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Further Investigations of the Fisheries Potential of the Exotic Varnish Clam (*Nuttallia obscurata*) in British Columbia.

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ABSTRACT

Varnish clams, *Nuttallia obscurata*, are a recently introduced exotic bivalve that have become well established in southern British Columbia. This species has attracted attention from commercial and recreational fishers and clam culturists, and has been identified as a potentially valuable fishery resource. This paper presents results of several projects to collect biological and ecological information on varnish clams, in support of fishery development.

The distribution of varnish clams in British Columbia continued to expand beyond the Strait of Georgia into Johnstone Strait and north along the west coast of Vancouver Island. They were found associated with other commercially important bivalves including Manila and littleneck clams, *Venerupis philippinarum* and *Protothaca staminea*, respectively, although generally higher in the intertidal zone. Varnish clam distribution extended lower in the intertidal zone on beaches that did not support large populations of Manila clams.

Experiments to examine competitive relationships between varnish and Manila clams showed evidence of competition when the two were placed together, with varnish clams having some competitive advantage in the upper intertidal zone and Manilas in the mid-intertidal zone.

Characteristics of harvest and processing of varnish clams were examined. Varnish clams >30 mm total length were harvested from mixed populations. Harvest efficiency was relatively high, 60-80%, for this size class. Breakage during harvest was low, approximately 2%, and shrinkage during processing was approximately 4%, evenly divided between weight loss due to water loss and losses due to mortality. Grit was purged readily from clams during wet storage within 48 hours. Commensal pea crabs, *Pinnixia faba*, were not purged from varnish clams even after 34 days.

Successful development of a varnish clam fishery depends on a consistent supply for the market. This could be achieved by allowing harvests of varnish clams from tenured foreshore under aquaculture permits. As the market becomes established, demand and price may allow for economically viable commercial harvest opportunities. Further work is required to develop biological information to support management of a sustainable commercial fishery.

RÉSUMÉ

La nutallie obscure (*Nuttallia obscurata*) est un bivalve exotique récemment introduit qui s'est bien établi dans le sud de la Colombie-Britannique. Suscitant l'intérêt de pêcheurs commerciaux et récréatifs ainsi que de conchyliculteurs, cette espèce pourrait constituer une ressource halieutique précieuse. Ce document présente les résultats de plusieurs projets visant à recueillir des données biologiques et écologiques sur la nutallie obscure, pour appuyer le développement de sa pêche.

La répartition de la nutallie obscure en Colombie-Britannique a continué de s'étendre au-delà du détroit de Géorgie, dans le détroit de Johnstone et au nord le long de la côte ouest de l'île de Vancouver. On la trouve associée à d'autres bivalves d'intérêt commercial, notamment la palourde japonaise (*Venerupis philippinarum*) et la palourde du Pacifique (*Protothaca staminea*), mais habituellement plus haut que ces dernières dans la zone intertidale. Sur les plages exemptes d'importantes populations de palourde japonaise, la répartition de la nutallie obscure s'étend plus bas dans la zone intertidale.

Des expériences ont montré que, lorsqu'on met la nutallie obscure et la palourde japonaise ensemble, il y a compétition entre les deux espèces, la première ayant un certain avantage concurrentiel dans la zone intertidale supérieure et la deuxième étant avantagée au milieu de la zone intertidale.

Nous avons examiné les caractéristiques de la récolte et de la transformation de la nutallie obscure en récoltant dans des populations mixtes des individus dont la taille totale dépassait 30 mm. Pour cette classe de taille, l'efficacité de récolte était relativement élevée, soit de 60 à 80 %. Le taux de coquilles cassées pendant la récolte était faible, soit environ 2 %, tandis que la perte de poids durant la transformation se chiffrait à environ 4 %, également attribuable aux pertes d'eau et aux pertes dues à la mortalité. Les nutallies obscures gardées dans l'eau pendant 48 heures ont facilement évacué le sable qu'elles contenaient. Par contre, même après 34 jours, les pinnothères commensaux (*Pinnixia faba*) n'ont pu être expulsés des nutallies.

Le succès du développement d'une pêche de la nutallie obscure dépend d'un approvisionnement constant pour le marché, ce qui pourrait être assuré en limitant la récolte de cette palourde à des concessions sur des estrans exploités en vertu de permis aquacoles. Lorsque le marché sera établi, la demande et le prix pourraient donner lieu à des occasions de récolte commerciale rentable. D'autres études sur la biologie de l'espèce sont nécessaires pour soutenir la gestion d'une pêche commerciale durable.

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INTRODUCTION

The Varnish Clam

The varnish clam, *Nuttallia obscurata*, is a recently introduced exotic bivalve that has become well established in southern British Columbia (Georgia Strait and Barkley Sound) over the last ten years (Forsyth 1993, 1997; Merilees and Gillespie 1995; Heath 1998; Gillespie *et al*. 1999). They have also been recorded from northern Puget Sound, Washington and in most major estuaries in Oregon (Gillespie *et al.* 1999; Dinnel and Yates 2000).

The official common name for *N. obscurata*, according to the American Fisheries Society (Turgeon *et al*. 1998), is purple mahogany clam. Harbo (1997) and Coan *et al*. (2000) used the vernacular dark mahogany clam. Individuals in British Columbia have registered a market name of "Savoury clam" with the Canadian Food Inspection Agency (CFIA) for purposes of marketing in Canada and the United States. For the purposes of this paper, *N. obscurata* is referred to as the varnish clam, also an accepted common name.

The native distribution of *N. obscurata* extends from the Japanese islands of Kyushu, Shikoku and Honshu, through Korea to the Yellow and Bohai Seas of China (Bernard *et al*. 1993; Coan *et al*. 2000). Note that *N. obscurata* is a senior synonym of *N. olivacea* and *N. solida* (Roth 1978), and thus, records of the distribution of these species (*e.g.*, Bernard *et al*. 1993) can be considered valid for varnish clams. The species has historically been placed in the genera *Psammobia*, *Sanguinolaria* and *Soletellina* (Coan *et al*. 2000).

Varnish clams are most frequently found in beaches with mixed sand, gravel and mud substrates (Gillespie *et al*. 1999). In soft substrates, varnish clams orient vertically, posterior-upwards, from just below the surface of the substrate to depths of at least 30 cm. In coarser substrates, clams are often skewed from the vertical, fitting around larger gravel and rocks. Varnish clams are generally found higher in the intertidal zone than other clam species, often associated with freshwater runoff of seepage. When varnish and Manila clam distributions overlap, varnish clams are found deeper in the substrate (Gillespie *et al.* 1999; Miyawaki and Sekiguchi 1999).

Varnish clams are synchronous broadcast spawners with planktonic larvae (Tsutsumi and Sekiguchi 1996; Miyawaki and Sekiguchi 1999). In the northwestern Pacific, varnish clams mature in one year, and spawn once per year in early May (Sun 1994). Optimal temperature for larval development is between 15-20°C, although larvae continued to develop at 25°C (Sun *et al*. 1997). Larval growth peaks between 15-20°C, with growth of 5.8-5.9 µm daily. Larvae metamorphose between 10-30°C. Larval survival and metamorphosis rates between 15-20°C were 50% and 80 %, respectively. Larval stages of *N. olivacea* were described and illustrated by Sakai and Sekiguchi (1992). Seasonality of spawning, duration of planktonic larval period and season of settlement in B.C. have not been determined (Gillespie *et al*. 1999).

Varnish clams have become established relatively rapidly in B.C. (Gillespie *et al*. 1999). Settlement can be generally distributed over the intertidal zone with post-settlement processes determining adult distribution and abundance (Peterson 1986; Olafsson *et al*. 1994; Miyawaki and Sekiguchi 1999). Adult varnish clams are most common in upper to mid-intertidal bivalve communities (Gillespie *et al*. 1999). They are primarily associated with Manila clams, *Venerupis philippinarum*, littleneck clams, *Protothaca staminea*, Eastern softshell clams, *Mya arenaria*, cockles, *Clinocardium nuttallii*, butter clams, *Saxidomus gigantea*, macoma clams, *Macoma balthica*, *M. inquinata* and *M. nasuta*, and *Tellina* sp.

Varnish clams filter feed from the water column, and utilize organic detritus in the substrate by locomotory and pedal-sweep feeding (Parker; Parker and Reid, unpublished manuscripts; Gillespie *et al*. 1999). They have also been reported to be siphonal deposit feeders, sweeping the inhalant siphon over broad areas of substrate to collect deposited materials (Tsuchiya and Kurihara 1980). Varnish clams are preyed upon by Lewis' moonsnails, *Euspira lewisi*, glaucous-winged gulls, *Larus glaucescens*, northwestern crows, *Corvus caurinus*, black oystercatchers, *Haematopus bachmani*, and possibly several crab species (Gillespie *et al*. 1999; Yates 1999). In the northwestern Pacific, varnish clams are preyed upon by juvenile flatfishes, which crop the siphons of the clams (Sasaki *et al*. 1999). The clams regenerate their siphon tips, forming a renewable resource to siphon-nipping flatfish.

As filter feeders, varnish clams can accumulate algal toxins responsible for paralytic shellfish poisoning (PSP) and faecal coliforms. Tests to date by the Canadian Food Inspection Agency (CFIA) indicate that uptake and purging rates for algal toxins was similar to those of Manila clams and Pacific oysters (*Crassostrea gigas*). Uptake and purging of faecal coliforms has not been extensively investigated to date.

Varnish clams host native pinnotherid crabs, *Pinnixia faba* (Gillespie 1995; Harbo 1997; Gillespie *et al*. 1999). Hart (1982) noted that immature *P. faba* are recorded in many bivalve species, but mature pairs are found only in the horse clam, *Tresus* spp. One of us (R. Marshall) has observed gravid female crabs in large (~45 mm) varnish clams. The crabs were 10-12 mm carapace width.

Age determination using interpretation and counts of annual rings on the shell surface, as is used in other clam species (Quayle and Bourne 1972), has proven difficult for varnish clams (Gillespie *et al*. 1999). However, length-based analyses indicate that varnish clams may grow at a similar rate to Manila clams, requiring approximately four years to reach 38 mm total length (TL) (Yates 1999; Gillespie *et al*. 1999).

The Phased Approach to Fisheries Development

Pacific Region policy requires that new or developing invertebrate fisheries proceed using the phased approach described by Perry *et al*. (1999). This approach requires that candidate species and fisheries progress through three phases of development. The first, termed "phase 0" requires collection and synthesis of all available biological and fisheries information on the target (and similar) species, with identification of significant information gaps that limit development of assessment and management frameworks. This is followed by "phase 1", in which surveys of small-scale experimental fisheries are undertaken to provide information found lacking in phase 0. Once sufficient information is available to formulate assessment and management frameworks, the fishery proceeds to "phase 2", a fully monitored and managed commercial fishery.

The phase 0 assessment of a potential varnish clam fishery was completed in 1999 (Gillespie *et al*. 1999). The authors recommended that continued research be directed to gathering information on biological, ecological and population dynamics characteristics of varnish clams. They indicated that examination of the ecological relations of varnish clams and other native or commercially important species was likely of greatest priority, followed by information on age, growth, reproduction, early life history, recruitment and stock productivity.

OBJECTIVES

This paper presents results of projects undertaken in 2000-2001 to collect information in support of development of fisheries for varnish clams in British Columbia. The paper will:

- provide updated information on distribution of varnish clams in British Columbia;
- review surveys of varnish clam distribution in Clam Management Area C (Powell River/Sunshine Coast;
- review surveys of varnish and Manila clam distribution on specific beaches;
- review results of experimental work to examine competitive relationships between varnish and Manila clams;
- review data collected that describes harvesting characteristics, including size distribution of harvested and unharvested clams, breakage, purging of sand and pea crabs, and shrinkage during wet storage; and
- present results of a market study.

SURVEYS OF GEOGRAPHIC DISTRIBUTION

Work undertaken in 2000-2001 to describe changes in varnish clam distribution included a detailed survey of Clam Management Area C along with collection of records from the public and exploratory surveys by DFO.

Qualitative beach surveys in Clam Management Area C were conducted during the summer of 2000. The purpose was to gather information regarding distribution of bivalve stocks, with special interest in determining Manila and varnish clam distribution.

Clam Management Area C is defined as Pacific Fishery Management Areas (PFMA) 15, 16 and 28 excluding subareas 15-2, 16-19, 16-20 and the intertidal areas of Twin Islands and Lasqueti Island. Area C includes what is locally known as the Sunshine Coast, extending from Toba Inlet in the north to Burrard Inlet in the south, and Savary, Hernando, Harwood and Texada Islands (Figure 1). Howe Sound and Burrard Inlet in the southern portion of the area are not accessed in the commercial fishery due to contamination closures, and were not included in the survey program. Narrows and Salmon Inlets were also not assessed in this survey due to distances involved and limited clam beaches in these areas.

Methods

Surveys were conducted using experienced clam harvesters licensed in the Area C commercial intertidal clam fishery. Harvesters were selected through an interview process and training, both in-class and on the beach, provided by Gormican Environmental Services. Emphasis was placed on collection and recording of data to ensure that reliable information would be returned from the survey.

Survey design utilized in this project was similar to that used for exploratory surveys conducted by DFO to determine presence and geographic distribution of intertidal bivalves (*e.g.*, Gillespie and Bourne 2000), except that abundance was classified. Each site was first walked to determine the presence or absence of bivalve species and to determine the extent of each species distribution. Identified species were then assigned a qualitative density rating of high, moderate or present based on the observed relative abundance on the beach. The absence of the species of interest (varnish and Manila clams) was also noted. The presence of shell without live specimens identified was noted separately as the probable presence of the species. Each beach assessed in this program was hand sketched and marked on a marine chart for later digitization and display using the geographical software ArcView™.

Two five-member survey teams were assembled consisting of four surveyors and one boat operator/crew supervisor. One crew operated from Lund and worked to cover the northern portion of Area C, while the second crew operated out of Saltery Bay and covered the southern portion. In total, 300 beaches (158 in the south and 142 in the north) were assessed over 14 days of surveying from May to July 2000 (Figure 2).

For other parts of B.C., the known distribution of varnish clams was compiled utilizing records reported in available literature, survey information from the Depuration Industry, exploratory surveys conducted by DFO, collections reported through scientific licenses, museum records and records submitted by the public.

Results

In total eleven species of intertidal bivalves were identified and rated within the area covered by this project. Species included varnish clams, Manila clams (*Venerupis philippinarum*), native littleneck clams (*Protothaca staminea*), softshell clams (*Mya arenaria*), butter clams (*Saxidomus gigantea*), horse clams (*Tresus sp.*), macoma clams (*Macoma sp.*), cockles (*Clinocardium nuttallii*), blue mussels (*Mytilus sp.*), Pacific oysters (*Crassostrea gigas*) and Olympia oysters (*Ostrea conchaphila*). For the purpose of this paper, information for species other than varnish, Manila, native littleneck and butter clams was not used. The goal of this survey was to determine distribution of varnish and Manila clams in the area, occurrence of other species was only noted opportunistically.

Vanish clams were widely distributed within Area C, with a higher incidence in the southern area (Table 1, Figure 3). Of the 300 survey sites, varnish clams were found at 107 (35.7 %) beaches. Shell only was found at an additional 16 beaches (5.3%).

When results are assessed by north and south regions, it is evident that varnish clams are more widely distributed in the southern region of Area C (Table 1, Figure 3). They occurred on 81 of 158 southern beaches (51.3 %) but only on 26 of 142 (18.3 %) beaches in the northern area. High abundance ratings occurred for 18.7 % of beaches surveyed overall, however, high densities were found at 27.8 % of southern beaches but only 8.5 % of northern beaches. High densities of both Manila and varnish clams on the same beach occurred only in the southern region, at 23 of 158 (14.6 %) beaches. There were no beaches in the northern area where high abundance of both species occurred, as no northern beach had a high density of Manila clams. Occurrence of shell only, without live clams found, was greater in the northern region; 9.2 % compared to 1.9 % of southern beaches.

Additional records reported since the Phase 0 report (Gillespie *et al.* 1999) include records for Barkley Sound, Ucluelet and Hesquiat Harbours (J. Osbourne, Nuu-chah-nuulth Tribal Council, pers. comm.), Clayoquot Sound (G. Gillespie) and Checleset Bay (J. Watson, Malaspina University College, pers. comm.) on the west coast of Vancouver Island, and Cameleon Harbour (G. Gillespie) and Salmon Bay (B. Rusch) in Johnstone Strait. Available records for northern Puget Sound, Washington State (Dinnel and Yates 2000; Gillespie *et. al.* 1999) were also included in Figure 4.

RELATIVE DISTRIBUTION OF VARNISH AND MANILA CLAMS

Concern has been expressed by clam harvesters and culturists that newly introduced varnish clams have been or will be competing for resources (space or food) with other clam species, particularly the economically important exotic Manila clam. Surveys were undertaken in 2000 in Area C and Baynes Sound to examine the relative distribution of varnish and Manila clams.

Methods

Surveys were conducted at two sites in Area C: Kent's Beach and Saltery Bay. Survey methods generally followed Gillespie and Kronlund (1999). A reference line was established on each beach parallel to the tide line. Strip clusters (transects) were systematically established perpendicular to the reference line, and quadrats placed systematically in each strip from a random starting point. Quadrats were dug with a clam scraper to a depth of at least 30 cm or deeper until clams were no longer encountered. All species and sizes of clams were collected by hand and stored in labelled bags for later processing. Each quadrat was processed by dividing the sample into species and legal and sublegal size categories (for species managed with a size limit). Total number and total weight of clams in each species/size category were recorded.

Similar surveys were conducted in the summer of 2000 at three sites on Denman Island: Fillogley Park, Henry Bay and Metcalfe Bay. Strip clusters were utilized, but were established at random intervals along a reference line. Quadrats were placed systematically, beginning at a random starting point along each transect. Transects varied in length between beaches, as the survey was designed to encompass the intertidal area between 3.2 and 1.4 meters above chart datum. Samples were dug in an identical manner as those at Kent's Beach and Saltery Bay, however, samples were passed through a 5 mm screen and processed directly at the time of sampling. Counts were taken of all species, using legal and sublegal categories when managed by a size limit. Individual measurements of total length (TL) to the nearest millimetre were recorded for all clams in each quadrat.

Tidal elevation of quadrats in both survey projects was determined through correlation of the time flooded by the returning tide for each quadrat, and interpolation using tidal computer software or tide tables published by the Canadian Hydrographic Service. Clam distribution within the intertidal zone of each survey was then plotted utilizing interpolated tidal elevations and the total number of varnish, Manila and littleneck clams found in each quadrat. The Friedman smoothing trendline function of the statistical software S-Plus 2000™ was utilized to display trends in graphic form for data collected for each beach.

Results

Kent's Beach was dominated by varnish clams, with virtually no other species present in significant numbers (Figure 5). This beach has a relatively steep slope and is relatively exposed compared to other beaches surveyed. Saltery Bay had a lower slope, was more protected and had more Manila and littleneck clams present (Figure 6). The beach at Fillongley Park had a relatively low slope but was fairly exposed, and had very high densities of Manila and littleneck clams (Figure 7). The beach in Metcalfe Bay had a relatively low slope and moderate densities of all three species (Figure 8). The beach in Henry Bay had a very low slope and supported high densities of Manila clams with relatively low concentrations of littleneck and varnish clams (Figure 9).

Kent's Beach and Fillongley Park are both in Provincial Parks. Kent's Beach has no significant Manila clam stocks to attract commercial fishing effort and the latter is designated as a Recreational Reserve (Harbo *et al*. 1997). Thus, clam stocks on these beaches would be only lightly impacted by recreational fishing. Saltery Bay is utilized in commercial clam fisheries, and is considered moderately impacted by these activities (R. Webb, DFO Parksville, pers. comm.). Henry Bay and Metcalfe Bay are both leased for commercial shellfish culture. These sites are highly impacted by harvests, artificial seeding of Manila clams and varying amounts of the beach covered are in anti-predator netting (approximately 15% of the Henry Bay beach and 75% at Metcalfe Bay [Munroe 2000]).

Distribution of varnish clams relative to tidal height is very different for the beaches examined (Figure 10). Most obvious is the expanded distribution of varnish clams to lower tidal levels at Kent's Beach, where potential competitors are virtually absent (Figure 5). Saltery Bay also had varnish clams at relatively high densities between 2.5 and 1.7 m above chart datum (Figure 6), in part because the upper beach lacked suitable substrate for other clam species. At Metcalfe Bay, varnish clams were virtually absent below 2.0 m (Figure 8). At Fillongley Park, they occurred primarily above 2.5 m (Figure 7) and at Henry Bay were present only at very low densities, increasing slightly above 3.0 m (Figure 9). Depth distribution appears to be limited to higher tidal elevations when Manila clams are abundant on the same beach. Whether this is due to the presence of Manila clams or to habitat characteristics that discourage Manila clams and promote development of large populations of varnish clams is unknown.

Munroe (2000) calculated habitat overlap for clam species encountered at the three beaches on Denman Island (Table 2). Varnish clams had the lowest habitat overlap with other species of the four clam species examined. Varnish clams had the highest overlap with Manila clams (35.6% ±10.5%) and lowest overlap with butter clams (3.8% ±0.8%). Manila clams had the highest overlap with littleneck clams (66.8% ±21.4%), followed by varnish (12.6% ±8.4%) and butter clams (34.1% ±36.0%). Butter clams had highest overlap with littleneck clams (54.0% ±28.4%).

COMPETITION EXPERIMENTS

Experiments were conducted to examine competition between varnish clams and Manila clams as suggested by Gillespie *et al*. (1999). Concern has been raised about the potential of the varnish clams to out compete the Manila clam, particularly on shellfish tenures where substrates are used primarily to rear Manila clams. The recent appearance of varnish clams in densities approaching or, in some cases, exceeding, those of the cultured organisms has alarmed tenure holders.

Controlled experiments, similar to those employed by Peterson and Andre (1980) were conducted using wire mesh cages buried in the intertidal zone on a shellfish tenure in Baynes Sound. The two clam species were placed in various combinations in these enclosures for a period of approximately 5 months. Assessment of competition was made using growth indices and survival rates.

Methods

Interspecific interactions were examined between varnish and Manila clams at two tidal elevations (2.5 and 1.5 m above chart datum). A randomized block design was employed at each tidal elevation utilizing three treatments with three replicates. Treatments consisted of varnish clams alone (No), Manila clams alone (Vp) and both species together (No+Vp).

Stocking densities were at the high end of densities typical of a cultured beach to maximize the likelihood of observing competitive interactions. Densities of 800 clams m^{-2} were used for the No treatment and 400 clams m^{-2} for the Vp treatment. The treatment with both species, No+Vp, was a combination of the alone treatments resulting in a total clam density of 1,200 m^{-2}.

Treatments were contained in wire mesh enclosures constructed of galvanized hardware cloth with a mesh opening of 0.6 cm. Enclosures were 50 cm long by 50 cm wide with a depth of about 35 cm. Holes were excavated in the substrate, enclosures placed in the holes and re-bar stakes pounded into the substrate to anchor each corner of the enclosure. All enclosures were then back-filled using substrate originating from the same source, comprised mainly of sand, shell and pea gravel. The few clams observed during the back-fill process were removed before introduction of the treatment clams.

Clams used in the experiments were collected from two locations on the beach (one for varnish and another for Manila) to eliminate differences due to substrate composition, tidal elevation or other factors that may have impacted their growth or survivorship.

Prior to burying the clams in each of the treatments, aggregate weights to the nearest gram and individual lengths to the nearest millimetre were determined. Clams were marked to eliminate the possibility of non-experimental clams entering the population during recovery. Marks were made using a standard three-sided file by filing a small (<1.0 mm) notch in the centre (opposite umbo) of the ventral margin of each clam resulting in a v-shaped groove in both valves.

Experimental clams were re-introduced to the enclosures with treatments randomly assigned once the enclosures were back-filled to the ambient substrate level. Mesh enclosures had been placed to leave approximately 5 cm of mesh extending above the surface. Clams were placed by hand in the top 5 cm of substrate and distributed evenly within the enclosure. Netting of approximately 1 cm mesh was placed over all enclosures and attached to the wire mesh of each enclosure using plastic cable ties to help prevent immigration and emigration of clams and to exclude predators.

The enclosures remained *in situ* for 145 days over the period of April to September 2001 which is typically the season of highest growth rates. At the end of the experiment, all clams and shells were removed from the enclosures by hand. Aggregate weights and individual lengths were then determined for each treatment.

Variables analyzed were:

- survival
- initial shell length (L_0)
- change in length (ΔL)
- initial whole animal wet weight (W_0)
- change in weight (ΔW)
- ΔW versus ΔL regressions

Initial and final lengths and weights were averages for each replicate enclosure. Clam weights were recorded as live wet weights which includes the weight of shell, tissue and associated shell contents. Changes in size (i.e., final minus initial lengths or weights) were used as measures of growth during the study. Regressions of ΔW on ΔL were used to assess changes in condition, or weight relative to length.

All variables, except ΔW versus ΔL regressions, were compared between treatments and tidal zones in a two-way analyses of variance (ANOVA).

ΔW versus ΔL regressions were compared between treatments and tidal zones in two-way analyses of covariance (ANCOVA). First, regression slopes were compared among Treatment×Zone combinations. Second, if those slopes did not differ significantly, regression elevations or intercepts were compared among treatments and tidal zones, assuming a common slope. A significant difference between, e.g., treatments, would indicate that, at any value of ΔL, ΔW was higher in one treatment than in the other.

Analyses were conducted separately for each species, each of which had three replicate enclosures for each of four Treatment×Zone combinations, providing a total sample size of 12 enclosures. Results were considered statistically significant if $p \leq 0.05$. All analyses were conducted using SYSTAT Version 7.0 software for statistical analyses.

Results

Table 3 provides results of ANOVA or ANCOVA comparing survival, initial size, growth, and condition among treatments and tidal zones. Means and adjusted means for Manila and varnish clams are in Table 4 and Table 5, respectively. The adjusted means for ΔW versus ΔL regressions are predicted values of ΔW for the overall average ΔL. A difference in adjusted means is equivalent to a difference in regression intercepts, if slopes do not differ and a common slope is assumed.

Overview and Comparison Between Species

Overall, Manila clam survival was marginally greater than varnish clam survival (Tables 3 and 4). The high survival observed for both species indicates that experimental enclosures and marking process did not seriously affect survival of either species. Over all enclosures, average survival of both species was >90% and survival in individual enclosures was never <80%.

Manila clams were initially larger than varnish clams, and grew more in length and weight during the study (see overall means in Tables 3 and 4, Figure 11). Growth in absolute terms (i.e., change in mm length or g weight) will usually be greater for larger organisms. However, even on a relative basis (i.e., growth as a % of original size), growth was greater for Manila clams.

The two species appeared to have different habitat "preferences". Manila clams grew more in the mid-tidal zone than in the high-tidal zone, whereas varnish clams survived and grew better in the high-tidal zone (Tables 3 and 4; see also below). Survival and/or growth of both species was generally lower when the other species was present in the enclosures, *i.e.*, each species appeared to have a negative effect on the other.

Manila Clams

Initial lengths and weights of Manila clams did not differ among treatments or tidal zones (Table 3), and initial clam size was similar for all Treatment×Zone combinations (Table 4). There were no significant treatment or zone effects on survival (Table 3), which was approximately 95% for all combinations (Table 4). Differences in growth in length and weight between tidal zones were highly significant ($p \leq 0.001$) (Table 3, Figure 11). Overall, growth increments in length and weight in the mid-tidal zone were approximately three times higher than in the high-tide zone (Table 4).

Treatment effects, or the effects of the presence or absence of varnish clams, on growth in length and weight of Manila clams were also significant (Table 3). Growth was depressed when varnish clams were present (Table 4). A Treatment×Zone interaction was evident, although not statistically significant (i.e., $p \leq 0.20$ but >0.05). In absolute terms, growth depression in the presence of varnish clams was greater in the mid-tidal zone. However, on a relative basis, growth of Manila clams in both zones was depressed by a similar amount (30-50%).

For Manila clams, treatment and tidal zone effects on growth in weight were similar to those on growth in length demonstrating that the two types of growth effects were correlated. Slopes of ΔW versus ΔL regressions did not differ significantly among Treatment×Zone combinations (p=0.31). Assuming a common slope, regression intercepts or adjusted means also did not differ significantly among Treatment×Zone combinations (Table 3). Adjusted means were similar for all Treatment×Zone combinations (Table 4). The effects of ΔL on ΔW were highly significant (p=0.001), indicating that even within Treatment×Zone combinations ΔW was strongly positively correlated with ΔL. Thus:

- for any given change in length (ΔL), the change in weight (ΔW) was similar in all enclosures
- the common regression for all enclosures was $\Delta W=0.428+1.034\times\Delta L$ (r^2=0.964; p<0.001), so that effects on ΔW could easily be predicted from effects on ΔL

Varnish Clams

At the start of the study, varnish clams in the mid-tide zone enclosures with both species present (i.e., "Together"×"Mid" in Table 5) were larger than clams in other enclosures. Consequently, the Treatment×Zone interaction was significant for both initial length and initial weight (Table 3).

Survival of varnish clams differed significantly between treatments and tidal zones (Table 3). Survival was approximately 5% lower when Manila clams were present, and approximately 5% lower in the mid-tidal zone than in the high-tidal zone (Table 5).

Growth in length did not differ significantly between treatments or tidal zones (Table 3, Figure 11), although ΔL was lower when Manila clams were present, and in the mid-tidal zone (Table 5). Effects of Manila clams on varnish clam growth in length were somewhat smaller than effects of varnish clams on Manila clam growth in length. For Manila clams, average ΔL was reduced 47% when varnish clams were present (Table 4). For varnish clams, average ΔL was reduced 32% when Manila clams were present (Table 5).

Treatment effects on growth in weight were much larger and statistically significant (Table 3, Figure 11); overall, ΔW was reduced three-fold when Manila clams were present (Table 5). This reduction was much greater in the mid-tide zone than in the high-tide zone, leading to a significant Treatment×Zone interaction. In the high-tidal zone, growth in weight of varnish clams was reduced by 26% when Manila clams were present. That reduction was slightly smaller than the reduction in Manila clam growth in weight in the same enclosures (34%). However, in the mid-tidal zone, varnish clams:

- grew as much or more in weight than varnish clams in any other enclosures when Manila clams were absent
- did not grow at all (ΔW=0.00 g; =100% reduction) when Manila clams were present

Slopes of ΔW versus ΔL regressions for varnish clams did not differ significantly among Treatment×Zone combinations (p=0.71). Therefore, intercepts or adjusted means were compared assuming a common slope. Results were similar to those for ΔW, indicating that there was little or no relationship between effects on growth in weight versus length (also easily inferred from Tables 2 and 4). Specifically:

- Treatment effects were significant, with growth in weight (ΔW) at any given value of ΔL reduced when Manila clams were present
- the Treatment×Zone interaction was significant because the effects of Manila clams on ΔW relative to ΔL were much greater in the mid-tide zone than in the high-tide zone
- the effects of ΔL on ΔW were not significant (p=0.266), indicating that even within Treatment×Zone combinations, growth in weight was not correlated with growth in length

Collectively, these results indicate effects on growth in weight of varnish clams are largely uncoupled from effects on growth in length. This conclusion applies to both experimental Treatment and/or Zone effects, and to whatever natural factors were responsible for growth differences among enclosures within Treatment×Zone combinations.

CHARACTERISTICS OF HARVEST

Size distribution of harvested varnish clams was sampled on three different occasions, July 5, August 3 and August 22, 2001. In total, 925 clams were measured for individual length and weight and were used in determining size distribution. Samples collected August 2 and 22, 2001 were taken as part of the harvest efficiency sampling, but represented the harvested portion of the sample.

Harvest efficiency and breakage was also sampled during harvest activities on two separate occasions. Efficiency and breakage was estimated using sample areas harvested by experienced harvesters and then sampled to determine the characteristics of the non-harvested portion of the varnish clam population. We could not find documentation of efficiency of experienced harvesters for intertidal clam fisheries.

Size Distribution

Methods

Size distribution was determined from samples of harvested product collected directly from harvesters. Harvesting occurred on Mac's Oysters Ltd. aquaculture tenure located in Fanny Bay, Baynes Sound. The location of harvest changed both in tidal height and general location on the beach between each harvest sample. Sampled clams were individually measured for total length to the nearest mm and weight to the nearest 0.1 g. Data collected were used to determine mean clam length and weight, and to determine length frequency and length-weight relationships of harvested clams.

Results

Harvested clams ranged between 27 and 51 mm total length (Figure 12) with a mean length of 41 mm. Average weight was 13.7 g (Figure 13) with a range of 3.5 g to 27.7 g. Only one clam below 30 mm (27 mm) was recorded and the majority of harvested clams (99 %) ranged between 33 and 49 mm, representing two standard deviations of the mean.

Harvest Efficiency and Breakage

Methods

Harvest efficiency and breakage was sampled directly during harvest activities on August 2 and 22, 2001. Both efficiency and breakage were assessed simultaneously within sample harvest areas of 1 m^2. Sample areas were marked using PCV corner markers and harvesters were requested to harvest these areas. Harvesting was by traditional clam harvesting equipment, long tined garden rakes or clam scrapers. Substrate was overturned using the rake and clams regarded as harvestable were picked out and placed into a 20 liter plastic pail (5 gallon bucket). Once harvest was completed, all clams removed from the sample area were retained as the harvest portion of the sample. Diggings within the area were then excavated by hand ensuring that no clams were crushed during sampling and screened using a 4.25 mm stainless steel mesh screen to remove all remaining clams. Clams retained from the diggings represented the non-harvested portion of the sample. Harvested and non-harvested samples from the same area represented the entire population of varnish clams.

On two occasions, two 1 m^2 areas were sampled to estimate harvest efficiency and harvest breakage, resulting in a sample size of four. Total number and aggregate weight of clams was determined for each sample, separating the harvested and non-harvested sample portions. Individual length and weight measurements were recorded for one of the samples taken on each of two sample days. From the total numbers of clams in the sample area, total harvest efficiency was calculated as the ratio of harvested clams to the total number of clams in the sample population (harvested : harvested and non-harvested clams). Total harvest efficiency was calculated for each sample and for pooled samples.

Harvest efficiency was also calculated based on clam size using minimum sizes of ≥30, ≥35, ≥38 and ≥40 mm total length. This calculation was only possible for samples where individual length and weight measurements were collected, or two of the four samples. Efficiency was calculated as the ratio of clams harvested equal to or above above the minimum size to the total number of clams in the population above the minimum size. Efficiencies were calculated for each of the two samples and for pooled samples.

Number of broken clams was recorded from each sample and used to estimate harvest breakage. Total breakage was calculated as a percentage ratio of the total number of broken clams to the total number of clams in the sample population. Breakage was estimated within the harvested and non-harvested portions of the samples so that comparisons could be made. Total breakage was also calculated using pooled sample results.

Results

Total harvest efficiency ranged from 0.42 to 0.75 within samples and resulted in an overall pooled efficiency of 0.55 (Table 6). Samples collected on the same days from the same general harvest area showed consistent values in both sets of samples. Samples collected on August 3 showed much lower total harvest efficiency, likely the result of the area being previously harvested (Figure 13).

Size specific harvest rates ranged from 0.48 to 0.80 with larger minimum sizes expectedly producing higher efficiencies (Table 7). From pooled samples, efficiencies ranged from 0.60 to 0.79, with the efficiency reaching 0.70 by 35mm and not exceeding 0.80 by 40mm.

Total breakage during harvest calculated for each sample ranged from 1.01 % to 3.79 %, with total breakage from pooled samples estimated at 1.89 % (Table 8). Breakage within the harvested portion of the samples ranged from 0.77 to 3.26 % while the non-harvested portion ranged from 1.00 to 5.36 %. Pooling of sample proportions produced a total breakage estimate in the harvested portion of 1.74 %, non-harvest breakage of 2.08 % and a total breakage of 1.89 %.

Purging of Pea Crabs and Grit

At the present time, the major marketing concerns facing shellfish producers with varnish clams are symbiotic pea crabs (*Pinnixia faba*) that inhabit a high proportion of these clams, and high grit content at the time of harvest. Concerns with pea crabs are that customers may find the crabs unsightly and therefore unappetizing, and consumers with crustacean allergies may fall ill after unwittingly consuming these small, often hidden crabs. Varnish clams tend to be more “gritty” than other marketed clams because varnish clams feed either through filtration or by pedal feeding, the latter resulting in grit being taken into the mantle cavity of the clam (Gillespie *et. al.* 1999). Grit can be an important factor in marketing, as grit free clams tend to be more desirable to the consumer.

The obvious solution to this problem is to purge crabs and grit from clams prior to shipping. In this study, beach and tank purging experiments were conducted to determine if the incidence of pea crabs could be significantly reduced. A simultaneous tank experiment was conducted to determine if grit could be purged to acceptable levels. Both of these methods are used by processors to purge grit from Manila clams.

There have been a number of claims that purging of crabs is achievable by wet storing clams in sacks for a period of four to five days and turning the bags daily (Mark Biagi, CFDC Powell River, pers. comm.). There are also accounts of male pea crabs (*Pinnotheres pisum*) leaving mussels when stored in water (Haines *et al*. 1994). We undertook a more formal investigation of purging methods to confirm or deny anecdotal accounts.

To purge grit from clams, the factors easiest for the processor to control are stocking density and purging time. This study investigated effects of stocking density and purging duration on levels of grit in clams. Effects of clam handling on purging rates were also investigated to determine if bagging and turning clams would significantly affect levels of grit retained in clams during the purging process.

Methods

Approximately 318 kg (700 lbs) of clams were collected from an experimental harvest in Fanny Bay on April 27, 2001. The harvested area was at the 1.7 m (5.5 ft) tide level and the substrate down to a depth of 25 cm was composed of gravel, sand, barnacle and oyster shell. A random sample of 126 clams was taken across the entire lot and analyzed for pea crab and grit content. Approximately 227 kg (500 lbs) were taken to the Mac's Oysters Ltd. depuration plant for the tank purging experiment while the rest were wet stored in the intertidal zone in Vexar™ sacks containing 14 to 16 kg (30 to 35 lbs) of clams per sack.

Tank purging

Clams were handled in accordance with Canadian Sanitary Shellfish Program (CSSP) depuration procedures. Harvested clams were sorted to remove dead and broken animals and sprayed with fresh water to remove sand and debris. Treatment weights of 2.3, 4.5, 6.8 and 9.1 kg (5, 10, 15 and 20 lbs) were placed into 30 cm by 45 cm by 10 cm baskets and the baskets then loaded into aluminium framed racks specifically designed to hold 20 baskets (five levels with four basket slots per level). Two racks were loaded for this experiment, one rack had the clams poured directly into the baskets, while in the other rack the clams were poured into onion sacks and laid out flat into the baskets. The onion sacks were used to duplicate beach purging conditions where clams are bagged and turned daily. Each level of the racks was loaded with each weight treatment. The location of the baskets within each level was selected at random. The racks were placed into a 7,000 l commercial depuration tank between April 27 and May 2, 2001. Temperature was maintained at 12°C for the duration.

After each 24-hour time period over the next five days, the tank was drained and the clams rinsed with fresh water. The clams held in onion sacks were turned over in addition to being sprayed. A minimum of 10 clams per tray were collected at the 0 hour, 24 hour, and 120 hour mark and sacrificed to determine grit and pea crab content. The clams were collected into plastic bags, refrigerated and processed within 24 hours.

After collection, the clams were steamed and dissected. Care was taken to check under the gills and near the mouth where most of the crabs were found. The clam shell length and the number of pea crabs present was recorded for each clam. The clams were then eaten and grit levels subjectively ranked in one of three categories:

- inedible - very high and distasteful amount of grit;
- edible with some grit - noticeable but not distasteful amount; and
- no grit.

Beach purging

Varnish clams harvested from Fanny Bay on April 27, 2001 were stored in Vexar™ bags containing 14 to 16 kg (30 to 35 lbs) of clams. These were laid out flat on a wet storage beach at the 1.7 m (5.5 ft) tide level. The bags were checked and rolled daily, tide permitting. On May 2, 2001 (120 hour mark), a random sample of 53 clams was taken from the lot and examined for the presence of crabs. Another sample of 78 clams was taken on May 27, 2001 (34 days after harvest).

Statistical Analysis

Pea crab data from the tank purging trials were analyzed using a fully factorial multivariate ANOVA with a multiple comparisons Tukey test using SYSTAT statistical software. Data were transformed using the arcsine of the square root of the proportion. The test was performed to determine if the proportion of clams containing crabs was affected by the duration of purging, presence of the bag, the weight of the clams per tray and combinations of the interaction terms. A linear regression was applied to the pooled data to determine if there was an overall reduction in the proportion of crabs over time. Crab content in relation to clam shell length was examined by histogram to determine if there was any correlation between the size of the clams and the probability of containing crabs. Significance was tested using a χ^2 test.

In the beach purging trials the proportion of crab incidence was calculated on the day of harvest, after five days and again after 34 days. Significance was tested using a χ^2 test.

Data from the purging of grit trials were analyzed using a two-way ANOVA to determine significance between treatment weights and the presence of the bag.

Results

Crab incidence in relation to shell length

The proportion of clams containing crabs increased as the shell length increased, from approximately 20% incidence in clams <40 mm to approximately 35% incidence in clams >45 mm (Figure 14). The χ^2 test provided strong evidence that the crab incidence is not equal in the different size ranges ($p<<0.001$, $\chi^2 = 181.1$, χ^2critical = 7.815).

Tank purging - crabs

After 120 hours in the tank, there was no detectable sign of crab purging. A fully factorial ANOVA with multiple comparisons Tukey test indicated that there was no significant difference in the proportion of clams containing crabs at the 0 hour, 48 hour, or 120 hour mark, with bagging and stocking density also having no effect ($p=0.36$). Since there were no differences in the treatments, the data were pooled and a linear regression applied. It revealed that there was no sign of purging and there was no correlation between time in the tanks and the percentage of crabs ($r^2 = 0.0277$, $p = 0.849$) (Figure 15). Throughout the entire period only two crabs were noted to have left clams.

Beach purging – crabs

The clams that were held intertidally had virtually identical percentages of crabs at day 0 as at day 34 (Figure 16), indicating that there was no purging of crabs using this method, even when held for over a month. χ^2 test results could not reject the null hypothesis that each of the proportions were equal ($0.9<p<0.95$, $\chi^2 =0.165$, χ^2 critical = 5.991).

Grit purging

Detectable levels of grit occurred in 51% of clams immediately after harvest. In all treatments with the exception of the 6.8 kg (15 lb) bagged treatment, the total levels of grit decreased to fewer than 20 % within 24 hours, while the 6.8 kg (15 lb) bagged trial remained at 38% at 24 hours (Figure 17, Figure 18). After 120 hours total grit levels had decreased further and the bagged clams had significantly lower (two-way ANOVA, $p <<0.001$) amounts of total grit. However, the percentage of clams containing grit was low for both treatments, 2.6% for bagged clams and 9.1 % for non-bagged clams. Weight treatments were not significant and made no difference to the purging process ($p=0.29$).

The initial percentage of clams with inedible amounts of grit was low at 5% and within 24 hours this percentage was reduced to 0.56%. After 120 hours the percentage of clams with inedible amounts of grit was 0% (Figure 19). Weight treatments and bag treatments were not a factor in purging of high amounts of grit (two-way ANOVA, $p=0.13$ for weight treatment and $p=0.31$ for bag treatment).

Shrinkage

Shrinkage is a term used by clam processors which typically refers to the total reduction in weight of clams from the time initially weighed at harvest to the time of shipping (*i.e.*, the difference between harvest weight and processed weight). The causes for shrinkage are usually the removal of grit from the outside of the clams, water loss from the clams, death of the clams either from shell breakage at harvest and initial transport or death during wet storage and final processing. Other sources of weight loss are the removal of shells that were dead prior to harvest and living clams that are mistakenly culled during processing.

This study examined shrinkage from the two most significant aspects; water loss during dry storage and mortalities from the time of harvest to final processing.

Methods

Water loss

Varnish clams were harvested from Fanny Bay on October 1, 2001 (n=117). An additional sample of Manila clams was taken for a comparison of shrinkage between the two species. The air temperature was 20°C and clams were harvested at the end of the tide cycle, such that clams were out of the water for approximately five hours prior to harvest. Weight to the nearest 0.1g was recorded for each clam.

The varnish clams were split into two groups. The control group (n=57) was kept in wet storage in a running seawater tank. Seawater temperature was 12 °C for the duration of storage. The second varnish clam group (n=60) and the Manila clam group (n=69) were placed into one l litre plastic containers. These containers were covered with lids and held in cold storage at 4°C. The initial weights of the varnish clams were not significantly different between the two groups, however, the Manila clams were significantly lighter than the varnish clams (Table 9).

The three groups were monitored for nine days. The clams were individually weighed to the nearest 0.1 gram for each of the first five days and again on the ninth day. Significant differences between the final weights of the varnish clam groups were tested using a t-test (two sample assuming equal variances).

After nine days, wet stored clams were split into two sub-groups and stored an additional 24 hours. One group was kept at 20°C and the other at 4°C. After 24 hours the treatments were analyzed for any changes in weight using a two-way ANOVA.

Mortality

Varnish clams were harvested during an experimental harvest on October 2, 2001. Each bag contained 14 to 16 kg (30 to 35 lbs) of clams and was removed from the place of harvest to a wet storage location. The clams were held inter-tidally until October 9, 2001.

On October 9, approximately 272 kg (600 lbs) of these clams were removed from wet storage. Approximately 227 kg (500 lbs) were washed, hand graded and packaged for shipping. The discarded clam shells were retained so that they could be weighed, and examined to determine the likely cause of death. Only shells that had at least part of both valves attached to the hinge were used when determining the cause of mortality. This eliminated the possibility of double counting individual clams if the valves were separated. A total of 352 shells were examined. The shells were classified into five categories:

- Broken at harvest - shells that show any amount of damage with no meat present in the shell. The absence of meat indicates that the shell was damaged at the time of harvest or initial transport and assumes that the clam died from the injury. A small percentage of clams may develop shell breakage in wet storage but these cannot be differentiated and were grouped with those assumed to be broken at harvest.

- Not broken – dead clams that died sometime after harvest but not due to shell breakage.
- Broken at processing – clams broken during the transport from wet storage or during processing. This was only assumed if the condition of the meat was fresh and obviously recent.
- Dead prior to harvest – empty shells that were mistakenly harvested by the diggers. These shells show loss of pigment and the growth of algae on the inner part of the shell that is characteristic of most dead shells found on the beach.
- Living – living clams that were mistakenly culled out during the grading process.

Using shell to meat ratio of healthy clams, the weight of the empty shells was converted into whole wet weight, which allowed a more accurate representation of the percentage of clams lost by weight. The conversion factor was:

$$\text{Whole wet weight} = 1.47 * \text{Shell weight.} \qquad (1)$$

Results

Water loss

The results of the water loss experiment indicated that varnish clams do not lose water at the same rate as Manila clams. After nine days of dry storage the varnish clams demonstrated only 0.6% weight loss (Figure 20). On the other hand, the Manila clams lost 5.6% of their weight on average over the same nine-day period. Surprisingly, the wet stored varnish clams gained 8.9% during the nine-day period. Figure 21 shows the results of the daily weight measurements. T-test results indicate that there was a significant difference between the final day weights between varnish clam treatments ($p = 0.049$, df. 114).

The varnish clams that were wet stored for 9 days that then moved to dry storage for 24 hours showed slight weight losses of 2.01% for the 20 degree clams and 1.26% for the 4 degree clams. These results were not however significant ($p>0.13$, df. 1,1,1,108) but likely would have showed significant losses if tracked for a longer period.

Mortality

Of the dead clams culled during processing, the overwhelming majority (78%) were apparently killed at the time of harvest, while 18% died of unknown causes during wet storage. The remaining 4 % were still alive, broken at the time of processing or dead prior to harvest (Figure 22). The total weight culled was estimated at 4.2 kg (9.3 lbs), which represented 1.8% of the total weight processed.

MARKET CONSIDERATIONS

Initial attempts at market development were undertaken by Albion Fisheries in Victoria. The target market was the restaurant trade in Vancouver and on Vancouver Island. Wholesale prices were maintained at or above Manila prices. The market was maintained in spite of inconsistencies in supply due in periods between harvest permits and changes in the primary processor obtaining experimental harvest permits. The current processor, Mac's Oysters Ltd., has explored export markets in the U.S. in addition to the product sold through Albion Fisheries. A food trade show in Vancouver in July 2000 featured varnish clams in an "Iron Chef" demonstration, and garnered positive response from attendees (M. Biagi, Community Futures Development Corporation Powell River, pers. comm.).

Enquiries from the processing and depuration industry indicate continued interest in developing markets for varnish clams. DFO and the B.C. Provincial government are currently drafting a Letter of Understanding (LOU) that will permit harvest of varnish clams under aquaculture permit from tenured foreshore.

An initial attempt to conduct a wild harvest in Area C was of limited success (R. Webb, DFO Parksville, pers. comm.). A three-day opening was held for Manila, littleneck and varnish clams in October 2001. The bulk of the landings were of Manila clams, with only 122 kg (268 lbs) of varnish clams landed. Diggers were disappointed with the price offered for varnish clams (~$1.00/lb) when Manilas were selling for considerably more (~$1.70/lb). Processors showed some interest in the product, but were reluctant to attempt to develop markets when the supply of varnish clams could not be guaranteed.

DISCUSSION

Geographic Distribution

From the results of the 2000 assessment of beaches in Area C it is apparent that varnish clams are widely distributed along the intertidal area of the Sunshine Coast. When combined with additional distributional information, varnish clams demonstrate a wide distribution throughout Georgia Strait, with a more sparse distribution along the West Coast of Vancouver Island. Scattered distribution records from the West Coast of Vancouver Island may be an artefact of the remoteness of the area and opportunities to observe varnish clams, rather than the actual distribution. Recent findings of varnish clam shell may extend the range of this species as far north as Checleset Bay on the west coast, the head of Toba Inlet on the B.C. mainland and into lower Johnstone Strait at Salmon Bay on eastern Vancouver Island. Since this species was first reported in the early 1990's from Boundary Bay and Newcastle Island (Forsyth 1993; Meriliees and Gillespie 1995), the pattern of expanding distribution has been consistent with that of a southern introduction point and larval drift as the distributional mechanism (Gillespie *et al.* 1999). The pattern is similar to that exhibited as newly introduced Manila clams expanded their distribution in British Columbia (Quayle 1964; Bourne 1982).

Results of the Area C survey also indicate introduction from a southern point in Georgia Strait. Varnish clam populations become increasingly established from south to north within Area C (Figure 3, Table 1). Increased incidence of high densities of varnish clams in areas open to the Strait and decreasing densities moving into inlets and channels was also demonstrated (Figure 3). This aspect was more pronounced in the northern area, which appears to be more recently settled, were high abundance was only indicated at Hernando, Savary and Harwood Island, one location in Lancelot Inlet and one location on the west side of West Redonda Island. Shell only findings in the most northerly regions of Area C possibly indicate recent invasion of these areas with populations yet to develop to the point of easy detection.

Findings of the Area C survey project combined with additional information sources indicate increasing distribution of varnish clams in a northerly direction on both coasts of Vancouver Island. Current limits of distribution on the west coast of North America are from Alsea Bay, Oregon (44º26'N, 124°03'W) (Coan *et al.* 2000) northwards to Cameleon Harbour (50°21'N, 125°18'W) and Ahous Bay, Clayoquot Sound (49°10'N, 126°01'W), with shells collected at Hesquiat Harbour (49°28'N, 126°25'W), Checleset Bay (50°07'N, 127°37'W), Toba Inlet (50°29'N, 124°24'W) and Salmon Bay (50°24'N, 125°58'W) possibly indicating populations further to the north and/or west.

Relative Distribution

Survey information reviewed here demonstrated a clear pattern of relative distribution of clam species in the intertidal zone. In most cases, varnish clam distribution was limited to the upper third of the intertidal zone, or peaked there. Manila density peaked at slightly lower elevations, followed by littleneck clams. Differences in tidal distribution of varnish clams may be due to the presence and abundance of Manila clams (competition) or due to greater tolerance of environmental conditions (*e.g.*, slope, substrate, or wave activity) that limit Manila abundance at some locations (adaptability). We have noted other beaches (*e.g.*, Manson's Landing, Cortes Island) where high varnish clam abundance is correlated with a greater slope and higher exposure. Varnish clams tend to be in porous substrates like sand or mixed sand and fine shell, that drain thoroughly.

There has been considerable debate as to the relationship of habitat overlap and competition, *i.e.*, whether high or low measures of habitat overlap indicate interspecific competition (Abrams 1980). If resources are not in short supply there is no competition, regardless of the level of overlap. If there is territoriality or competitive exclusion, intense competition may be occurring but not reflected in the measure of habitat overlap. However, habitat overlap remains an effective tool for describing community organization.

Examination of the habitat overlap values calculated at Denman Island reveals that the greatest levels of overlap occur between Manilas and littlenecks (66.8%) and littlenecks and butters (54.0%)(Table 2). In fact, Manilas have similar overlap values with butters (34.1%) and varnishes (35.6). It would be difficult to argue that littlenecks or butters have limited Manila distribution, even though they have measures of habitat overlap equal to or greater than varnishes. It could be argued that varnish clams place an upper limit on the tidal distribution that did not exist before, but one could easily argue that it is Manilas that are limiting varnishes to higher tidal elevations than they would inhabit in the absence of Manilas (*e.g.*, Kent's Beach). It appears that all have found a niche.

Because varnishes generally live above Manilas, joint fisheries can be undertaken in which fishers utilize varnishes on the beginning and end of tidal cycles, in addition to those that might be taken at "Manila depths". It is still unclear what effect varnishes will have on culture situations where Manilas are planted and removed on a regular basis. In periods where adult Manilas are absent from the beach, varnishes could expand their distribution lower in the intertidal zone. However, data from culture tenures on Denman Island were not clear – varnishes were limited to the highest tidal extremes at Henry Bay, but were found lower on the tide at Metcalfe Bay (Figure 10).

Competition Experiments

The enclosure experiments show that varnish clams have a marginally greater effect on the growth of Manila clams than vice versa in the high-tide elevation. The mechanism for this effect is believed to be competition for a limited resource; likely to be either food or space or a combination of these two factors (Peterson and Andre 1980). The bimodal feeding methods of varnish clams may bestow a competitive advantage as, presumably, they would be able to continue food intake over a longer period than Manila clams that rely on submergence for feeding.

In the mid-tide zone the magnitude of effects of varnish clams on Manila clams was similar to that observed in the high-tide zone. However, varnish clam growth was significantly decreased by the presence of Manila clams at this tidal elevation. Perhaps this elevation is the optimal habitat for Manila clam growth, which all being equal, is greater than that of varnish clams. Observations on a number of beaches indicates that there appears to be a natural habitat selection process with Manilas dominating numerically at mid-tide and the reverse true at higher tide elevations.

For Manila clams, growth in length and weight are highly correlated. In varnish clams, there appears to be little relationship between effects (tide elevation and treatment) on the two growth variables, regardless of cause.

It is tempting to conclude that effects on tissue weight or growth of varnish clams were largely uncoupled from effects on shell size or growth. However, whole organism wet weights were used which may be subject to greater variance in varnish versus Manila clams. Further, energetic resources may have been dedicated to gonad development which may alter the relationship of growth in length and weight. A better understanding of the timing of spawning in varnish clams may help to resolve this issue.

A caveat to the above interspecific competition analysis is that the experiments did not address intraspecific competition effects. Treatments with both species present had higher densities than either species alone and it is conceivable that similar growth impairment may have resulted from density dependant factors alone.

Characteristics of Harvest

Results of the size distribution sampling indicates that clams above 30 mm are being targeted in the harvests (Figure 12). Only one clam <30 mm was documented from the harvest, and was likely not intentionally harvested. The size distribution of harvested varnish clams in this study was similar to that of Manila clams harvested from aquaculture tenures (where size limits do not apply), as this would be the expected size of clams for the market place.

Total harvest efficiency was demonstrated to be dependent on the underlying initial population of clams in the sample area. Samples taken on August 3, 2001 showed a population having a higher proportion of small clams (<30 mm). This was likely the result of the area having been previously harvested (approximately 2 months prior) at which time a proportion of the larger clams would have been removed but small clams would remain. Previous harvest likely affected the total efficiency of the sample harvest in this area, but was not likely to have influenced the size specific harvest efficiencies as the number of clams <30 mm are not utilized in the estimates.

Size specific harvest efficiencies proved to be fairly consistent between the two sample locations with the exception of the ≥30 mm size category. The difference in this portion of the sample can be attributed to the low abundance of clams <35 mm in the second sample area (Figure 13). Results of this analysis indicate that the expected efficiency of varnish clam harvests would be between 0.60 and 0.80 for clams >30 mm when harvesting under similar daylight conditions. This may be overestimated somewhat by the structure of the efficiency test. Diggers were instructed to dig a 1 m^2 plot completely and did so. Normal harvesting does not dig a complete area, as diggers will selectively dig high density areas that represent a small proportion of the total area available to harvest. However, the samples were taken in areas that were selected by the harvesters, so the situation might be fairly representative of normal harvesting practices. Efficiency would be expected to decrease when considering a larger area or during night-time harvest, as it becomes more difficult to locate clams under low light conditions.

Breakage of clams during harvest was shown to be low in all samples collected, with overall total breakage estimated at approximately 2 %. Breakage was shown to be higher in the non-harvested portion of the sample, which was expected due to harvesters discarding broken clams from their harvest that were likely to die prior to market.

Physical conditions of the harvest area play a large role in the breakage levels during harvest. The area where samples were collected was a fine gravel/shell beach with few large rocks. Communication with harvesters indicated that substrate type has a dramatic effect on the incidence of breakage, as gravel substrate with large rocks causes more breakage as the substrate is overturned than a fine gravel/mud beach. Therefore, breakage samples may represent what could be expected from close to ideal substrate with experienced harvesters and may represent the low end of what could be expected for harvest breakage. Levels of breakage seen in these results are not what would be expected from a wild harvest from a less favourable substrate type.

Harvest timing was also favourable during the collection of breakage samples. Daylight harvesting may result in less total breakage, as harvesters have adequate light to harvest in a more meticulous manner. Harvesters were also regular employees of Mac's Oysters, hired as the clam harvesting crew, and may have harvested in a manner resulting in less breakage than would be expected during a wild harvest were time is limited and harvesters may be less experienced.

Purging of pea crabs does not appear to be possible with the methods investigated. Both tank trials and beach trials had no indications of crab purging after a full five days. It is difficult to say if the purging process may have increased in the tanks after the five day period, but beyond that length of time it is no longer commercially viable to hold the clams in a tank. However, it seems unlikely the purging process would have increased after the five day (120 hour) mark because the beach stored clams showed no signs of purging even after 34 days. Other methods need to be investigated to induce pea crabs to vacate their host clams. Some alternatives may be chemical treatment, or desiccation periods. No chemical treatments have been attempted to date, and preliminary desiccation trials have not indicated increased purging.

A more immediate and promising method for decreasing the pea crab content in varnish clams may be size selection of clams and harvest site selection. The results of the crab content in relation to size analysis revealed that larger clams had a greater proportion of crabs while the smaller clams (<40 mm shell length) have the lowest proportions of crabs at around 20%. Other preliminary work has indicated that the crab content may also be tide level related, with clams in the higher tide levels having lower crab content, which is consistent with results from Haines *et al*. (1994) for *Mytilus edulis*. There is promise that site and size selection may be the key to reducing the proportions of clams containing crabs.

To date, most of the concerns surrounding pea crabs have been based on supposition and conjecture. The actual health risk of unknowingly eating small crabs in clams should be explored. Similarly, the market inplications of clams containing crabs is not known. Do pea crabs decrease consumer appeal for varnish clams? Pea crabs were actually considered a “value-added” product in oyster stews on the East Coast in 1700’s (MacKenzie 1996).

Purging of grit from varnish clams in a tank system proved to be effective and clams can be purged to acceptable levels for shipping rapidly. The high grit content clams (inedible) were reduced from 50% to less than 1% of the sample within 24 hours, which is acceptable for shipping to market. Total grit levels were reduced to low levels (<20%) within 24 hours and <10% within 120 hours. Clams that were bagged had significantly lower levels of grit, however, grit levels from the non-bagged clams were also at levels acceptable for shipping. The reason for the bagged clams having lower total grit levels is unclear, but it may be due to the restricted flow through the bags. When faced with lower flow rates Manila clams tend to filter more vigorously, which may contribute to lower grit levels.

The results of the water loss experiment indicated that varnish clams retain water levels in dry storage more effectively than Manila clams. It was interesting to note that the varnish clams in wet storage gained 8.9% of their initial weight over the nine day period. This suggests that varnish clams can absorb and retain much more water than they do when exposed to tidal cycles and may plump when held sub-tidally or in a tank environment. The reason for low shrinkage in dry stored varnish clams may be because the clams were already desiccated and there was little remaining water to be lost. This would also explain why there was significant weight gain in wet stored clams. Observations of meat content on the day of harvest did not, however, show signs of desiccation as both meat content and quality were very high. Since the clams were harvested under natural conditions and clams are usually wet stored inter-tidally, which approximates natural conditions, it may be reasonable to assume that low water loss during dry storage will be indicative of shrinkage during commercial operations.

The losses due to post-harvest mortality were low: approximately 1.8% over seven days of wet storage. As most of the clams appear to have died due to shell breakage at harvest, these losses could possibly be reduced further. The other sources of shrinkage such as processing breakage and wet storage mortality are unavoidable and were demonstrated to be at levels that are insignificant on a commercial scale in this study.

Based on the data collected it appears that varnish clams have relatively low shrinkage levels when shipped on a commercial scale. A reasonable estimate of the expected total shrinkage is around 2% for water loss and 2% for mortality loss making for a total shrinkage of around 4%. In a worst case scenario one might expect a water loss of 8.9%.

Fishery Potential

Varnish clams have a number of biological characteristics that contribute to fishery potential. They are an attractive clam with high meat:shell weight ratios. They have a good shelf life, suffering low mortality during storage and shipping. They are very abundant on many beaches, and appear to have productivity characteristics that would contribute to recovery from harvests. In limited attempts to develop Industry interest in varnish clam fisheries to date, primary deterrents have been lack of market opportunities, lack of consistent supply, and disinterest by diggers discouraged by price.

The primary concern amongst processors is the consistency of supply of varnish clams required to develop strong markets. Market development could be supported by harvests from tenures, which would provide a market for wild harvests as well. Purported losses in Manila production from tenures, although not yet defensibly documented, may be offset by the economic gains from harvest and sale of varnish clams.

Processors are concerned that rapid development of varnish clam fisheries could have adverse effects on market development. If large quantities of varnish clams are available before the market is established, then the value of the product will be artificially low. Once a low price is set, it would be difficult to increase in the future. A slower approach would allow the varnish clam to be marketed as a higher-value product as consumer awareness increases. Once markets and price are established, a full-scale commercial fishery would realize higher unit value for their product.

Management Considerations

The results from the competition experiments indicate that competition between varnish and Manila clams favours varnish clams at higher tidal elevations with the reverse true at mid-tide elevations. If interspecific competition, rather than density dependant effects, exists between these species at mid-tidal elevations, varnish clam growth will be less than that of Manila clams and it would be expected that, over time, Manila clams will dominate. However, this is premised on having equal harvest pressure on both stocks. Removal of Manila clams through harvesting will clearly give the advantage to varnish clams remaining in the substrate. The question remains, however, if both species are harvested with equal efficiency, will Manila clams dominate at mid-elevation?

Gillespie *et al*. (1999) discussed the effectiveness of size limits for the potential management of varnish clam fisheries. They noted that most other commercially exploited intertidal bivalves in B.C. were managed using size limits (Bourne 1987). There was concern, however, that a size limit might not effectively achieve management objectives if there were high levels of breakage in discards, or if discarded clams were unable to rebury and did not survive. The favourable results of harvest efficiency studies undertaken here indicate that breakage is not a major concern, at least in good substrates. We also observed that previously harvested areas maintained relatively large numbers of small clams, implying that survival of undersize clams was good. Therefore, size limits remain a viable option for varnish clam fisheries, once description of size at maturity characteristics of varnish clams are complete.

Utilization of a Total Allowable Catch (TAC) for varnish clam fisheries would require considerable assessment effort to develop stock information time series similar to those used in fisheries for Manila clams. The depuration fishery for Manila clams in the South Coast is managed using beach-specific TACs determined from annual stock surveys and harvest rates determined annually from abundance reference points (Gillespie 2000). The fishery for Manila clams in Area 7 in the Central Coast is managed using an overall TAC and subarea ceilings derived from annual surveys on index beaches and a feedback gain model (Gillespie *et al*. 2001). Both of these approaches required a number of years of data before the models could be developed.

CONCLUSIONS AND RECOMMENDATIONS

Varnish clams continue to establish high density populations in the Strait of Georgia and to extend their distribution in Johnstone Strait and on the West Coast of Vancouver Island. Varnish clams tend to be distributed at a higher elevation in the intertidal than that of Manila clams; when populations of both Manila and varnish clams are present on the same beach, habitat overlap occurs. However, the higher intertidal is generally dominated by varnish, while the mid-intertidal dominated by Manila clams. On beaches that do not support significant populations of Manila or littleneck clams, varnish clams may extend throughout the intertidal region.

Competition between Manila and varnish clams was shown to occur using growth indices of changes in length and weight over the summer growing period. Varnish clams demonstrated competitive advantage in the upper intertidal and Manila clams in the mid-intertidal. Impacts of density dependant factors and intraspecific competition were not assessed in this study and may have partially contributed to the results.

Varnish clams ≥30 mm were targeted in experimental harvests. Harvest efficiency was estimated to be between 0.6 and 0.8, dependant on the density and size distribution of the underlying clam population. Breakage sampled directly at harvest was low in all samples and resulted in a total breakage estimate of approximately 2%, consistent with estimates of shrinkage during processing. Shrinkage during dry storage was shown to be relatively low compared to Manila clams. Harvest, wet storage and processing practices did not result in shrinkage estimates unacceptable to commercial scale operations. Purging of grit to levels acceptable for market is achievable in relatively short time (two days) with no significant differences between treatment weights or the use of bags and daily turning. Pea crabs are not purged using normal holding procedures, even after more than 30 days. Further investigation of harvest sites, intertidal elevation and clam size specific incidence of crabs may reduce the overall incidence of crabs in harvested clams.

Varnish clams represent an additional resource to be utilized by intertidal clam harvesters and culturists. The development of fisheries for varnish clams will be driven primarily by Industry, and likely await market development, which depends upon consistent supply. If agreement is struck allowing tenure holders to harvest and sell varnish clams, this supply could lead to established markets, which will then benefit development of commercial fishing opportunities. Detailed landings information from harvested tenures will allow examination of the productive characteristics of varnish clams and allow us to determine if the "control" of varnish clam densities through harvest will increase Manila clam production from these tenures.

Development of assessment and management frameworks for varnish clam fisheries require biologically-based reference points. The effectiveness of a size limit, and the biological information from which to select an appropriate size, are currently not known. Use of TACs or other reference points based on population characteristics or density require experimental manipulations or a longer history of stock responses to harvest. This information is best obtained through small-scale experimental fisheries that explore economic potential, Industry interest and provide information on stock dynamics of both harvested and unharvested popualtions. The opportunity to harvest varnish clams from tenures should likewise be structured in a way that provides scientifically defensible information related to stock responses to harvest and to changes in Manila clam production before and after reduction of varnish clam populations.

Recommendations

1. **Proceed with implementation of monitored small-scale commercial opportunities through harvests from aquaculture tenures and the regular commercial fishery.** Varnish clams have demonstrated sufficient quality to support market demand and occur in high abundance on some aquaculture tenures and beaches presently harvested by the commercial fishery. Harvesting from tenures will allow tenure operators a means of obtaining some financial benefit from the species while further establishing a market through consistent supply to the marketplace. If a substantial market exists for the varnish clam, commercial harvesters may benefit from tenure developed markets. Harvests will also allow processors to further develop handling, purging and processing methods for varnish clams originating from both tenures and wild harvest. Catch reporting and sampling programs are required for these harvests, to collect information to further determine productive capabilities of the species and harvest characteristics under open harvest conditions. Limited opportunities will allow Industry to explore fishery potential without placing large portions of the stock at risk to over-exploitation. Such information will also allow for investigations into the response of varnish clams to harvesting pressure and could be useful for future management decisions.

2. **Continue research into basic biology of varnish clams in British Columbia.** Information gaps noted by Gillespie *et al.* (1999) included information on reproductive biology, age and growth, early life history and recruitment. Investigations of reproductive biology are ongoing, seeking to develop a biologically defensible size limit, should one be required for management. Information on age and growth and recruitment are required for developing models to support an assessment framework for the rational utilization of a potentially economically important resource.

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Table 1. Number of beaches with varnish, Manila, littleneck and butter clams and percentage of total (in parentheses) in each abundance category by species and area from the Area C distributional survey, 2000.

Southern Area (n = 158)

	Abundance Category				
	High	Moderate	Present	Shell	Absent
Varnish	44	16	21	3	74
	(27.8)	(10.1)	(13.3)	(1.9)	(46.8)
Manila	64	36	22	1	35
	(40.5)	(22.8)	(13.9)	(0.6)	(22.2)
Littleneck	45	29	34	1	49
	(28.5)	(18.4)	(21.5)	(0.6)	(31.0)
Butter	13	13	20	20	92
	(8.2)	(8.2)	(12.7)	(12.7)	(58.2)

Northern Area (n = 142)

	Abundance Category				
	High	Moderate	Present	Shell	Absent
Varnish	12	4	10	13	103
	(8.5)	(2.8)	(7.0)	(9.2)	(72.5)
Manila	0	10	44	1	87
	(0.0)	(7.0)	(31.0)	(0.7)	(61.3)
Littleneck	4	7	29	8	94
	(2.8)	(4.9)	(20.4)	(5.6)	(66.2)
Butter	1	2	8	17	114
	(0.7)	(1.4)	(5.6)	(12.0)	(80.3)

Combined (n = 300)

	Abundance Category				
	High	Moderate	Present	Shell	Absent
Varnish	56	20	31	16	177
	(18.7)	(6.7)	(10.3)	(5.3)	(59.0)
Manila	64	46	66	2	122
	(21.3)	(15.3)	(22.0)	(0.7)	(40.7)
Littleneck	49	36	63	9	143
	(16.3)	(12.0)	(21.0)	(3.0)	(47.7)
Butter	14	15	28	37	206
	(4.7)	(5.0)	(9.3)	(12.3)	(68.7)

Table 2. Habitat overlap (% +/- 95% CI) of varnish, littleneck, butter and Manila clams for three beaches on Denman Island, 2000.

	Varnish	Littleneck	Butter	Manila
Varnish	-	12.611 (±8.455)	3.787 (±0.758)	35.566 (±10.469)
Littleneck		-	53.991 (±28.389)	66.801 (±21.449)
Butter			-	34.074 (±35.973)
Manila				-

Table 3. Results (p-values) of two-way ANOVA comparing survival, initial sizes and growth of Manila and varnish clams between treatments (i.e., absence or presence of the other species) and tidal zones. Statistcally significant results (p≤0.05) are bolded.

	Species					
	Manila clam			Varnish clam		
Variable	Treatment	Zone	Treatment ×Zone	Treatment	Zone	Treatment ×Zone
Survival	0.264	0.946	0.700	**0.028**	**0.021**	0.653
Initial length (L_0)	0.643	0.481	0.965	**0.033**	**0.021**	**0.019**
Change in length (ΔL)	**0.024**	**0.001**	0.146	0.252	0.192	0.911
Initial weight (W_0)	0.713	0.629	0.890	**0.036**	0.257	**0.014**
Change in weight (ΔW)	**0.011**	**<0.001**	0.098	**0.001**	0.076	**0.014**
ΔW versus ΔL	0.266	0.218	0.456	**0.004**	0.226	**0.014**

Table 4. Manila clam mean survival, length, weight and growth and adjusted means for growth in length and weight from the competition experiments at Fanny Bay, Baynes Sound, 2001.

Variable	Treatment	Zone		
		High	Mid	Both
Survival (%)	Alone	97.3	96.0	96.6
	Together	92.7	93.6	93.1
	Both	95.0	94.8	94.9
		High	Mid	Both
L_0 (mm)	Alone	40.0	39.4	39.7
	Together	39.6	38.9	39.3
	Both	39.8	39.1	39.5
		High	Mid	Both
ΔL (mm)	Alone	0.93	3.31	2.12
	Together	0.51	1.75	1.13
	Both	0.72	2.53	1.62
		High	Mid	Both
W_0 (g)	Alone	16.8	16.0	16.4
	Together	16.2	15.7	16.0
	Both	16.5	15.9	16.2
		High	Mid	Both
ΔW (g)	Alone	1.37	3.93	2.65
	Together	0.90	2.22	1.56
	Both	1.14	3.08	2.11
		High	Mid	Both
ΔW vs ΔL (g) Adjusted means	Alone	1.95	2.53	2.24
	Together	1.83	2.12	1.98
	Both	1.89	2.32	

Table 5. Varnish clam mean survival, length, weight and growth and adjusted means for growth in length and weight from the competition experiment in Fanny Bay, Baynes Sound, 2001.

Variable	Treatment	Zone		
		High	Mid	Both
Survival	Alone	97.2	93.2	95.2
(%)	Together	93.5	87.9	90.7
	Both	95.3	90.5	92.9
		High	Mid	Both
L_0	Alone	37.2	37.1	37.2
(mm)	Together	37.0	39.5	38.3
	Both	37.1	38.3	37.7
		High	Mid	Both
ΔL	Alone	1.42	0.94	1.18
(mm)	Together	1.00	0.60	0.80
	Both	1.21	0.77	0.99
		High	Mid	Both
W_0	Alone	11.6	10.8	11.2
(g)	Together	11.3	13.0	12.2
	Both	11.5	11.9	11.7
		High	Mid	Both
ΔW	Alone	0.93	1.07	1.00
(g)	Together	0.69	0.00	0.35
	Both	0.81	0.54	0.67
		High	Mid	Both
ΔW vs ΔL	Alone	0.85	1.08	0.97
(g)	Together	0.69	0.07	0.38
Adjusted means	Both	0.77	0.58	

Table 6. Efficiency of varnish clam harvesters from Fanny Bay, Baynes Sound, August 2001.

		Harvested			Screenings			Total
Date	Sample	n	Weight (g)	# Broken	n	Weight (g)	# Broken	Efficiency
3-Aug-01	1	288	3,633	3	402	3,040	4	0.42
3-Aug-01	2	517	7,745	4	567	5,886	10	0.48
22-Aug-01	1	413	5,172	9	172	1,662	6	0.71
22-Aug-01	2	337	5,011	11	112	1,375	6	0.75
Totals		1,555	21,561	27	1,253	11,963	26	0.55

Table 7. Estimated size-specific harvest efficiency of varnish clams from Fanny Bay, Baynes Sound, August 2001.

		Harvest Efficiency by Size Class			
Date	Sample	≥30 mm	≥35 mm	≥38 mm	≥40 mm
3-Aug-01	1	0.48	0.63	0.72	0.79
22-Aug-01	1	0.76	0.78	0.79	0.80
Pooled Samples		0.60	0.71	0.77	0.79

Table 8. Estimated breakage of varnish clams from Fanny Bay, Baynes Sound, August 2001.

Date	Sample	% Breakage in Harvest	% Breakage in Screenings	Total % Breakage
3-Aug-01	1	1.04	1.00	1.01
3-Aug-01	2	0.77	1.76	1.29
22-Aug-01	1	2.18	3.49	2.56
22-Aug-01	2	3.26	5.36	3.79
Pooled Samples		1.74	2.08	1.89

Table 9. Initial weights of wet stored varnish and Manila clams, Mac's Oysters Ltd., Fanny Bay, April 2001.

Treatment	N	Average weight (g)	SD
Control – wet stored varnish clams	57	12.9	3.89
Dry stored varnish clams	60	13.1	4.67
Dry stored Manila clams	69	10.6	2.79

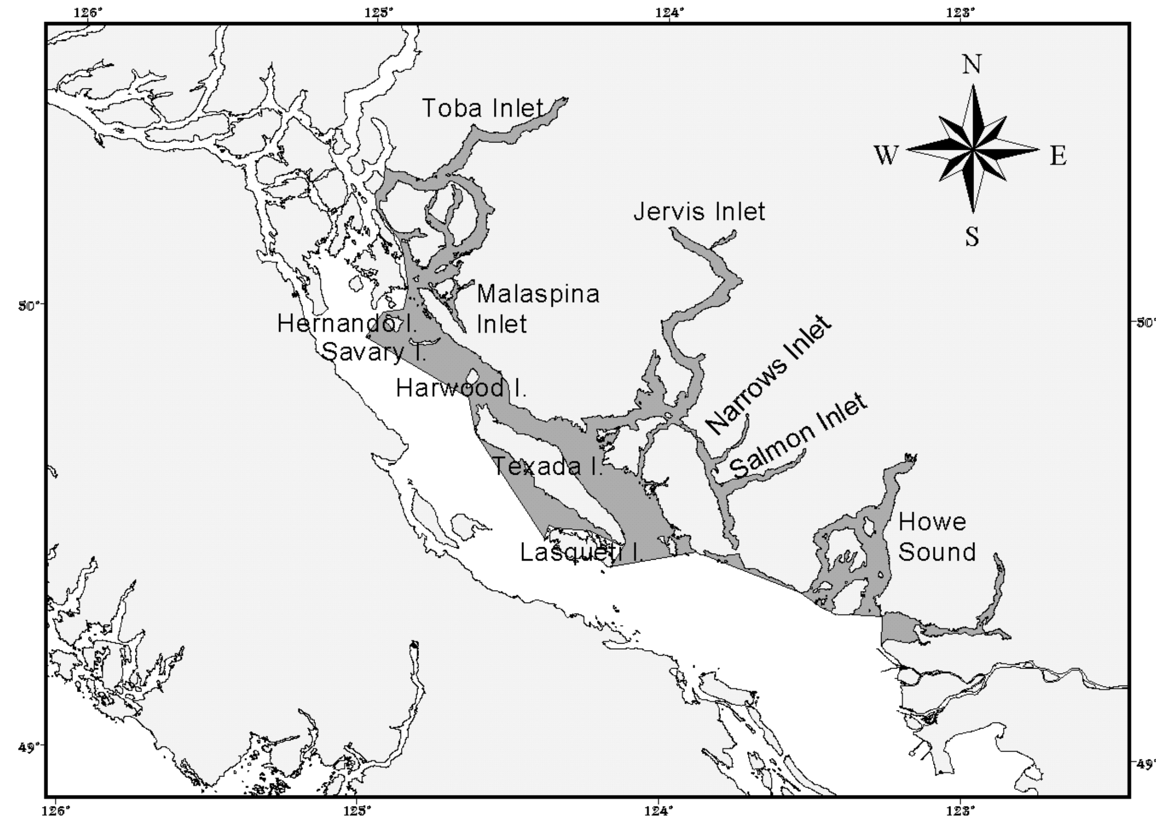


Figure 1. Clam Management Area C (shaded area) in British Columbia.

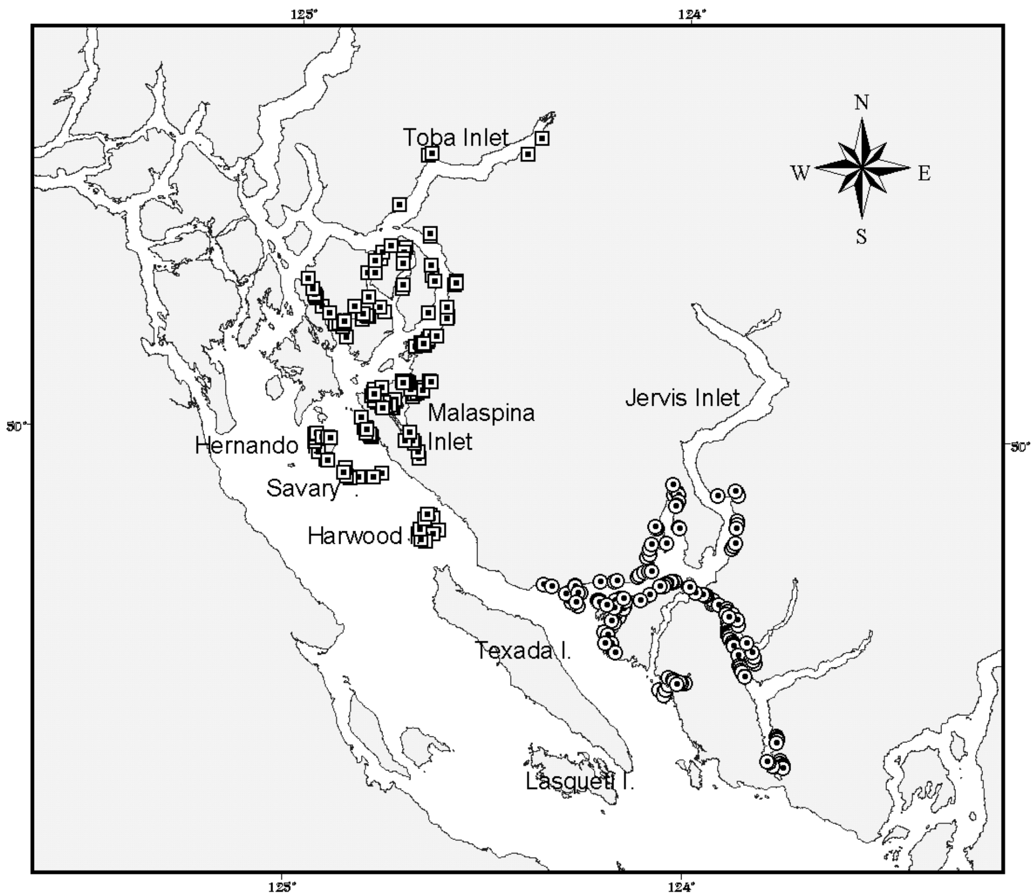


Figure 2. Beaches sampled in Area C, 2000. Squares represent northern locations and circles southern locations.

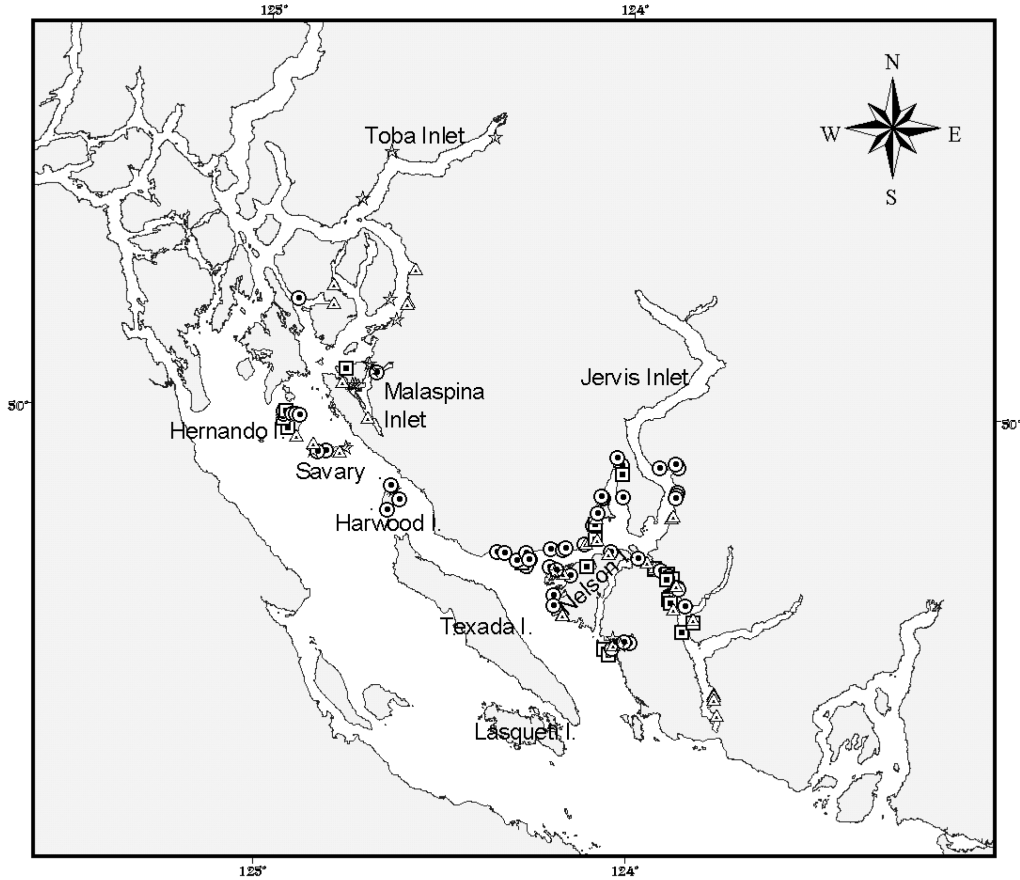


Figure 3. Density of varnish clams at beaches surveyed in Area C, 2000. Circles represent high density, squares moderate density, triangles presence and stars shell only.

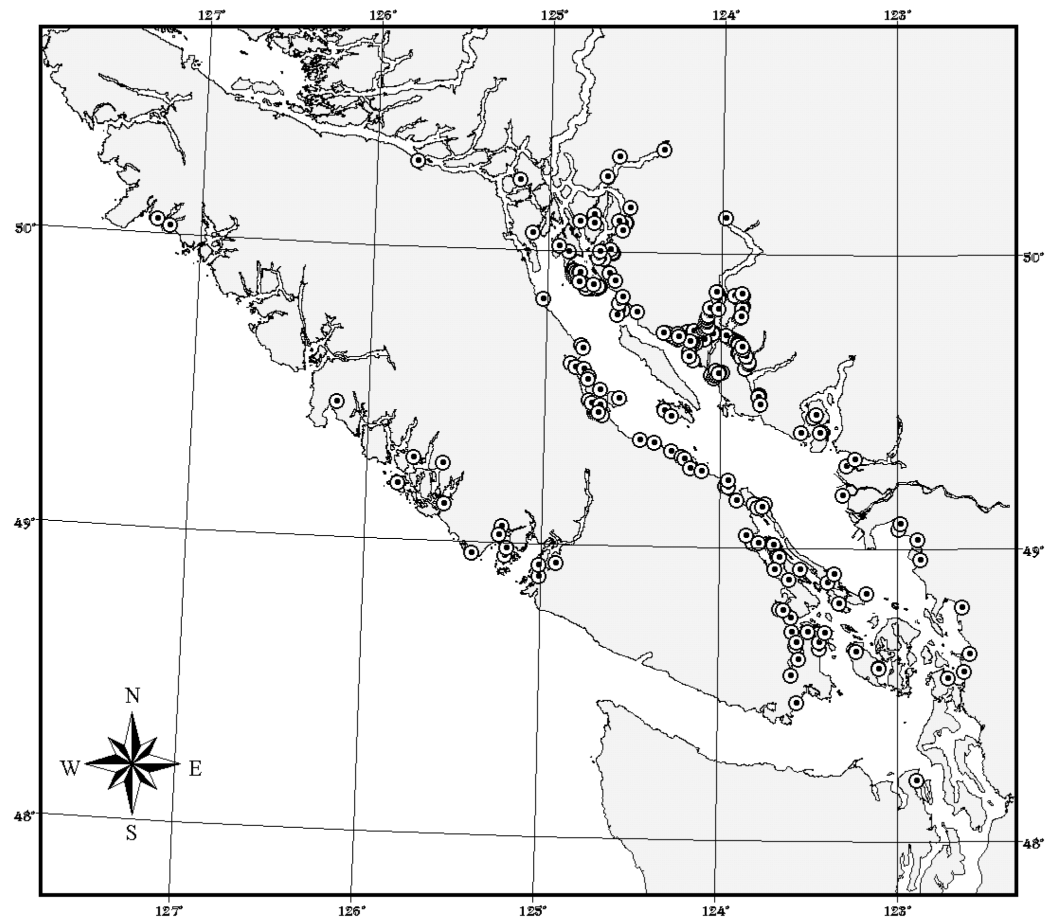


Figure 4. Varnish clam distribution in British Columbia and Washington State.

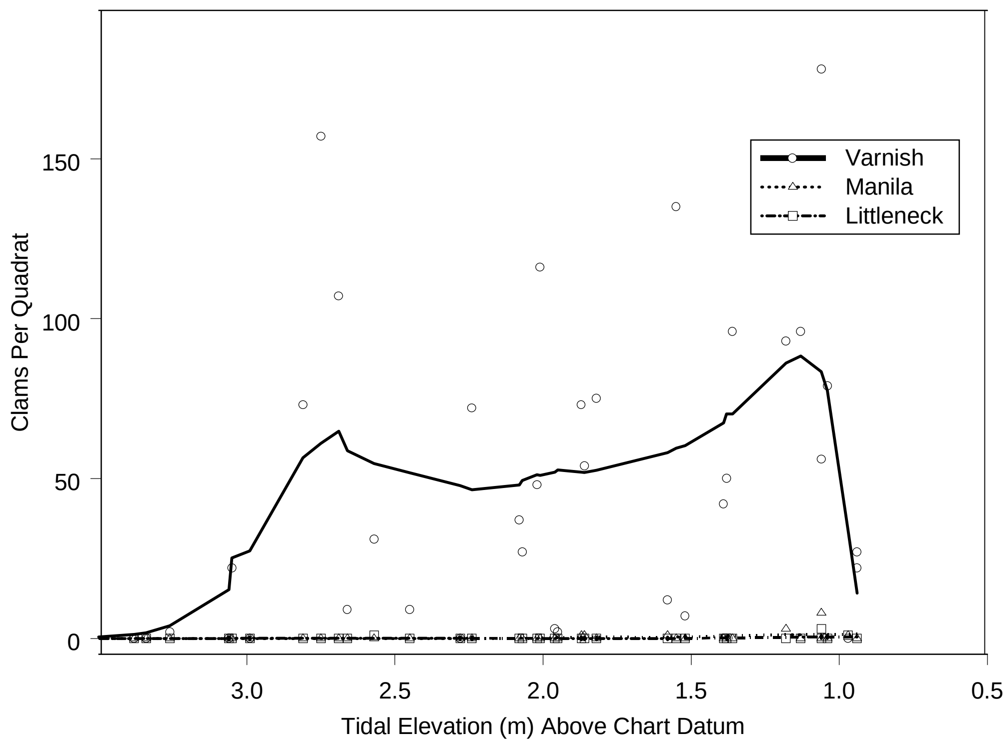


Figure 5. Clam distribution by tidal elevation, Kent's Beach, Powell River, July 18, 2000.

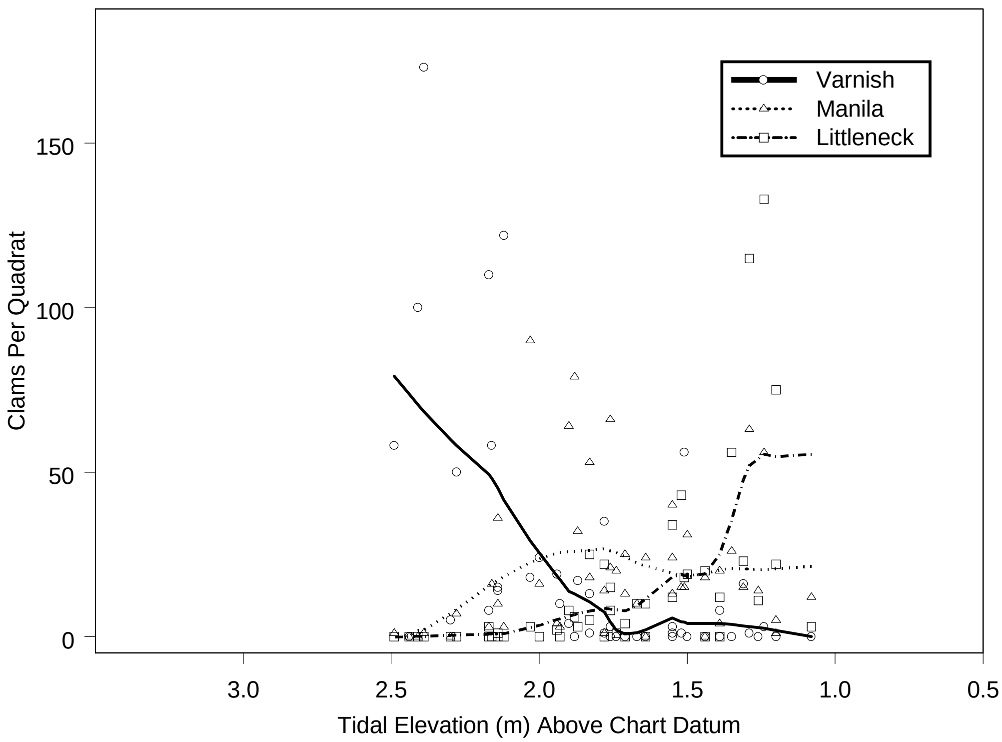


Figure 6. Clam distribution by tidal elevation, Saltery Bay, Powell River, August 29, 2000.

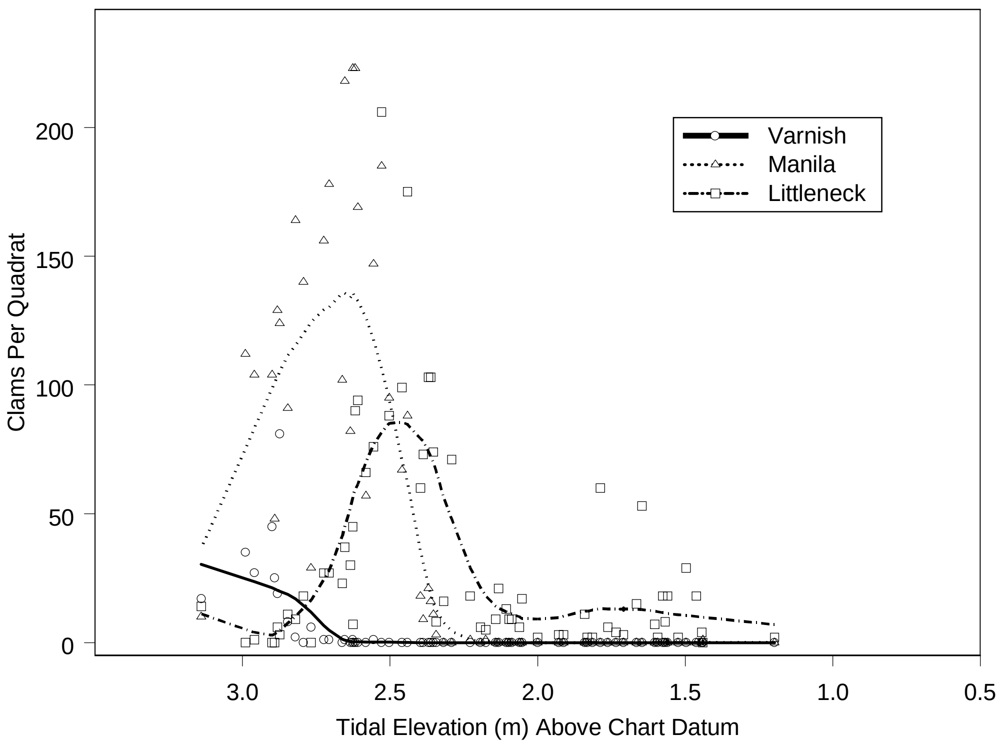


Figure 7. Clam distribution by tidal elevation, Fillongly Park, Denman Island, 2000.

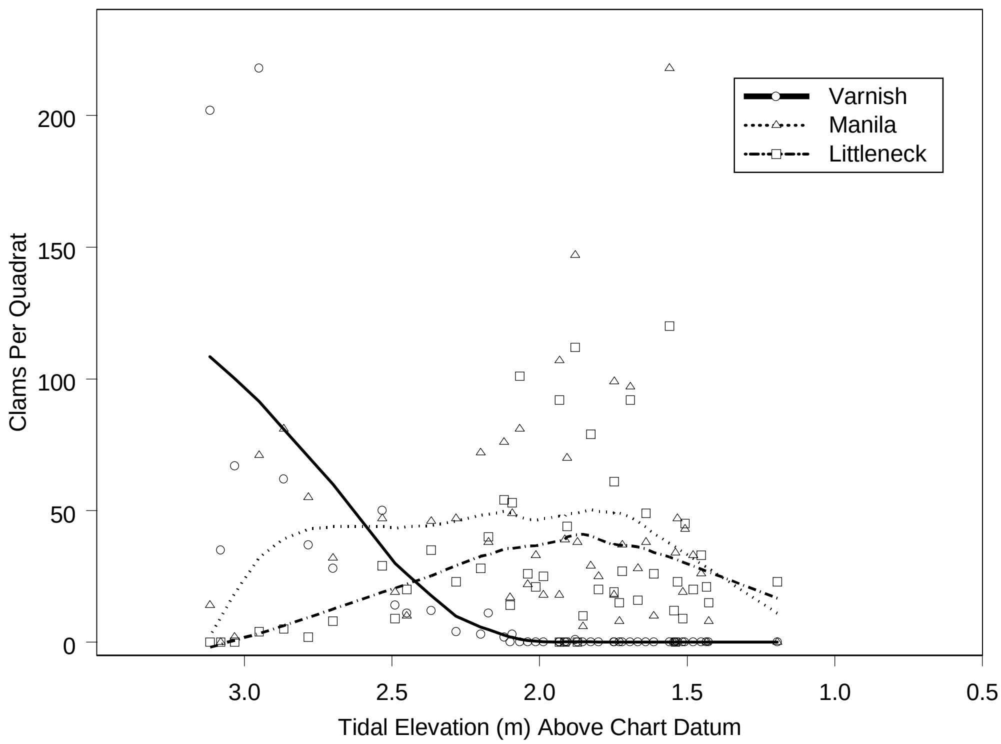


Figure 8. Clam distribution by tidal elevation, Metcalfe Bay, Denman Island, 2000.

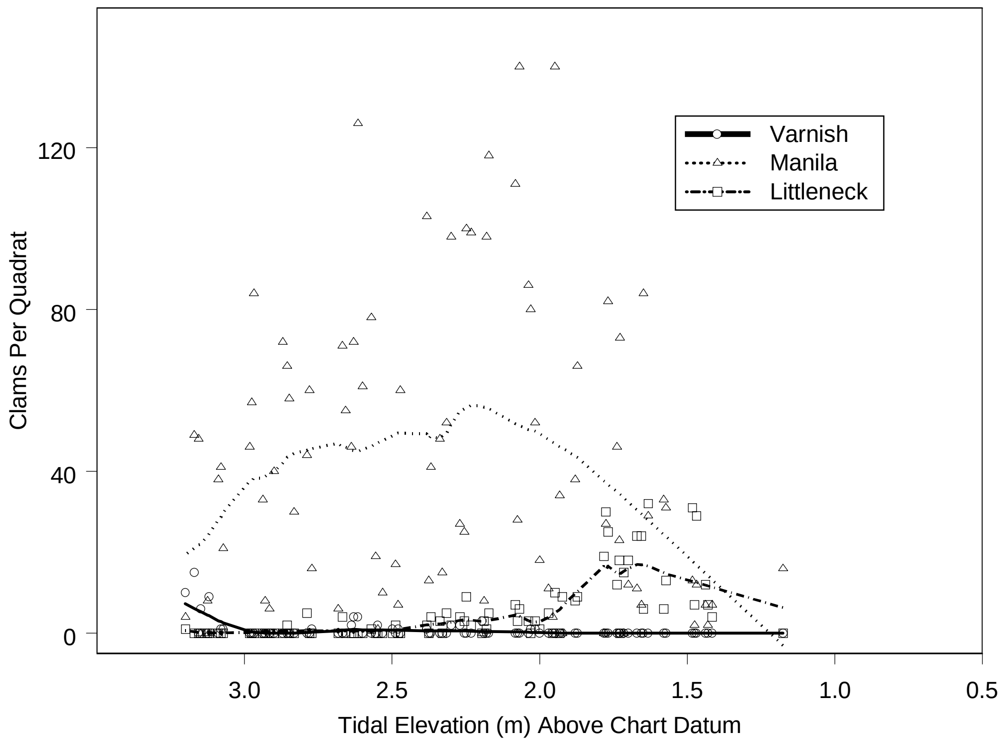


Figure 9. Clam distribution by tidal height, Henry Bay, Denman Island, 2000.

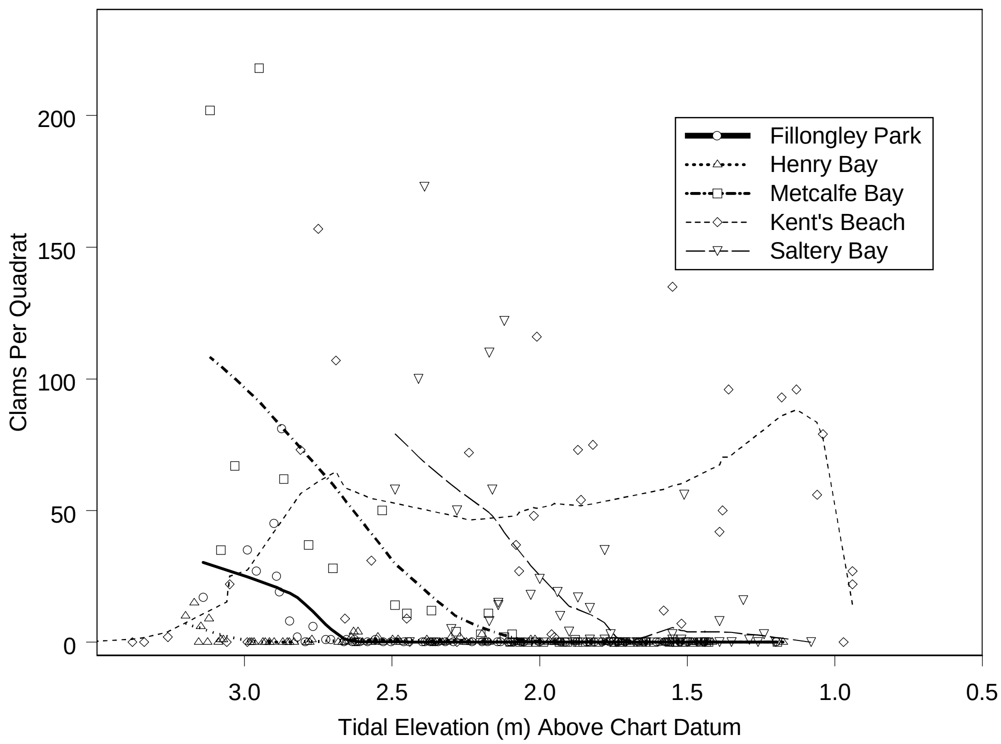


Figure 10. Varnish clam distribution by tidal elevation on all beaches surveyed 2000-2001.

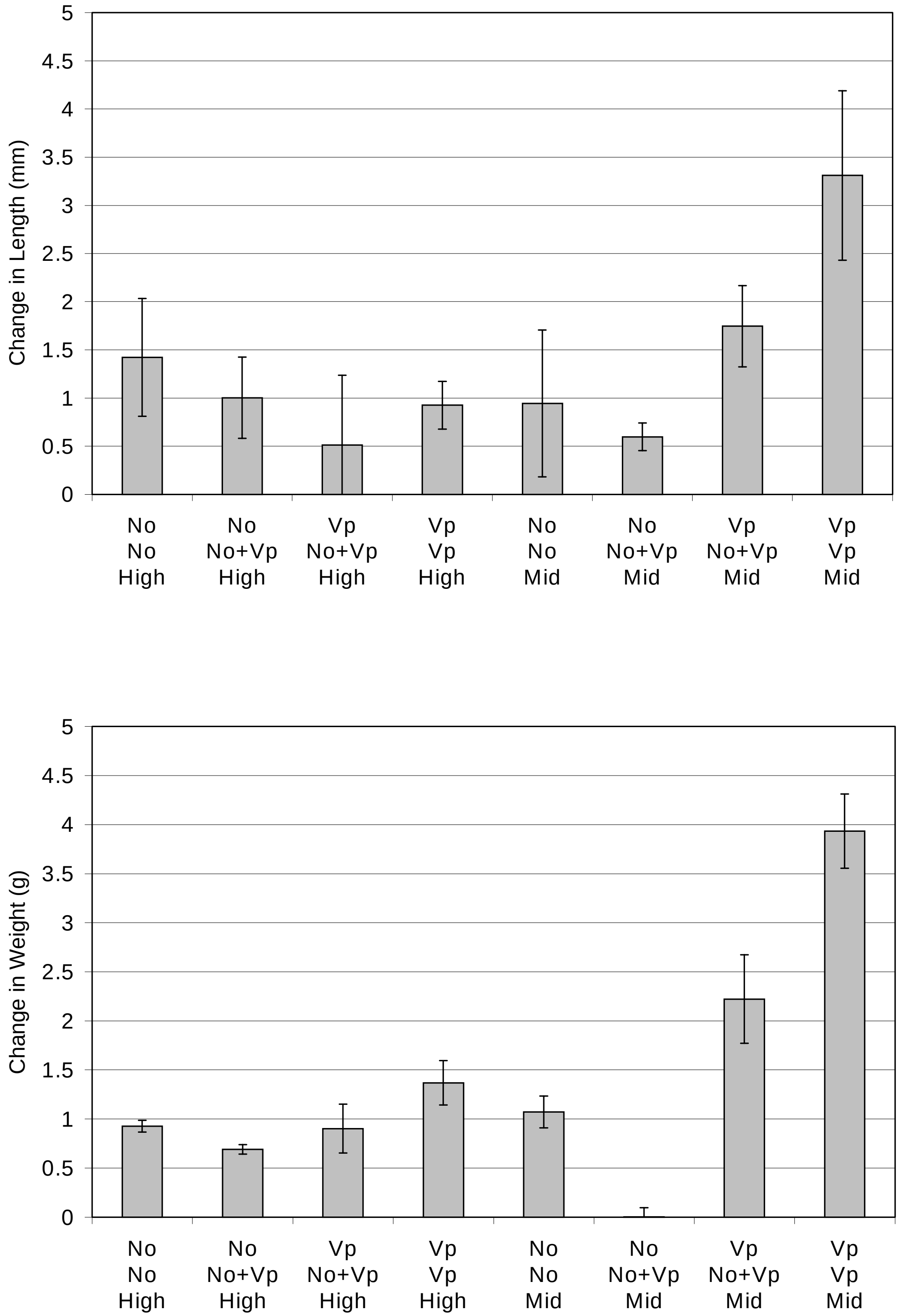
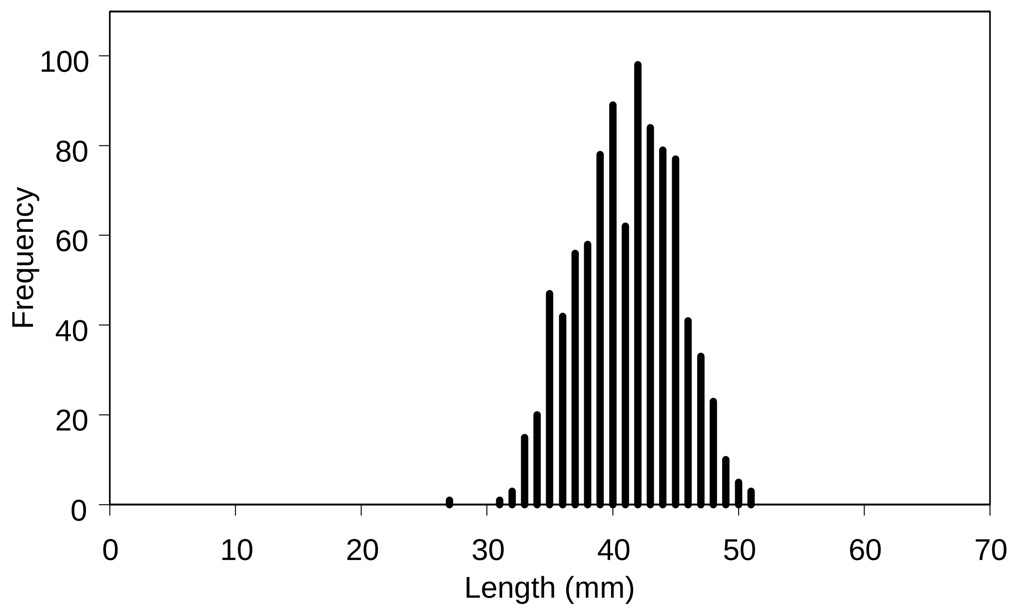


Figure 11. Change in length (mm) and weight (g) for all treatments and species combinations of varnish and Manila clams from the competition experiments in Fanny Bay, Baynes Sound, 2001.



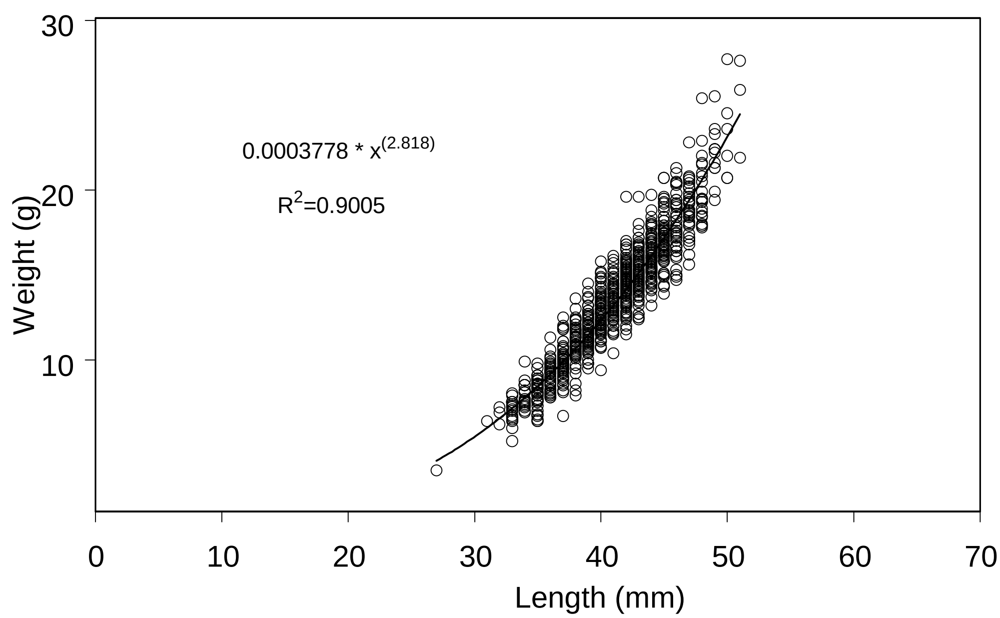
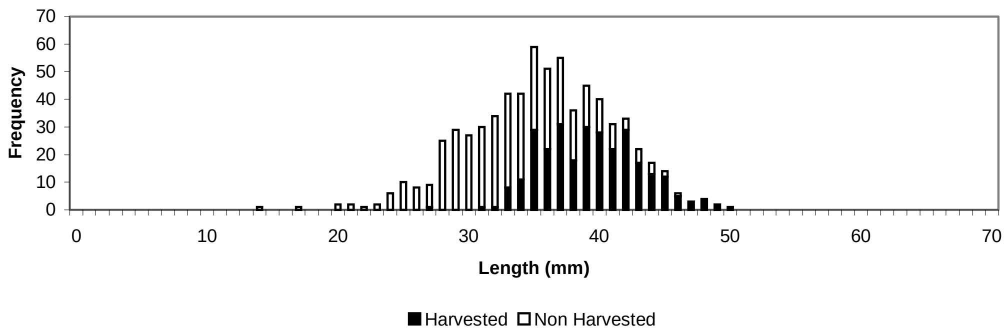
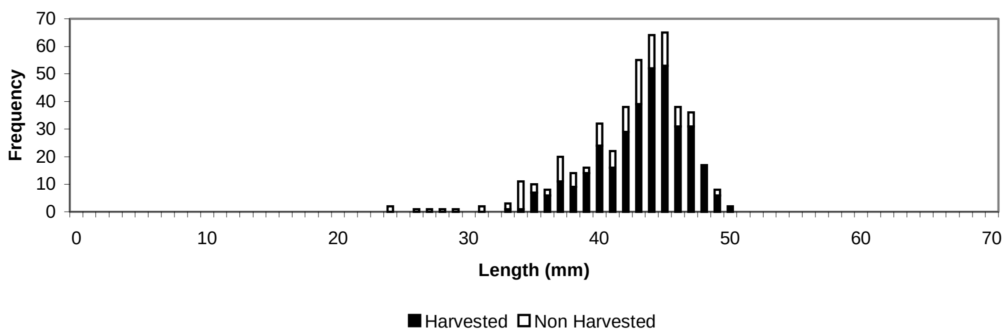


Figure 12. Length frequency (top) and length-weight relationship (bottom) of varnish clams sampled from harvests in Fanny Bay, Baynes Sound, July and August 2001.

Sample 1



Sample 2



Pooled Samples

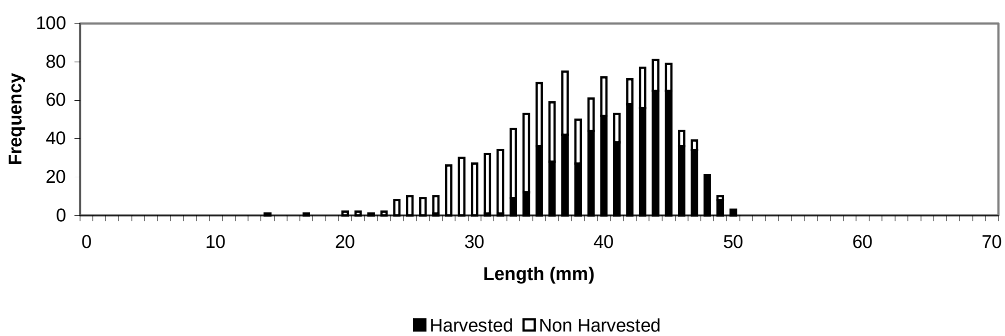


Figure 13. Length frequencies of varnish clams collected from harvest efficiency samples in Fanny Bay, Baynes Sound, August 3 and 22, 2001.

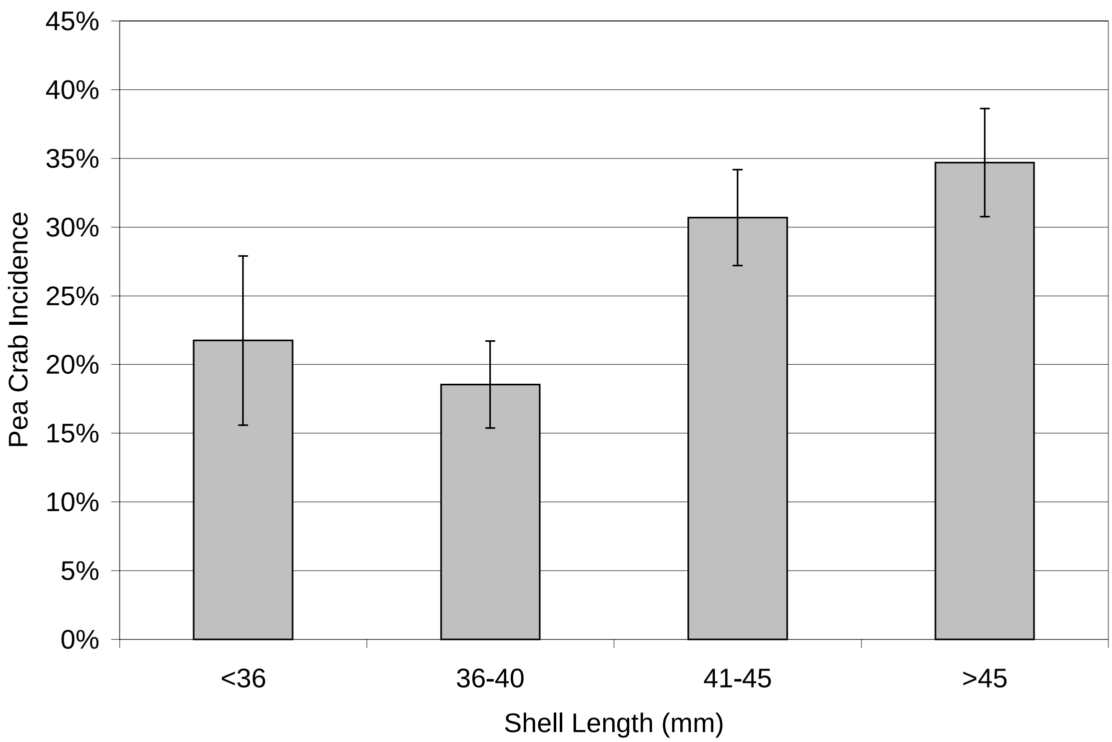


Figure 14. Pea crab incidence (%) in varnish clams by clam size class, Fanny Bay, April 2001. Error bars are ±1 SD.

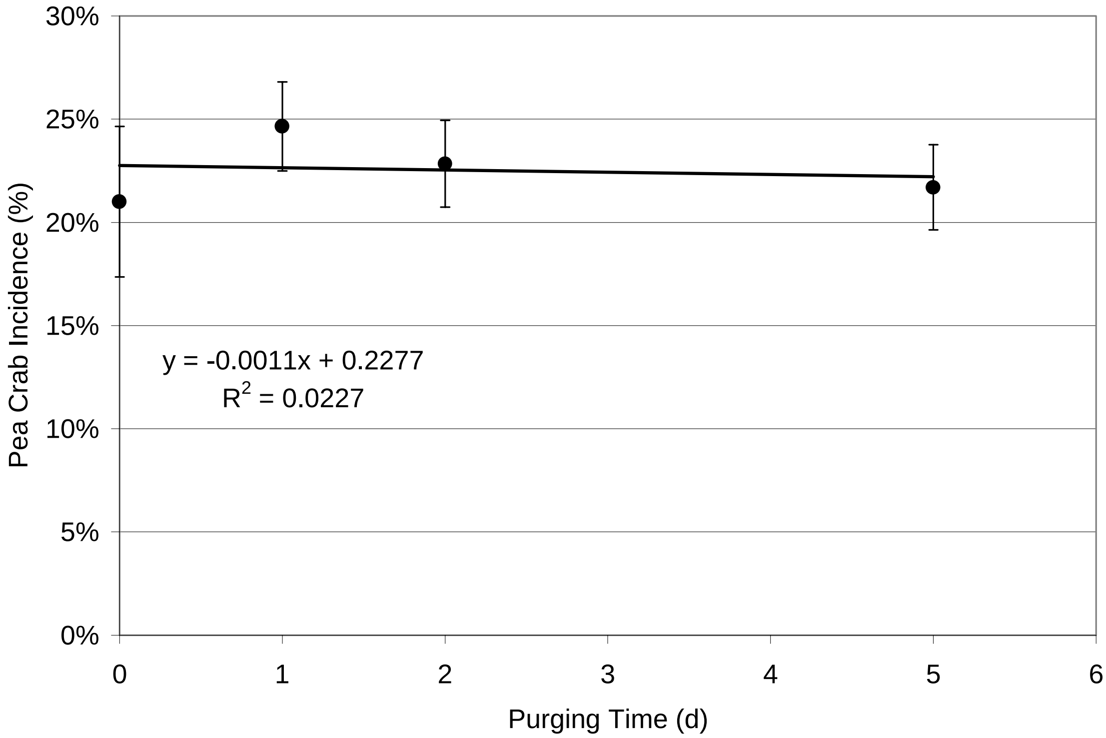


Figure 15. Pea crab incidence (%) in varnish clams purged in a land-based tank system, Mac's Oysters Ltd., Fanny Bay, April 2001.

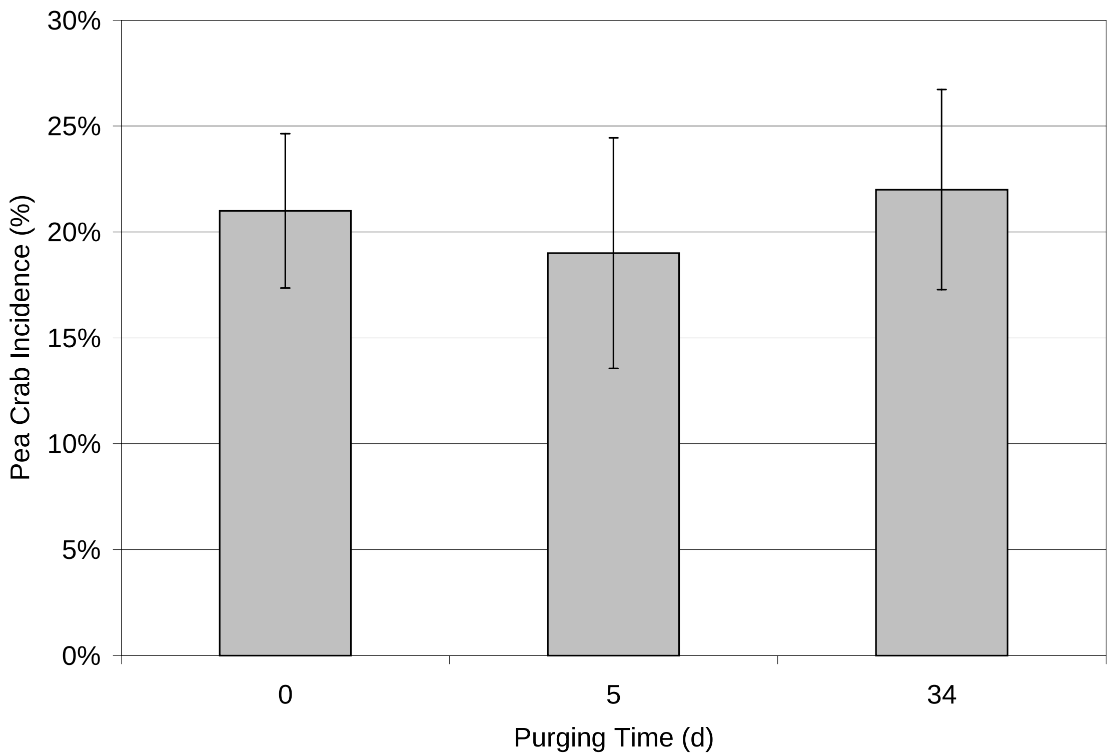


Figure 16. Pea crab incidence (%) in varnish clams purged on the beach, Mac's Oysters Ltd., Fanny Bay, April 2001.

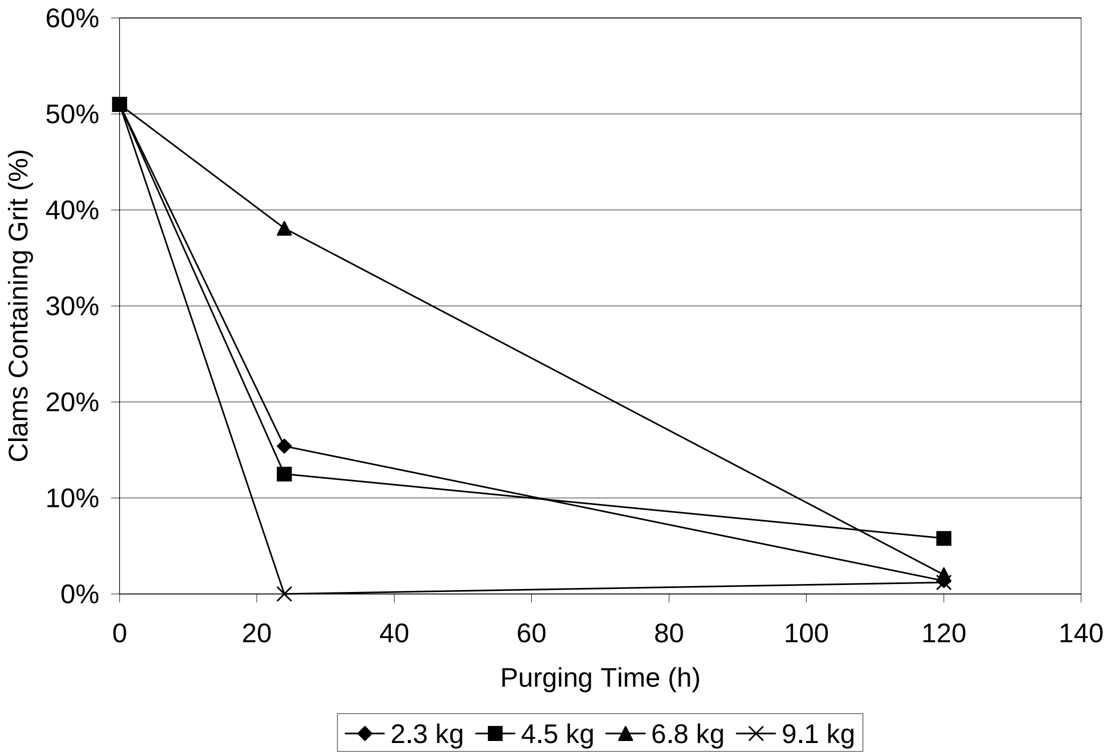


Figure 17. Total grit levels in varnish clams when held in bags in trays in a land-based tank system, Mac's Oysters Ltd., Fanny Bay, April 2001.

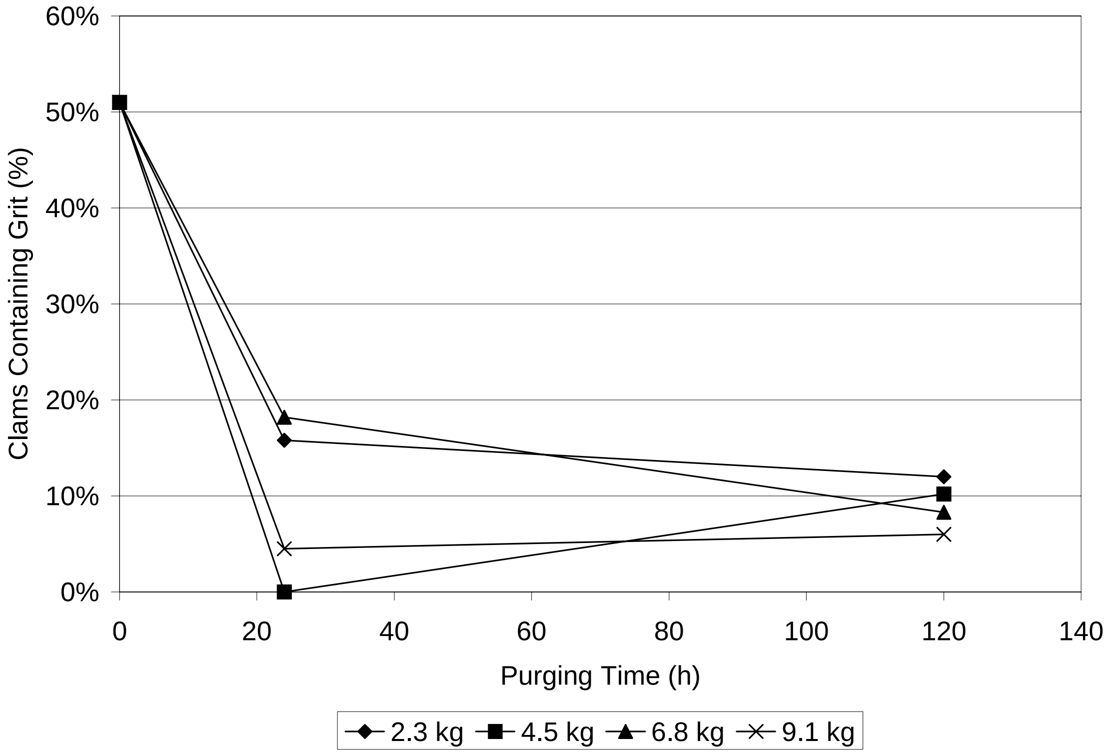


Figure 18. Total grit levels in varnish clams held in trays in a land-based tank system, Mac's Oysters Ltd., Fanny Bay, April 2001.

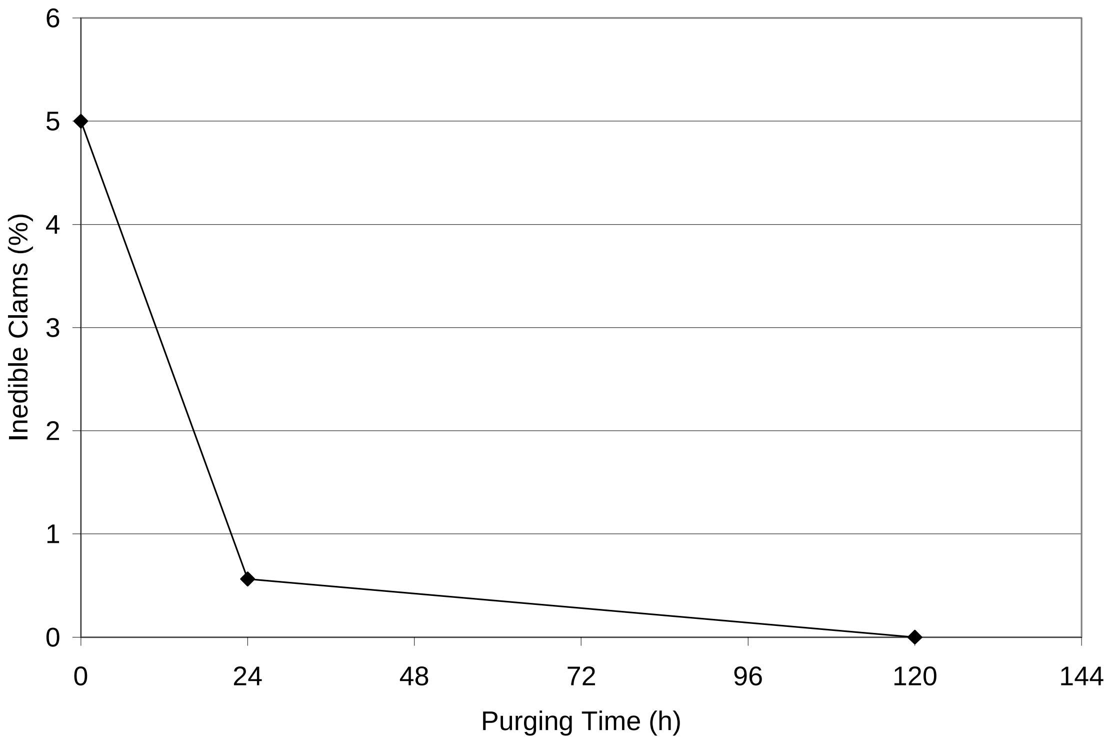


Figure 19. Percentage of varnish clams with high grit levels over time held in a land-based tank system, Mac's Oysters Ltd., Fanny Bay, April 2001.

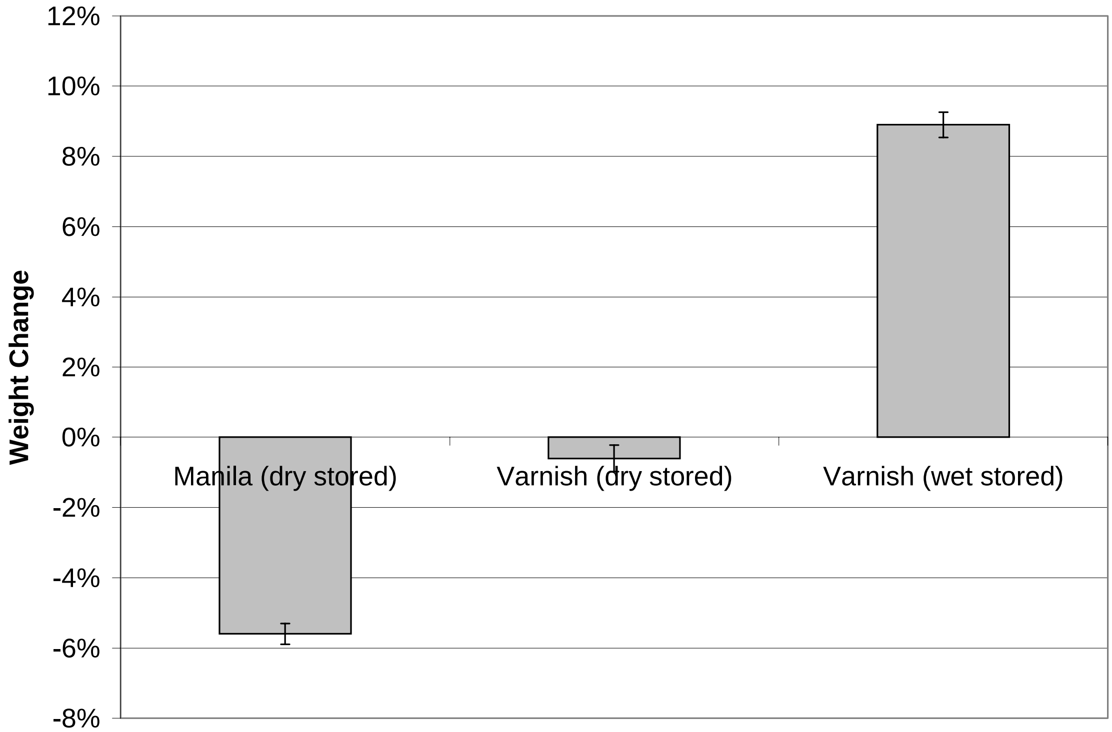


Figure 20. Percent weight change (±SE) of varnish and Manila clams after nine days of wet storage, Mac's Oysters Ltd., Fanny Bay, April 2001.

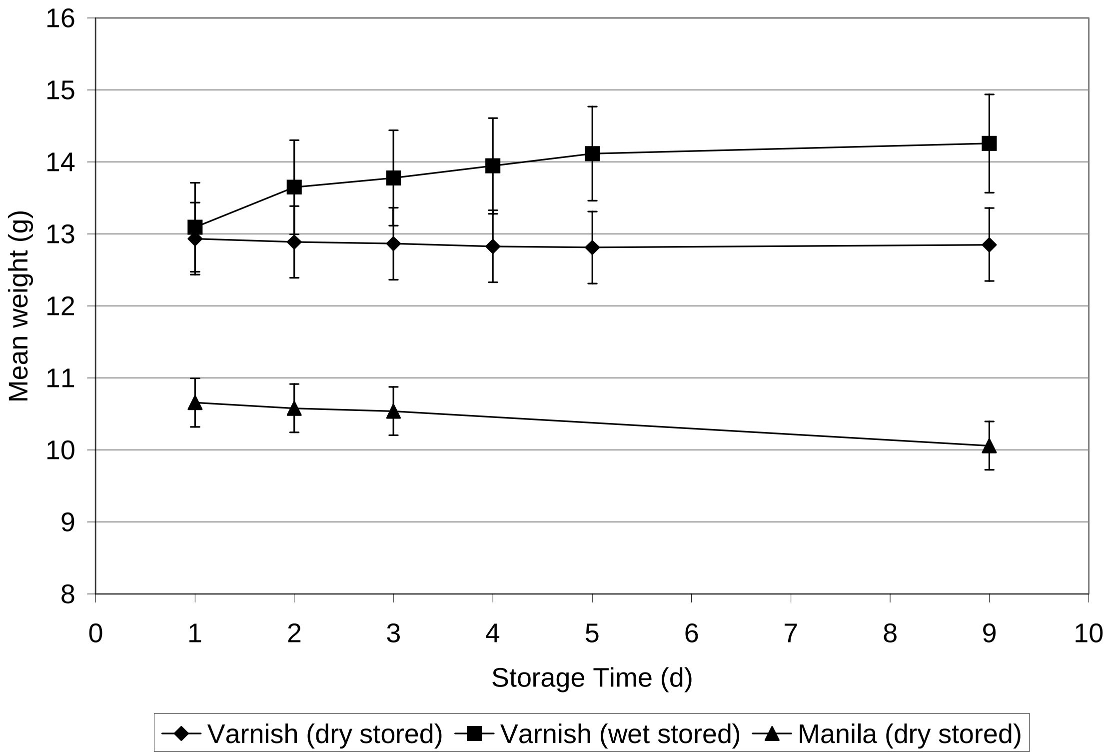


Figure 21. Mean wet weight (±SE) of varnish and Manila clams in wet and dry storage, Mac's Oysters Ltd., Fanny Bay, April 2001.

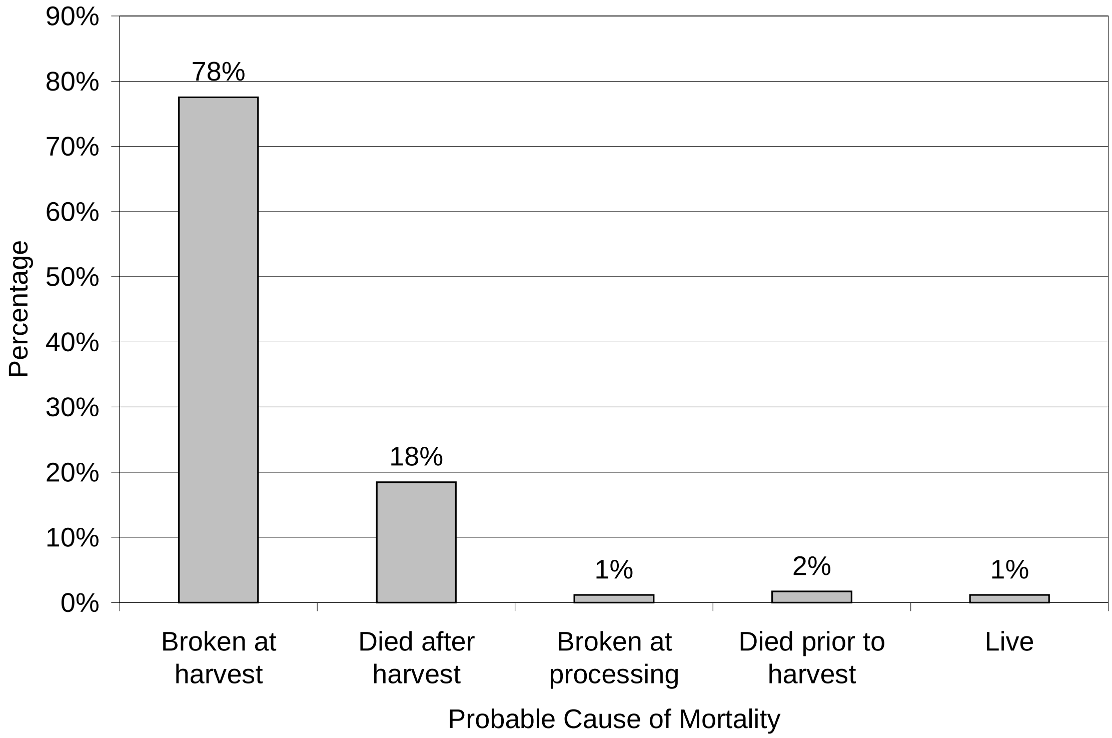


Figure 22. Causes of mortality of varnish clams from time of harvest to time of processing (n=352).

APPENDIX

PSARC INVERTEBRATE SUBCOMMITTEE
Request for Working Paper – Varnish Clam Phase 1 Studies

Date Submitted: September 28, 2001

Individual or group requesting advice: Fish Management, BC Fisheries, Canada Futures Development Corporation of the Powell River Region, (Funding agencies: Fisheries Renewal BC, HRDC), Pacific Shellfish Growers Association.

Proposed PSARC Presentation Date: November 2001, progress to date

Subject of Paper (title if developed): Varnish Clam Phase 1 Studies in Georgia Strait, Progress Report

Lead Author(s): Graham Gillespie, Stephen Gormican

Fisheries Management Author/Reviewer: Dan Clark, Randy Webb

Rationale for request: An invasive, non-native intertidal bivalve has become widely distributed in the Strait of Georgia, including clam tenures, and it is suspected that there are quantities significant enough to provide for a commercial fishery. Research was initiated to define distribution, investigate market potential and develop reference points (appropriate size limits) and ecological interactions prior to developing a management strategy to incorporate varnish clams into the existing intertidal clam fishery.

Stakeholders Affected: Intertidal clam harvesters, shellfish lease tenure holders, First Nations, Coastal Communities.

How Advice May Impact the Development of A Fishing Plan: Reference points (appropriate size limits) and ecological interactions may define management strategies to define a sustainable fishery. Interest in the harvest of varnish clams from aquaculture lease tenure has been raised as an economic benefit and as a potential for competition with cultured Manila clams. Policy on permitting this species to be harvested and marketed from aquaculture tenure requires information on distribution, densities, harvest and handling methods. Including varnish clams in the intertidal clam fishery may improve the economic sustainability of the clam fishery.

Question(s) to be addressed in the Working Paper:
What are the patterns of distribution for varnish clams (habitat preferences: tidal height, current, geographic limits).
What are the densities and biomass on specific beaches in the Powell River area?
What are the harvest, handling, storage or transport techniques for varnish clams and are they different than for native littleneck or Manila clams?
What are the specifics of size frequency, density and interaction with other species?
What is the market potential for varnish clams (Savoury clam)?

Objectives of Working Paper:
To present information on distribution, density, biomass, population structure and biology of varnish clams.
To suggest potential fishing and processing techniques specific to varnish clams, considering breakage, packaging, handling, wet storage requirements and purging of sand, pebbles and pea crabs.
To present information on competitive interaction studies.
Potential market and value of product landed.