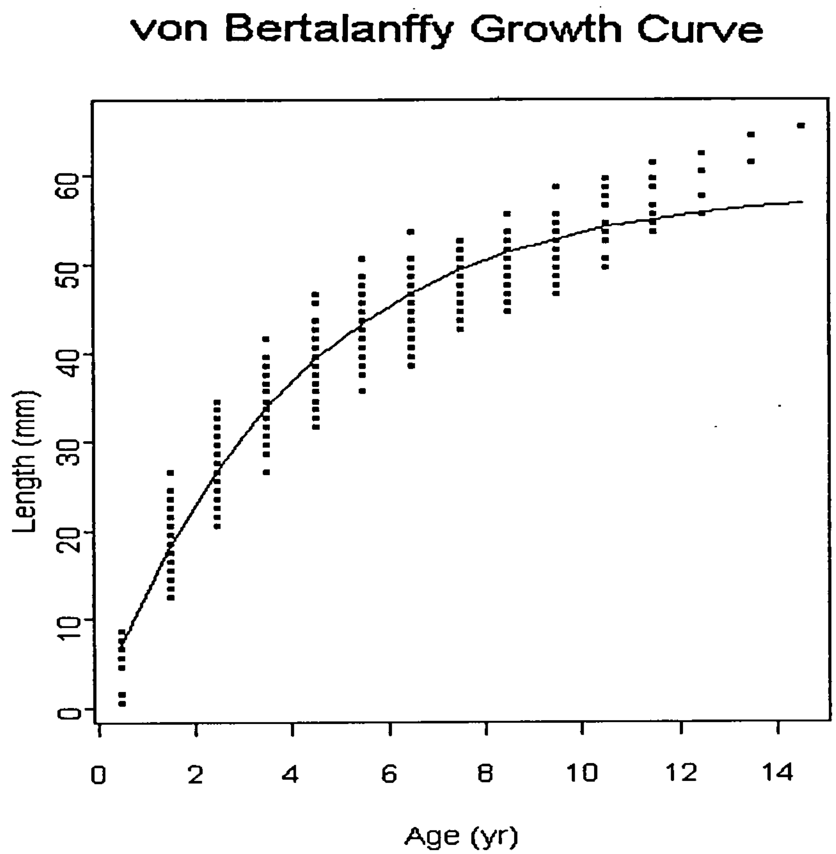

Fig 5. Catch Curve of Compsomyax subdiaphana collected in Trincomali Channel 1995.